AN INVESTIGATION OF THE ECOLOGY OF WATER DISTRIBUTION SYSTEMS

A thesis submitted for the degree of
Doctor of Philosophy

Andrew C. Smart,
University of Leicester, Department of Zoology, 1989

ABSTRACT

Animal infestations of water distribution systems are a cause of considerable concern for the water industry. The appearance of an animal at a consumer's tap often gives rise to complaints. This study, in Anglian Water, Oundle Division, Northamptonshire, U.K. investigated the ecology of the infesting community and its management.

Mains sampling used sequential flushes at the hydrant and a model for animal removal was constructed. Tap sampling collected animals from filters at the tap and an index of emergence (density in a day's consumption) and degree of infestation (based on density and the ability to cause complaints) were devised. Reservoir sampling used a perspex trap to sample the water column and sediments. Methods to determine the environmental and operational characteristics of the system were also devised.

Community clustering on the basis of animal density determined five distinct community types. Operational and environmental parameters did not coincide with any of the types, though correlations indicated that highest densities occurred at sites further (in time) from treatment with a low turnover time. Sites fed by slow sand filters were not recolonised by chironomid larvae nor to the degree of other sites by other taxa. No successional sequence was found and it was concluded that animals recolonised on the basis of a 'competitive lottery'.

The relationship between density at the tap and in the main was considered and seasonal changes in the degree of infestation between sites confirmed that water from rapid gravity filtration leads to more severe animal problems, particularly during the summer.

Benthic animals penetrated treatment in low numbers, but reservoirs near treatment were dominated by limnetic animals. Many died and became an indirect food source for infesting animals, but some survived and colonised pipes. Reservoirs at the extremes of the system were not influenced by these taxa and were 'extensions' of the distribution system.

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For Grandad

So Many Summers

Beside one loch, a hind's neat skeleton,
Beside another, a boat pulled high and dry:
Two neat geometries drawn in the weather:
Two things already dead and still to die.

I passed them every summer, rod in hand,
Skirting the bright blue or the spitting gray,
And, every summer, saw how the bleached timbers
Gaped wider and the neat ribs fell away.

Time adds one malice to another one -
Now you'd look very close before you knew
If it's the boat that ran, the hind went sailing.
So many summers, and I have lived them too.

Norman MacCaig, *A Man In My Position*, 1969.

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Most of all my thanks go to Anne for helping get me through all this, and much more...

CONTENTS

SUMMARY

Chapter 1) Introduction and study site.....xv
Chapter 2) Sampling methods.....xvi
Chapter 3) Investigation of potential errors.....xvii
Chapter 4) Methods for examination of environmental parameters.....xvii
Chapter 5) Taxonomy and life histories of infesting animals.....xviii
Chapter 6) Correlation of community structure with environmental and operational parameters.....xix
Chapter 7) Investigation of succession and colonisation by examination of community structure under different regimes of flushing.....xx
Chapter 8) The effect of frequency of disturbance on species richness, diversity and density of 'problem taxa'.....xx
Chapter 9) The relationship between animals in the distribution system and animals emerging at the tap.....xxi
Chapter 10) The role of Reservoirs and Service Towers.....xxi

PART I: INTRODUCTION

CHAPTER 1) INTRODUCTION AND STUDY SITE

1.1) General Introduction.....2
1.1.1) Public health consequences of infestations.....3
1.1.2) The nature of infestations of potable water.....3
1.1.3) Objectives of the project.....4
1.2) History of Infestation Problems 6
1.2.1) Water treatment methods.....7
1.2.2) Penetration of organisms and food sources.....8
1.2.3) Bacterial colonisation of the distribution system.....9
1.2.4) Methods of control.....9

1.3) Preliminary Survey of infestation problems in the U.K.....10
1.4) Study sites and description of system.....13
1.4.1) Northampton Supply Zone and Pitsford Supply Zone.....13
1.4.2) Ravensthorpe Supply Zone.....21
1.4.3) Wing Supply Zone.....21
1.4.4) The Distribution System.....22
1.5) Extent of Infestation prior to research.....22
1.6) Consumer complaints.....23

PART II: METHODS OF SAMPLING AND TAXONOMY

CHAPTER 2) SAMPLING METHODS

2.1) Introduction.....27

Section A: Reasons for use of flushing as sampling method
2.2) Available Methods of sample collection.....28
2.2.1) Scrape-and-Reline.....28
2.2.2) Air-Scouring.....28
2.2.3) In-line traps and filters.....29
2.2.4) Swabbing.....29
2.2.5) Flushing.....30
2.2.6) Consideration of sampling methods available.....31

Section B: Sample Collection Method
2.3) Establishment of drift hypothesis.....32
2.4) Test of sampling model.....36
2.4.1) Methods.....36
2.4.2) Results.....40
2.4.3) Discussion.....45
2.5) Calculation of Quantitative information from the five sites used to produce the sampling model.....46

Section C: Subsampling
2.6) Subsampling technique.....48
2.7) Investigation of subsampling procedure for random distribution 49
2.7.1) The effect of varying subsample numbers.....49

2.7.2) The frequency of random distribution in samples for different taxonomic groups.....50
2.7.3) The effect of animal density and subsample dilution on frequency of random distribution in subsamples.....53
2.8) Discussion.....56

CHAPTER 3) INVESTIGATION OF POTENTIAL ERRORS

3.1) Introduction.....58
3.2) Effect of corrosion on quantitative data.....58
3.2.1) Methods.....59
3.2.2) Results and Discussion.....59
3.2.3) Conclusions.....59
3.3) Investigation of animal removal at different rates of flushing.....61
3.3.1) Methods 61
3.3.2) Results.....62
3.3.3) Discussion.....62
3.4) Investigation of success rate of animal removal using the method.....62
3.4.1) The determination of the relative values of flushing and pyrethrin followed by air-scour as methods of sampling.....66
3.4.1.1) Methods.....66
3.4.1.2) Results.....66
3.4.2) Investigation of flush sampling relative to air-scour at low rates of flow.....66
3.4.2.1) Methods 66
3.4.2.2) Results.....69
3.4.3) Discussion of flushing alone relative to other methods.....69
3.5) Limitations applying to the sampling method.....71

CHAPTER 4) METHODS FOR EXAMINATION OF ENVIRONMENTAL PARAMETERS

4.1) Introduction.....73

Part I: *Environmental Characteristics*
4.2) Field measurements of water quality.....73
4.2.1) Total Chlorine.....73

4.2.2) Dissolved oxygen.....74
4.2.3) pH.....74
4.2.4) Temperature.....74
4.3) Carbon in potable water.....75
4.3.1) Initial processing of water samples for carbon analysis.....75
4.3.2) Dissolved organic carbon.....75
4.3.3) Particulate organic carbon.....78
4.3.4) Total organic carbon.....78
4.4) Iron and Turbidity.....78
4.5) Sediment analysis.....79
4.5.1) Dry weight of sediments.....79
4.5.1.1) Methods.....81
4.5.2) Dry weight of organic matter.....82
4.5.3) The effect of iron salts and waters of hydration on determination of the percentage organic matter.....83
4.5.3.1) Methods.....84
4.5.3.2) Results and Discussion.....84
4.6) Microbiological analysis.....87

Part II: Operational Characterisics

4.7) Consumption Rate.....87
4.8) Rate of flow.....88
4.9) Pressure.....88
4.10) Pipe age, material and diameter.....90
4.11) Air-scour and scrape-and-reline history.....90
4.12) Age of water (Travel time).....90
4.13) Service Reservoirs and Water Towers.....91
4.14) Reservoir Water.....91
4.15) Tuberculation.....91

CHAPTER 5) TAXONOMY AND LIFE HISTORIES OF INFESTING ANIMALS

5.1) Introduction.....94
5.2) Methods of identification.....94
5.3) Chironomids.....95
5.3.1) Chironomid life history and habit.....95
5.3.2) Chironomid access to the distribution system.....98

5.3.3) Chironomid larvae in the distribution system and their control.....100
5.3.4) Identification of larvae present in the distribution system.....101
5.3.5) Tanypodinae.....102
5.3.6) Chironominae.....102
5.3.6.1) Chironomini.....102
5.3.6.2) Tanytarsini.....103
5.3.7) Orthocladiinae.....104
5.3.8) Chironomid pupae in samples from the system.....105
5.3.9) Gut contents of chironomid larvae present in the study area.....105
5.3.10) Variation of size of chironomid larvae during the course of the study.....105
5.4) Other Insects.....106
5.5) Isopoda.....106
5.5.1) The life cycle of *Asellus aquaticus*.....107
5.5.2) The diet of *Asellus* and *Gammarus*.....107
5.5.3) *Asellus aquaticus* in distribution systems and its control.....108
5.5.4) Isopods in the study area.....109
5.6) Oligochaeta.....110
5.6.1) Life cycle and diet of oligochaetes.....110
5.6.2) Oligochaetes in the distribution system and their control.....111
5.6.3) Oligochaetes in the study area.....112
5.7) Copepoda.....112
5.7.1) Cyclopoid copepod life history and diet.....112
5.7.2) Penetration of treatment by cyclopoid copepods.....113
5.7.3) Cyclopoids in distribution systems and their control.....114
5.7.4) Cyclopoid copepods in the study area.....114
5.7.5) *Acanthocyclops*.....114
5.7.6) *Megacyclops*.....116
5.7.7) *Paracyclops*.....117
5.7.8) *Eucyclops*.....117
5.7.9) Harpacticoidea.....119
5.8) Cladocera.....119
5.8.1) The life history and habit of Cladocera.....120
5.8.2) Cladocera in the distribution system and their control.....120

5.8.3) Cladocera present in the study area.....120
5.8.4) *Alona*.....121
5.8.5) *Chydorus*.....122
5.8.6) *Graptoleberis*.....122
5.9) Ostracoda.....123
5.10) Acarina.....123
5.10.1) Halacaridae.....124
5.10.2) Other Acarina.....125
5.11) Mollusca.....125
5.11.1) Bivalvia.....126
5.11.2) Gastropoda.....126
5.12) Microturbellaria.....127
5.13) Tardigrada.....127
5.14) Nematoda.....127
5.15) Other animals known to occur.....128

PART III: EXPERIMENTAL WORK IN THE SYSTEM

PART IIIA) ANIMALS IN THE DISTRIBUTION SYSTEM

CHAPTER 6) CORRELATION OF COMMUNITY STRUCTURE WITH ENVIRONMENTAL AND OPERATIONAL PARAMETERS

6.1) Introduction.....130
6.2) Sampling Methods.....130
6.3) Sampling Sites.....132
6.4) Data Analysis Methods.....132
6.5) Kendall's Correlation Coefficient: Results and Discussion.....141
6.5.1) Environmental parameters and operational characteristics.....141
6.5.2) Effect of measured conditions in the main on the community.....144
6.5.2.1) Chironomidae.....144
6.5.2.2) Copepoda.....144
6.5.2.3) Chydorids.....147
6.5.2.4) Acarina.....147
6.5.2.5) Other Taxa.....148
6.5.3) Investigation of relationships between taxa.....148
6.6) Analysis using Hierarchical Cluster Analysis: Results and Discussion.....150

6.6.1) Taxonomic characterisation of clusters.....150
6.6.2) Characterisation of clusters using environmental and operational parameters.....154
6.7) Clustering using environmental and operational parameters.....160
6.8) General Discussion.....165

CHAPTER 7) INVESTIGATION OF SUCCESSION AND RECOLONISATION BY EXAMINATION OF COMMUNITY STRUCTURE UNDER DIFFERENT REGIMES OF FLUSHING.

7.1) Introduction.....168
7.2) Sampling Methods.....169
7.3) Site Choice.....169
7.4) Relationship between environmental parameters: Results and Discussion.....170
7.5) Site by Site Changes: Results and Discussion.....183
7.5.1) Sites sampled on a two-monthly basis.....183
7.5.1.1) Church Mount, Guilsborough.....183
7.5.1.1.1) Chironomids.....183
7.5.1.1.2) Copepods.....185
7.5.1.1.3) Chydorids.....186
7.5.1.1.4) Mites.....186
7.5.1.1.5) Other Taxa.....197
7.5.1.2) Scott Close, Ravensthorpe.....197
7.5.1.2.1) Chironomids.....197
7.5.1.2.2) Copepods.....197
7.5.1.2.3) Chydorids.....198
7.5.1.2.4) Mites.....198
7.5.1.2.5) Other Taxa.....198
7.5.1.3) Berry Close, Rothersthorpe.....198
7.5.1.3.1) Chironomids.....199
7.5.1.3.2) Copepods.....199
7.5.1.3.3) Chydorids.....200
7.5.1.3.4) Mites.....200
7.5.1.3.5) Other Taxa.....200
7.5.1.4) Back Lane, Chapel Brampton.....210
7.5.1.4.1) Chironomids.....210
7.5.1.4.2) Copepods.....210
7.5.1.4.3) Chydorids.....211
7.5.1.4.4) Mites.....211
7.5.1.4.5) Other Taxa.....212

7.5.2) Sites sampled on a four-monthly basis.....212
7.5.2.1) West Way, Weedon.....212
7.5.2.1.1) Chironomids.....212
7.5.2.1.2) Copepods.....213
7.5.2.1.3) Other Taxa.....213
7.5.2.2) Stanford Close, Cold Ashby.....213
7.5.2.2.1) Chironomids.....213
7.5.2.2.2) Copepods.....220
7.5.2.2.3) Chydorids.....220
7.5.2.2.4) Mites.....220
7.5.2.2.5) Other Taxa.....221
7.5.3) Sites sampled on a six-monthly basis.....221
7.5.3.1) Brookside, Weedon.....221
7.5.3.1.1) Chironomids.....221
7.5.3.1.2) Copepods.....221
7.5.3.1.3) Chydorids.....222
7.5.3.1.4) Mites.....222
7.5.3.2) West Haddon Road, Cold Ashby.....222
7.5.3.2.1) Chironomids.....222
7.5.3.2.2) Copepods.....229
7.5.3.2.3) Chydorids.....229
7.5.3.2.4) Other taxa.....229
7.5.4) Sites sampled after periods greater than six months.....229
7.5.4.1) Park Lane, Watford.....229
7.5.4.1.1) Taxa present at Park Lane, Watford.....229
7.5.4.2) Parsons Close, Nether Heyford.....230
7.5.4.2.1) Taxa present at Parsons Close, Nether Heyford.....230
7.5.4.3) Wakefield Way, Nether Heyford.....230
7.5.4.3.1) Taxa present at Wakefield Way, Nether Heyford..... 237
7.6) Discussion of species trends.....237
7.6.1) Chironomid larvae.....239
7.6.2) Harpacticoids.....240
7.6.3) Cyclopoid copepods.....241
7.6.4) Chydorids.....242
7.6.5) Mites.....242
7.7) General Conclusions.....243

CHAPTER 8) THE EFFECT OF FREQUENCY OF DISTURBANCE ON SPECIES RICHNESS, DIVERSITY AND DENSITY OF 'PROBLEM' TAXA.

8.1) Introduction.....245
8.2) Diversity and species richness: Huston's General Hypothesis of Species Diversity.....246
8.2.1) The relationship between taxonomic richness, diversity and environmental parameters at undisturbed sites.....248
8.2.1.1) Methods.....248
8.2.1.2) Results and Discussion.....249
8.2.2) Diversity and frequency of population reduction.....249
8.2.2.1) Methods.....252
8.2.2.2) Results and Discussion.....252
8.2.3) The relationship between Diversity and taxonomic richness with likely measures of population reduction and population growth rate.....254
8.2.3.1) Methods.....254
8.2.3.2) Results and Discussion.....254
8.3) The relationship between particular problem species and the frequency of population reduction and environmental factors.....254
8.3.1) Methods.....254
8.3.2) Results and Discussion.....262
8.3.2.1) Chironomini.....262
8.3.2.2) Tanytarsini.....262
8.3.2.3) Orthocladiinae.....262
8.3.3) Conclusions.....263
8.4) Suggestion for work to determine whether animals in mains occur at random or in a predictable fashion.....263

PART IIIB) ANIMALS AT THE CONSUMERS' TAP

CHAPTER 9) THE RELATIONSHIP BETWEEN ANIMALS IN THE DISTRIBUTION SYSTEM AND ANIMALS EMERGING AT THE TAP.

9.1) The need for information about animals at taps.....265
9.2) Introduction.....266
9.3) Study sites.....266

9.4) Methods....270
9.4.1) Tap filtration methods....270
9.4.2) Laboratory techniques....272
9.4.3) Index of emergence....273
9.4.4) Degree of infestation 273
9.4.5) Mains sampling....274
9.5) Results and Discussion....275
9.5.1) Emergence index of species groups....275
9.5.2) Emergence at Ravensthorpe and Pitsford....275
9.5.3) Emergence index related to rate....279
9.5.4) Variation in the emergence index at the tap....279
9.4.5.1) Ratio of chydorids in the main and at the tap at Whilton....289
9.5.5) Emergence index relative to animal density....289
9.5.6) Degree of infestation at the tap....293
9.5.7) Degree of infestation at the tap and in the main....293
9.6) General Discussion....293
9.7) Conclusions....296

PART IIIC) ANIMALS IN SERVICE RESERVOIRS AND TOWERS

CHAPTER 10) SERVICE RESERVOIRS AND TOWERS

10.1) Introduction....295
10.2) Qualitative analysis of service reservoir and water tower fauna....296
10.2.1) Methods....296
10.2.1.1) Sample sites....297
10.2.2) Results....297
10.2.3) Discussion....297
10.3) Methods of sampling to obtain relative measures of density....305
10.3.1) Test of sampling methods....305
10.4) Analysis of Service Reservoirs during 1988 using a measure of Relative Density....307
10.4.1) Introduction of possible scenarios....307
10.4.2) Survey Sites....308
10.4.3) Methods....308
10.4.4) Results and Discussion....311
10.5) General Conclusions....317

PART IV: CONCLUSIONS

CHAPTER 11) GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK TO AID MANAGEMENT OF INVERTEBRATE INFESTATIONS OF THE DISTRIBUTION SYSTEM.

11.1) Introduction.....322
11.2) Quantitative sampling methods for distribution systems including mains, service reservoirs and towers.....322
11.2.1) Sampling methods for the distribution system.....322
11.2.2) Sampling methods for animals emerging at the tap.....322
11.2.3) Sampling methods for Service Reservoirs.....323
11.3) The relationships between the operational and physical characteristics of water mains - construction, material,condition, age, etc. - and animal infestation.....323
11.4) The effect of treatment works final waters on animal infestations of mains, in particular to identify the principal food sources of the mains fauna.....325
11.5) Survey strategies using these methods for the monitoring of levels of infestation, to guide the derivation of quality objectives.....326
11.5.1) Survey strategies for the distribution system.....326
11.5.2) Survey strategies for animals emerging at the tap.....327
11.5.3) Survey strategies for Service Reservoirs.....327
11.6) Priorities for future work.....327

PART V: APPENDICES

Appendix I: Data for hydrants E, F and G, site 2: Obelisk Rise, Northampton, Northants.....330
Appendix II: Computer programs to produce quantitative results using the sampling model and examples of input and output.....333

Appendix III: Environmental parameters recorded and estimated for undisturbed sites sampled during May/June and October 1987.....362
Appendix IV: Environmental measurements taken on sampling occasions and estimated for disturbed sites sampled during April 1986 to May 1988.....369
Appendix V: Detailed sketch maps of undisturbed sites sampled for Chapter 6.....374
Appendix VI: Animal density per 10 metres of pipe at undisturbed sites sampled during May/June and October 1987.....397
Appendix VII: Agglomeration schedules for dendrograms constructed using Ward's method (Ward 1963) and used in Chapter 6.....406
Appendix VIII: Detailed sketch maps of disturbed sites sampled for Chapter 7.....414
Appendix IX: Animal density per 10 metres of pipe from disturbed sites sampled between April 1986 and May 1988.....423
Appendix X: Data used to consider Huston's General Hypothesis of Species Diversity.....433
Appendix XI: Norgren Filter animal densities and index of emergence for each taxa on each sampling occasion during 1988.....437
Appendix XII: Relative density of animals per litre in samples removed from service reservoirs during 1988.....449

PART VI: REFERENCES.....452

SUMMARY

Chapter 1) Introduction and study site.....xv
Chapter 2) Sampling methods.....xvi
Chapter 3) Investigation of potential errors.....xvii
Chapter 4) Methods for examination of environmental parameters.....xvii
Chapter 5) Taxonomy and life histories of infesting animals....xviii
Chapter 6) Correlation of community structure with environmental and operational parameters.....xix
Chapter 7) Investigation of succession and colonisation by examination of community structure under different regimes of flushing.....xx
Chapter 8) The effect of frequency of disturbance on species richness, diversity and density of 'problem taxa'.....xx
Chapter 9) The relationship between animals in the distribution system and animals emerging at the tap.....xxi
Chapter 10) The role of Reservoirs and Service Towers.....xxi

Chapter 1) Introduction and study site.

The required quality of water emerging at the consumers' tap has been established (Anon 1982) but it is often the case that these requirements, laid down by the U.K. Department of the Environment, are not met. Animal infestations are particularly difficult to control and are likely to occur in any water distribution system fed by a surface water source.

In the U.K. there is no health hazard from these infesting animals though their ability to transport bacteria through treatment should be considered. The animal community that infests the distribution system tends to be benthic meiofauna, consisting of both infauna and epifauna, and exists as populations in the pipes themselves without requiring continuous immigration of animals that penetrate treatment processes.

Early work on this problem related to untreated water or systems with uncovered service reservoirs. As time progressed, so the development of treatment processes and a closed supply network has advanced, but animals are still present. During the 1970's and 1980's, taxa have appeared that are common in distribution systems but not in natural conditions (*Alona protzi* and *Paratanytarsus inquilinius*). The chironomid *Paratanytarsus inquilinius* which has only ever been identified from water supply systems, is particularly adapted to the system and causes many problems.

Various water treatment methods are now used, but all are susceptible to penetration by infesting taxa and organic material. The latter is a possible direct food source and provides a substrate for bacteria on which many infesting taxa may exist. Chemical dosing to reduce bacteria has led to most systems maintaining a chlorine residual but this residual level will not affect infesting animals. The current technique for removal of infestations is to dose the system with pyrethrin or permethrin every few years. Various mechanical operations are available to deal with local outbreaks.

At the time the study commenced, little information was available about the state of the supply zones in the study area. It was known that *Asellus*, a serious problem in the past, had been severely reduced in density if not completely eradicated, but chironomid larvae were becoming a problem, along with oligochaete worms and snails.

Complaints information showed a summer peak in complaints and that only 1.1% of the total complaints were due to animals, which shows the serious nature of animal complaints relative to pressure, discolouration and taste and odour.

Chapter 2) Sampling method.

It was necessary to develop a quantitative method of sampling the distribution system. The methods that were available to this study were tested and their relative merits are discussed. Five possible means of sampling the main were considered, swabbing; 'in line' traps; scrape-and-reline; air-scour and flushing. Flushing was considered the simplest and most efficient method of obtaining information from the distribution system and a simple hypothesis relating to the manner in which animals would be removed from the pipe was established.

A lack of quantitative information about the animals that infest water supply led to a sampling hypothesis that aimed to continually flush and collect deposits at a hydrant until a constant basal level, the 'drift', was attained. Each flush filters water containing a ceratin density of animals and sediment from the pipe and carried in the water that is pulled into the pipe by the sampling process (the drift). As the number of samples increases, so more animals will be removed from the pipe until animal density decreases to a basal level. Experimental tests of this hypothesis determined that after three to five samples the drift level was reached. Further work established that there was no significant difference between these samples and therefore it was decided that three samples would be used to assess the density of animals in any pipe. The use of three samples from each hydrant led to the construction of a sampling model that enabled quantitative information to be calculated from the data available.

Taxa present were counted in the laboratory in subsamples removed after random mixing. Various tests were carried out to establish the ideal number of subsamples and the distribution of subsamples to enable significance tests to be applied to transformed data from the three samples removed at each hydrant.

The random mixing technique was found to produce subsamples that fitted a Poisson distribution and a square-root transformation was applied to the data. In some cases a negative binomial distribution was found though subsequent tests showed this was more likely to be a heterogeneous sampling of a Poisson distribution. This indicated that there was no increase in accuracy of counting between five, ten or fifteen subsamples, and five were chosen to represent samples throughout the study. Samples with large numbers of chydorids and oligochaetes often deviated from the random distribution because laboratory techniques failed to cope with large quantities of sediment.

Chapter 3) Investigation of potential errors

The sampling method devised in Chapter 2 was tested to determine its use in the system and the success of removal in different taxa.

The possible effects of corrosion in the main on the use of assumed pipe volume in the sampling model were determined by a computer simulation of the effects of corrosion. The outcome showed that corrosion in the main has an insignificant effect on the production of quantitative data from the main. However, if direct comparison between sites using animal density is required care must be taken in the choice of measure; corrosion has no significant effect on the values for density per unit pipe length, but does affect density per unit pipe volume.

A coefficient of removal was devised and used to examine the success of flushing at different rates of flow and the proportion of animals removed at both high pressure and low pressure sites in the distribution systems.

Flushing at different rates indicated that only a low proportion of Halacarids and large chironomid larvae in the pipe were removed when flushing was carried out at low rates of flow. This work led to the conclusion that quantitative information is only valid when flushing over 7.0 $l\ s^{-1}$ is carried out. The effectiveness of flushing at both high pressure and low pressure sites was considered by following a flush sample series with air scour. These tests indicated that even at low rates of flow it is possible to remove some taxa (Chydoridae and Copepoda) but that the Halacaridae (and probably chironomid larvae) are not totally removed during flushing at low rates of flow. A discussion of the limitations of the sampling technique and recommendations for its use in the system is included.

Chapter 4) Methods for examination of environmental parameters.

The use of the sampling method to provide quantitative information about the mains community is of little use without consideration of the environmental conditions within the distribution system.

Various field measurements of water quality were undertaken on water samples from the main. The carbon in the system was considered by measuring the dissolved organic and particulate organic carbon present in water samples removed from the main prior to sampling. Measures of iron and turbidity in the water (on a parish basis) were provided by McElroy and Barnsby (1988).

Measurements of both dry weight of sediment and ashed weight of sediment from all the samples were undertaken. The effects of water loss from iron salts was investigated and found to be insignificant in the samples tested.

Various operational aspects of the main were investigated. The rate of flow while sampling and the pressure in the sampled main were recorded in the field. Information regarding the air-scour and scrape and reline history of sites and pipe material were obtained from Water Authority personnel. Using network analysis and the plans of the system, crude measures of the 'age' of the water (time taken to travel from treatment) and the consumption rate in the main (index of residence time in each pipe length) were calculated.

Each of these measurements was classified for use in the analysis in Chapter 6.

Chapter 5) Taxonomy and life histories of infesting animals.

During the course of the experimental work on the distribution system, reservoir and taps, a total of 37 taxonomic groups were separated. The most frequent groups were identified to species where possible, though not all were used as species in the subsequent analysis. The life histories and ecology of each taxa and the literature relating to their role in infestations of distribution systems and methods of control are reviewed.

The life history of chironomids in natural conditions is described and related to possible means of access to the distribution system by these animals. The control of problem species, notably *Paratanytarsus inquilinius*, found in the distribution system is outlined. A total of 17 larval genera of Chironomidae were found in the distribution system studied, along with pupae of Orthocladiinae, Tanytarsini and the *P.inquilinius* complex (which contained eggs in the pupal exuviae).

Asellus were rare in the study area but have been the cause of severe infestations and still appear in other distribution systems in the U.K.. The life cycle of *Asellus* under natural conditions indicates that penetration of treatment by viable eggs (a feature long thought impossible by the water industry) is possible. Past and present control methods are discussed. The apparent success of control is indicated by the few occurrences of *Asellus meridianus* during the study, though whether these animals were the remnants of a past infestation or the colonisers for a new infestation is unclear since previous animals were never identified to species.

Oligochaetes from the system were identified to family only, naids of the *Nais communis/variabilis* group being the most abundant. These animals reproduce in the system by asexual budding as well as sexual reproduction and hence infestation can be rapid if a suitable environment is present.

Other taxa include smaller animals which can be present in very high

densities. Cyclopoids and Chydorids being the most abundant. Cyclopoids in the system include both benthic species and species that penetrate treatment as numbers increase in the raw water. Chydorid Cladocera are found with eggs thoughout the year and are reproductive in sites following only a two month period between flushes.

Three different types of Acarina were present, Hydracarina, Halacaridae and Tyroglyphidae. The Halacaridae were the most frequently occurring and numerous, and are likely to penetrate from populations in the sand filters rather than the raw water. The Hydracarina show a seasonal pattern of penetration and are linked with the raw water density.

Various less abundant groups, the nematodes; Ostracoda; Mollusca and Tardigarada are also discussed briefly.

Chapter 6) Correlation of community structure with environmental and operational parameters.

Using the sampling methods devised in Chapter 2, a number of sites throughout the system were sampled during June and October 1987 to determine the relationship between the community and the environmental conditions found in the system.

Since flow regimes in the system were not always over the recommended 7.0 l s^{-1}, analysis was carried out on two data sets, animal density per unit pipe length and relative density. The relationships between taxa and between taxa and environmental parameters were investigated using Kendall's rank correlation coefficient (Kendall 1970). Age of water and consumption rate showed some relationships with a number of taxa, suggesting distance from treatment and turnover of water in the pipe have an effect on the community structure.

The data was clustered on the basis of the community structure, using Ward's method of hierarchical cluster analysis (Ward 1963) and dendrograms were produced that showed sites with similar community characteristics did cluster together. Five community types were distinguished from the samples: few species in low densities; naid worm dominated with low densities of chironomids; *Chydorus* dominated; *Paracyclops* dominated; and Chironomid dominated. Attempts to fit the environmental data to these dendrograms proved inconclusive and led to an alternative method of analysis being attempted. Sites were clustered on the basis of environmental parameters and the dendrogram was labelled using density of chironomids, naids and *Hydrobia*, the major problem species in the system. This method did indicate links between particular taxa and the clustered communities based on environmental and operational parameters.

Chapter 7) Investigation of succession and colonisation by examination of community structure under different regimes of flushing.

The effects of seasonality on the recolonisation of sites were determined by sampling a number of sites at different frequencies of flushing. A change from rapid gravity filtered water to slow sand filtered water at half the sites enabled a direct comparison of the effects of two different treatment processes on the community structure and on how animals penetrating treatment affect recolonisation.

The results for sites sampled on two, four, six, and more than six monthly basis are discussed on a taxonomic basis for each site and a general discussion of each taxonomic group is included. It appears that sites which are far from treatment recover to a greater degree than sites which are close to treatment (in travel time). *Acanthocyclops robustus* and Hydracarina appear directly related to the penetration of treatment by animals in the raw water and are seasonal in their appearance. The difference in recolonisation between sites following the change in treatment methods was marked. Far fewer animals recolonised at sites which changed to slow sand filtration, due to less animal penetration and less organic material in the water produced from the slow sand filters.

Chapter 8) The effect of frequency of disturbance on species richness, diversity and density of 'problem taxa'.

The frequency of disturbance by flushing and the population growth rate was assumed to have an effect on diversity and species richness (Huston 1979). The hypothesis of intermediate disturbance (Huston 1979) is discussed and the data from the experimental work in Chapters 6 and 7 is considered with regards to this model.

Various environmental parameters are considered as possible measures of population growth rates, but the results of fitting the data to the model are inconclusive. However, graphs of diversity and taxonomic richness with the frequency of population reduction (flushing) suggest the data is uniform and that a competitive lottery is occurring rather than a successional sequence.

The effect of frequency and disturbance on density in the mains were considered using particular problem taxa, the Chironomidae. The aim to determine whether a relationship exists so that for a particular environmental parameter and flushing regime, animal density can be predicted, enabling management at an appropriate flushing frequency to reduce levels. Attempts to fit the data to any such model proved inconclusive due to the biased nature of the data used in Chapter 7. The possibility of such a model being applied following research using a controlled system is discussed.

Chapter 9) The relationship between animals in the distribution system and animals emerging at the tap.

The importance of establishing the links between consumer complaints and animals emerging at the tap is discussed. A number of sites were sampled during 1988 using Norgren Filter Units. Two measures of animals at the taps, the index of emergence and the degree of infestation, were devised to aid comparison of the data between sites.

Results showed that water from S.S.F. was generally of better quality than that from R.G.F. with fewer animals. Water from R.G.F. showed particular species followed seasonal patterns as found by Chapter 7. The rate of flow through the tap did not have any significant affect on the density of animals emerging and the effects of seasonality and pyrethrin dosing are discussed.

The degree of infestation at sites did show seasonal variation increasing in June to September despite pyrethrin dosing in May. Four sites were examined on the basis of the degree of infestation in the main as well as at the tap. These sites indicated that a direct relationship between the emergence of taxa at the tap and their density in the pipe is likely. Of the four sites sampled at the tap and the main, one site was distinct from the remainder - this site being considerably closer to treatment than the other three.

Chapter 10) The role of Reservoirs and Service Towers.

A qualitative investigation of the fauna of reservoirs and service towers was undertaken from samples collected during cleaning operations during 1985/86. The occurrence of many species was widespread and each taxon is discussed.

A method of producing a relative measure of animal density in service reservoirs was devised, using a perspex trap (Schindler 1969) normally used to sample the water column. In this instance the sampler was used to collect information about both the water column and the sediment floc layer at the bottom of the reservoir.

Four in-line reservoirs were sampled during 1988 using this method to produce a relative measure of animal density at each site. The community in service reservoirs was found to differ with distance (in time of travel) from the treatment works. Those reservoirs close to treatment were under the influence of the animals penetrating from the raw water, while those at some distance from treatment were under the influence of the distribution system itself. Benthic animals did penetrate treatment in low numbers but did not become established at those sites near to treatment. Copepod nauplii and adults that penetrate from the raw water were able to survive passage through the system and seeded the

distribution system seasonally with both living and dead animals.

The absence of chironomid larvae and adults from the reservoirs studied suggests that these were not sites where chironomid larvae are reproducing. Sediment build up seems to have a major role in determining the community present in the reservoirs. The taxonomic richness of the qualitative data was considerably greater than that found during the quantitative sampling of the 'cleaned' reservoirs.

PART I: INTRODUCTION

CHAPTER 1) INTRODUCTION AND STUDY SITE

1.1) General Introduction.....2
1.1.1) Public health consequences of infestations...3
1.1.2) The nature of infestations of potable water..3
1.1.3) Objectives of the project.....4
1.2) History of Infestation Problems 6
1.2.1) Water treatment methods.....7
1.2.2) Penetration of organisms and food sources....8
1.2.3) Bacterial colonisation of the distribution system.....9
1.2.4) Methods of control.....9
1.3) Preliminary Survey of infestation problems in the U.K.....10
1.4) Study sites and description of system.....13
1.4.1) Northampton Supply Zone and Pitsford Supply Zone.....13
1.4.2) Ravensthorpe Supply Zone.....21
1.4.3) Wing Supply Zone.....21
1.4.4) The Distribution System.....22
1.5) Extent of Infestation prior to research.....22
1.6) Consumer complaints.....23

CHAPTER 1) INTRODUCTION AND STUDY SITE

1.1) General Introduction

The problem of animal infestations in water supply is widespread but little understood. The various Water Authorities and Water Companies accept that animals do exist in the mains but only privately acceed to the scale of the problem. Despite water treatment, in supply areas where the water is from a surface source (river or reservoir derived) rather than from a ground source, there are invariably invertebrate infestations of the distribution system.

These infesting invertebrates are known to exit at consumers' taps, sometimes in considerable numbers, leading to complaints which frequently result in bad publicity for the water undertaking concerned. Infesting animals may also cause taste or discolouration problems resulting from stained carapaces or frasse.

The problem in this country is not a health hazard (see section 1.1.1), but the exit of an animal at a consumer's tap can be very disturbing, and the cost of controlling infestations, particularly of noticable invertebrates such as *Asellus aquaticus* Linn. and chironomid larvae, may be considerable.

In 1982, The U.K. Department of the Environment acted on the EC directive relating to the quality of drinking water intended for human consumption, publishing circular 20/82 (Anon 1982). This circular relates to the quality of water emerging from the consumer tap and states, under the microbiological parameters section, that:

> " Water intended for human consumption should not contain pathogenic organisms . . . . .
> . . . nor should such water contain:
> - parasites
> - algas
> - other organisms such as animalcules "

Replies to a circular letter sent by this author to water undertakings in the U.K. in 1986, and discussion with the Water Research Centre (WRc) and staff on the Water Industry Training Association course I.31 'The control of animal infestation in water mains' resulted in the realisation that this parameter is unlikely to be met by many river or reservoir derived supplies in the U.K.. If this is indeed the case, any research applied to this problem will be of value since attempts will be made in the future to allocate an acceptable level of 'animalcules' as their total removal will not be feasible.

1.1.1) Public Health consequences of infestations

Markall and Barham (1987) stated that there is no direct threat to public health in the U.K. from infesting animals. However, Chang (1960) suggested that nematodes pentrating treatment may be able to carry viable bacteria in their gut. Levy *et al.* (1986) found that bacteria were associated with four animal groups present in an American distribution system. Their study indicated that the greatest number and diversity of bacteria were present on amphipods in the pipes. This was linked to the relatively large size (compared to the other infesting animals) and benthic habit of this group. The amphipod in question, *Hyallela azteca* Saussure, permitted the passage of coliform bacteria through treatment, and release a viable form in its faeces. The chance of animals containing bacteria and penetrating treatment is not high, since levels of coliform bacteria are reduced in storage reservoirs, but does exist. Koojimans (1966) commented that tropical species of *Cyclops* are suspected of carrying the Guinea worm parasite. This problem was considered recently by Cairnross and Tayeh (1988) who linked records of occurence of dracunculiasis (Guinea worm disease) with dry season water supply in the Sudan. Cairnross and Tayeh found that ground water sources (boreholes and wells) produced significantly fewer cases of the disease than water surface sources (river derived) but pipe systems were not considered in the study. If a storage reservoir was to contain contaminated cyclopoids, it is possible they could penetrate and survive treatment to be taken in drinking water from the tap.

1.1.2) The nature of infestations of potable water

The community present in the distribution system, resembles the hyporheos described by Gledhill (1985), (A mixed community where surface freshwater organisms mix with subterranean forms.) but lacks "surface organisms" in any number because of their inability to survive without light or airspaces.

It is assumed by the water industry that the source of infestations in the distribution system is usually benthic animals penetrating treatment works, surviving and breeding in the distribution system and thus establishing a population of a size which may lead to consumer complaints (Collingwood 1970).

Available control methods, both physical (see section 2.2) and chemical (pyrethrin dosing) are successful locally. However, these methods fail to totally eradicate infesting animals once they become established in a pipe system. Reinfestation, particularly from dead ends (small diameter pipes which do not carry water into other pipes and hence have no through flow) at the extremities of the system is common (Mitcham

and Shelley 1980).

There is a lack of correlation between those animals penetrating treatment and those present in samples from parts of the distribution system, (Barham 1985, Evins and Greaves 1979, Greaves and Evins 1972) suggesting that the survival of animals in the system is influenced by the characteristics of the system rather than by the numbers penetrating treatment. The initial stages of reinfestation may be directly related to the animals penetrating treatment, some of which are able to establish a population in the mains. Infestations may be self-sustaining, with animals feeding on iron bacteria lining the inside of the pipes. H.P.Moon (cited in Macan & Worthington 1972) examined the gut contents of *Asellus* from distribution systems and found the presence of iron bacteria. Other evidence (Collingwood 1970) suggests that organic input through treatment is a major factor in sustaining the populations of infesting animals in the mains. The various factors which may affect the presence and numbers of infestations are shown in Figure 1.1).

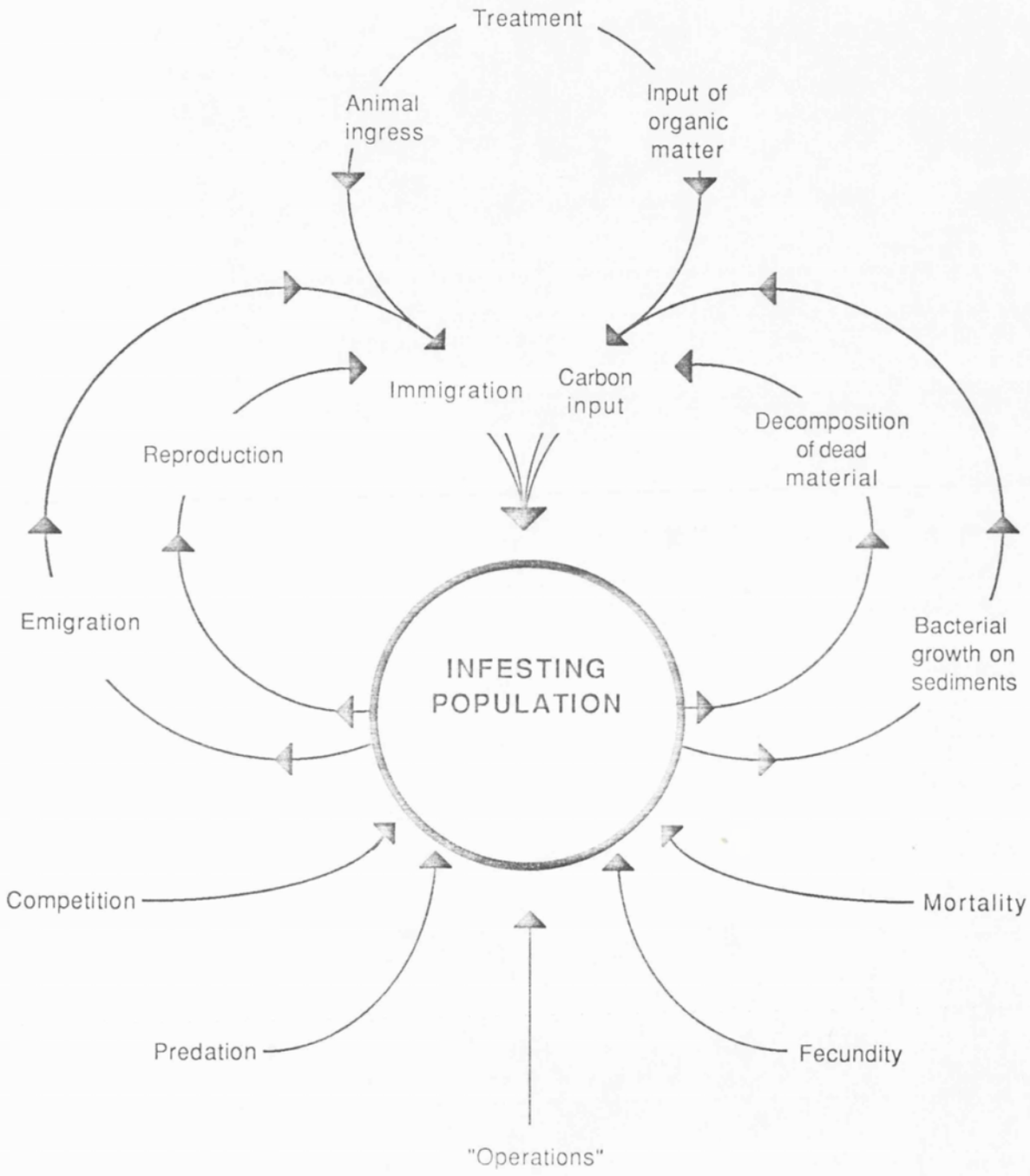
1.1.3) Objectives of the project

This project was concieved with the following ideal objectives:

1) To develop quantitative sampling methods for distribution systems including mains, service reservoirs and towers.
2) To determine the relationships between the operational and physical characteristics of water mains - construction, material, condition, age, etc. - and animal infestation.
3) To determine the effect of treatment works final waters on animal infestations of mains, in particular to identify the principal food sources of the mains fauna.
4) To develop survey strategies for the monitoring of levels of infestation, to guide the derivation of quality objectives.

Bearing in mind the complexity of the ecosystem and the difficulty of working in a pipe network designed to maintain an uninterrupted supply of water to the consumer, the project aim was to investigate various aspects of the system determining which features affect infestations. Indication of the relative strength of the interactions shown in Figure 1.1 will provide information for more detailed future studies of the major factors influencing the distribution system.

Fig.1.1) Model of the pipe ecosystem and factors influencing infestation populations



1.2) History of Infestation Problems

Animal infestation of water mains is not a well researched subject. A large number of species of aquatic animals have been recorded from mains (Smalls and Greaves 1968, Kooijmans 1966) including some vertebrates, such as eels. Coe and Elvidge provide a concise summary of the problem in Chapter 10 of The Water Practice Manual 4 (Brandon 1984) with recommended treatment methods but no references to the cause and effects of animals in mains. More details regarding methods of investigation of infestations appear in Water Research Centre (WRc) publications (Ainsworth [ed] 1981, Williams *et al.* 1986).

Animals in water supply have been a subject of considerable concern since the problems of infestations in the Hamburg drinking water supply were outlined by Kraepelin during the 1800's. This work, summarised in Hastings (1937), on an unfiltered supply, found that the street mains were simply an extension of the River Elbe, from which the water supply was taken. Kraepelin's examination did indicate that conditions in the mains were not always the same as in the river, and that during the winter months, when the river life was dormant, animals in the mains continued to flourish. The introduction of sand filtration in 1894 led to the death of the pipe population, presumably due to lack of food (Hastings 1937).

An early British infestation, involving *Polyzoa*, 'pipe-moss', occurred in Torquay in 1910, (Chapman 1913) when a high quality unfiltered water was suddenly found to contain animals, which led to blockage of valves and water meters. This infestation was traced to a storage reservoir where *Polyzoa* were believed to have been introduced from the feet of birds. Again the problem was solved by the introduction of filtration.

Just as initial infestation problems were solved by filtration, so a second stage of infestations was solved by a simple restriction of access. Many undertakings suffered from severe infestations by chironomid larvae, which emerged in considerable numbers from taps (Bahlman 1932, Ingram and Bartsch 1960). These problems led to the development of chemical control methods (Flentje 1945, Silvey 1956), but invariably these infestations were the result of uncovered service reservoirs or storage tanks in the system.

In the U.K. during the 1950's and 1960's, attention focused on infestations of predominantly oligochaetes and *Asellus aquaticus*, which created serious problems in some systems (Kelly 1955, Houghton 1968). These were resolved by treatment using pyrethrin which enabled the dosing of entire systems without interrupting supply to consumers.

More recently, severe infestations involving the parthenogenetic chironomid *Paratanytarsus iniquilinius* Krüger (Williams 1974), have been a problem in the U.K.. These animals have also been controlled by pyrethrin (Burfield and Williams 1975), and more recently permethrin, but infestations rarely appear to be cleared. Reinfestation by various taxa is frequent and can be rapid, with surviving animals in the system and penetration of treatment both playing a role.

1.2.1) Water Treatment Methods

Potable water in distribution systems can come from two sources, ground water or surface water. Ground water has never been recorded with infestations present (unless mixed with surface derived supplies). River water is often stored in reservoirs in order to ensure a reliable year round supply. Storage also reduces the bacterial numbers relative to river water, aiding water purification. However, storage alters the animals and plants associated with the water and neccessitates treatment of the water to remove phytoplankton and zooplankton.

The first slow sand filter became operational in 1829 and the majority of potable water is now subjected to some form of filtration process. These water treatment systems are designed to purify the water; to remove taste and odour; and to remove the possibility of bacterial growth in the system, (notably coliform bacteria, which are broken down during the treatment phase). They include systems such as microstrainers; sedimentation tanks; rapid gravity filters, pressure filters and slow sand filters (Rowlands 1982, Twort 1985).

Microstrainers are often used prior to filtration by the processes described below. These microstrainers consist of a large drum filter, (usually between 20 - 60 µ in mesh size) with an open end, into which the raw water is fed. The drum spins and is backwashed at different rates depending on the rate of rotation.

Slow sand filters rely on the presence of the 'Schmutzdecke', a layer of bacteria, algae and zooplankton, on the top of the filter bed, which actively filters the water. Solids are removed in the top 25 mm of a bed of sand between 400 and 600 mm thick. As the filter becomes clogged the flow rate drops and the top layer is 'skimmed' to restore filtration rates of 2 - 5 m^3/m^2/day. Slow sand filters use no chemical coagulants, have a high water quality which tends to be uniform, but suffer from a low rate of flow, poor colour removal and the possibility of collapse, which then allows both the 'Schmutzdecke' and the organisms in the raw water access to treatment.

A column of sand acts as the filter in rapid gravity filtration where the entire column of sand (750 to 900 mm) is used. When the filter

becomes clogged, the sand column is backwashed to restore rates of flow of 150 m^3/m^2/day. The major disadvantage of this system is that filters block rapidly without some form of preceding filter system, particularly when algal blooms occur.

The latest treatment works include a method of 'flotation'. Wilkinson et al. (1980) described the various aspects of treatment at Bewl Bridge Treatment works in Kent and how each treatment affects the density of phytoplankton and zooplankton in the water. They concluded that air flotation was more successful at zooplankton removal than sedimentation or filtration.

1.2.2) Penetration of organisms and food sources

Penetration by invertebrates, algae and organic material provides both the benthic colonisers and a food source for the organisms in the system. Collingwood (1977) suggested rapid sand filtration (rapid gravity filtration) is more susceptible to penetration than slow sand filtration, and Rowlands (1982) indicated that with rapid gravity filtration final water quality is more variable than that from slow sand filters. This confirms the observation of Houghton (1968) that a change from slow sand filtration to rapid gravity filtration led to an increase of available food in the final water, which resulted in a severe infestation of *Asellus aquaticus* in the South Essex system.

The quantity of organic material used by animals in the system has not been established, but Collingwood (1970) calculated that at a treatment works with an average algal penetration, there will be sufficient organic material available per year to support a population of 4-5 *A.aquaticus* per metre length of pipe in a 1100 km. system. Other possible food sources are discussed below and in Chapter 5. Scott (1975) suggested that water-bourne organic material has a significant role as food. His study of storage reservoirs in Gwent showed that the main areas of infestation were linked to supplies from one reservoir, either directly or as a supplementary source.

Other means of animal penetration are known. Hart (1957) suggested that the infestation in his study was caused by faulty ball valves on water from a previous source, certainly access to the system is possible in this manner. Terrestrial invertebrates and vertebrates also gain access, through faulty service hatches in storage reservoirs and during mainlaying or repairs, but treatment penetration is the most likely origin of colonising infestation animals.

1.2.3) Bacterial colonisation of the distribution system.

It is important to consider the process of microbial succession within the system, since this is a potential food source. Olsen and Nagy (1984) predicted microbial succession occurred in four stages resulting in the formation of a stable biofilm within the pipe.

i) Absorption of organic molecules onto solid surface.
ii) Adhesion of molecules onto this 'conditioned' surface.
iii) Formation of biofilm at interface.
iv) Dynamic equilibrium (growth equivalent to destruction) of biofilm.

Kooijmans (1966) suggested the biofilm is in turn followed by 'grazing' protozoa; anaerobic bacteria and macroinvertebrates.

Olsen and Nagy (1984) suggested a direct relationship between the total organic carbon (T.O.C.) in water supply and colony forming units of bacteria. As bacterial numbers and oxygen consumption increase, the increase in oxygen demand leads to a drop in the chlorine residual in the system, enabling an increase in the survival of bacteria. Tetlow and Hayes (1988) suggested that within a system the chlorine residual drops off rapidly, stating that in systems they have studied, a drop (from residual levels of 0.5 mg l^{-1}) of as much as 90% occurs within one day after entry into the system. The microbial status of the system will affect any attempt at animal control within the mains using chlorine. Many filamentous fungi are resistant to chlorine and actinomycetes may be able to recover in the presence of chloramines, an alternative method of treatment (Olsen and Nagy 1984).

Allen *et al.* (1980) reported that studies of the microbiology of the system frequently underestimate bacterial numbers because tuberculations are not taken into account. These have higher bacterial populations than the distribution waters, and actinomycetes frequently present at their surface. Lee *et al.* (1980) used a simulated pipe system to study the effects of bacteria on the corrosion of pipes. They reported water with a T.O.C. of less than 0.5 mg l^{-1} is capable of supporting 10^7 to 10^8 viable organisms on sediments in a 0.3 m test section (2.5 cm diameter). This indicates that as well as organic detritus from treatment, bacteria are present in large enough numbers to be a food source for infesting animals.

1.2.4) Methods of Control

Treatment methods involving chemical dosing are widely used (Sands 1969, Evins 1980) by water undertakings in this country. Koojimans (1966) listed the concentrations of chlorine and copper sulphate which have been

used in the past to control infestations, and a review of many methods of treatment used for different animal groups (Smart 1987) is summarised in Table 1.1. However little is known about the 'true' efficiency of control methods, other than the results of laboratory toxicity tests (Mitcham and Shelley 1980, Edwards and Learner 1963) which may have little relevance to the environment within the distribution network, or the application of such control methods.

The available methods for control are discussed at some length by WRc. publications (Ainsworth [ed.] 1981, Williams *et al.* 1986). Various mechanical operations are used (described in section 2.2) on a regular basis, notably flushing and air-scouring of mains. Many undertakings also use scrape-and-relining to repair badly corroded cast iron mains in the system and remove the habititat frequented by infesting organisms.

Chemical methods widely used are chlorine, pyrethrin and permethrin dosing. Chlorine residuals restrict microbial activity and are reported to aid animal infestation control, but Ainsworth *et al.* (1980) examined water samples from various distribution systems and found only 15% contained free chlorine, these being mainly ground water supplies. It appears from information within the industry, that ground water supplies only become infested where supplies are mixed with surface water sources.

Pyrethrin has been used successfully against *Asellus aquaticus* and Chironomidae on a large scale by several undertakings. This large scale treatment appears neccessary because of problems with *Asellus* reinfestation on a smaller scale. Information from water undertakings in the U.K. suggests most consumer complaints regarding animals relate to *Asellus*. Infestations by *Asellus* are now effectively controlled using permethrin (which requires no dechlorination) but *Asellus* removal can lead to an infestation by other taxa such as oligochaete worms (Phillips 1960), or water mites (Mitcham and Shelly 1980), if not followed by flushing. This suggests a need to understand the ecology of the system in order to manage the community to maintain populations of all taxa at levels below those which cause complaints.

1.3) Preliminary survey of infestation problems in the U.K.

A written request for information on animal problems was circulated in 1985 to all water undertakings and regional councils involved in water supply throughout the U.K.. Replies indicated that the problem is widespread, though many undertakings were unable to provide any information.

Numerous animals have been recorded (see Chapter 5) and one undertaking has established that complaints peak in July and October. (see section 1.5).

TABLE 1.1) SUMMARY OF TREATMENT PROCEDURES CITED IN SMART 1987

Key:
+ : successful
- : failure to remove
* : rapid reinfestation following
? : unknown

TAXA	CONTROL PROCEDURE					
	$Cu/CuSO_4$	Chlorine	Chloramine/ Copperchlorine-ammonia	Pyrethrin	Permethrin	Other
Nematodes		24p.p.m. 100min Crabhill (1956) + 20p.p.m. 2.5hrs Collins (1958) +				Prechlorination before filters. Mott (1981) + 1% saline Collins (1958) +
Oligochaetes	1p.p.m. and 1.5p.p.m.24hrs Jobling (1964) + 1p.p.m. 6hrs Edwards and Learner (1963) +	5p.p.m. 17min Collins (1958) + 20p.p.m. Jobling (1964) + 0.5p.p.m. Hart (1957) + Edwards and Learner (1963) +	2p.p.m. Collins (1958) + Crabhill (1956) +			1% saline 50min Collins (1958) + 1% saline Edwards and Learner (1963) +
Cladocerans		2p.p.m. Hart (1957) +	Crabhill (1956) +	Mitcham and Shelly (1980) -	Mitcham and Shelly (1980) +	
Copepods	English (1958) +		Crabhill (1956) + (* due to treatment)			

Table 1.1) continued

TAXA	CONTROL PROCEDURE					
	$Cu/CuSO_4$	Chlorine	Chloramine/ Copperchlorine-ammonia	Pyrethrin	Permethrin	Other
Amphipods				Crowther and Smith (1982) *	Crowther and Smith (1982) +	Flushing. Smalls (1965) + *
Isopods			Holland (1956) reproduct. + Collingwood (1964) reproduction +	Oliver (1961) + Hart (1957) + Turner (1956) +	Abram et al (1980) +	ultrasonics Turner (1956) ?
Insects		50p.p.m. Flentje (1945) +	4p.p.m. 24hrs Silvey (1956) +	3p.p.m. Flentje (1945) + Burfield and Williams (1975) + * Mitcham and Shelly (1980) + *	Mitcham and Shelly (1980) +	0.1 p.p.m. D.D.T. Flentje (1945) +
Molluscs		1.0 p.p.m Oliver (1961) + 3 p.p.m. Counts (1980) -				
Flatworms		2 p.p.m. Kelly (1955) +				

Of the 13 replies which related to animals present in supply, three were from areas supplied by ground sources. Of these three, two had no records of animals in the distribution system, and one, which had changed supply to include water from a surface source, found that animals appeared in the system at recordable levels following the change. This suggests that the role of treated water is significant in either supplying the initial colonisers of systems, the carbon input to sustain the system or both.

1.4) Study sites and description of the system

The study area was in Anglian Water, Oundle Division. It covered the three districts which make up the Western Area of the Division, Market Harborough, Daventry and Northampton. This area comprises approximately the central third of the county of Northamptonshire in England (Fig. 1.2). The Water Authority has experienced reorganisation over the period of this study and the above districts may not necessarily be current. Each district contains areas within five supply zones (Fig. 1.3). Wing, Pitsford East, Pitsford West and Ravensthorpe supply zones are fed by their respective treatment works and Northampton supply zone is fed from Pitsford, Grafham and Wing treatment works. Wherever possible sites will be referred to by supply zones (Figs. 1.4 - 1.8), which are likely to remain constant despite administrative area changes.

1.4.1) Northampton Supply Zone and Pitsford Supply Zone

Pitsford water has a capacity of 18×10^6 m^3 and the reservoir yield for supply is 36000 m^3/day (36 thousand cubic metres per day or t.c.m.d.). Water for storage at Pitsford Water is abstracted from the River Nene at Duston Mill, with 0.18×10^6 m^3/day pumped into the storage reservoir during October to April. Pitsford Treatment Works treats 45000 m^3/day and final water is fed into the Pitsford East Supply Zone; Pitsford West Supply Zone and part of the Northampton Supply Zone.

Water entering Pitsford Treatment Works from the storage reservoir is pre-chlorinated and treated with ferric sulphate to coagulate particles in the raw water. Dosing with lime stabilises the sludge blanket that forms during clarification and the water is then passed through rapid gravity filters which operate at 50 litres/m^2/hr. The treatment works has eight filters of both graded sand and anthracite and sand. Following filtration, water undergoes prechlorination in Pitsford Contact Tank (2 hours contact) and before passage into the system is dosed with sulphur dioxide. This ensures a chlorine residual of 0.2 to 0.3 mg l^{-1}, resulting in a detectable chlorine level at the extremes of the system.

Fig. 1.2) Sketch map of the U.K. indicating approximate location of study area

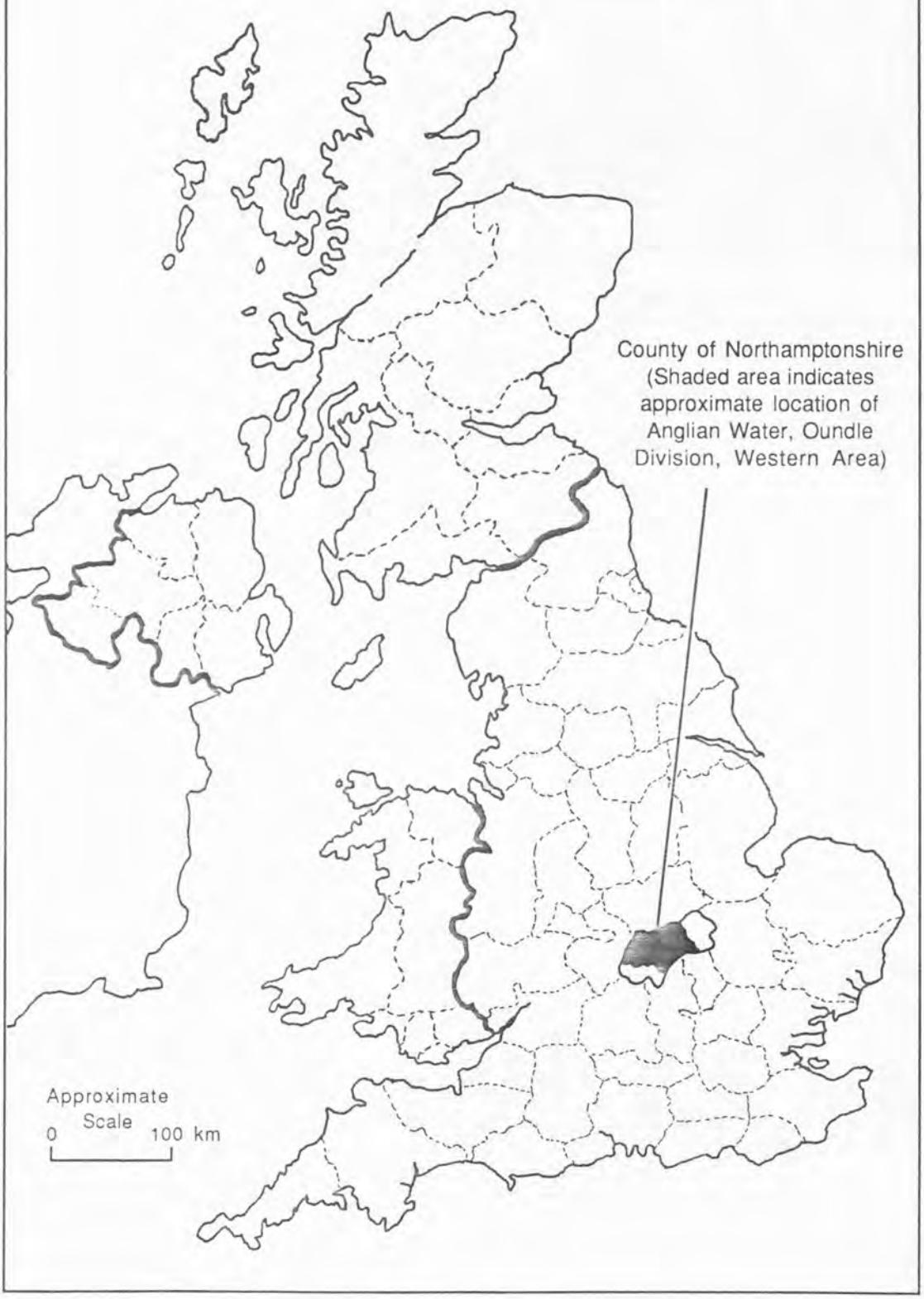


Fig. 1.3 Anglian Water, Oundle Division, Western Area

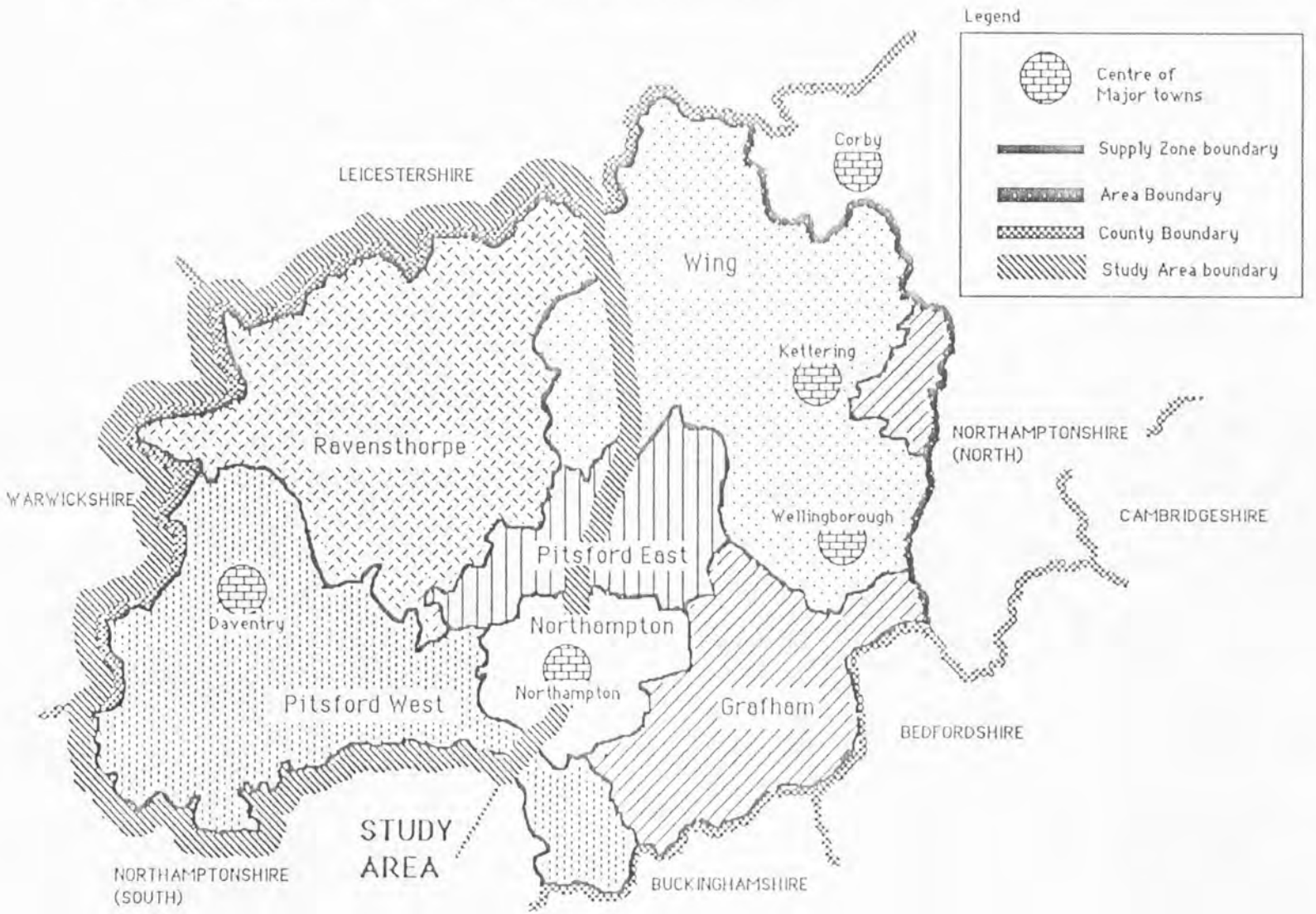


Fig. 1.4) Sketch Map of Ravensthorpe Supply Zone

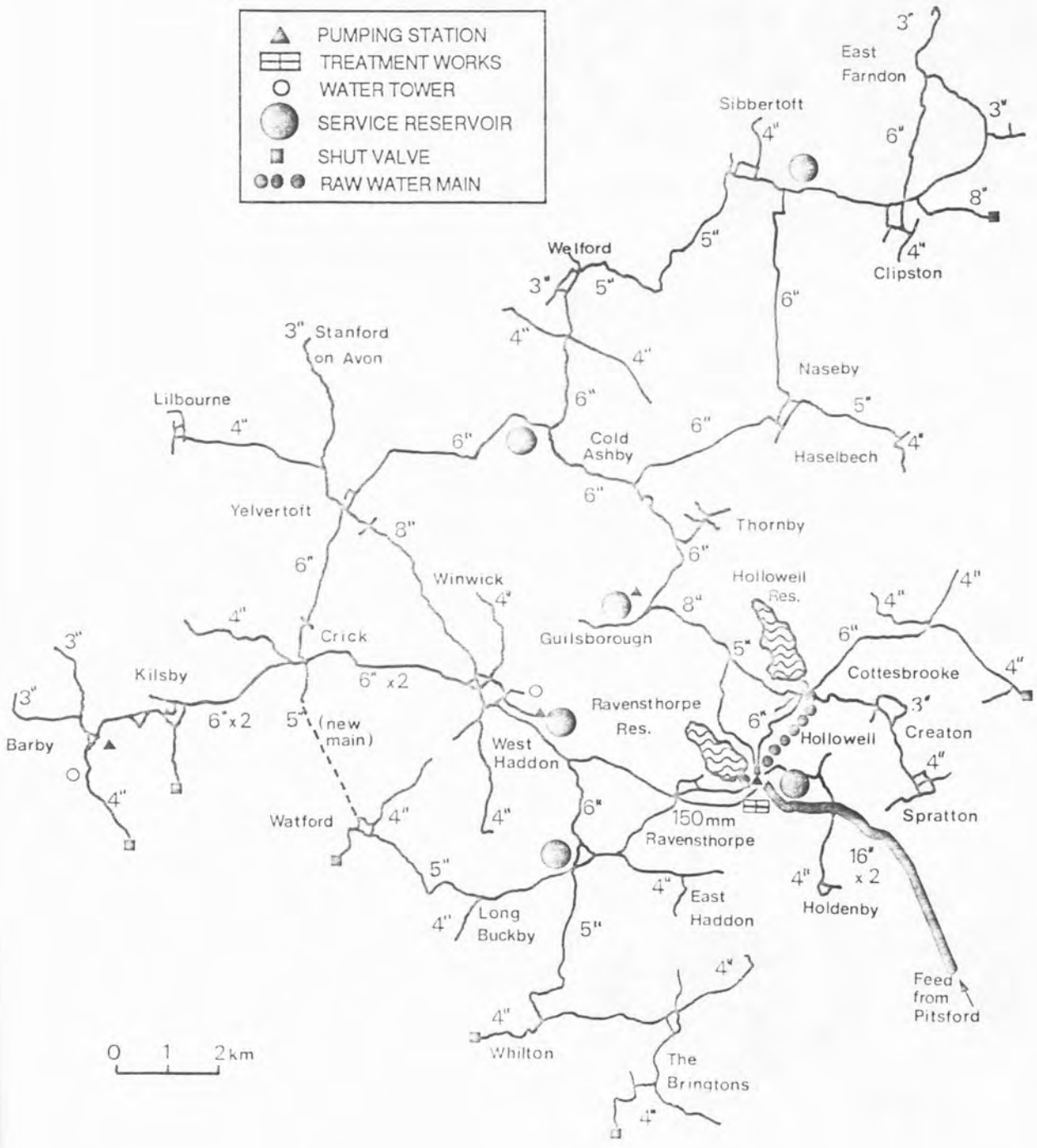


Fig. 1.5) Sketch Map of Wing Supply Zone (Area within Market Harborough District only)

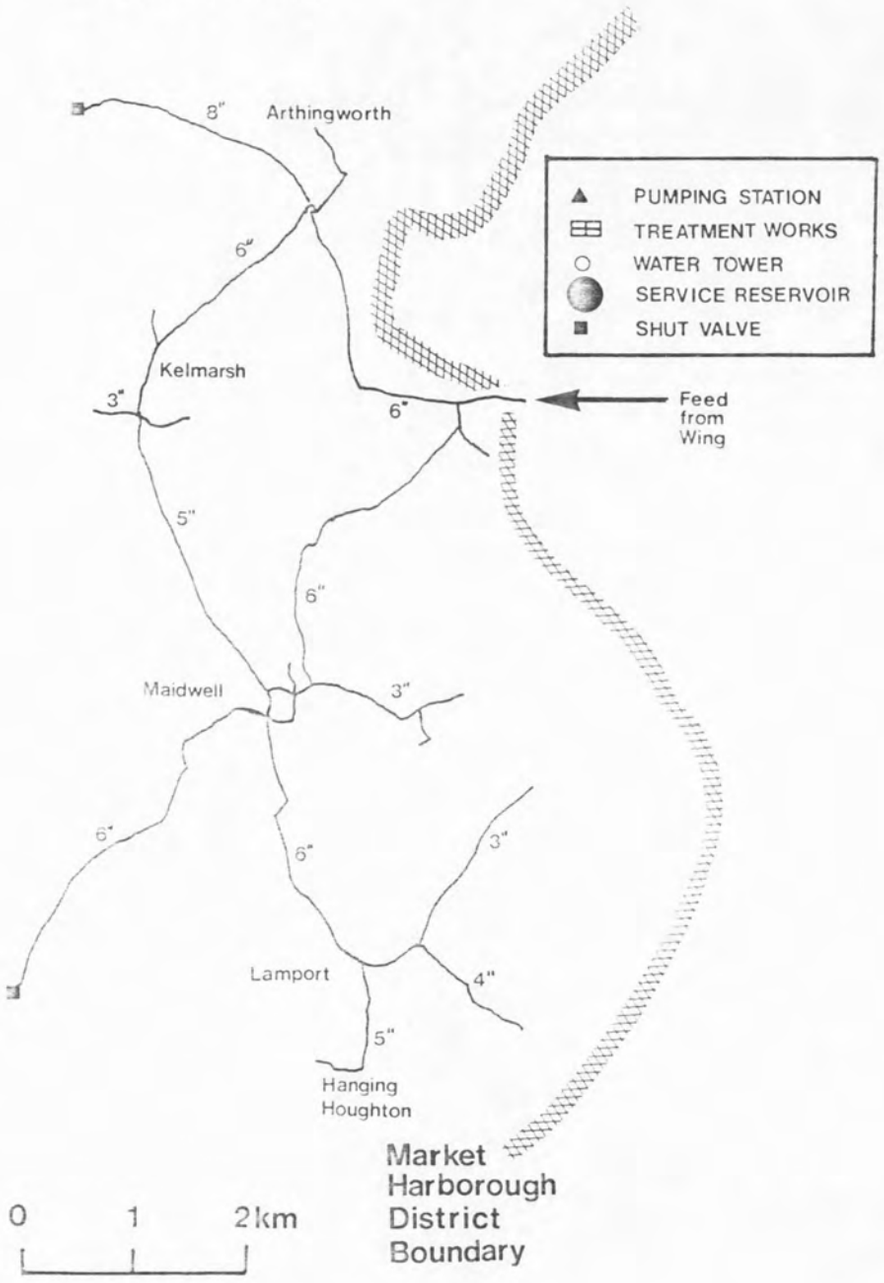


Fig. 1.6) Sketch Map of Pitsford East Supply Zone

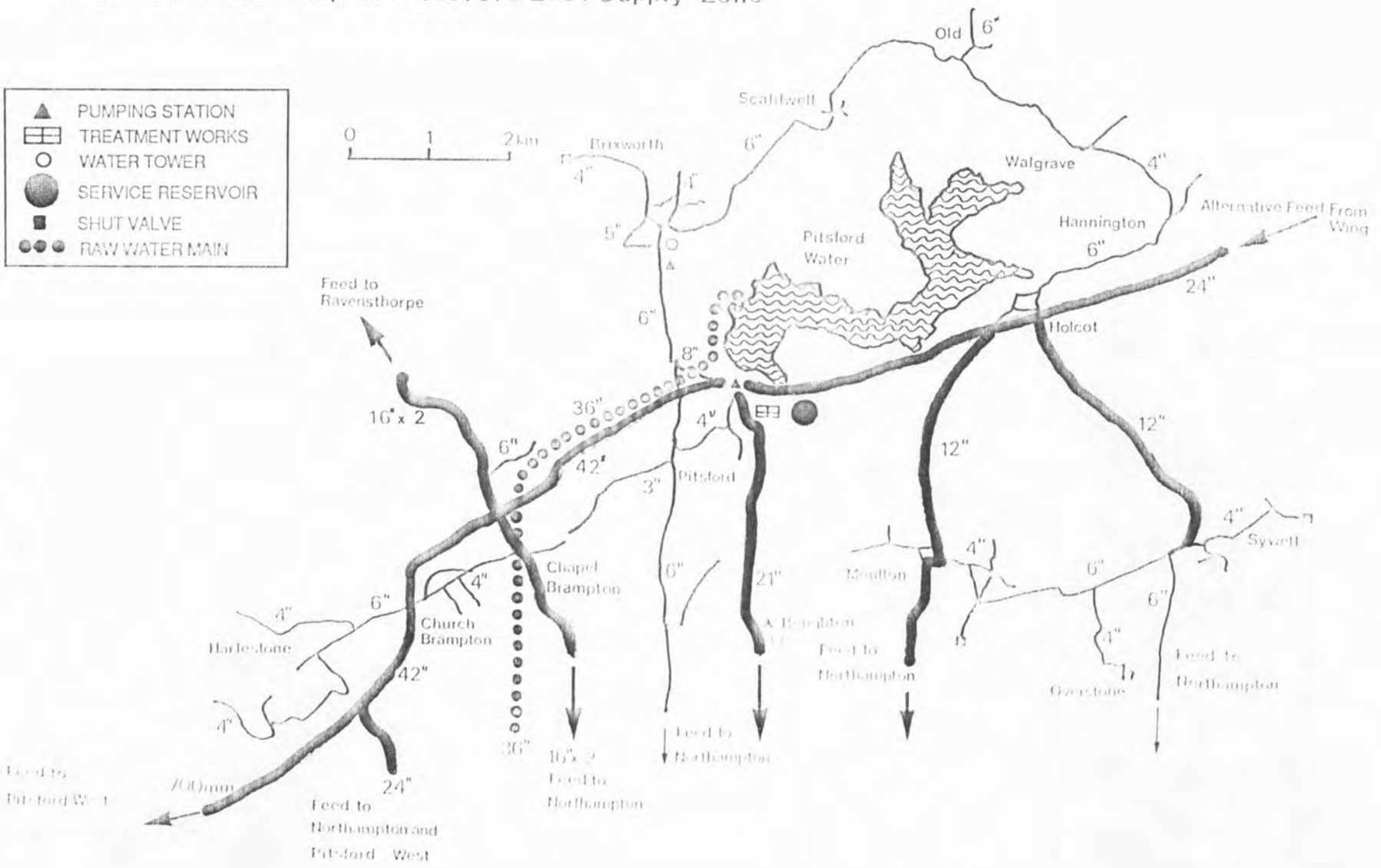


Fig. 1.7) Sketch Map of Northampton Supply Zone

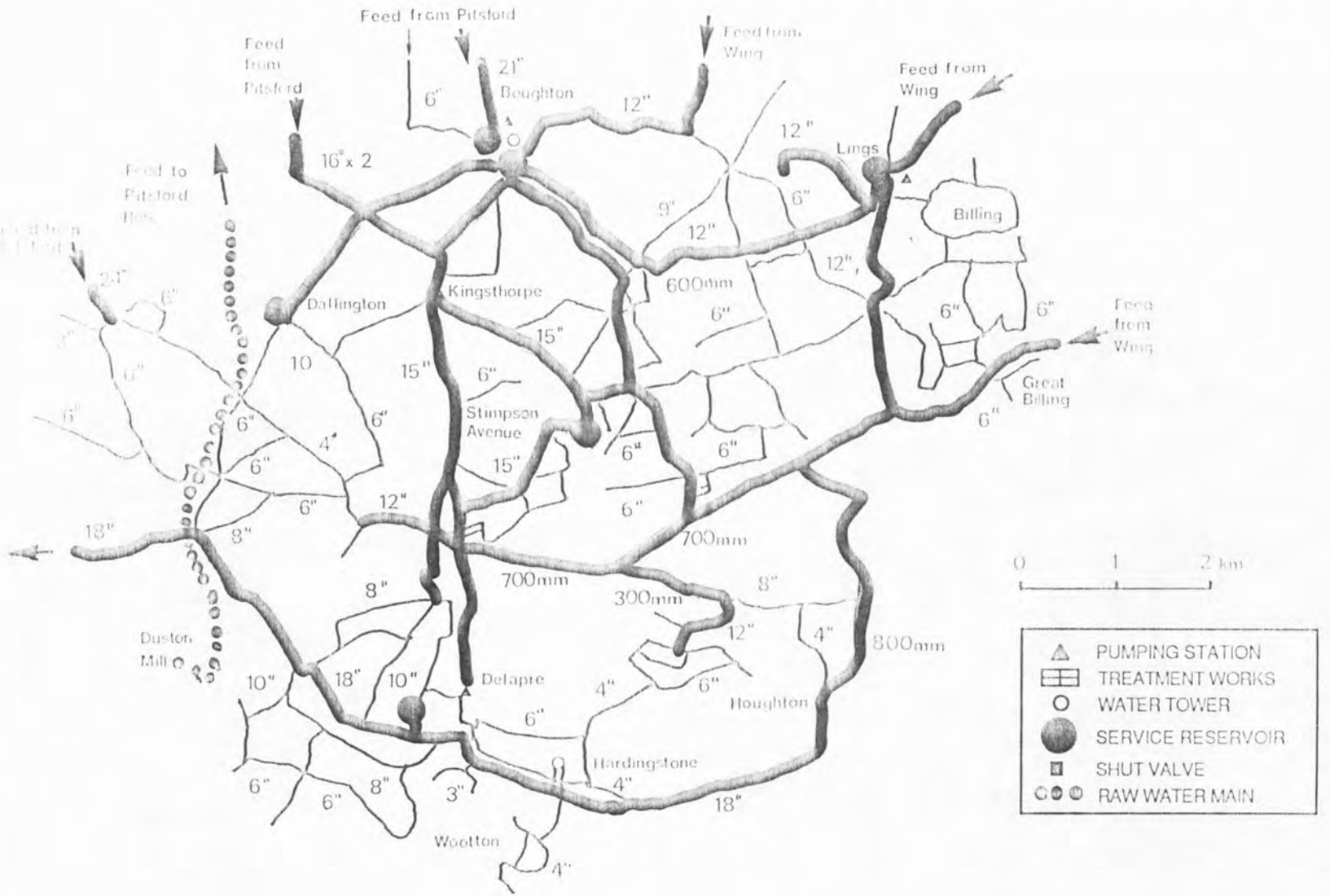
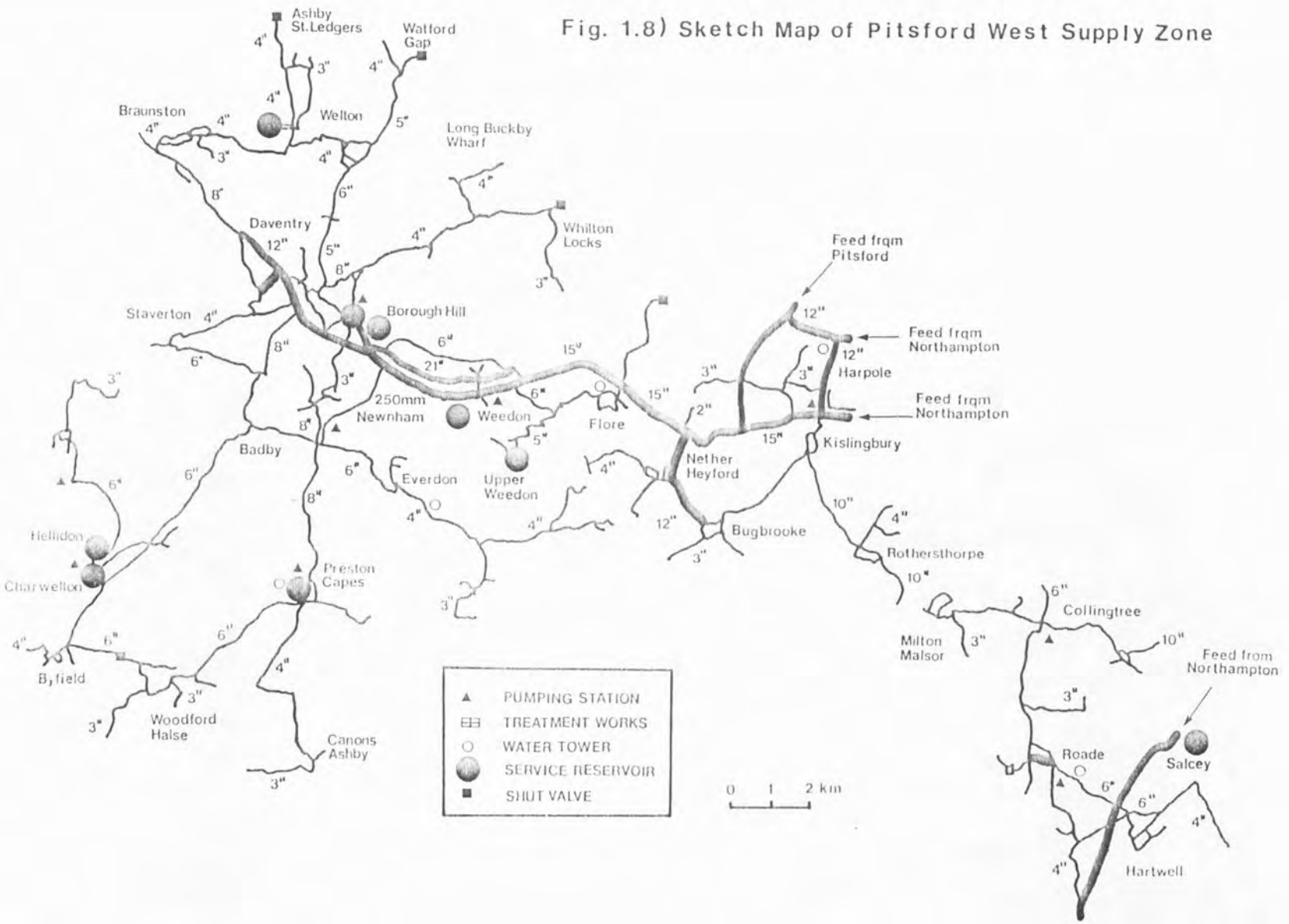


Fig. 1.8) Sketch Map of Pitsford West Supply Zone



Water from Pitsford Treatment Works is also fed to a number of service reservoirs in the Northampton Supply Zone where the water is mixed with supplies from Grafham Treatment Works and Wing Treatment Works (see section 1.4.3). Since sampling from the Northampton Supply Zone entailed working in areas with a high number of consumers (who would be removed from supply); traffic control problems; drainage problems; and mixed source water in some areas; sample sites from this supply zone were chosen on only three occasions.

1.4.2) Ravensthorpe Supply Zone

Prior to July 1987, the Ravensthorpe Supply Zone was fed with water from Pitsford Treatment Works, while Ravensthorpe Treatment Works underwent refurbishment. Ravensthorpe Treatment Works came on line during July 1987 with new slow sand filters.

The raw water sources for Ravensthorpe Treatment Works are Hollowell and Ravensthorpe storage reservoirs which have respective capacities of 2.06×10^6 m^3 and 1.88×10^6 m^3. Primary filtration takes place in a rapid gravity filter followed by slow sand filtration, where the biochemical oxidation of organic matter occurs. The water is then reoxygenated in an aeration tank, chlorinated in a contact tank and dosed with sulphur dioxide and caustic soda as required to ensure the correct chlorine residual. Finally, ammonium sulphate is added to form chloramines, which provide the disinfection of supplies and last longer in the system than free chlorine.

1.4.3) Wing Supply Zone

Rutland Water is fed from the Rivers Welland and Nene, and has a capacity of 124×10^6 m^3. Water passes through Wing Treatment Works at rates between 2.3×10^5 m^3/day and 2.8×10^5 m^3/day. Treatment consists of the addition of a coagulant (ferric sulphate) followed by lime to control the pH of the water. Carbon is added to remove any taste and odour present in the water and the addition of a polyelectrolyte at this stage aids coagulation in the upward flow pulsators (clarification). The water then passess through rapid gravity filters and chlorine is added. The water has a minimum contact time of 1 hour before castic soda is added to control the pH of the final water and ammonium sulphate is added to form a chloramine residual rather than free chlorine.

Only one site was used in the small part of this supply zone included in Market Harborough District (Fig. 1.5).

1.4.4) The Distribution System

The majority of the pipes in both Pitsford and Ravensthorpe Supply Zones are cast iron, though a considerable area in the south of the Pitsford Supply Zone has been scraped and relined (section 2.2.1), and much of the Ravensthorpe Supply Zone has been air-scoured (section 2.2.2). In many areas, the flow rates are low, either due to the distance from the source, or the topography of the area.

1.5) Extent of Infestation at the beginning of the study.

Records of 'animal related samples from distribution' from Anglian Water, Oundle Division, since 1982 indicated a number of Parishes in the Western Area which were known to have animals present.

It appears that the distribution system suffered from infestations of *Asellus* in the areas supplied by Pitsford, the *Asellus* numbers being reduced by small scale pyrethrin dosing at local sites though reinfestation often occurred. Chironomids were not associated with the Pitsford Supply Zones until the change from Ravensthorpe to Pitsford Water in the 1960's. The spread of chironomids throughout the eastern half of Oundle Division was attributed to water from Grafham Water Treatment Works in the early 1970's (A.Longhurst pers.comm.). Cyclopoids and Chydorids, had been recorded in some locations, but from the samples taken during this study these taxa appeared to be ubiquitous and were probably missed in the past where chironomids and *Asellus* have been dominant. Snails were also present at a number of locations, and were thought to be local problems. Originally only present at two locations in the system, (A.Longhurst pers.comm.) snails had been found in 7 parishes prior to this project. Snails are not killed by pyrethrin, and the high chlorine concentrations needed to kill snails would require the isolation of infested pipes from supply. Snails are renowned within the water industry for causing taste and odour problems, particularly if not removed after control.

In the Western Area of Oundle Divison, target chlorine levels aim to maintain a measurable residual in mains at the extreme of the system. These levels (often less than 0.1 mg l^{-1}) vary between and within distribution systems and are not high enough to control any infesting animals (Koojimans 1966). Permethrins and pyrethrins have been used to curb small scale outbreaks of *Asellus* using a pyrethrin dosing trailer (Morgan 1985), and were used on the entire system, with dosing at treatment, during May 1986.

No systematic flushing took place following this pyrethrin dosing. Systematic flushing during a dosing exercise is a method recommended initially by the Water Research Association (W.R.A.),(Sands 1969), to

ensure that target levels of pyrethrin reaches the extremes of the system. This was further recommended by the WRc, (Ainsworth [ed.] 1981, Williams *et al.* 1986) as a means of removing dead animals, which may cause taste and odour complaints. Target levels were not attained at numerous dead ends at the extremes of the system during pyrethrin dosing in 1986, which may have led to animals surviving and reinfesting the system. This study was able to examine a number of live samples from sites with pyrethrin present in the mains. These samples showed that despite pyrethrin being present, a total kill of animals was rare. However, it was not the intention of this project to test control efficiency and this aspect of the study was not continued.

A similar dosing of the entire system was undertaken during May 1988, after the main sampling of the study had been completed, but during the tap and reservoir work (Chapters 9 and 10).

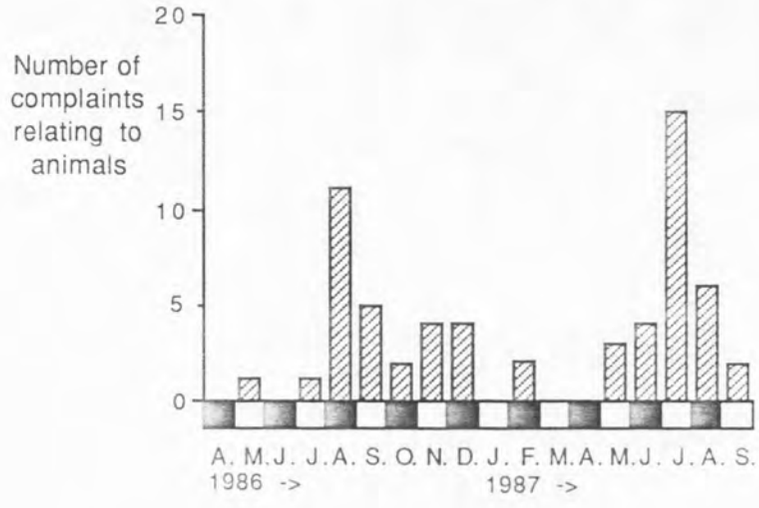
Pitsford and Ravensthorpe Supply Zones are not typical of supply zones throughout the U.K., since pyrethrin dosing has led to *Asellus* becoming uncommon compared to supply zones that have not been regularly dosed with pyrethrin.

1.6) Consumer complaints

It has proved difficult to determine the history of complaints in the area due to the lack of biological details regarding complaints. Records of 'worm' to 'frog' have been recorded as animal complaints in the past which has led to a lack of information about infestations in the records. An initial investigation of detailed consumer complaints records between 1982 and 1986 in Oundle Division provided little information; it being quite likely that the areas which indicated a high presence of animals were actually indicating the areas where tolerance to such occurrences was low. The records themselves gave little or no indication of the animals which caused the complaint (except *Asellus* on some occasions).

Between July 1986 and September 1987, quarterly complaints records supplied by Anglian Water, Oundle Division, indicated that, of all incidents reported relating to water supply (complaints regarding pressure, taste or odour, animals, discolouration, hardness or flooding of property from main), complaints about animals were never more than 1.1% of the total. The animals 'score' was never higher than 4th on the list of six, behind complaints about pressure, discolouration, and taste and odour. Despite this animal complaints are of considerable importance to the water industry. Pressure, discolouration and to some extent taste and odour can be explained away to the satisfaction of many consumers, but consumer reaction is more severe following the appearance of infesting animals.

Fig. 1.9) Animal related complaints in Oundle Division during the period April 1986 to September 1987



The complaints data relating to animals obtained from Anglian Water over this period show that despite a low number of recorded complaints, distinct peaks occur during the summer months, notably August 1986 and July 1987. Pyrethrin dosing was carried out in early May 1986, so these levels may be artificially low because of treatment. Complaints data for the same area in 1984 and 1985 was not available

The distribution of complaints in time between April 1986 and September 1987 is indicated by Figure 1.9 and shows a peak of complaints during the summer months, June to September. This may be an indication of a seasonal increase in the infesting populations, but may also be due to less water in the system during this time. This drop in water level could have affected the numbers of animals emerging at taps, but a seasonal change in the water usage habits of the consumer may have led to animals being more easily noticed during the summer even if the exit rate remained constant. The number of complaints is low, but pyrethrin dosing during May 1986 will have affected these numbers. No information was available for previous periods.

PART II: METHODS OF SAMPLING AND TAXONOMY

CHAPTER 2) SAMPLING METHODS

2.1) Introduction.....27

Section A: Reasons for use of flushing as sampling method

2.2) Available Methods of sample collection.....28

2.2.1) Scrape-and-reline 28

2.2.2) Air-scouring.....28

2.2.3) In-line traps and filters.....29

2.2.4) Swabbing.....29

2.2.5) Flushing.....30

2.2.6) Consideration of sampling methods available.....31

Section B: Sample Collection Method

2.3) Establishment of drift hypothesis.....32

2.4) Test of sampling model.....36

2.4.1) Methods 36

2.4.2) Results 40

2.4.3) Discussion.....45

2.5) Calculation of Quantitative information from the five sites used to produce the sampling model.....46

Section C: Subsampling

2.6) Subsampling technique.....48

2.7) Investigation of subsampling procedure for random distribution 49

2.7.1) The effect of varying subsample numbers.....49

2.7.2) The frequency of random distribution in samples for different taxonomic groups.....50

2.7.3) The effect of animal density and subsample dilution on frequency of random distribution in subsamples...53

2.8) Discussion.....56

CHAPTER 2) SAMPLING METHODS

2.1) Introduction

Monitoring animal infestations in water distribution systems has always been difficult because of a lack of quantitative information. In order to quantify invertebrate infestations a number of problems must be overcome. These are:

i) knowing precisely what portion of the distribution system is being sampled;

ii) being certain that all the infesting animals have been removed, and;

iii) sampling from a system designed to maintain an uninterrupted supply of water to the consumer.

The most commonly used method of sampling the distribution system for animals is to flush water and sediments from the mains at a fire hydrant. Past work in this field by the Water Research Council (Greaves and Evins 1972, Ainsworth [ed.] 1981) produced a logarithmic scale of abundance applied to net samples removed from the distribution system by flushing water for a fixed period through a hydrant. This scale of abundance is a measure of the relative severity of infestation but applies only to animal collection. The removal techniques used mean that animals collected in a hydrant net sample in this manner may originate some distance from the sampling point.

The lack of quantitative information led to the examination of a particular type of dead-end main as a means of quantifying the animals in a known length of pipe. These are small diameter mains (3", 4", 80 mm or 100 mm) which are single legs, off a large diameter (greater than 5") trunk main, with a fire hydrant at the end of the leg. Initially, large diameter trunk mains were examined and were found to contain low numbers of animals relative to small diameter legs. It is possible that animals may be present in these large diameter pipes but are not removed by flushing. This small number of animals varied between taxa and from site to site and has been termed the 'drift'.

A number of different methods for animal and corrosion removal are used by the water industry and each of these was investigated (section 2.2). The method chosen was flushing in view of its simplicity and applicability throughout any system in any water undertaking. A model of animal removal using serial flushes at particular types of sites was developed and tested to determine the quickest method of producing useful quantitative information.

2.2) Available methods of sample collection

The potential methods of sampling the distribution system and their use in this project are discussed below. More detailed information is available in Ainsworth [ed.] (1981), Williams et al. (1986) and Brandon [ed.] (1984).

2.2.1) Scrape-and-reline:

Scrape-and-reline is an operation where corroded pipes are scraped internally by a flail. A small section of pipe is removed following scraping to allow insertion of cement relining equipment. By halting the scraping process before the section to be removed was cleaned, sections of pipe were obtained in an unaltered state. These sections were capped while still wet and returned to the laboratory where all deposits inside were removed. Examinations of these deposits indicated that no animals were present. This was attributed to various possible causes:

i) Scrape-and-reline procedure meant that the length of pipe was drained before cutting, removing many animals. In the future flushing the main through a hydrant net before draining would collect the animals present.

ii) On cutting, a quantity of water still in the main, which could carry animals and deposits with it, was lost.

iii) In the area in question it was subsequently discovered that recent air-scour operations had occurred so the pipes were unlikely to contain any animals.

The method suffers further restrictions as to where samples can be taken within the system, since only certain areas of the pipe network are scrape-and-relined at any one time.

2.2.2) Air-scouring:

Air-scouring involves the isolation of a section of the distribution system by closing valves, so that a single feed main flows directly to an exit hydrant with no branches between. A compressor is set up to pump air into the system at an input hydrant on the feed pipe. The compressor has an internal valve which switches, allowing 'slugs' of water into the main between compressed air. These slugs of water are forced along the length of main under pressure and remove sediments and corrosion products from within the pipe. The process is very efficient but will only clean an entire network if all dead-ends have hydrants to allow air and water to escape. In practice, this rarely occurs, and the isolation of many dead-ends frequently fails because valves are missing or faulty.

Air-scouring was tested by this study as a means of obtaining qualitative samples, but as yet, no method of accurately measuring the water entering the sample from 'upstream' has been found. However, all air-scour operations ensure that water used to clean the mains contains low levels of animals and hence will be insignificant relative to the mains fauna. By estimating the quantity of water expelled during an air-scour procedure, it was possible to produce relative measures of density per unit volume flushed.

The major problem with air-scouring is operational. The two-man unit is normally in constant use on the system by the operations and maintenance section of Anglian Water, Oundle Division. Hence its employment in sampling procedures is costly and requires considerable organisation.

Sample collection can lead to problems of damage to hydrant nets by large particles, or bursting when fine sediments are present (because of the pressures involved when using a compressor to pump air down the main). This was solved by using hydrant nets of 1 m and 2 m length.

2.2.3 'In-line' traps and filters

The use of 'in-line traps' at Deacon meter fittings (Holland 1956, Kemsley 1980), was considered. These traps consist of brass or stainless steel gauze boxes which are inserted into the flow of water, and collect any animals present in that flow. However these were dismissed since the system to be investigated no longer uses Deacon meters and installation of traps would have been expensive. The possibility of using the filter system devised by Milner (1979) to sample mains in a treatment works was also considered too costly. This filter unit bolts onto a main and water flowing through the pipe is channeled through the filtration unit. This is a useful method in a water treatment works, but is of no use in a distribution system since mains would have to be dug out for the sampling device to be fitted.

2.2.4) Swabbing:

Swabbing has been used as a means of removing loose deposits from inside the distribution system. A single path through the system is determined, by closing valves, with an input hydrant and a single exit hydrant. A foam or rubber swab is then inserted at the input hydrant. The swab removes deposits from the main and emerges along with the sediment and corrosion at the exit hydrant. A hydrant net on the exit standpipe is used to collect the deposits from the main and the swab.

The method suffers from the potential for swab loss, (particularly if system plans are inaccurate) which can cause problems in the system if a

hard rubber swab is lost. The choice of a swab that is too hard can lead to the blockage of a main under low pressure.

Furthermore, damage to swabs by the corrosion on the pipe frequently results in their destruction prior to emergence from the exit hydrant. After seeing swabbing in operation at the Water Industry Training Association, it was apparent that only infrequently did an intact swab with large amounts of sediments appear at an exit hydrant.

The potential benefit of this method is that providing the swab does not break up, an entire length of main can be sampled, without the need to examine the water flowing into that main. Swabbing suffers from requiring a prior knowledge of the condition of the main, since the wrong grade of swab could result in pipe blockage or swab destruction, both of which will lead to a failure to sample.

2.2.5) Flushing:

Flushing is widely used as a control method for local infestations and has been recommended by the WRc as a means of obtaining qualitative samples from the infestating community.

Flush samples are collected using a WRc hydrant net (142 µ mesh, available from Henry Simon Ltd., Stockport, Cheshire.) attached to a Vernon-Morris flow gauge (Plate 1). The flow gauge records the rate of flow in gallons per minute or litres per second. By sampling for a known period of time, an approximate measure of the volume of water containing sediments flushed from the standpipe is possible. Alternatively, five minute flushes at a standpipe are used to determine the relative infestation level.

Sampling using the WRc nets is restrictive in that if pressures are high, or vary, the net can be blown off the standpipe. Also, if a large quantity of sediment is present in the pipe, the bag will burst within the first minute of sampling. It is possible that animals within the net are damaged by large particles of inorganic debris present in the sample. However, these problems can be reduced by using 1 m or 2 m hydrant nets rather than the standard 600 mm.

When flushing, a flow rate high enough for organic and inorganic deposits should be attained to ensure removal of all animals. The sample flow rates required to remove animals (Specific gravity about 1) which are loosely attached to the pipe surface (for example 7.6 l s^{-1} for a 100 mm diameter pipe) have been calculated (Durand and Condolois 1952) and are tabulated in Ainsworth [ed.] (1981). When this flow rate is not attained only a qualitative sample is possible.

2.2.6) Consideration of sampling methods available

Of the four methods considered, flushing was chosen as the best for application to this study. The most important factor in this choice was that once a site has been found where disruption of the system will be minimal, it could be flushed independent of Water Authority personnel, or large amounts of equipment, a drawback of air-scouring and scrape-and-reline operations.

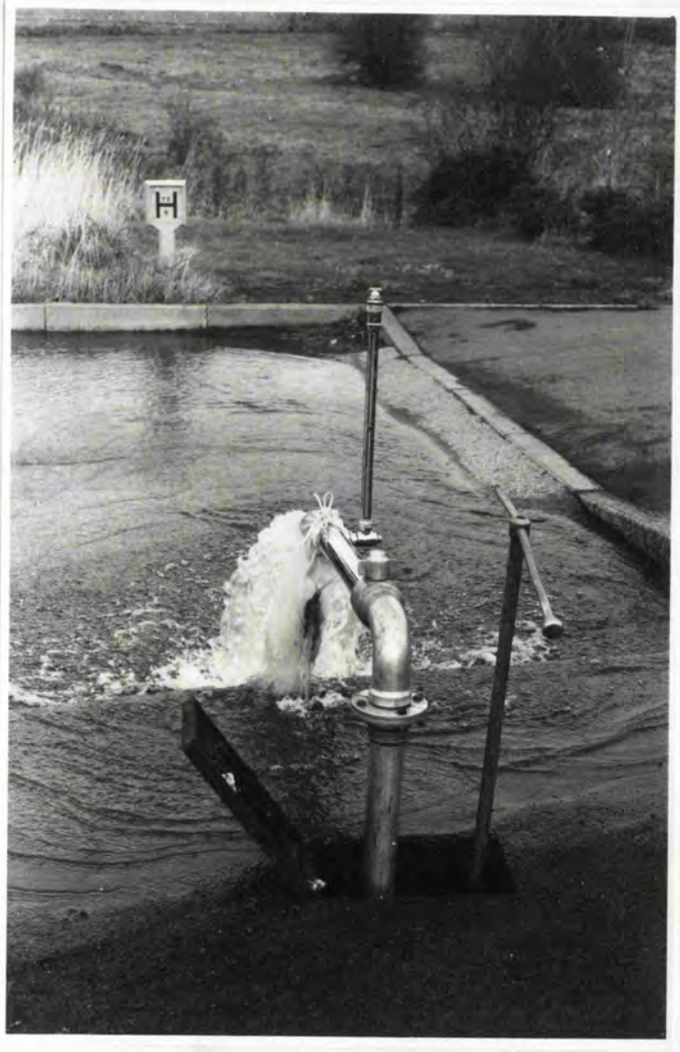


Plate 1) Sample collection in progress using flushing with collection of sediments in a hydrant net.

Section B) Sample collection method

2.3) Establishment of 'Drift' hypothesis

Previous work providing samples from the distribution system relied on period of time between flushes or volume flushed and produced a relative measure of density rather than a quantitative measure. This has resulted in a lack of knowledge of the true density of animals in the pipes, and led to problems with the availability of sample sites.

It was hypothesised that sequential flushing of a fire hydrant on a dead-end for a specific period of time, would remove all the animals in that dead-end. Removal would be indicated by a series of samples which contained only low densities of animals, showing no significant difference from the animal densities in the large diameter trunk main which fed the dead-end being sampled. Examination of the sample sequence determined the point at which further flushes were unnecessary (Fig. 2.1). This enabled a simple equation to be constructed which calculated the number of animals in the pipe length being sampled.

The 'drift hypothesis' is based on the assumption that when a hydrant is flushed, the water flushed from that hydrant is a greater volume than that of the length of pipe being examined, and that this 'extra' volume of water carries with it animals. These animals comprise the drift (the limnetic community in the flowing water and any animals removed from an 'upstream' benthic community), and will also be captured in the hydrant net. Unless an allowance is made for the numbers involved, this drift may contaminate quantitative samples.

Preliminary work at Wakefield Way, Nether Heyford, Northamptonshire, (Fig. 2.2), suggested that this was the case. Five sequential samples were removed from one hydrant, and in 5 of the 6 taxa which showed significant differences between samples (One-way analysis of variance [ANOVA], $p < 0.01$, χ^2 for chironomids > 2 mm), the first sample was significantly different from the remaining four (Student Newman Keuls Multiple Range Test [Q Test], $p = 0.05$, Table 2.1). This led to the production of an equation which removes the 'drift' from a hydrant sample value to determine the number of animals removed from a pipe length.

If: v = volume of sampled pipe length (calculated from diameter on plan and estimate of length from hydrant to feed in the field).

r_s = rate of flow for sample; r_d - for drift

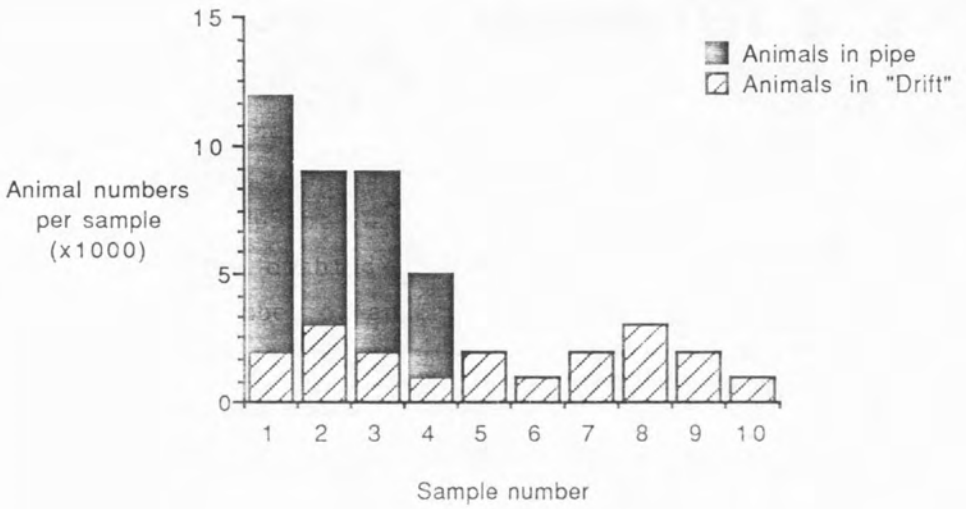
t_s = period of hydrant flush for sample; t_d - for drift

X = animals in a sample

D = animals in a drift sample (from the same hydrant as X).

Q = animals in a specified pipe length

Fig 2.1) Diagrammatic representation of hypothesis behind sampling stategy



As samples are removed from the main during a series of flushes, the animals present in the pipe itself are collected along with the 'drift' fauna. As the number of samples collected increases, the animals in the pipe are removed. Further flushing leads to the collection of animals at 'drift' density only.

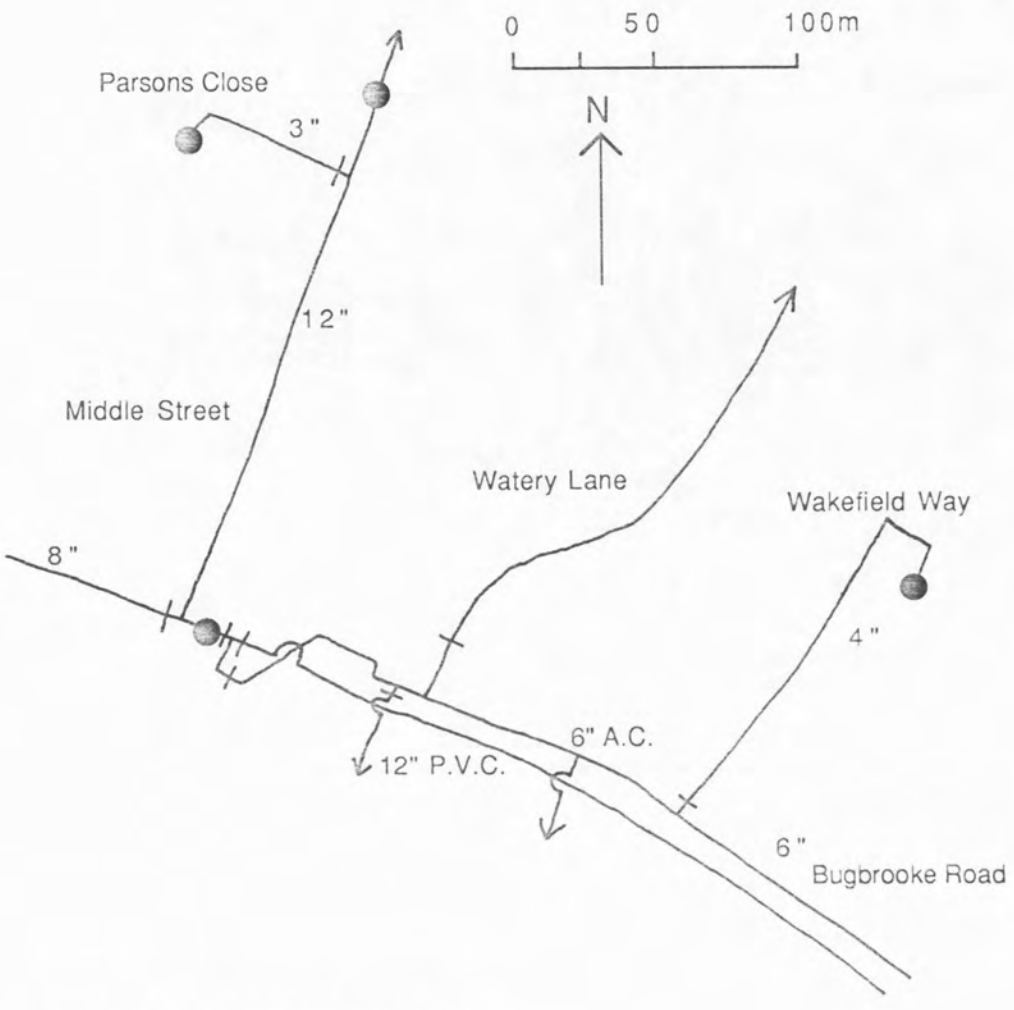


Fig. 2.2) Sample sites at Nether Heyford, Northants.

Table 2.1) Mean densities per 1000 litres flushed from a 4" pipe at Wakefield Way, Nether heyford, Northants.

taxa	Flush Number				
	1	2	3	4	5
chironomid (> 2 mm)[1]	152*	22	6	41	7
chironomid (< 2 mm)[1]	80	80	180	80	200
chironomid (total)	232	102	186	121	207
harpacticoids[1]	19360*	1080	1320	1240	800
cyclopoids[1]	240*	40	60	40	40
chydorids[1]	560*	160	180	80	200
halacarids	240	80	60	160	80
oligochaetes[1]	80*	0	0	40	0
nematodes	80	40	0	40	40

Key:

[1] - sample sequences that showed significant differences between samples at $P < 0.05$.

* - first flush samples that were significantly differnet from the remaining four.

i) The 'potential' pipe volume (v) is removed from the sample volume ($r_s.t_s$) to produce a value for the volume of drift in the sample **(1)**.

(1) volume of drift = $r_s.t_s - v$

ii) The animal numbers from the drift sample (D) are divided by the volume of that drift sample ($r_d.t_d$) to produce a value for drift as density per litre **(2)**.

(2) animal density in drift = $D/(r_d.t_d)$

iii) The drift density **(2)** is multiplied by the volume of drift in the sample **(1)** to produce the number of drift animals in the sample **(3)**.

(3) drift animals in sample = $(r_s.t_s - v)(D/(r_d.t_d))$

iv) The number of drift animals in the sample **(3)** is subtracted from the number of animals in the sample volume (X) to produce a value for the number of animals removed from the pipe length (Q), **(4)**.

(4) $Q = X - (D(r_s.t_s - v)/r_d.t_d)$

2.4) Test of sampling model

The model was tested at two sites in Oundle Division, Anglian Water (Northampton and Daventry Districts). (Figs. 2.3 & 2.4, hydrants A - I) Hydrants A to C at Site 1: Chapel Brampton, a village northwest of Northampton in the Pitsford Supply Zone, and six hydrants, D to I, located on the distribution network at Site 2: Obelisk Rise, Northampton, a housing estate in north Northampton (Northampton Supply Zone).

2.4.1) Methods

At each site, the 'potential volume' of each pipe was calculated by measuring the pipe length to the nearest metre (following 1:2500 plans) using a measuring wheel in the field and calculating the volume of water inside the pipe, assuming the pipe to be 'as new', having no corrosion present. (Potential errors due to this assumption are discussed in section 3.2)

Samples were removed from the pipes at the maximum rate of flow (between 7 l s^{-1} and 16 l s^{-1} in order to remove deposits), and for a period of time that allowed twice the potential volume of each pipe to be flushed. Before the first sample was collected the hydrant was 'cracked'

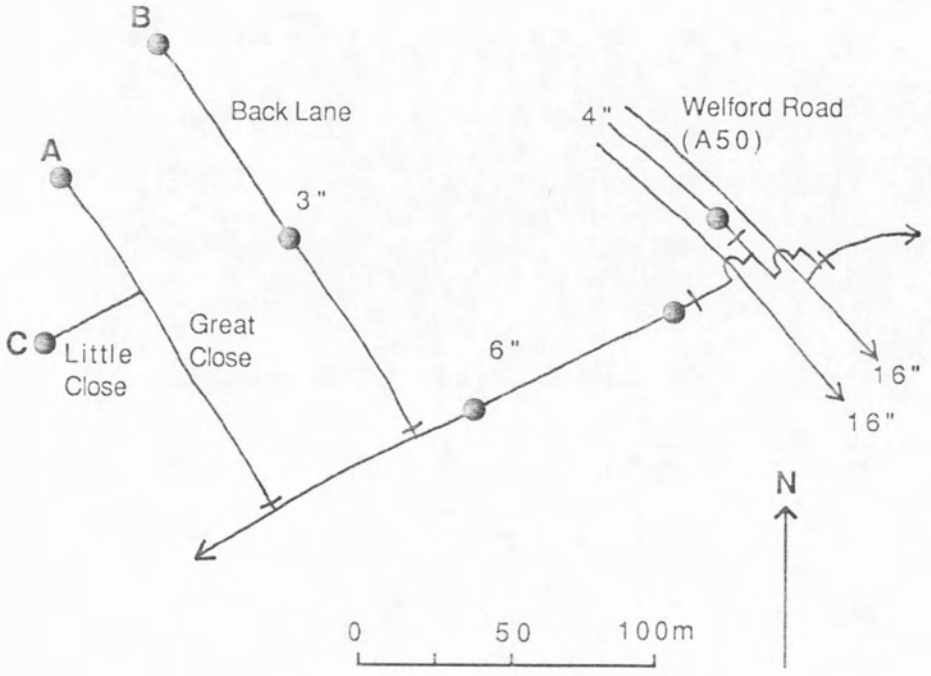


Fig. 2.3) Sample sites at Chapel Brampton, Northants.

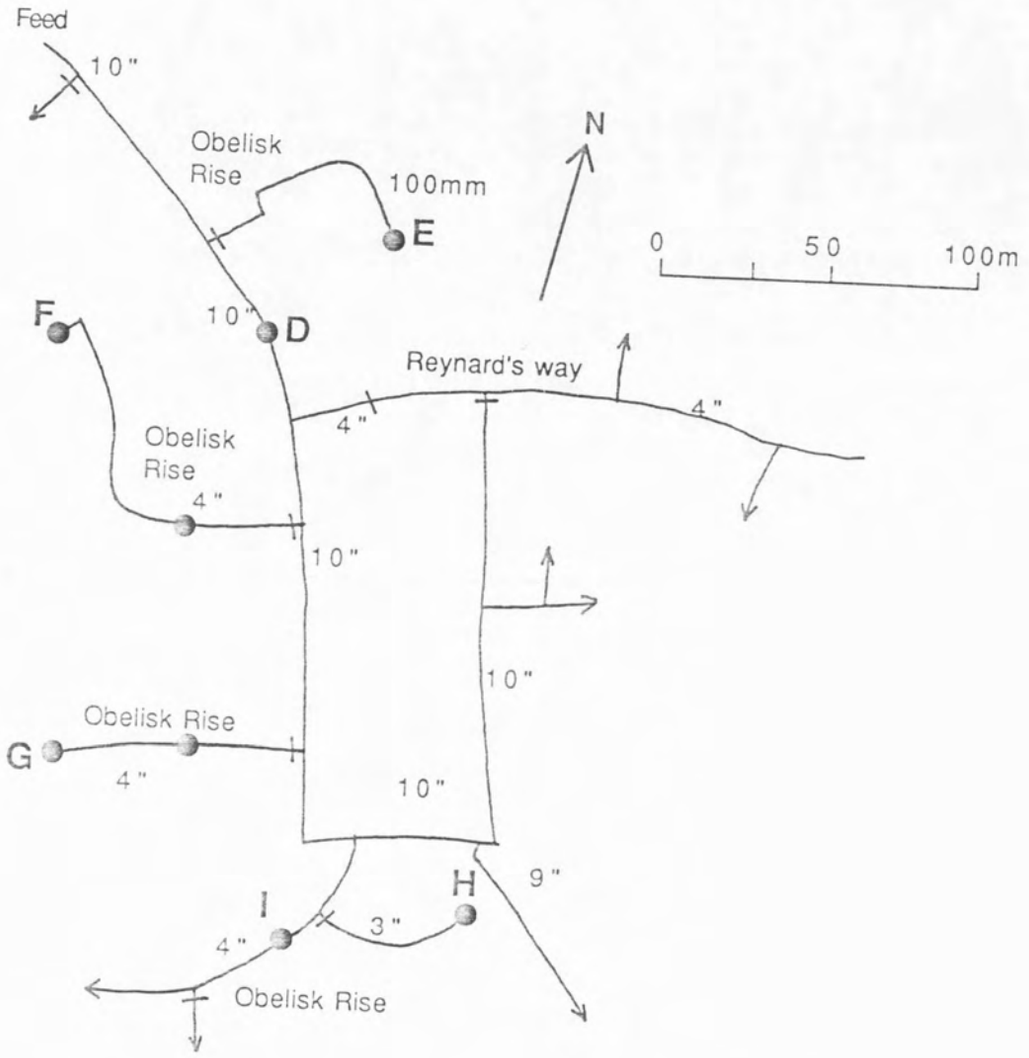


Fig. 2.4) Sample sites at Obelisk Rise, Northampton, Northants.

(opened for a short period of time at the lowest rate of flow possible) to remove any stagnant water from the hydrant bowl. Cracking a hydrant entails the removal of stagnant water and any 'terrestrial' sediment from the bowl of the hydrant. This appears as dark brown or black organic matter in the stream of water, and once this has disappeared the hydrant is closed prior to removal of a sample.

Samples were collected by connecting a standpipe to the hydrant outlet, fitting a Vernon Morris flow gauge to measure the rate of flow, and collecting the sample in a WRc hydrant net (142 μ mesh) attached to the outlet of the flow gauge as described in Anon (1983). The hydrant net affects the reading of the flow gauge and was held horizontal to obtain a more accurate estimate of the flushing rate during sampling. (This rate can be checked by flushing for a short period of time without the net at the end of the sampling sequence.) As the flow rate increases and decreases from the required flow, water is entering the net, but this is considered a minimal quantity relative to the total quantity of water flushed. Sample collection was timed from the moment the required flow rate was attained to the moment of closing the hydrant.

At site 1, hydrant A failed to produce a sample (because the quantity of sediment burst the hydrant net) and was flushed clean and used to produce a 'drift density' for the site which could be compared with the sequences from hydrants B and C. At hydrants B and C, a total of 5 samples was collected in sequence from each hydrant.

At site 2, hydrant D, on the 10" main was flushed for a known period of time to determine the density of animals carried in the feed to hydrants E, F and G. Hydrants E, F and G were flushed in sequence five times (Hydrant G three times owing to drainage problems). The remaining hydrants H and I were flushed but sample sequences could not be collected due to drainage problems.

After preservation in 70% industrial methylated spirit (I.M.S.) samples were returned to the laboratory for examination. Samples were filtered through 2 mm and 152 μ Endecott sieves and the residue from each sample greater than 2 mm was emptied into a sorting tray. Larger organisms such as snails and large chironomids were then removed. Depending on the amount of sediment present, the remainder of each sample was then diluted between 1:10 and 1:400. Five subsamples of 5 ml were removed using an automatic pipette with an aperture cut to approximately 3 mm diameter. Randomization within the sample was achieved by pouring the sample between two beakers (500 ml or 100 ml depending on the dilution volume) before the removal of each subsample. This technique produces a distribution of animals within the sample that approximates to a Poisson series (section 2.6).

Each subsample was then examined and counted in a 'Bogarov trough' (a perspex counting trough, described by Smith (1988), under a stereoscopic zoom microscope (magnification x15 - x30).

Numbers of each major taxonomic group (section 2.5) were subjected to one-way analysis of variance (ANOVA) to determine whether any significant differences occurred between the densities of animals in each sample. Where differences were significant, analysis using a Student Newman Keuls Multiple Range Test (Q Test) was used to indicate which samples in the series accounted for the significant difference.

Since randomization of the sample produced subsamples which approximate to a Poisson series, data for analysis by ANOVA and Q Test was root transformed prior to analysis.

For each of hydrants B, C, E, F and G the flush sequence was tested (above) to determine at what stage in the sequence samples ceased to be significantly different (when drift levels appear). Each flush in the sequence (1 to 5) was then compared against the relevant drift sample (from hydrants A and D), to investigate whether the two methods of analysis indicate drift levels at the same stage in the sample sequence.

2.4.2) Results

A total of 36 taxonomic groups from 5 sites was examined and 23 cases showed no significant difference between animal densities in samples after the first or second flush (Fig. 2.5 and 2.6); 11 cases showed no significant difference over all five flush samples (Fig. 2.7) and 2 cases showed a significant difference in samples after the second flush (Fig. 2.8).

The first set of results (Fig. 2.5 and 2.6) consists of taxa inhabiting the pipe which were removed in the first two flushes. The second set (Fig. 2.7) consists of those taxa without an established population in the pipe, showing no significant difference from the drift sample. The third set (Fig. 2.8) consists of taxonomic groups with large numbers of individuals in the first two samples and smaller numbers (but still greater than drift levels) in the third or fourth samples. In order to test the sampling model, the drift value removed from site A was compared with the first, second, third, forth, and fifth samples from sites B and C until there was no significant difference between the three sites (ANOVA $p < 0.01$). When there was no difference between the drift sample and the samples from sequential flush sampling, it was assumed that the drift level had been reached. This was repeated for samples removed at hydrants D to G.

The results for hydrants B and C, are shown in Table 2.2a and 2.2b). Levels of significant difference between flushes are indicated (from a

Fig. 2.5) Back Lane, Chapel Brampton, Northants.
Halacarid density variation with flushing

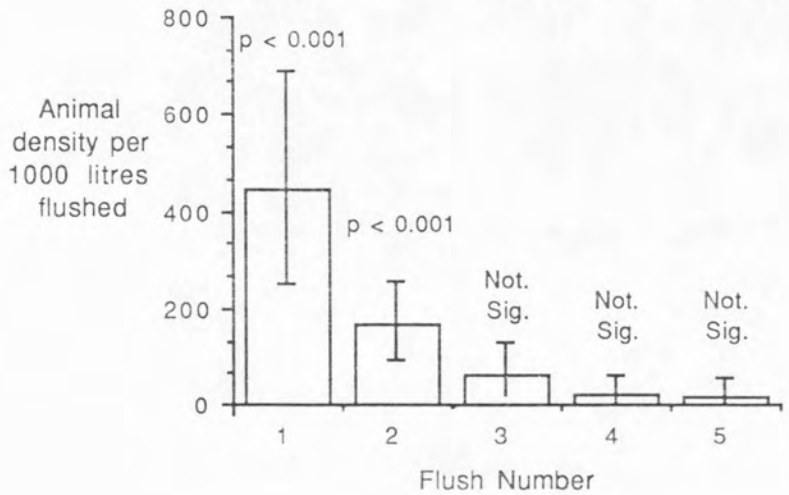


Fig. 2.6) Back Lane, Chapel Brampton, Northants.
Harpacticoid density variation with flushing

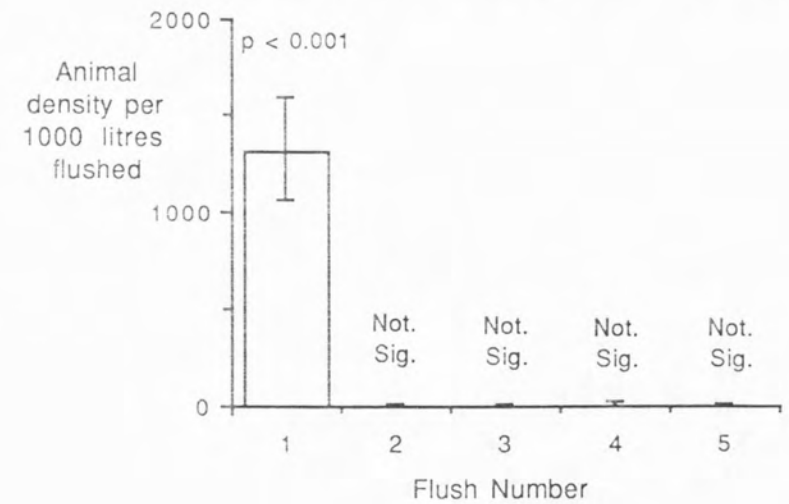


Fig. 2.7) Back Lane, Chapel Brampton, Northants.
Cyclopoid density variation with flushing

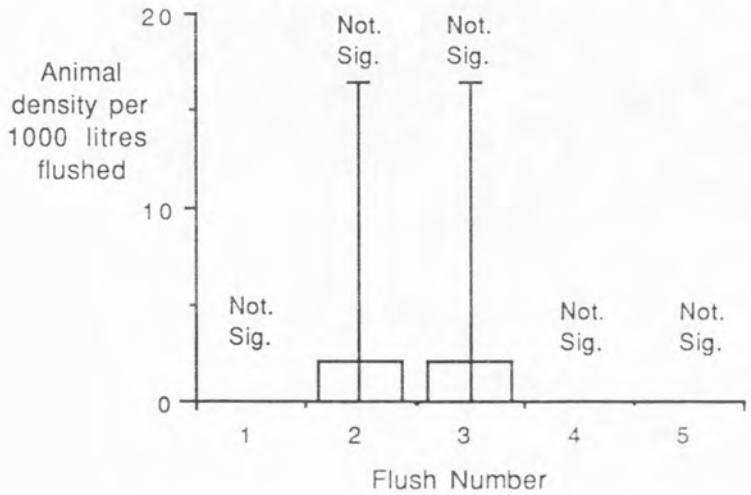


Fig. 2.8) Back Lane, Chapel Brampton, Northants.
Chydorid density variation with flushing

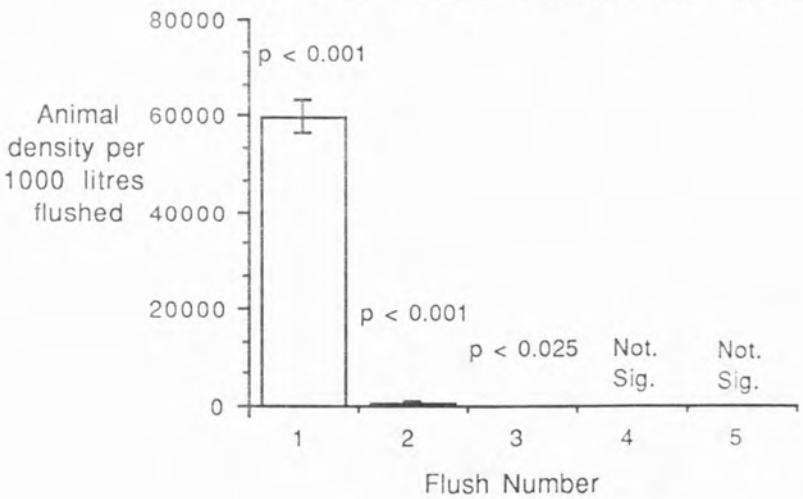


Table 2.2) a: Hydrant B, Back Lane, Chapel Brampton, Northants,
Agreement of sequential samples with drift

Taxonomic group	Animal density per 1000 litres in drift sample	Animal density per 1000 litres in each flush sample: Flush Number 1	2	3	4	5	Comparison of flush samples within sequence: Flush Number 1	2	3	4	5	Comparison of flush samples with drift: Flush Number 1	2	3	4	5
Chironomid larvae (< 2 mm)	1	33	3	0	0	0	1	d	d	d	d	1	D	D	D	D
Harpacticoids	1	1312	3	3	6	3	1	d	d	d	d	1	D	D	D	D
Cyclopoids	1	0	3	3	0	0	d	d	d	d	d	D	D	D	D	D
Chydorids	1	59823	726	47	48	11	1	2	d	d	d	1	2	3	D	D
Halacarids	4	445	167	64	22	15	1	2	d	d	d	1	2	D	D	D
Oligochaetes	0	87	83	20	13	0	1	2	d	d	d	1	2	D	3	D
Nematodes	0	27	37	0	2	0	2	1	d	d	d	1	2	D	D	D
Tardigrades	0	85	15	3	2	0	d	d	d	d	d	1	2	D	D	D

Column 2 - Drift density: Density/1000 litres flushed from the large diameter feed or a nearby clean pipe.
Column 3 - Animal density: Density/1000 litres flushed in each of 5 sequential flushes at the hydrant.
Column 4 - Comparison within sequence: 5 subsamples from each of the flushes compared using ANOVA and QTEST to determine significant differences. Numbers refer to ranked values where they differ from remaining values, d refer to point at which samples are not significantly different (the assumed 'drift').
Column 5 - Comparison with drift sample: 5 subsamples from each flush compared to 5 subsamples from drift density using ANOVA and QTEST. Numbers refer to ranked higest values - D refers to no significant difference with drift density. This D is actual drift and can be compared with assumed drift to assess sampling success.

Table 2.2) b: Hydrant C, Little Close, Chapel Brampton, Northants,
Agreement of sequential samples with drift

Taxonomic group	Animal density per 1000 litres in drift sample	Animal density per 1000 litres in each flush sample: Flush Number 1	2	3	4	5	Comparison of flush samples within sequence: Flush Number 1	2	3	4	5	Comparison of flush samples with drift: Flush Number 1	2	3	4	5
Chironomid larvae (< 2 mm)	1	0	0	0	0	2	d	d	d	d	d	D	D	D	D	D
Harpacticoids	1	2175	4	2	7	5	1	d	d	d	d	1	D	D	D	D
Cyclopoids	1	368	0	2	2	2	1	d	d	d	d	1	D	D	D	D
Chydorids	1	19835	555	87	48	15	1	2	3	d	d	1	2	3	4	D
Halacarids	4	824	121	84	38	25	1	2	2	d	d	1	2	3	D	D
Oligochaetes	0	22	2	2	2	9	1	d	d	d	2	1	D	D	D	2
Nematodes	0	16	0	0	0	0	1	d	d	d	d	1	D	D	D	D
Tardigrades	0	8	0	0	0	0	1	d	d	d	d	1	D	D	D	D

Column 2 - Drift density: Density/1000 litres flushed from the large diameter feed or a nearby clean pipe.
Column 3 - Animal density: Density/1000 litres flushed in each of 5 sequential flushes at the hydrant.
Column 4 - Comparison within sequence: 5 subsamples from each of the flushes compared using ANOVA and QTEST to determine significant differences. Numbers refer to ranked values where they differ from remaining values, d refer to point at which samples are not significantly different (the assumed 'drift').
Column 5 - Comparison with drift sample: 5 subsamples from each flush compared to 5 subsamples from drift density using ANOVA and QTEST. Numbers refer to ranked higest values - D refers to no significant difference with drift density. This D is actual drift and can be compared with assumed drift to assess sampling success.

Student-Newman-Keuls Range Test [Q-Test]) in the central and righthand columns. The significant difference from the density of animals in the feeder mains (Hydrant A at site 1) is in the right hand columns, and the difference between samples in the central column. The estimated numbers of each taxon in the pipe are in the left hand column.

The data for Hydrants E to G are included as Appendix I and support the conclusions drawn from the data displayed in Table 2.2.

2.4.3) Discussion

Examination of the data (Table 2.2a and b) for Site 1 (Chapel Brampton) confirms that the third flush sample is not always the drift sample, but can also contain numbers of animals from within the pipe. At hydrant C (Table 2.2b), it appears that drift level is not always reached by the third sample in a sequence of samples from the same hydrant (chydorids and halacarids). Chydorids also fail to reach drift levels at Hydrant B (Table 2.2a) if difference from the drift level at hydrant A is considered.

At hydrant C, chydorid numbers in the third were significantly larger than the drift (fifth) sample but were relatively insignificant compared to the sum of the first two samples. As can be seen in Figure 2.8, the relative difference in numbers is so great that the method can be accepted as having worked. This failure to totally remove the animals in the pipe will not be a constant factor and is likely to change with the internal state of the pipe.

The lack of agreement between the differences within a flush sequence and with the drift sample (central and right hand columns in Table 2.2) can be explained by the fact that only one drift sample was taken and this for a short period of time due to drainage problems. If further samples could have been taken (at hydrant H), then a better assessment of the drift would have been possible.

In 31 of 36 cases tested the agreement between the two tests (sample similarity and drift similarity) was 100%, in 32 cases agreement was 100% that the third sample in the flush sequence was the drift. This indicates that at high rates of flow (15 l s^{-1}), the method is valid as a means of quantifying mains fauna.

These results indicated that it would be possible to quantify animals in the pipe using only three flush samples. Thus when significant positive differences existed between the first sample and the remaining samples (where animals eventually reached drift densities), it was possible to quantify animals per unit length or unit 'potential volume' of pipe. Using the sampling equation (4) described above, it was possible to produce an equation modified for use with only three flush samples:

$$(5)\quad Q = X_1 + X_2 - (D(r_1.t_1 + r_2.t_2 - V)/r_d.t_d)$$

where Q = animals in a specified pipe length.

X_i = animals in the ith sample, (i = 1,2).

D = animals in the third (drift) sample.

r = rate of flushing: r_d - drift, r_i - sample i

t = period of flushing: t_d - drift, t_i - sample i

V = 'potential volume' of small diameter main

If samples are taken for the same period of time and at the same rate of flow this equation **(5)** reduces to **(6)**:

$$(6)\qquad Q = X_1 + X_2 - 2D + (D.V/r.t)$$

At low densities of animals, both X_1 and X_2 were checked to ensure they were larger than the drift to be subtracted or the equation led to erroneous results. This was done by testing data (animal density per 1000 litres) for each sample prior to quantitative analysis.

2.5) Calculation of quantitative information from the five sites used to produce the sampling model

Using the equation **(5)** outlined in section 2.4.3 (above), a computer program was constructed to produce the quantitative data for each site. This file was originally written in 'BASIC' and translated to 'FORTRAN 77' with the help of J.L.Beckett (University of Leicester, Computer Centre), and has been modified over the period of this study. Two programs have been regularly used, one for subsampled animals 'Quant.for' and one for animals removed prior to subsampling 'Quantchir.for' (Appendix II.A(i) and II.B(i)). Examples of the input files are included (Appendix II.A(ii) and II.B(ii)) and examples of the output (Appendix II.A(iii) and II.B(iii)).

Using the two computer programmes included in Appendix II, the numbers of animals present in the pipes sampled at hydrants B, C, E, F and G (above) were calculated and the quantitative information is given in Table 2.3.

Table 2.3) Animal numbers in pipe at Hydrants B, C, E, F and G

Taxon	Hydrant (Location)				
	B(BL)	C(LC)	E(OR)	F(OR)	G(OR)
Chironomid larvae (removed > 2mm)	5	drift	20	32	33
Chironomid larvae (subsampled < 2mm)	48	-	drift	112	80
Chironomid larvae (total)	53	drift	20	144	113
Harpacticoids	1724	2200	drift	80	96
Cyclopoids	drift	373	1413	208	720
Chydorids	70144	21065	307	1520	1032
Halacarids	720	945	965	524	714
Oligochaetes	drift	478*	drift	drift	drift
Nematodes	128	240	-	-	-
Ostracods	-	-	drift	drift	-
Tardigrades	200	60	-	-	-

Key:

'*' : indicates sample which required checking with a Q - Test because sample three was larger than sample two (no significant difference between these at P = 0.05).

'-' : indicates absence of taxonomic group

'drift' : indicates animals are present but densities are not significantly greater than those in the drift sample

B(BL) : Hydrant B / Back lane, Chapel Brampton

C(LC) : Hydrant C / Little Close, Chapel Brampton

E(OR) : Hydrant E / Obelisk Rise, Northampton

F(OR) : Hydrant F / Obelisk Rise, Northampton

G(OR) : Hydrant G / Obelisk Rise, Northampton

Section C) Subsampling

2.6) Subsampling technique

Samples were emptied from the hydrant net as outlined in section 2.4.1. This initial filtering stage was checked using a 75 µ sieve and only rarely did any animals penetrate the 152 µ sieve. Animals which were found to escape the 152 µ sieve are those which were not collected in full by the hydrant net in any case, notably cyclopoid nauplii and nematodes.

Initial attempts to separate animals from sediments in the field using a 'sampler/sorter' were abandoned. The 'sampler/sorter' consisted of an elutriation bucket and a filter run with different meshes that would collect sediments and animals of different size categories. Unfortunately, the water pressure when sampling was too great for filters to operate without clogging leading to overflow.

Various laboratory methods such as a sorting trough (Smalls and Greaves 1968) and elutriator (Magdych 1981) were considered as means of removing animals from sediments to aid counting, but a method of direct counts of subsamples was used because:

a) samples were preserved prior to subsampling;
b) animals in the samples were small;
c) samples frequently contained fragments of animals (such as chydorid carapaces) and large amounts of floccular material smaller than the animals;
d) direct counting tended to be rapid relative to other methods available.

The sample was resuspended in between 50 ml and 400 ml of distilled water, depending on the amount of material present, and mixed by pouring between two beakers to establish a random distribution of animals within the sample volume. A subsample was removed and the sample was mixed once more.

Five subsamples were removed and each counted under x15 - x30 magnification in a Bogarov trough. All whole animals present in the sample were considered to have been alive in the distribution system. Tests found that animals in a sample stored after collection, remain active for 4 hours, although copepods were killed in samples taken at high rates of flow while chironomids and chydorids survived. Examination of those live samples showed that the method of counting preserved samples was valid.

The following groups were counted in subsamples:
Chironomidae; Harpacticoida; Cyclopoida; Cladocera; Acarina; Oligochaeta;

Nematoda ; Ostracoda; Tardigrada; Turbellaria; Gastropoda; and *Asellus*. A number of each group was removed for further identification.

Whenever possible, 30 animals were mounted on slides for further identification. If animals in a particular taxonomic group occurred less than this number of times in a subsample, the greatest number possible was removed. Animals were sometimes removed from more than one subsample to obtain as many mounted specimens as possible from each taxon enabling identification to genus and species (see Chapter 5).

2.7) Investigation of subsampling procedure for random distribution

The dispersion of the above taxa within the subsamples was examined for randomness to determine whether the calculation of error values for animal density per unit volume flushed was justified. This enabled transformed data from sequential flush samples to be compared using ANOVA. The distribution was analysed using the χ^2 test for the index of dispersion (I) as described by Elliott (1977).

Where $\chi^2 = I.(n - 1) = s^2.(n - 1)/\bar{x}$

and I = sample variance/theoretical variance

$= s^2/\bar{x}$

$= \Sigma(x_i - \bar{x})^2/(\bar{x}.(n - 1))$

s^2 = sample variance

$\bar{x}$ = sample mean

n = number of sampling units

x_i = sample

The aspects of subsampling considered included the number of subsamples removed; the taxa counted; the density in the sample and the dilution factor involved. The results are discussed below.

2.7.1 The effect of varying subsample numbers

In order to determine the ideal number of subsamples two pipes at Chapel Brampton, Northants. were sampled. A total of eleven flush samples was examined, subsampling with 5, 10, and 15 replicates. Each set of replicates was tested using the χ^2 test for random dispersion (Elliott 1977) described above.

The results, (Table 2.4) show 97% of samples with 5 subsamples removed randomly dispersed, 90% of those samples with 10 subsamples, and 84% of those samples with 15 subsamples.

Samples with the greatest numbers of individuals present, tended to

be those with subsamples showing a contagious distribution. Higher numbers of subsamples resulted in higher numbers of contagious samples.

It was probable that the contagious distributions were due to heterogeneous sampling of a Poisson distribution, in which case the data would fit a negative binomial distribution.

An attempt was made to fit a negative binomial distribution to the contagious data. In order to test any fitted equation statistically, a first approximation is required for the constant k:

$$\text{Estimate of } k = \hat{k} = (x^2 - s^2/n)/(s^2 - x)$$

The approximations produced by the above equation gave values for $\hat{k}$ which were large enough for the aggregation in the samples to be considered too small to merit treating as contagious distributions, (J.A.Bullock, pers. comm.), but to continue to treat as random, since k has a very large positive value as randomness increases.

If the contagious distributions are treated as random, the percentage random in each set of subsamples becomes : 5 subsamples, 97%; 10 subsamples, 96%; 15 subsamples, 97%; all of which are above the expected value of 95% from the significance of the χ^2 test. This suggests that the number of subsamples does not affect the accuracy of estimations of animal numbers in the sample.

This enables all the samples to be treated as having animals distributed randomly within them prior to subsampling. Hence a density value with confidence limits for the number of animals per unit volume sampled can be produced from a set of subsamples.

2.7.2) The frequency of random distribution in samples for different taxonomic groups.

The subsampling technique leads to a varied number of animals and different subsample dilutions from each sample. Assuming the subsamples to be removing animals from a Poisson distribution as outlined above differences between taxonomic groups were investigated.

A total of 317 subsample series were examined, 10 of each dilution (where possible) being chosen for each taxonomic group. The results are shown in Table 2.5.

Chydorids and oligochaetes showed a low frequency of random distribution prior to subsampling. These often occur in high numbers in the same samples, along with large quantities of sediment, and this may lead to a reduction in the random distribution within subsamples (section 2.6.3).

Table 2.4: Random distribution of animal numbers in subsamples and the number of subsamples from Chapel Brampton, Northants.

No. of subsamples:	5			10			15		
Distribution type	re.	ra.	co.	re.	ra.	co.	re.	ra.	co.
chironomid larvae	0	4	0	0	7	0	0	6	2
harpacticoids	0	11	0	0	10	1	0	10	1
cyclopoids	0	7	0	0	7	0	0	6	2
chydorids	1	10	0	0	8	3	0	8	3
mites	1	10	0	0	11	0	1	10	0
oligochaetes	0	9	0	2	8	0	0	10	0
nematodes	0	6	0	1	8	0	0	9	1
tardigrades	0	5	0	0	5	0	0	5	0
ostracods	0	0	0	0	1	0	0	0	2

Key:
Distribution type: re. = regular
ra. = random
co. = contagious

Table 2.5: The frequency of random dispersion of animal numbers in subsamples relative to taxonomic group.

Taxonomic Group	Total number of tests	Total number of tests showing random dispersion	%
Chironomidae	43	36	84
Harpacticoida	46	43	93
Cyclopoida	54	44	81
Chydoridae	51	35	69
Acarina	50	38	76
(Halacarids	36	31	86)
Oligochaeta	60	41	68
Nematoda	4	4	100
Ostracoda	9	9	100
Total	317	250	79

Acarina frequently showed a contagious pattern of distribution. This was initially believed to be due to their attachment to larger organisms such as chironomid larvae during sample processing. However, samples up to May 1986 were found to have been contaminated by terrestrial mites, similar to the Tyroglyphidae in the system (section 5.10.2). This contamination occurred either during sampling or during the subsampling process. Contamination in subsampling was removed from May 1986 onwards by ensuring all glassware and storage jars were cleaned immediately before introduction of any material. Samples with any possibility of contamination were not used in the data in brackets (Halacaridae) in Table 2.5 which shows a higher frequency of random dispersion.

The subsamples that are not random rarely show a regular distribution but tend to show a contagious distribution which fits a negative binomial distribution. In these instances values for $\bar{x}/\hat{k}$ are large and hence $\hat{k}$ is small, with 26 (approximately 10%) of 244 samples tested having a $\hat{k} < 10$, implying a large aggregation, since maximum contagion occurs as $\hat{k}$ tends to zero (Elliott 1977 p. 75).

2.7.3) The effect of animal density and subsample dilution on frequency of random distribution in subsamples.

Table 2.6 indicates the frequency of random distribution and density of animals in each sample. Sets of subsamples were chosen so as to include at least 10 of each density range for each taxonomic group. When less than 10 were available for any taxon, the maximum number possible was used. Subsamples with large numbers of animals frequently showed contagious distributions. This occurred particularly with chydorids and oligochaetes which are the most dominant taxa subsampled in such numbers (these two groups also showed the lowest frequency of random distribution, section 2.6.2). At low densities χ^2 is insensitive so the value of 88% for 0 - 20 animals is a potentially inaccurate representation of the true situation.

Table 2.7 shows the effect of different dilution factors from the same data set. The most conspicuous difference between dilutions is the decline in the percentage with a random distribution as the dilution increased. This was attributed to a number of causes:

i) Sediments sometimes blocked the end of the auto-pipette used to remove the subsamples, acting as a filter. Where observed, this was solved by subsampling again.

ii) Large quantities of sediment obscured animals leading to a reduction in the accuracy of counting.

iii) Large numbers of animals (over 500) led to less accurate counting. This was resolved by secondary subsampling at greater dilutions for

Table 2.6) The number of animals and frequency of random distribution of animals in subsamples.

(number of random cases/
number of cases tested)

Taxa	Numbers of animals in subsamples: 0-20	20-50	50-100	100+
Chironomid larvae (< 2mm)	20/22	4/6	2/2	1/2
Harpacticoids	21/26	4/4	2/6	1/1
Cyclopoids	26/26	7/9	3/5	1/2
Chydorids	13/14	1/3	4/8	10/19
Halacarids	19/20	8/9	3/5	1/2
Oligochaetes	19/22	2/5	4/6	6/15
Percentage of random cases	90.8	72.2	56.2	50

Table 2.7) The distribution of animal numbers in subsamples removed from samples at different dilutions

Dilution factor:	10	20	40	80+
regular	1	0	0	0
random	56	50	45	34
contagious	6	13	13	26
total	63	63	58	60
Percentage random	89	79	77	57

abundant groups.

Each of i) to iii) applied to samples which had large numbers of animals and large amounts of sediments. These samples tended to be those containing chydorids and oligochaetes (see section 2.6.2) which showed the lowest frequency of random distribution.

2.8) Discussion

The above work led to a conflict in the subsampling strategy. The Poisson model has been used to compare the sequential samples and obtain drift levels which have then been used to estimate densities of animals in the pipes. However, subsamples did not always fit the Poisson distribution, but in some instances, particularly with the larger samples, showed contagion which fitted a negative binomial distribution.

Despite this problem it was decided that the Poisson distribution gave the best approximation to the distribution within mixed samples at the time of subsampling. Heterogeneous sampling of that distribution, which approximates to a negative binomial, occurred mainly in samples with high densities of animals and sediments. These samples tend to be collected at low rates of flow which then yielded qualitative rather than quantitative results.

CHAPTER 3) INVESTIGATION OF POTENTIAL ERRORS IN SAMPLING METHODS

3.1) Introduction.....58
3.2) Effect of corrosion on quantitative data.....58
3.2.1) Methods.....59
3.2.2) Results and Discussion.....59
3.2.3) Conclusions.....59
3.3) Investigation of animal removal at different rates of flushing.....61
3.3.1) Methods 61
3.3.2) Results.....62
3.3.3) Discussion.....62
3.4) Investigation of success rate of animal removal using the method.....62
3.4.1) The determination of the relative values of flushing and pyrethrin followed by air-scour as methods of sampling.....66
3.4.1.1) Methods.....66
3.4.1.2) Results.....66
3.4.2) Investigation of flush sampling relative to air scour at low rates of flow.....66
3.4.2.1) Methods 66
3.4.2.2) Results.....69
3.4.3) Discussion of flushing alone relative to other methods.....69
3.5) Limitations applying to the sampling method.....71

CHAPTER 3) INVESTIGATION OF POTENTIAL ERRORS IN SAMPLING METHODS

3.1) Introduction

The method described in Chapter 2 is proposed as the best method available for obtaining quantitative samples from water mains, under normal operational and financial conditions. There are three problems which apply to this method:

i) It is possible for this method to be applied at any point within the system but it must be at some place where drift levels are known to be constant. The assumption that drift levels are constant is not a feature of the system that can be easily tested, since drift levels can only be easily measured at high rates of flow, where the pipe sediment and animals are known to be cleared. Certainly at sites sampled at high rates of flow, drift levels are obtained which remain relatively constant.

ii) The internal diameter of the pipe is assumed to be 'as new' rather than reduced (so the volume of the pipe is overestimated). The magnitude of errors due to corrosion was determined using a computer simulation. This simulation calculated results depending on the actual volume of the pipe (using actual data from a sample sequence) from the same numbers of animals in a pipe.

iii) There is no way of knowing at low rates of flow whether removal has been completed. Measures of the removal of animals as rates of flow increased were determined from samples taken at a series of hydrants on the same pipe leg at the village of Nether Heyford, Northants. Each hydrant was sampled at various rates of flow lower than the maximum attainable, resampled at the maximum rate of flow and a coefficient of removal used to compare the sampling success at different rates of flow.

This coefficient was devised to account for the proportion of animals present in the flush sequence at a hydrant that was removed by any single flush (section 3.3.1). To investigate the efficiency of flush sampling, samples were removed by flushing at high rates of flow and resampling by flushing after pyrethrin dosing. This process was repeated at Haselbech (a site with low rates of flow), using flushing and air-scour (in place of pyrethrin). These investigations of the effect of rate of flow on removal were compared using a coefficient of removal.

3.2) Effect of corrosion on quantitative data

The assumption that the pipe being sampled is pristine in nature with no corrosion or tuberculation affecting its internal wall, was not always the case. This was particularly relevant at sites sampled during the 'community' work (Chapter 6), where a main was followed from feed to numerous dead ends. These sites encompassed a far greater range of pipe

age and flow regime than sites used to test the sampling model (Chapter 2), or the reinfestation work (Chapter 7). Sites with old mains with low flows are likely to have been reduced in diameter by tuberculations.

In such instances comparisons of animal density per unit volume will be open to criticism because of the lack of knowledge of the internal condition of the main. One option was to consider density as a measure of animal numbers per unit length of pipe, though this measure still suffers from the initial use of pipe volume in the sampling model which is used to determine the number of animals in any given pipe.

3.2.1) Methods

A test was carried out to determine the magnitude of error assuming pipes to be in various stages of corrosion using data from a sample taken at Church Mount, Guilsborough during May 1986. The value used for the internal diameter of the pipe in the Fortran file 'Quant.for' (Appendix II.A(i)) was modified (three times) prior to running the program with data identical in every other respect.

3.2.2) Results and Discussion

Table 3.1 indicates the differences obtained for three values which could be used to measure infestations. The number of animals per site, the number of animals per unit pipe length and the number of animals per unit pipe volume (assumed). As can be seen, there is considerable difference between the density per unit volume (dv) and very little difference between the other values at different levels of corrosion. The number of animals per site and density per unit length showed no significant difference between the values produced at different states of corrosion. Every density per unit volume value was found to be significantly different from 'no corrosion' at the 5% level (X^2 test).

3.2.3) Conclusions

The results derived from the equation using the same data but a different pipe diameter clearly indicate that pipe corrosion could be a major source of error if animal density per unit pipe volume is used when comparing sites. The values produced from the same data indicate that for 50 % assumed corrosion an error ranging from 360 - 400 % occurs compared with no corrosion. The effect of the same assumed corrosion on estimates of total animal numbers in pipes has a much reduced error (range 96 - 100 % of an estimate with no corrosion), and hence the error range of density per unit length of pipe is also reduced (97 - 100 %). Neither of these values show significant differences between the values produced despite different diameters of pipe. This result indicates that for a direct

Table 3.1) Test of the effects of up to 50% corrosion on estimation of animal numbers and densities.

	Number of animals estimated in pipe	Density of animals per 100 litres of pipe volume	Density of animals per 10 metres of pipe length
Assumed percentage corrosion of pipe length = 0			
chir(s)	72	5	4
harp.	4314	293	230
cyclop.	27353	1852	1455
chyd.	5064	343	270
hala.	1385	94	74
ostra	112	8	6
Assumed percentage corrosion of pipe length = 25			
chir(s)	71	9	4
harp.	4288	517	229
cyclop.	27349	3292	1455
chyd.	5064	609	270
hala.	1362	164	73
ostra	112	14	6
Assumed percentage corrosion of pipe length = 50			
chir(s)	69	18	4
harp.	4270	1156	228
cyclop.	27346	7408	1455
chyd.	5064	1371	270
hala.	1345	364	72
ostra	112	30	6

Key

chir(S) = small chironomids (< 2mm)
harp. = harpacticoid copepods
cyclop. = cyclopoid copepods
chyd. = chydorid copepods
hala. = halacarid mites
ostra. = ostracoda

All values are rounded up to whole numbers of animals.

comparison between sites, animal numbers per unit length of pipe is the value subject to the smallest error. The unit length was chosen to be 10 metres in order to keep numbers reasonable, but to ensure that each site contains a number of unit lengths.

3.3) Investigation of animal removal at different rates of flushing.

This work was of considerable importance for the application of the method in areas where the rates of flow available were lower than 16 l s^{-1}. An experiment was devised to determine the efficiency of removal of different taxonomic groups at different rates of flushing, using a small network of 4" diameter mains at Manor Park, Nether Heyford, Northants. The pipe network had an available maximum flow of 15 l s^{-1} to 16 l s^{-1}. A series of hydrants were sampled at flow rates from 4 l s^{-1} to 11 l s^{-1}, followed by a flush at the maximum rate of flow (16 l s^{-1}). Whether the final sample differed in animal density from the drift level at each hydrant (third sample) was determined. A removal coefficient was devised to measure the proportion of animals in the pipe removed on a scale of 0 (no removal) to 1 (total removal), enabling the efficiency of animal removal by the first sample at each hydrant to be determined.

3.3.1) Methods

Each hydrant was flushed three times in sequence at a specified low rate of flow, followed by a flush at 16 l s^{-1}. The method used to collect and process samples was as described in Chapter 2. In some instances the quantity of water removed from the main did not reach the 'twice pipe volume' recommended, due to drainage problems, but where possible this quantity of water was flushed during each sample. Samples were removed from 5 hydrants with repective flow rates of 4, 5, 6, 7, and 11 l s^{-1}.

Comparison of density of animals collected per unit volume (1000 l) of water was made between first and final flushes (taken at 16 l s^{-1}), using a coefficient of removal. The coefficient of removal, R, was produced for any single flush in a sample sequence by dividing the animal density in that single flush by total animal density of all the flushes in the sample sequence (7).

R = Coefficient of removal

d_{si} = density per unit volume of sample number i
(calculated from 5 subsamples)

(7) $$R_i = d_{si}/(d_{s1} + d_{s2} + \ldots + d_{s(n-1)} + d_{sn})$$

The first and third samples at each hydrant were tested for significant differences with the fourth (high rate of flushing) sample by analysis of variance of the five subsamples from each sample (χ^2 in the case of chironomids greater than 2 mm in size removed from sediments).

3.3.2) Results

Coefficients of removal were calculated separately for the first (Table 3.2a, Fig. 3.1) and fourth (Table 3.2b) samples, and for the first and second samples combined (Table 3.2c, Fig. 3.2). A test (using ANOVA) was carried out on all four samples to determine whether there were significantly more animals in the pipe than drift levels. Where drift levels were not exceeded, that is where there was no significant difference between flush samples implying the animals in all samples were drift, the "*" is absent. Where this was not the case, but animals were absent from the samples, the coefficients have been denoted "Abs.".

3.3.3) Discussion

The results in Table 3.2a indicate that in the 22 cases where the first sample was significantly different to the drift, 18 had a removal coefficient of greater than 0.7, when 1.0 would be ideal. Of these 22, Table 3.2c indicates that only one remains below 0.7 when both first and second flush are taken into account, and 12 have removal coefficients of over 0.9. Two sample sequences failed to attain drift levels by the third sample in the sequence in the case of 'subsampled chironomids' (those that penetrated a 2 mm sieve) (Table 3.2b). However these data related to particularly small numbers of animals. They indicate that different animal groups are removed at different rates depending on the rate of flow at which the sample was removed from the main.

Small chironomids (subsampled) and cyclopoid copepods appeared to have a relatively low removal coefficient in the first flush which may indicate a benthic mode of life rather than epibenthic. In both these cases the second flush removed sediments which were left by the first flush and increased the removal coefficient to a greater degree than with other taxa.

3.4) Investigation of success rate of animal removal using the method

At two sites, one of high and one low rate of flow, it was possible to investigate the efficiency of the sampling method by comparing removal coefficients as described above from an initial sampling with a second sampling using a different sampling method which removed any remaining animals.

Table 3.2) Coefficients of removal at different flushing rates

KEY:

* indicates a significant difference between the density of animals per 1000 litres flushed in the sample (or samples) and the third sample (drift) in each flush sequence at the hydrant. The fourth sample (Table 3.2b) shows the removal at 16 l s^{-1} after three flushes at the rate shown on the column headings.

Chiron.(L) : chironomid larvae collected in a 2 mm mesh
Chiron.(s) : chironomid larvae smaller than a 2 mm mesh
Harpactic. : harpacticoid copepods
Cyclopoid. : cyclopoid copepods

a) First sample in sequence of four.
Total removal by the first flush is indicated by 1.00*.

Rate of Flush	4 l s^{-1}	5 l s^{-1}	6 l s^{-1}	7 l s^{-1}	11 l s^{-1}
Chiron.(L)	0.00	0.31*	0.31	0.46	0.71
Chiron.(s)	0.45*	0.80*	0.76*	0.65*	0.74*
Harpactic.	0.74*	0.96*	0.94*	0.94*	0.99*
Cyclopoid.	0.50	0.62*	0.71*	0.89*	0.67*
Chydoridae	Abs	0.93*	1.00*	0.98*	0.99*
Halacarids	0.67	0.94*	0.93*	0.88*	0.85*

b) Sample four (High rate of flushing)

Total removal by first and second samples is denoted by 0.00

Rate of Flush	4 l s^{-1}	5 l s^{-1}	6 l s^{-1}	7 l s^{-1}	11 l s^{-1}
Chiron.(L)	1.00	0.31	0.37	0.16	0.14
Chiron.(s)	0.25*	0.07	0.13*	0.07	0.07
Harpactic.	0.00	0.01	0.03	0.01	0.00
Cyclopoid.	0.22	0.09	0.26	0.00	0.24
Chydoridae	Abs	0.00	0.00	0.01	0.00
Halacarids	0.11	0.05	0.04	0.06	0.10

c) Samples one and two

Total removal is indicated by 1.00.

Rate of Flush	4 l s^{-1}	5 l s^{-1}	6 l s^{-1}	7 l s^{-1}	11 l s^{-1}
Chiron.(L)	0.00	0.54	0.32	0.79	0.72
Chiron.(s)	0.68	0.89	0.85	0.90	0.86
Harpactic.	0.87	0.98	0.95	0.99	0.99
Cyclopoid.	0.62	0.88	0.74	0.89	0.71
Chydoridae	Abs.	0.99	1.00	0.99	1.00
Halacarids	0.78	0.94	0.95	0.93	0.87

Fig. 3.1) Removal Coefficient of first flush

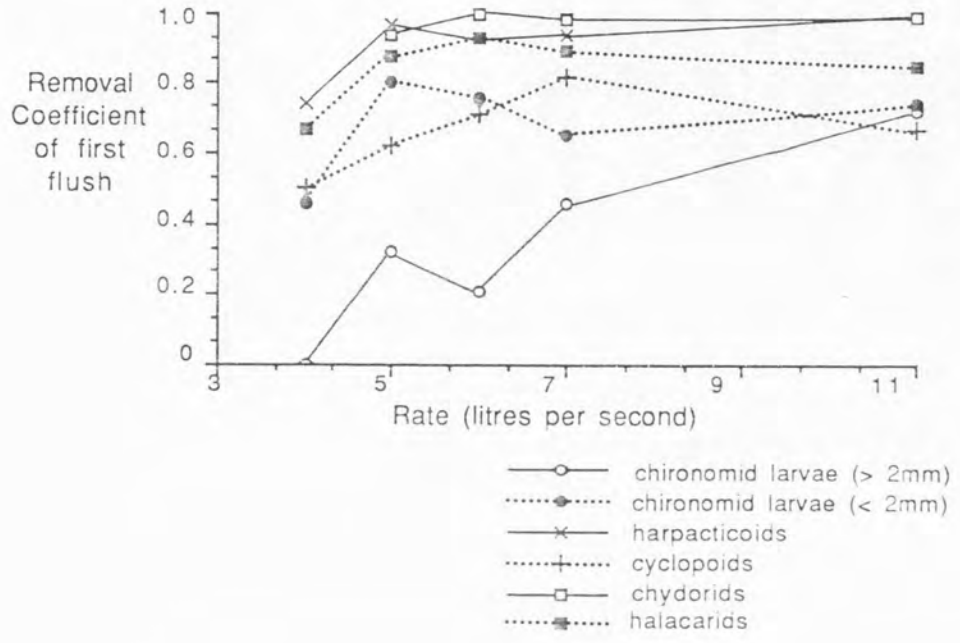
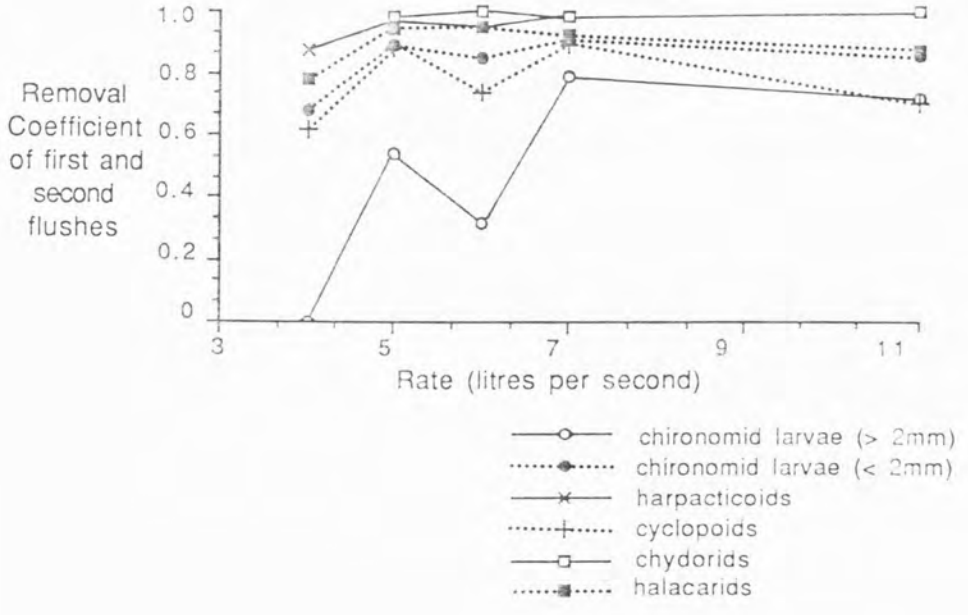


Fig. 3.2) Removal Coefficient of first and second flushes



3.4.1) The determination of the relative values of flushing and pyrethrin followed by air-scour as methods of sampling at high flow rates.

Two sites at Nether Heyford, Northants. were sampled as follows prior to pyrethrin dosing of the system in May 1986:

Wakefield Way - flushed 200 g.p.m. (gallons per minute) (approximately 15.15 l s^{-1}) for 4 minutes

Parsons Close - flushed 150 g.p.m. (approximately 11.35 l s^{-1}) for 4 minutes

An indication of the success of flushing as a means of removal was produced by sampling the sites following pyrethrin dosing.

3.4.1.1) Methods

Using the methods outlined in Chapter 2, sites were sampled on 16th April 1986. The entire system was then dosed with pyrethrin by Anglian Water as part of a long term programme to remove *Asellus* infestations. Following this dosing, on May 28th 1986, over one month from the previous sample, each site was air-scoured, and the animals removed during this process collected in a hydrant net. The animals were counted and removal coefficients calculated as in section 3.3.1.

3.4.1.2) Results

Neither site (Table 3.3) showed particularly high coefficients of removal for the first sample, except for Harpacticoids, though flush sequences followed the pattern expected by the model (Chapter 2). The Parsons Close site suffered from low densities of animals relative to the Wakefield Way data. The low removal coefficients calculated for Acarina at Wakefield Way suggested that either removal was not complete after the first flushing series was taken, or that the animals had re-established themselves in the pipe, either by recolonisation or by reproduction.

3.4.2) Investigation of flush sampling relative to air-scour at low rates of flow

Three hydrants at the village of Haselbech in Northants. were sampled during June 1987 prior to routine air-scour the following day. The success of removal of animals by the flushing method was measured using the removal coefficient previously described by comparing the density of animals in the air-scour samples with the densities in the flush samples.

3.4.2.1) Methods

Three hydrants on 4" legs in the village of Haselbech were sampled as in Chapter 2. The air-scour team had previously cleaned up to Hydrant A on the 5" main feeding the system (Fig. 3.3). The samples were processed

Table 3.3) Removal coefficients of pre-pyrethrin sample and post-pyrethrin sample.

Wakefield Way, Nether Heyford

Taxonomic group	pre-pyrethrin flush sequence 1	2	3	4	5	post-pyrethrin flush sequence 6
Harpacticoida	0.81	0.07	0.04	0.05	0.03	0.01
Cyclopoida	0.45	0.09	0.09	0.09	0.09	0.18
Cladocera	0.36	0.15	0.21	0.06	0.15	0.06
Acarina	0.24	0.14	0.05	0.14	0.09	0.33

Parsons Close, Nether Heyford

Taxonomic group	pre-pyrethrin flush sequence 1	2	3	4	5	post-pyrethrin flush sequence 6
Chironomidae	0.50	0.50	0.00			0.00
Harpacticoida	0.87	0.09	0.03			0.01
Cyclopoida	0.80	0.00	0.20			0.00
Cladocera	0.80	0.10	0.00			0.10

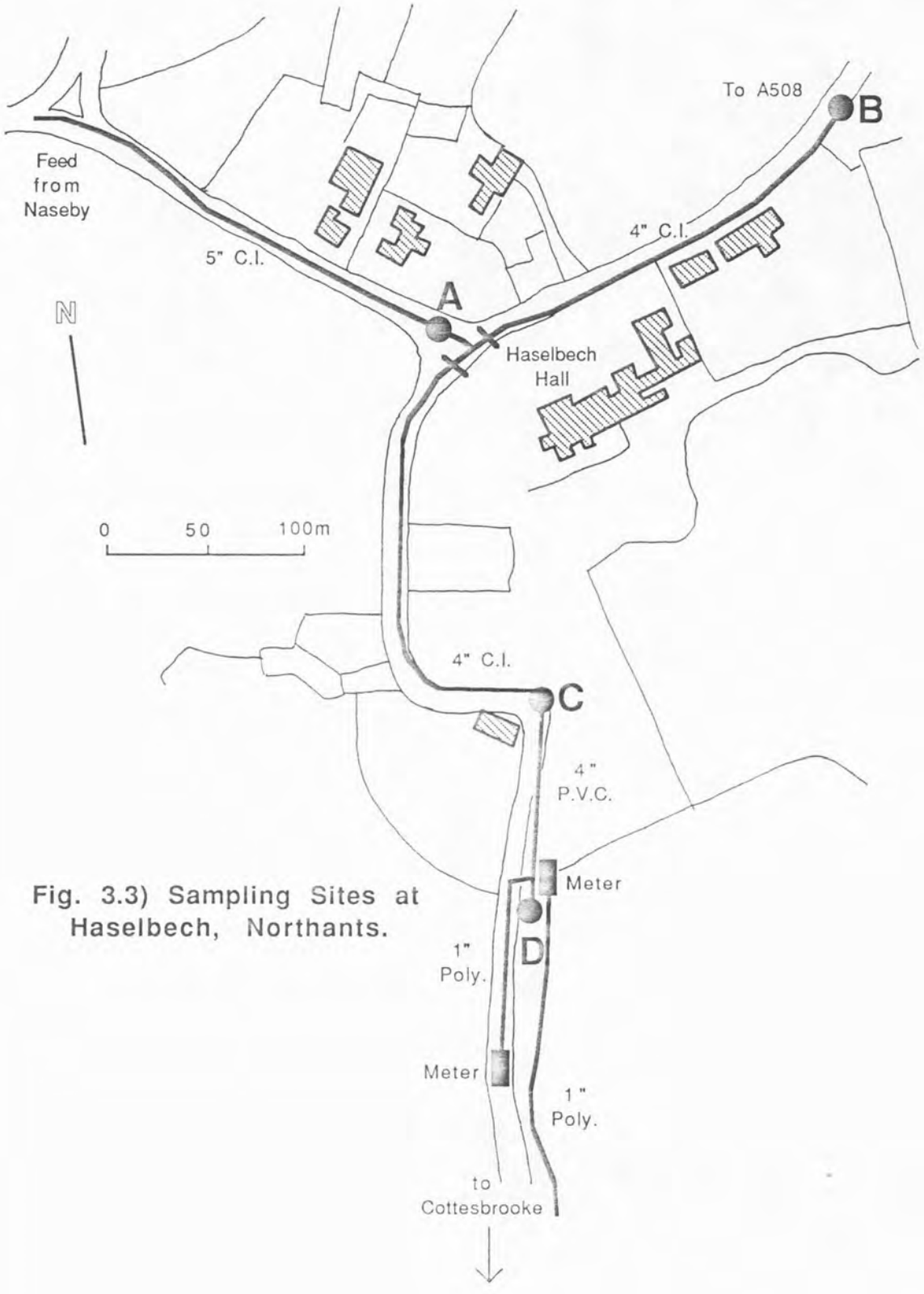


Fig. 3.3) Sampling Sites at Haselbech, Northants.

as described in Chapter 2 to give an estimate of the density of animals in the pipe and the density of animals per unit volume in the third flush in the flushing sequence, the drift.

A rough measure of density of animals collected per unit volume was produced by estimating the time taken to fill a 30 litre drum with water assuming a constant rate of flow for the period of the air-scour procedure. Prior to the pump being connected, water was flushed through the hydrant and this rate of flow was also estimated.

Four measures of density of animals collected per unit volume were analysed using ANOVA, in order to determine any differences between the samples, the flushing sequence of three flushes, and the flush and air-scour sample combined. The flush samples were taken at a particularly low rate of flow, 3.2 l s^{-1}, owing to the constraints on the system in this area.

3.4.2.2) Results

Table 3.4 indicates the coefficient of removal for each species group at each hydrant, calculated as described in section 3.1. Total removal would be indicated by '1.00' in column 1, '1.00' in column 2 and '0.00' NS in column 3. In column 3, significant differences to the third (drift) sample from the flush sequence are denoted by '*H' (higher) and '*L' (lower).

3.4.3) Discussion of flushing alone relative to other methods

Even at low rates of flow it is possible to remove the vast majority of Chydoridae and Harpacticoidea, but not halacarid mites. Air-scour is able to remove larger quantities of material than flushing at these low rates of flow. Flushing at low flow rates will reduce the accuracy of estimates of densities of any animals able to cling to pipe walls. This has been previously recorded with *Asellus* (Smalls and Greaves 1968, and Williams *et al.* 1986). In the case of Halacaridae at Hydrant B, Haselbech, significantly higher numbers were found in the air-scour samples than in the drift sample which indicates that any analysis of this family will be subject to error where rates of flow are this low. A large proportion of the sites used for assessment of community structure suffered from a low rate of flow and could only be treated qualitatively, or using a relative measure of density (Chapter 6).

The pyrethrin work supports the work at Manor Park, Nether Heyford (section 3.3) showing quantitative samples were taken at high rates of flow, with the exception of Halacaridae.

Table 3.4) Removal Coefficients Of Flush and Air-scour sequences at Haselbech, Northants.

	First flush (first sample)	First and Second Flush (first and second sample)	Flush and Air-scour (final [fourth] sample)
Hydrant B $6.2ls^{-1}$			
Chydoridae	0.88	0.95	0.03 NS
Halacaridae	0.30	0.46	0.43 *H
Hydrant C $4.2ls^{-1}$			
Chydoridae	0.95	0.98	0.01 *L
Halacaridae	0.58	0.77	0.10 NS
Hydrant D $3.2ls^{-1}$			
Harpacticoidea	0.63	0.81	0.03 *L
Chydoridae	0.94	0.98	0.01 NS
Halacaridae	0.50	0.72	0.20 *H
Oligochaeta	0.98	0.99	0.00 NS

(* denotes significant difference from the drift value in the flush sequence. *L significantly lower; *H significantly higher; NS not significantly different from the drift value (third sample) in the flush sequence)

3.5) Limitations applying to the sampling method

The calculations used in the method were subjected to a number of possible errors:

a) Pipe diameter may not have been as recorded on the plan.

b) Pipe lengths may have been inaccurate

c) Pipe volume varied considerably due to corrosion.

d) Flushed volumes were slightly greater than those recorded.

These could not be avoided and therefore estimates of density of animals were underestimates.

CHAPTER 4) DETERMINATION OF EXAMINATION OF ENVIRONMENTAL PARAMETERS

4.1) Introduction.....73

Section A: Environmental Characteristics

4.2) Field measurements of water quality.....73
4.2.1) Total Chlorine.....73
4.2.2) Dissolved oxygen.....74
4.2.3) pH.....74
4.2.4) Temperature.....74
4.3) Carbon in potable water.....75
4.3.1) Initial processing of water samples for carbon analysis.....75
4.3.2) Dissolved organic carbon.....75
4.3.3) Particulate organic carbon.....78
4.3.4) Total organic carbon.....78
4.4) Iron and Turbidity.....78
4.5) Sediment analysis.....79
4.5.1) Dry weight of sediments.....79
4.5.1.1) Methods.....81
4.5.2) Dry weight of organic matter.....82
4.5.3) The effect of iron salts and waters of hydration on determination of the percentage organic matter.....83
4.5.3.1) Methods.....84
4.5.3.2) Results and Discussion.....84
4.6) Microbiological analysis.....87

Section B:: Operational Characterisics

4.7) Consumption rate.....87
4.8) Rate of flow.....88
4.9) Pressure.....88
4.10) Pipe age, material and diameter.....90
4.11) Air-scour and scrape-and-reline history.....90
4.12) Age of water (Travel time).....90
4.13) Service Reservoirs and Water Towers.....91
4.14) Reservoir Water.....91
4.15) Tuberculation.....91

CHAPTER 4) DETERMINATION OF EXAMINATION OF ENVIRONMENTAL PARAMETERS

4.1) Introduction

Various parameters were determined that relate to the environment in the pipe itself in order to consider what determines the different community types present in the pipes (Chapter 6) and the effect of repeated flushing at sites (Chapter 7).

Determination of environmental conditions in the distribution system is somewhat difficult since there is no real way of determining precisely what the features inside the pipe are. Any work that is carried out in the operating supply system, rather than in controlled conditions, must rely on samples of water and sediments removed from the pipe by flushing and an assumption that these reflect the conditions inside the main.

The various environmental parameters used in this study are discussed below and, where appropriate, detailed methods used to evaluate the parameter for a section of pipe are given. Each parameter was assigned to a class, ranked from 1 to 4, to enable ease of processing for Chapter 6, and the classes are given for each parameter. Values for environmental and operational parameters are tabulated in Appendix III (Chapter 6) and Appendix IV (Chapter 7).

Section A: Environmental Characteristics

4.2.) Field measurements of water quality

Prior to sampling a hydrant for animals, the hydrant was 'cracked' to remove any stagnant water remaining in the hydrant bowl since the last flush. As soon as this water was removed, (once the water ran 'clear'), the hydrant was closed down to the minimum possible flow and a water sample of approximately 2 litres was removed by allowing water to trickle out from the hydrant at the lowest rate possible. This water was assumed to be characteristic of the water in the main and was immediately tested for chlorine, pH, temperature and dissolved oxygen using field instruments.

4.2.1) Total Chlorine

Chlorine was measured using a Lovibond comparator (Tintometer Ltd., Salisbury, England.) in the range 1.0 mg l^{-1} to < 0.1 mg l^{-1}. The test used 'DPD No. 4' tablets to measure total chlorine. The levels of chlorine recorded were assigned to the classes shown overleaf:

1: $Cl \geq 1.0$

2: $0.5 \leq Cl < 1.0$

3: $0.1 \leq Cl < 0.5$

4: $0.1 > Cl$

The free chlorine residual was not usually above 0.5 mg l^{-1} in the supply zones studied. Values above 0.5 mg l^{-1} may be due to contamination of the test by oxidised manganese, from the pipe wall. High levels of total chlorine frequently occurred in water samples where large quantities of fine sediment was present which suggests that the chlorine test may be affected by particles in the sediment.

4.2.2) Dissolved Oxygen

Oxygen levels were measured using a Mackereth probe dissolved oxygen meter. Two models were used during the course of this study, a Jenway model P.O.M.2 and an E.I.L. model 1520. The percentage saturation was recorded and assigned to the following classes:

1: $O_2 \geq 80\%$

2: $40\% \leq O_2 < 80\%$

3: $20\% \leq O_2 < 40\%$

4: $20\% < O_2$

4.2.3) pH

The pH of the water sample was measured using combination probe pH meters. Two different pH meters were used during the course of the study, an Kent/E.I.L. 3055 model 673 pH meter with a Russell probe and a Griffin portable pH meter with an E.I.L. probe. Both meters were calibrated with pH 4.0 and pH 7.0 or 9.0 buffers. The pH was in the range 7.2 to 7.8 in all undisturbed sites, with over 50% of values lying between 7.4 and 7.6. The measured accuracy of the instruments involved was ± 0.2 but performance in the field was considerably less accurate with poor replication. Since Anglian Water aim to maintain a constant pH in potable water, the pH has been considered as a constant.

It is generally accepted that this pH range will have no effect on the infesting animals. Certainly this is the case for cladocera and copepods (Fryer 1980, Fryer and Forshaw 1979) and chironomid larvae (Oliver 1971).

4.2.4) Temperature

Water temperature was recorded using a mercury thermometer (± 0.5°C), placed into the water sample while flushing was underway. The temperature was assigned to the classes shown overleaf:

1: °C < 4

2: 4 ≤ °C < 8

3: 8 ≤ °C < 16

4: 16 ≥ °C

4.3) Carbon in potable water

Total organic carbon (T.O.C.) is the carbon in organic compounds which is converted to carbon dioxide by oxidation, once any inorganic carbon present has been removed. This T.O.C. contains both dissolved organic carbon (D.O.C.) and particulate organic carbon (P.O.C.) in a water sample, and the two make up varying proportions of the T.O.C.. Available organic carbon (A.O.C.), considered to be the most important measure of carbon, contains both of these types but is mainly particulate organic carbon. A.O.C. measurement is undergoing considerable research but the methods currently in use are time consuming and costly and therefore other measurements of carbon, D.O.C. and P.O.C., were used during this study.

4.3.1) Initial processing of water samples for carbon analysis

A sample of 200 ml was removed from the water sample taken at the hydrant and was returned to the laboratory in order to determine the levels of dissolved organic carbon and particulate organic carbon.

The sample was then separated into fractions by filtering through pre-ashed filter paper (Whatman GF/C) under vacuum. The residue and a sample of approximately 20 ml of filtrate were collected and frozen to enable ease of batch processing. The freezing process has been found to not affect levels of P.O.C. (A.Watson pers. comm.) or T.O.C. (M.Turrell pers. comm.). A number of both distilled and deionised water samples were included as blanks to estimate the levels of carbon contamination during the filtering and storage process.

Filtration of the 200 ml water sample through pre-ashed (GF/C) filter paper separates the dissolved organic carbon (D.O.C.) and the particulate organic carbon (P.O.C.). These were then analysed separately.

4.3.2) D.O.C.

D.O.C. was measured using a Model 700 Total Organic Carbon Analyser (O.I.Corporation, College Station, Texas, U.S.A.) at Anglian Water, Oundle Division, Gt. Billing Laboratory. This machine produces a value for T.O.C., P.O.C. and D.O.C. but could not cope with the particle size of P.O.C. samples collected by this project.

The following description of the operations carried out by the T.O.C. analyser is based on information contained in the instruction manual

(Anon 1986). The sample was acidified by phosphoric acid to remove any inorganic carbon present. This acidification also led to the release of any volatile organic carbon (purgeable organic carbon) present in the sample, which was lost. (Purgeable organic carbon is assumed to be minimal in most measurement of organic carbon, which corresponds to non-purgeable organic carbon.) The sample was oxidised by potassium persulphate ($K_2S_2O_8$), which reacted at 100°C, oxidizing any organic carbon present into carbon dioxide. The resulting mass of carbon dioxide equivalent to the mass of organic carbon present in the sample, was measured using an infra red gas analyser.

A 3 ml volume of each sample was diluted by half and duplicates were analysed for T.O.C. present. Distilled deionised water blanks and standards of potassium hydrogen pthalate were used to calibrate the machine and blanks were subtracted from the samples. When the replication was less than that shown by the standards and the blanks, a further replicate was measured, and the nearest two were used to produce a mean. In some instances samples contained large quantities of organic carbon and the results were outside the linear measurements used by the machine. These samples were further diluted and replicates were measured at the greater dilutions.

All bottles and jars were washed with distilled deionised water, as was the filtration system between samples. However, repliction was poor and a number of the distilled deionised controls analysed gave values that indicate contamination occurred in some instances. It is possible that this contamination arose from the use of plastic rather than glass vials and jars to store the D.O.C. samples or contamination by dust.

These contaminated controls recorded values ten times higher than expected levels. When this occurred samples were rejected (*, Table 4.1). The T.O.C. analyser frequently produced counts for background levels and standards that were higher than expected but errors were not always consistent. Since there was doubt as to the accuracy of these D.O.C. measurements, the concentration was not calculated, but the recorded values per 3 ml were used as a relative measure. The levels of D.O.C. measured per 3 ml of sample were assigned to the classes shown below for use in analysis of data in Chapters 6 - 8:

1: D.O.C. ≤ 5

2: $10 \geq$ D.O.C. > 5

3: $20 \geq$ D.O.C. > 10

4: $20 <$ D.O.C.

Table 4.1) Examples of readings from D.O.C. analysis

Run A:

Sample	mg l^{-1} in sample
Blank 0.0 mg l^{-1}	0.43320
	0.43478
Standard 5mg l^{-1}	5.28008
	5.34963
Church Mount Guilsborough 15.07.86	2.55475
	2.69551
Park Lane Watford 11.07.86	2.99413
	2.90779
2nd Blank, 0.0 mg l^{-1}	0.85747
	0.53608

Run B:

Sample	mg l^{-1} in sample
Blank 0.0 mg l^{-1}	0.25207
	0.20582
Standard 5mg l^{-1}	5.40729
	4.43385
H2/Brampton Lane 15/06/87	4.76887
	4.71773
Distilled deionised control 15/06/87	23.4710*
	23.4617*
Tithe Road, Weedon 12/06/87	6.12264
	6.01052
Orchard Close Hollowell 02/06/87	43.0608*
	43.0512*
Distilled deionised control 03/06/87	1.61227
	1.24074

4.3.3) P.O.C.

Particulate organic carbon was analysed using a method from Thames Water (Anon 1987), which appears to be based on a method used by Walkley and Black (1934) and Mebius (1960). Processing initial test samples suggested it would be appropriate to use the 'Thames Water' modification for sand samples within the method (after filtration) because of the quantity of sediment present.

In Piper (1950), the Walkley and Black method is criticised for recovery rates lower than 100 percent. In order to test the method, solutions of sucrose, ascorbic acid and potassium hydrogen pthalate, were analysed. All three gave carbon recovery in the range 33.5% to 42.5% which was much lower than expected. The test was repeated and the mean percentage recovery was found to be 36.98 ± 0.68 for ascorbic acid; 37.62 ± 1.62 for sucrose and 36.68 ± 1.20 for potassium hydrogen pthalate. The reason for this low recovery was not determined by this study, but since all concentrations of standard tested (1, 2 and 3 mg ml^{-1}) showed similar recovery levels, the P.O.C. levels recorded were assumed to be relatively constant.

These values were used as a relative score of P.O.C. and were assigned to the following classes:

1: P.O.C. ≤ 2

2: $4 \geq$ P.O.C. > 2

3: $8 \geq$ P.O.C. > 4

4: $8 <$ P.O.C.

4.3.4) T.O.C.

T.O.C. is normally determined by addition of P.O.C. and D.O.C. However, the failure of the method used to produce P.O.C. levels (section 4.3.3) to give a high percentage recovery means that any attempt to measure T.O.C. in the water sample is likely to be erroneous. It was not felt that the estimated 30 - 40% recovery was sufficient to justify multiplying by a correction factor to estimate 100% of the P.O.C. present in the sample. Therefore the carbon information relating to the water quality in the main remained as two separate measures, a quantitative measure of D.O.C. and a relative measure of P.O.C.

4.4) Iron and Turbidity

This information was provided from tap samples by the Anglian Water Discolouration Survey (McElroy and Barnsby 1988) and the results are recorded on a parish basis. The parish record was calculated from 19 samples over the period of one year and classified as follows:

Iron : mg l^{-1}

1: mg $l^{-1} \leq 0.05$

2: $0.05 <$ mg $l^{-1} \leq 0.1$

3: $0.1 <$ mg $l^{-1} \leq 0.2$

4: $0.2 <$ mg l^{-1}

Turbidity: (Jackson units)

1: turbidity ≤ 0.4

2: $0.4 <$ turbidity ≤ 1.0

3: $1.0 <$ turbidity ≤ 4.0

4: $4.0 <$ turbidity

The study areas of the two projects did not coincide. Where no tap samples were available, sites were not included in subsequent analysis.

4.5) Sediment analysis

Two aspects of the sediment were considered in order to determine the effect of sediment on the animals in the pipes:

i) The total dry weight in the pipe.

ii) The quantity of organic material in the pipe (i.e. the available carbon in both the sediment and animals).

Each of these is somewhat difficult to measure, because of the multiple flushing process which obtained the samples. The hypothesis and methods which overcome the potential errors are discussed below.

4.5.1) Dry weight of sediments.

Each hydrant sample consisted of three flush samples. The first and second were assumed to contain animals and sediment from the main, and the third was considered to consist of the drift (section 2.2). A simple measure that would show differences between sites was devised.

For three different types of hydrant sample, each flush within a sequence may be quite different, but primary flushes at different sites could be similar. If hydrant A was a site with low levels of sediment, flushed every two months, the hypothetical sediment removal pattern might be as shown in Figure 4.1 - all the pipe sediment removed in the first flush and drift sediments present in all three. Hypothetical removal patterns are also shown in Figures 4.2 and 4.3 for hydrants B and C, which are initial samples from a small diameter main fed directly from a large diameter main (Fig. 4.2) and a small diameter main fed by other small diameter mains in the system (Fig. 4.3). In the case of hydrant B, all the sediments in the pipe will be removed over the three flushes, while at hydrant C sediments will remain in the pipe after three flushes.

Fig. 4.1) Hypothetical sediment removal from reinfestation site (after several months of flushing)

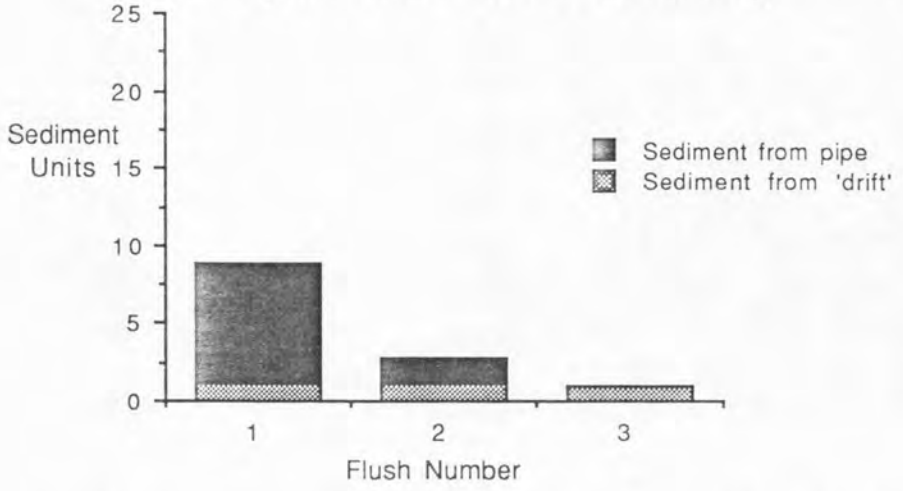


Fig. 4.2) Hypothetical sediment removal from a new site (small diameter main with large diameter feed)

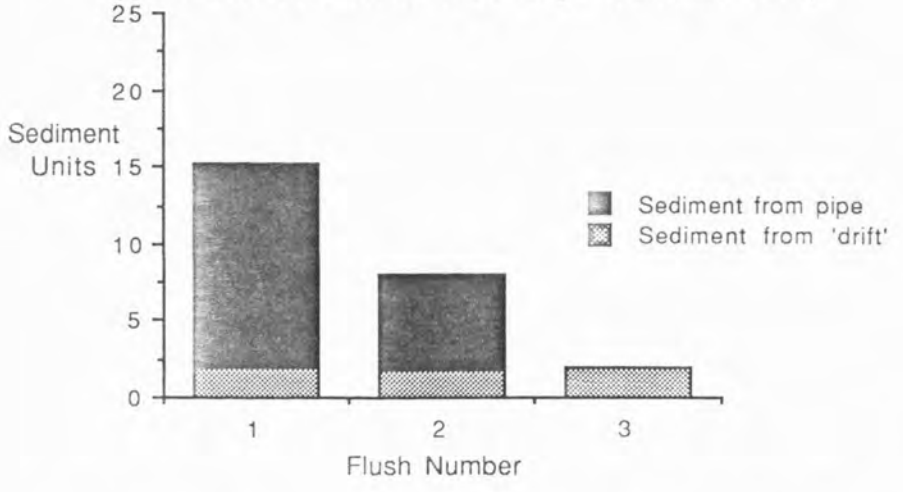
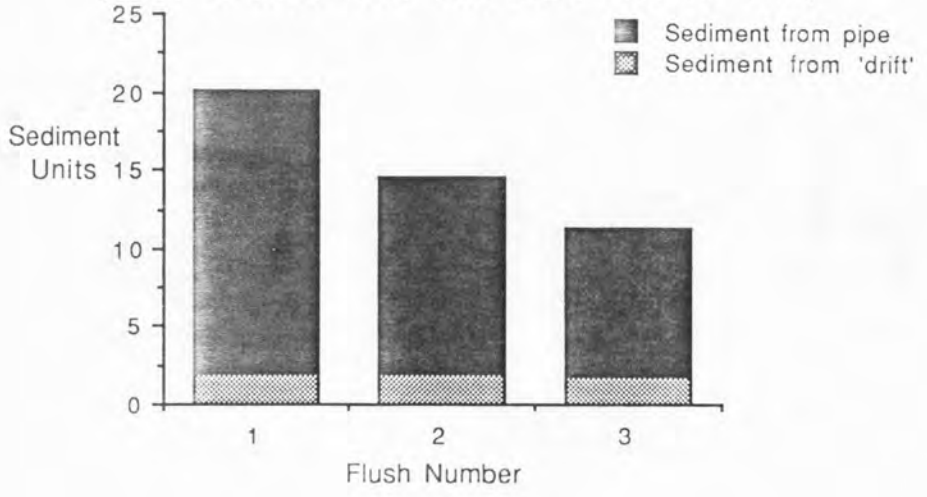


Fig. 4.3) Hypothetical sediment removal from a new site (small diameter main with small diameter feed)



At hydrant C (Fig. 4.3) the drift levels of sediment are likely to be higher than at hydrant B due to the water flow feeding small diameter rather than large diameter mains.

As can be seen from the figures, the use of the first samples will not neccessarily show any difference between sites though a difference exists over all three flushes. The combination of all three samples will indicate where large quantities of sediments are present because true drift levels (flush three at Hydrants A and B) will not be attained without sediments still be being removed in the third samples at some sites (Hydrant C).

So for each hydrant sample, the secondary and tertiary flush were combined and the subsamples previously removed for counting were returned to the samples. Subsamples from primary flush samples were not replaced because animals had been removed from these subsamples during counting for identification. The proportion of total sediment and animals removed in the subsamples was calculated and the final results corrected by this factor. At some sites, where a considerable quantity of stones was present in the main, the correction factor was estimated by using the dry weight of one subsample, multiplied by five (because five subsamples were removed), and accepting that an underestimate of the total dry weight would result.

4.5.1.1 Methods

Each sample was filtered, either onto a weighed piece of Whatman GF/C filter paper (pre-ashed at 550°C for 4 hours), or through a 142 µ mesh (the same dimension as a hydrant net) and weighed in foil containers which had been stored in a dessicator with silica gel.

These sediment samples were then heated in an air oven at 60°C for 24 hours followed by a vacuum oven at 60°C for 24 hours. On removal from the vacuum oven, samples were allowed to cool in a dessicator with silica gel, and then re-weighed. The dry weight was calculated by difference.

Samples took different lengths of time to reach a constant weight so completion of the drying process was checked by repeating for the largest samples in each batch. If the result was not correct to the nearest 0.01 g, the entire batch was reheated and reweighed. This was repeated a maximum of three times for any tray.

Total quantity was then calculated for the primary flush sample and all samples were summed. Sediment dry weight was recorded in all three flushes to the nearest 0.1 g. All sampling occasions (flush samples taken at any flow rate over 3 l s^{-1}) were assigned to the classes overleaf:

1: $g \leq 50.0$

2: $100.0 \geq g > 50.0$

3: $200.0 \geq g > 100.0$

4: $200.0 < g$

In addition a factor relating to the quantity of water passing through the collection net was included for sampling occasions when flow rates were in excess of 7.0 l s^{-1} (sites with quantitative values of animal density), and the reinfestation samples (samples with a low quantity of sediment present).

If the sediment quantity was low, a sample taken with a large volume of water could appear to have as much sediment as a sample taken with a low volume of water. To remove this possible error, the sediment total for every sample taken (over 7.0 l s^{-1}) was divided by the total volume of water flushed from the hydrant over all three flush samples combined, and adjusted to give the quantity of sediment removed per 1000 litres over all three flush samples from each hydrant.

These values were assigned to the following classes:

1: g 1000 $l^{-1} \leq 5.0$

2: $10.0 \geq$ g 1000 $l^{-1} > 5.0$

3: $20.0 \geq$ g 1000 $l^{-1} > 10.0$

4: 20.0 > g 1000 l^{-1}

4.5.2) Dry weight of organic matter

To estimate the quantity of organic material in the pipe two assumptions were made:

i) that the dry weight of sediment (section 4.5.1) measured is a relative measure of sediment in each pipe; and

ii) that the proportion of iron salts present in each sample is constant relative to the quantity of sediment (section 4.5.3).

Assuming these two statements are true, the quantity of sediment organic matter that was removed from each pipe when sampling occurred was determined as weight loss on ignition. It included animal and other material, but did not include large chironomid larvae, which were removed and mounted separately. Dean (1974) found that the percentage organic carbon (determined by chromatography) and the percentage loss on ignition at 550°C gave a correlation coefficient, r, of 0.97.

A portion of each sample previously used to calculate the dry weight of sediment was dried in a vacuum oven at 60°C for 24 hours and stored in a dessicator with silica gel to ensure no uptake of moisture as the sample cooled. Samples from the dessicator were weighed and placed in crucibles of known weight and then ashed at 600°C for 12 hours. Each sample was then allowed to cool in a dessicator and was reweighed, the

crucible weight subtracted and the percentage loss of weight on ignition calculated. This percentage loss of weight on ignition was then used to produce a measure of organic material in the sample by multiplying with the dry weight of each sample calculatated in section 3.5.1.

Some measure of the volume of water flushed was included where quantitative information on animals was available. Therefore, two measures of organic material were calculated:

i) The quantity of organic material per 1000 litres flushed (when samples were over 7.0 l s^{-1}) and

ii) The quantity of organic material present in the three flushes (for all samples).

These values were assigned to the following classes:

Quantity per 1000 litres flushed:

1: g 1000 $l^{-1} \leqslant 0.6$

2: $1.2 \geqslant$ g 1000 $l^{-1} > 0.6$

3: $2.4 \geqslant$ g 1000 $l^{-1} > 1.2$

4: 2.4 > g 1000 l^{-1}

Dry weight of organic material present in the three flushes comprising a sample:

1: $g \leqslant 5.0$

2: $10.0 \geqslant g > 5.0$

3: $20.0 \geqslant g > 10.0$

4: $20.0 > g$

4.5.3) The effect of iron salts and waters of hydration on determination of the percentage organic matter

A potential error when determining the percentage organic matter by combustion is that organic material has a wide temperature range of combustion. This can overlap inorganic substances such as the water of hydration in iron salts and carbonate. Mook and Hoskin (1982) showed that the problem of waters of hydration in clays could produce errors as large as 20% when considering organic contents of sediments. They discuss two areas of concern:

i) that CO_2 from carbonates is driven off and will cause errors in estimation of loss on ignition and

ii) that water of hydration in clays will also be lost with the same effect.

Carbonate breakdown into CO_2 was not a problem in this instance since the levels at which CO_2 is initially lost from carbonates are in the region 640°C to 680°C with loss completed by 850°C (Konrad et *al.* 1970). Any organic material ignited in the 250°C - 600°C bracket and as the temperature did not exceed 640°C, no carbonate breakdown was possible.

However, water of hydration was a problem since not only clays (if present) but also iron salts hold water which was driven off at low temperatures. Research into pipe corrosion by Anglian Water and Hatfield Polytechnic has found that deposits from the inside of mains gave a peak in the region of 110°C - 320°C when ashed which is thought attributable to iron and waters of hydration (M.Turrel pers. comm.).

4.5.3.1) Methods

A number of samples were investigated to determine the level of error due to the presence of iron salts. Experimental design meant that only samples with large quantities of sediments could be tested (to retain sufficient for later ashing). Each sample was divided into a number of portions and to each was added a blank (distilled deionised water), or a volume of 10% sodium hypochlorite. These samples were then heated for 4 hours at 100°C following the method proposed by Mook and Hoskin (1982) for determination of waters of hydration of clays.

This digestion process removes the organic material from the samples, leaving inorganic material only. Each digestion would remove more organic material until a constant level of inorganic carbon remained. The digestion process was repeated up to five times, alternated with washing in distilled deionised water. A blank, with distilled deionised water was heated for two occasions only.

The sediment from each sample was then filtered through a pre-ashed (600°C, 4 hours, Whatman GF/C) filter paper. This was then air dried (60°C for 24 hours) and vacuum dried (60°C for 24 hours). The quantity of sediment was then weighed, ashed at 600°C for 12 hours, and reweighed. The percentage weight loss on ashing being calculated by difference.

A portion of sediment from the same site was also ashed at 600°C for 12 hours without any digestion process and the loss of weight on ignition was calculated as a percentage. This sample was used as a control.

4.5.3.2 Results and Discussion

The results for each sample are shown in Table 4.2, and plotted on Figure 4.4. Figure 4.4 shows the number of occasions digestion was carried out and the decline in the percentage weight loss. The base level was taken to be at the fourth or fifth digestion (whichever was lower). This was assumed to be the percentage weight loss due to inorganic material, since at this point all organic matter had been digested.

The controls (sediments ashed in a normal manner) showed the percentage weight loss due to both organic and inorganic material, and though these appeared generally higher than the digested blanks the values were not found to be significantly different from each other

Table 4.2) Percentage weight loss on ignition of samples with and without organic material

Site	Control	Blank	Digestion number 2	3	4	5
WEST HADDON 26.05.87-2	23.24	19.65	18.70	14.98	14.36*	-
WEST FARNDON 19.10.87-11	11.92	8.26	14.22	13.68	11.77	7.68*
WEST FARNDON 19.10.87-10	14.60	11.95	16.71	12.64	12.92*	-
WATFORD 03.06.87-4	-	10.69	9.84	11.08	9.93*	-
WATFORD 03.06.87-1	14.57	15.21	10.89	-	-	12.87*
UPPER WEEDON 12.06.87-1	6.16	5.01	6.98	6.25	6.67	6.06*
WATLING ST. 27.05.87-1	18.47	16.67	16.02	11.94	8.31*	-

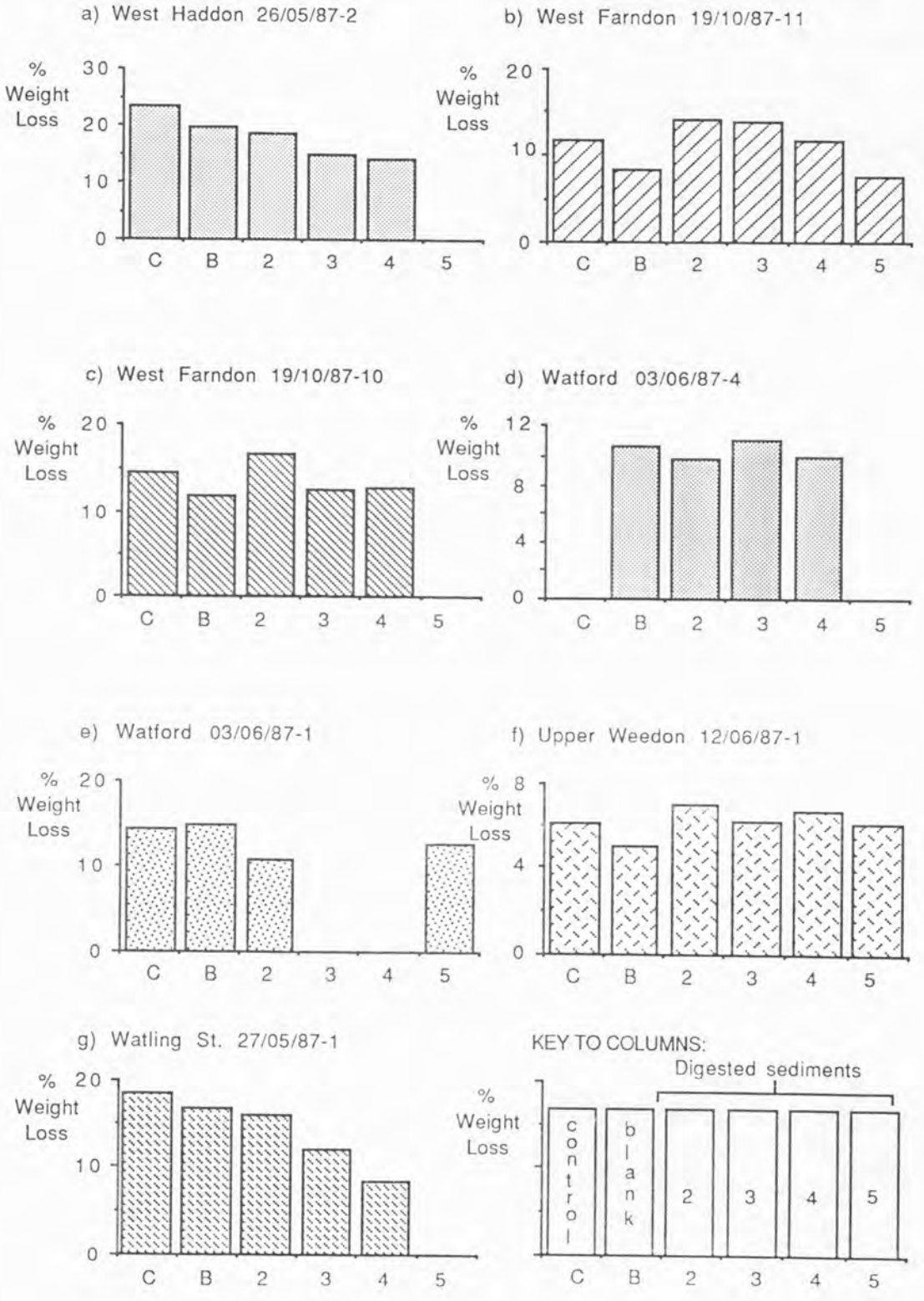
Methods

Control: Sample ashed without digestion of either organic or inorganic carbon.

Blank: Sample ashed after digestion with distilled deionised water - thus containing both organic and inorganic carbon.

Digestion: Sample ashed following 2 or more digestions with 10% sodium hypochlorite - thus containing only inorganic carbon.

Fig. 4.4) Percentage weight loss in sediment samples with and without organic material



(χ^2, p = 0.05).

The mean proportion of weight loss due to inorganic material was calculated by comparing the percentage weight loss due to both organic and inorganic material (blanks) and the percentage weight loss due to inorganic material alone (digested samples marked with * in Table 4.2). However, χ^2 tests for similarity between blanks and digested samples showed no significant difference (p = 0.05). Though some weight loss does occur (Fig. 4.4) it was not considered significant and could not be attributed to inorganic material.

4.6) Microbiological analysis

Bacteria in the water and sediment found in the distribution system have been considered a potential food source (Chapter 1). A measure of the density per unit volume water was attempted.

Water samples from flushes at four reinfestation sites were cultured on plates of agar at 22°c for 3 and 7 days and 37°C for 24 hours. However, the amount of activity (number of colony forming units) was so great at two sites that the sampling procedure was obviously leading to contamination. It was not possible to easily sterilise field equipment used in flushing, and a sampling strategy derived entirely to obtain microbiological samples from the mains themselves was beyond the scope of this project.

It proved impossible to undertake the sampling programme as well as preparing cultures and plates to measure microbiological activity in the sediments removed from inside the main.

Section B: Operational Characteristics

4.7) Consumption Rate

Consumption rate is the term used in this study to account for the rate of renewal of water in the pipe, an index of the residence time of the water. The consumption rate in the main was estimated from the number of households and farms fed by any leg. Average consumption of properties, provided by Mr. B.Young, Anglian Water, Oundle was 787 l day^{-1} per household (Western Area) and 2846 l day^{-1} per farm (from records of 100 metered farms over 1 year). Pipe legs were classified on the basis of a scale of consumption and hence flow through the pipe.

Each length of pipe sampled was examined on the 1:2500 plan of the system and the number of properties and farms fed from that leg was estimated (This may not provide accurate information, but is likely to place sites in the correct class).

The number of properties on each leg were summed and multiplied by

the appropriate value to give the consumption between each hydrant, or the feed and the first hydrant (denoted by the letters a, b, c, d, and e on Fig. 4.5). Hydrants in sequence were given values relating to the score on the length of pipe flushed at that hydrant and the lengths of pipe fed after the hydrant's position (as indicated in the flags on Fig. 4.5a). As systems became more complicated some flow values were simply halved (Fig. 4.5b), or assumed to be equal (Fig. 4.5c). Without true network analysis this cannot be improved upon as a measure, since flow rates and the locations of feed pipes to many properties are unknown. It was classified in litres per day as follows:

1: Cons. $\geqslant$ 55090
2: 24397 $\leqslant$ Cons. $<$ 55090
3: 7870 $\leqslant$ Cons. $<$ 24397
4: 7870 $>$ Cons.

4.8) Rate of flow

These values were recorded in the field using the Vernon Morris Flow Gauge at each hydrant sampled. The flow rate was either the constant flow rate at which sampling was carried out, or in cases where variation occurred during sampling (which were very infrequent), the mid-point between the maximum and minimum rate attained was used. Flow rates of less than 3 l s^{-1} led to samples being discontinued.

The presence of the hydrant net on the end of the Vernon - Morris gauge can lead to erroneous measurements. Holding the net horizontal is a method which allows the pressure caused by the net to decrease and a true reading can be taken. In some cases a check was made by removing the hydrant net without shutting the hydrant. When large hydrant nets (2m) were used, this problem did not arise to such an extent because of the lack of pressure buildup in the net.

The flow rates were assigned to the following classes:

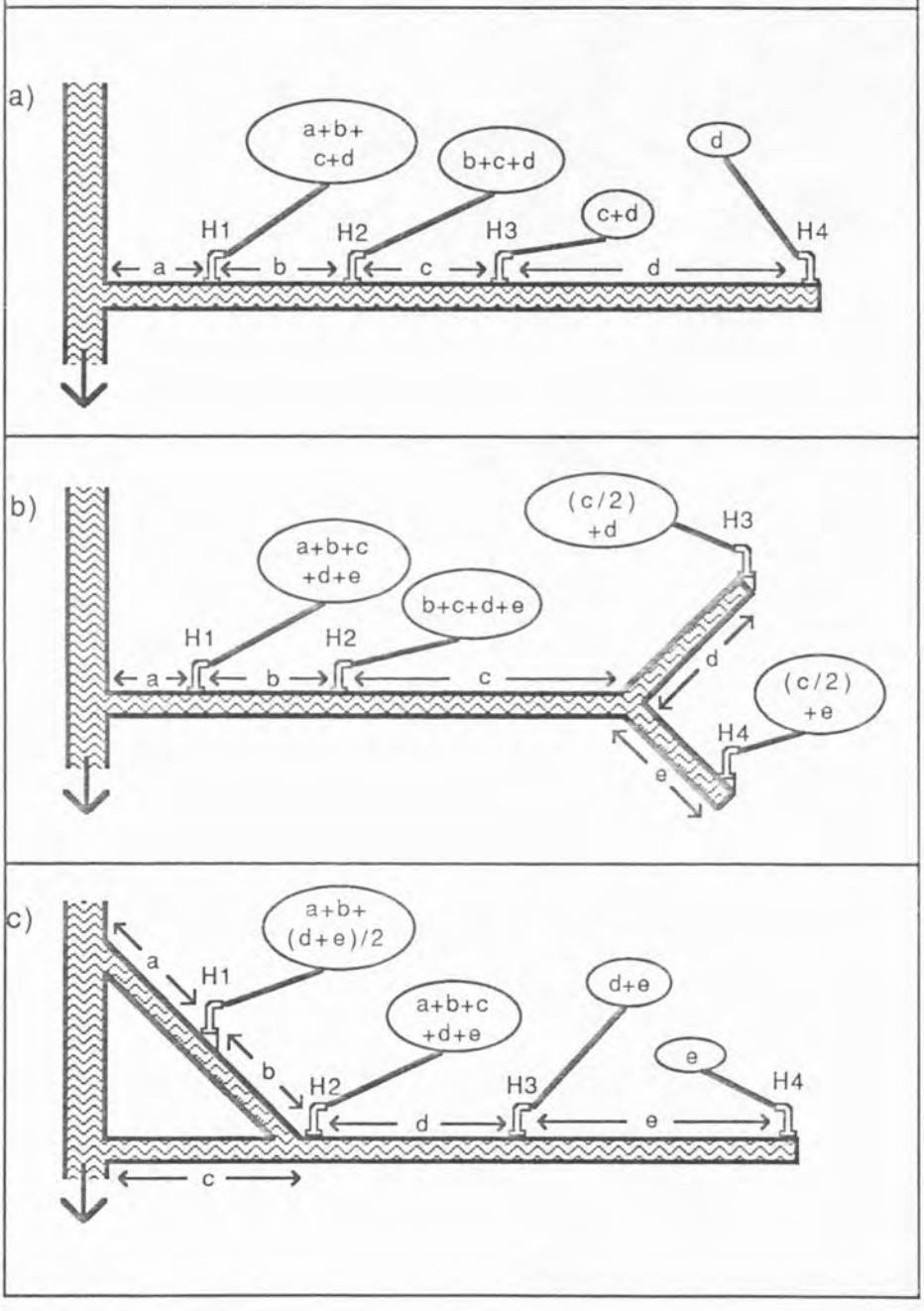
1: l s^{-1} $\geqslant$ 12
2: 8 $\leqslant$ l s^{-1} $<$ 12
3: 6 $\leqslant$ l s^{-1} $<$ 8
4: 6 $>$ l s^{-1}

4.9) Pressure:

After sampling was completed, the pressure was recorded by fitting the standpipe with a Vernon-Morris Pressure Gauge and recording the pressure in bars. Since the pressure in the system varies with demand, all readings of pressure were taken at the time of sampling - out of peak consumption times. The values were assigned to the following classes:

Fig. 4.5) Diagrammatic representation of method of calculation of consumption rate of water in the mains

(a, b, c, d and e represent the consumption in litres per day for each pipe section)



1: bar $\geq$ 4

2: 2 $\leq$ bar < 4

3: 1 $\leq$ bar < 2

4: 1 > bar

4.10) Pipe age, material and diameter

These criteria were considered from information available on 1:2500 plans of the Districts. Other additional information has been obtained from the Inspectors and Superintendents of the Districts concerned. Age proved impossible to estimate since no records of the dates when mains were laid were available.

Material (abbreviated as follows):

P: uPVC

C: Relined concrete

I: Cast iron

Diameter: (abbreviated as follows)

3: 3 "

4: 4 "

8: 80 mm

1: 100 mm

4.11) Air-scour and Scrape-and-reline history

This was made available by Mr. A.Leeson, Supt., Market Harborough District and Mr. J.Hadland, Northampton District Office, Cliftonville. (For details of the processes involved see chapter 2). All scrape-and-reline operations were carried out within the last 5 years, and no further information was available, so the presence of 'C' as a label for pipe material (above) was decided to be the only record of scrape-and-reline used in the analysis in Chapter 6.

Air-scour was found to be similar, with only one site air-scoured six months prior to sampling. All other sites had either never been air-scoured, or had no information available.

4.12) Age of water (travel time)

This has been calculated for areas in the Ravensthorpe Zone and the Pitsford West Zone, by obtaining data from Network analysis by Mr. B.Langston at Anglian Water, Aqua House, Peterborough. The network analysis package used was the WRc Watnet II package and produces estimates of flow rates, speed of flow and pipe lengths. Using the speed of flow and the pipe lengths travelled, it has been possible to estimate the amount of time it takes for water to travel from the treatment works

or source to the sample site.

The values used were for peak times, but off peak and average flows are all determined by the use of a constant conversion factor, so the values will be relative. The fastest possible route for the water (flow rate) was always used in the calculation of these times, and the water was assumed to bypass, or pass straight through service reservoirs and water towers.

Values were assigned to the classes shown below:

1: hrs. < 12

2: 12 ⩾ hrs. < 24

3: 24 ⩾ hrs. < 48

4: 48 ⩾ hrs.

4.13) Service Reservoirs and Water Towers

Using the maps of the distribution system, the number of reservoirs and towers the water passes through was calculated and recorded using the following classification:

1: 0

2: 1

3: 2

4: 3+

4.14) Reservoir Water.

Water in the samples came from three different sources, the slow sand filter at Ravensthorpe Water Treatment Works, The rapid gravity filters at Wing Water Treatment works , and the rapid gravity filters at Pitsford Water Treatment Works. These have been labelled as follows:

R: Ravensthorpe, slow sand filter

P: Pitsford, rapid gravity filter

W: Wing, rapid gravity filter

4.15) Tuberculation

The tuberculation that builds up inside the mains can be estimated using a fibrescope. However, an examination of a 3" main in a field trial indicated that little could be determined by a researcher not trained in the use of this instrument about the state of corrosion in the main.

The time and cost involved in developing the technique to use the equipment correctly and determine the reduction of the internal diameter of mains (Carruthers and Evins 1985), led to this aspect of the state of the mains being ignored.

CHAPTER 5) TAXONOMY AND LIFE HISTORIES OF INFESTING ANIMALS

5.1) Introduction.....94
5.2) Methods of identification.....94
5.3) Chironomids.....95
5.3.1) Chironomid life history and habit.....95
5.3.2) Chironomid access to the distribution system.....98
5.3.3) Chironomid larvae in the distribution system and their control.....100
5.3.4) Identification of larvae present in the distribution system.....101
5.3.5) Tanypodinae.....102
5.3.6) Chironominae.....102
5.3.6.1) Chironomini.....102
5.3.6.2) Tanytarsini.....103
5.3.7) Orthocladiinae.....104
5.3.8) Chironomid pupae in the distribution system.....105
5.3.9) Gut contents of chironomid larvae present in the study area.....105
5.3.10) Variation of size of chironomid larvae during the course of the study.....105
5.4) Other Insects.....106
5.5) Isopoda.....106
5.5.1) The life cycle of *Asellus aquaticus*.....107
5.5.2) The diet of *Asellus* and *Gammarus*.....107
5.5.3) *Asellus aquaticus* in distribution systems and its control.....108
5.5.4) Isopods in the study area.....109
5.6) Oligochaeta.....110
5.6.1) Life cycle and diet of oligochaetes.....110
5.6.2) Oligochaetes in the distribution system and their control.....111
5.6.3) Oligochaetes in the study area.....112

5.7) Copepoda.....112
5.7.1) Cyclopoid copepod life history and diet.....112
5.7.2) Penetration of treatment by cyclopoid copepods.....113
5.7.3) Cyclopoids in distribution systems and their control.....114
5.7.4) Cyclopoid copepods in the study area.....114
5.7.5) *Acanthocyclops*.....114
5.7.6) *Megacyclops*.....116
5.7.7) *Paracyclops*.....117
5.7.8) *Eucyclops*.....117
5.7.9) Harpacticoidea.....119
5.8) Cladocera.....119
5.8.1) The life history and habit of Cladocera.....120
5.8.2) Cladocera in the distribution system and their control.....120
5.8.3) Cladocera present in the study area.....120
5.8.4) *Alona*.....121
5.8.5) *Chydorus*.....122
5.8.6) *Graptoleberis*.....122
5.9) Ostracoda.....123
5.10) Acarina.....123
5.10.1) Halacaridae.....124
5.10.2) Other Acarina.....125
5.11) Mollusca.....125
5.11.1) Bivalvia.....126
5.11.2) Gastropoda.....126
5.12) Microturbellaria.....127
5.13) Tardigrada.....127
5.14) Nematoda.....127
5.15) Other animals known to occur.....128

5.1) Introduction

The aim of this chapter is to introduce the invertebrates which occurred in samples taken during the course of this study. The method used to identify each taxon is described and the species found listed. Where relevant, details of life histories and ecology are included. Any case studies of infestation of distribution systems by these animals are included, along with relevant control methods.

The animals found in the mains are generally benthic species, which are pre-adapted to the environment which occurs. Kraepelin (1886) cited in Hastings (1937) suggested that isolation of species in the mains would eventually lead to the development of a separate community from the source water. One example of this change was found in London (Hastings 1937) where *Niphargus*, a subterranean crustacean (not recorded in the source water), was found breeding in culverts beneath a filter.

Paratanytarsus inquilinus is another example of a species which occurs in mains but not in raw water sources. Anglian Water (Anon 1978) found no individuals of this species in the benthos of Grafham Water, though it was present in the mains fed by this reservoir. *Paratanytarsus inquilinus* Krüger has evolved a parthenogenetic pharate adult stage only found in one other member of the same genus (Langton 1984), from which the larva is indistinguishable.

5.2) Methods of Identification

Animals were removed from subsamples and mounted in polyvinyl lactophenol and chlorazol black or lignin pink (Harding and Smith 1960); euparol or dimethyl hydantoin formaldehyde resin (D.M.H.F., Breckon and Evans 1969, obtained from Asco Labs., 52 Levenshulme Rd., Gorton, Manchester) where indicated. In many cases animals could only be identified by dissection and examination of particular characters as described in the text below. Dissection was carried out under x20 - x40 magnification using tungsten needles sharpened in hot sodium nitrite (Harding and Smith 1960) and shaped as neccessary. Where dissection was required, not all of the animals were always dissected, but animals were grouped as a 'type' and identified. If all those dissected were not found to be the same genus or species, further identification of all individuals of the 'type' was carried out. Generally, once the species present in the main were known, it was possible to identify whole animals from certain characteristics unique to species (except in the case of some cyclopoids).

5.3) Chironomids

The life history, habit and a review of the literature relating to chironomid larvae in distribution systems is given below, followed by details relating to the genera removed during this study.

5.3.1) Chironomid Life history and habit

The life history of Chironomids was reviewed by Pinder (1986) and Oliver (1971). The cycle begins with the laying of egg masses in a gelatinous matrix. If the egg stage is resistant to treatment (chlorination), then penetration of filters by viable eggs may be possible. Chironomid larvae have four instars and Oliver (1971) suggested that the first instar be classified as a 'larvule', since all investigated species behave in a similar manner, with the first instar swimming in the plankton and feeding on algae and suspended detritus. (In stream-living species this would lead to rheophilic species being carried away, but no flowing water species were included in his review.) In the case of animals emerging from eggs in filter beds, or 'larvules' in the raw water the movement into the plankton will increase the chance of passage through the filters, should penetration of the filter occur.

Once in the appropriate habitat, the first or second instar larvae enter the mode of life which is continued throughout the remainder of the instars. All non-predatatory Chironominae construct a larval case on or within the substrate. The structure of this varies with genus and habitat. Pinder (1986) suggests that Orthocladiinae may also build cases. The sediment present in a pipe is of importance for tube building as well as for its nutritional value. If there is no sediment in the pipe, species may not be able to survive. Pinder (1986) stated that as a general rule, Orthocladiinae and Diamisinae (which were found on one occasion in preliminary work at Church Brampton) can be linked with rocks and gravel while Chironominae and Tanypodinae are found where sand and silt predominate.

In river systems, larval dispersal has been investigated along with 'macroinvertebrate drift' and may be density related. Dimond (1967) proposed four possible mechanisms whereby invertebrates enter the drift, but Elliott (1967) suggested that very few animals enter the drift and then only for the shortest possible period, returning to the benthos rapidly (though the numbers present depends on the behaviour of benthic invertebrates). In the case of the mains, it is probable that dispersal of parthenogenetic species is density related, since it is unlikely that any change in conditions within the system will lead to behavioural changes which allow animals to leave the benthos.

Chironomid larvae complete development in temperatures ranging from 0

to 32°C and can cope with pH ranging from roughly 5 to 9, though the majority of species occur in pH 6 to 8. Tanypodinae are known to be able to withstand low oxygen concentrations.

Few Chironomidae are restricted to a single mode of feeding, though most taxa use predominantly one method. The scheme taken from Bryce and Hobart (1972) (below) shows the different feeding methods attributed to each taxon found in the distribution system:

Tanypodininae -	predators
Orthocladiinae -	scrapers
Chironominae:	
Tanytarsini -	filter feeders
	detritivores
Chironomini -	all feeding strategies

Tanypodinae are predominantly carnivorous, along with some Chironomini such as *Chironomus attenuatus* which Loden (1974) found to predate oligochates). Loden's study found that *Polypedelium* and *Endochironomus* fed only after construction of a tube from sediments, while *Cryptochironomus* and *Chironomus attenuatus* never constructed tubes but 'wandered about'. Naids were taken by both *Polypedelium* and *Endochironomus*. However, these genera of chironomini frequently lost prey by biting naids in half, which enabled both sections of the worm to escape. Gut analysis of individuals of the genus *Polypedelium* taken from the distribution system showed no evidence of predation, but guts full of ingested sediments (Smart pers. obs.).

Procladius were also found by Loden (1974) to actively predate Oligochaeta, and Vodopich and Cowell (1984) found *Procladius culiciformis* positively selects other chironomids, cladocera and ostracods. The Tanypodinae pierce and suck prey as well as ingesting captured animals. Vodopich and Cowell found that, though Tanypodinae larvae showed no preference for different types of grain size in the sediment in laboratory experiments, they did show a positive correlation with the organic content of the sediment (possibly due to more prey species being available). Pinder (1986) stated that strong correlation occurrs between organic content of sediments and density of Chironominae and Tanytarsini, but is frequently masked by the effects of environmental variables.

Walshe (1951) investigated the feeding habits of specific types of chironomid larvae and found that *Polypedelium* sp. and *Microtendipes pedellus* build short tubes of sediment and stretch out from the tube, gathering sediment from the surrounding area and dragging it back to the tube entrance using a salivary secretion which they spread with the

anterior prolegs. Other genera such as *Tanytarsus* and *Micropsectra*, build large 'rambling' tubes on or below the surface of the substrate and maintain a respiratory current through these tubes, feeding in a similar manner to that described above. It is likely that the majority of species of Chironominae found in the mains will feed in this way, with tubes on or just under the sediment (attached or unattached) gathering sediment to ingest from the area in front of the tube.

Tanytarsus, *Diamesa* and *Cricetopus* have been recorded (McClachan *et al.* 1978) to take large quantities of detritus and organic material. Their study found that the third and fourth instar of *Cricetopus* took different proportions of algal and detrital material due to the limitations of mouth size. So, different instars of each species may have different dietary requirements. McClachan *et al.* (1978) concluded that due to handling times and feeding rates a species will only exist if: ..."a satisfactory range of particles exists for a sufficient period of time.". This implies that in the mains, food particles of the correct size must be present in sufficient quantity and throughout the year to enable a population of larvae to exist. It is worth considering the effect of flushing to remove sediments as a means of restricting the quantity of available food to species such as *Tanytarsus* and *Polypedelium*.

Infestation by chironomid larvae will be limited by:

a) a lack of substrate for tube builders

b) a lack of substrate to use as food (should there be insufficient particles in the final water or seasonal variation).

c) removal of prey species which are taken by Tanypodinae

The growth and developement of larvae relates to temperature as well as food, a lower temperature leads to inactivity in some genera.

The pupal stage can be free living or sedentary. As a pharate adult a stimulus leads to movement to the surface of the water. Various stimuli may be involved, including light, temperature, oxygen, feeding in the fourth instar larvae and endogenous rhythms. Any species requiring light as a stiumulus for emergence will not emerge but will preseumably die in the pupal stage.

Most chironomids undertake mating by flying in mating swarms. If emergence is possible in service reservoirs or water towers, numbers must be fairly high for reproduction to occur successfully if swarming is involved. A detailed knowledge of the swarming behaviour of the species in the mains would be of use to determine which species can make use of service reservoirs as breeding sites.

5.3.2) Chironomid access to the distribution system

Chironomids can cause the breakdown of slow sand filters. When present in large enough numbers the empty larval tubes left by emergent insects allow raw water direct penetration of the filter without any biological action in the "Schmutzdecke" (Kemna 1900, cited in Hastings 1937).

Animals must gain access to the distribution system in any of three ways:

a) by entering through the raw water
b) by entering at the filter
c) by entering service reservoirs

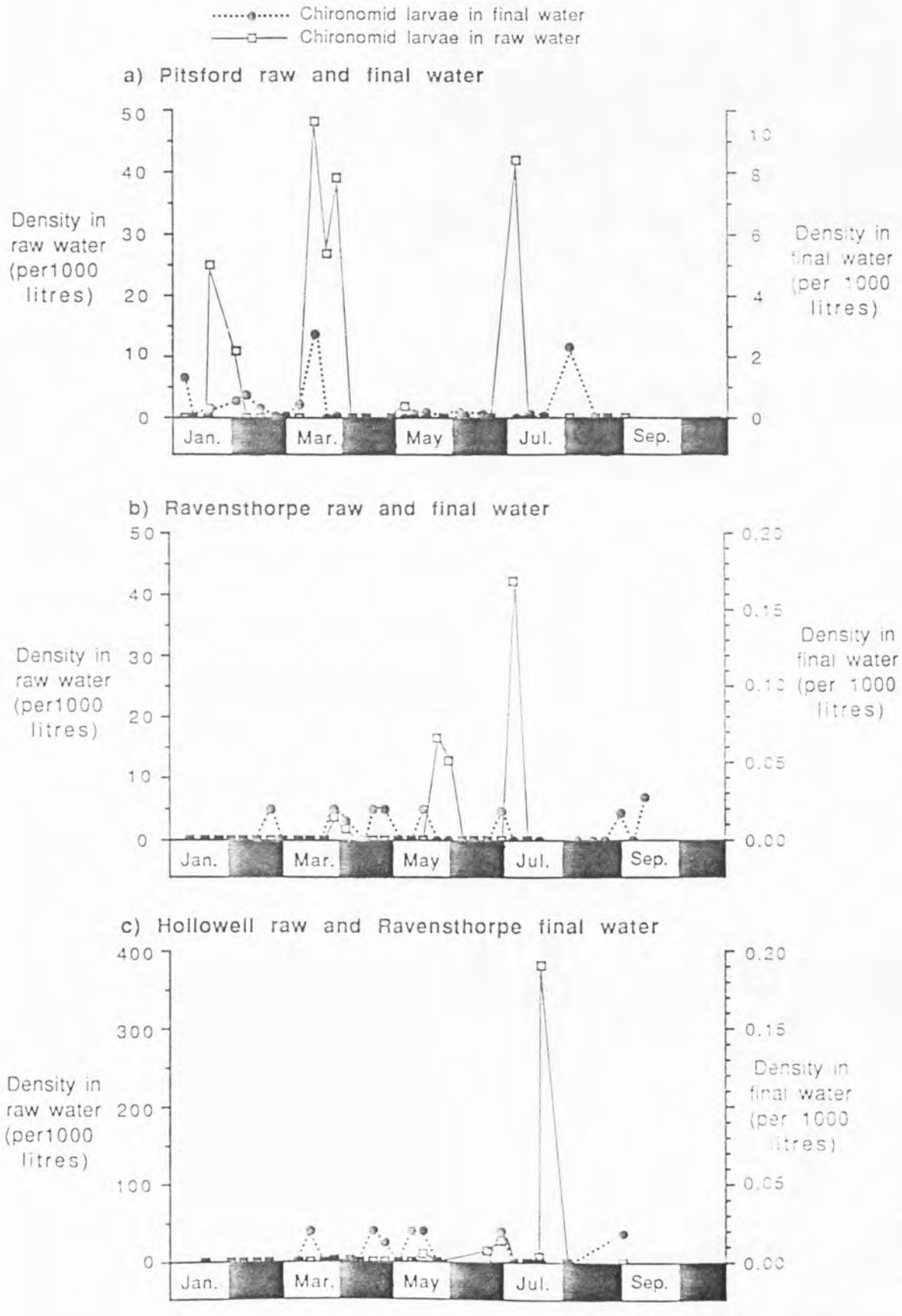
Ridley (1975) considered the problems caused by the emergence of chironomids at storage reservoirs, but this emergence causes far more problems when it occurs near to filters at water treatment works. If the treatment works is near to the reservior the problem may be considerable. Barham (1986) suggests the reason Wing Treatment Works does not suffer from chironomid larvae in the final water to the same degree as Pitsford Treatment Works is that it is situated away from the reservoir.

Flynn and Bolas (1985) found a means to halt adult access to filters and sedimentation tanks by means of water sprays, which reduce the number of floc masses (potential egg laying sites) and inhibit the swarming of adults. This method, carried out at Bewl Bridge Treatment Works in Kent, was modified by Anglian Water and used at Pitsford and Wing Treatment Works. The success of the modified method was examined by Barham (1986) who found that during 1985, the chironomid peaks in the final water at Pitsford Water Treatment Works increased significantly during the periods when the spray system was not operational.

Raw and final water data for 1985 (Barham 1986) and 1988 (unpubl. data) collected by Anglian Water (using Norgren filters at treatment works) indicate (Fig. 5.1) that larvae penetrating treatment do not follow the patterns observed in raw water. This suggests that animals are absent from the raw water and penetrate treatment at the filters, thus appearing in the final water. This suggests that the numbers penetrating filters are reduced by the modified sprinkler system (Barham 1986).

Service reservoirs are also a likely point of access for some chironomids. During the course of the study swarms were observed on several occasions at service reservoir sites. Service reservoirs are supposedly sealed to restrict access, but Anglian Water (Markall and Barham 1987) has found that 'insectocutors' at some sites capture large numbers of flying insects including chironomids. Certainly the majority

Fig. 5.1) Chironomid larvae in raw and final water during 1988



of reservoirs investigated (Chapter 10) contained large numbers of *Tegenaria* spiders which must exist on flying insects either penetrating from the exterior or emerging from inside the reservoir. Some form of mesh screen surrounded by foam rubber that would lie over the hatch access beneath the sealed hatch would restrict ingress from outside the reservoir and enable the species attempting ingress to be collected and identified.

5.3.3) Chironomid larvae in the distribution system and their control

Some species of chironomid that inhabit the mains are known to be parthenogenetic, such as *Corynoneura scutellata* and some *Paratanytarsus* sp.

In 1971, complaints of chironomids in Southend led to the discovery of parthenogenetic chironomids, *Parytanytarsus inquilinus* (Williams 1974, the life cycle of which is described by Langton 1974). Unlike *Coryoneura scutellata* and other *Paratanytarsus* sp., *Paratanytarsus inquilinus* does not have to emerge as an adult prior to producing eggs, and so can mainatain a population within the pipes, never requiring to emerge into an air space in a service reservoir or water tower.

Burfield and Williams (1975) report the use of pyrethrin to control the Southend infestation, but believe sufficient *Paratanytarsus* escaped treatment to reinfest the system within 4 months. Mitcham and Shelley (1980) found that reinfestation of a system following pyrethrin treatment took 20 weeks, but that following subsequent treatment with permethrin there was no reinfestation after 90 weeks.

Chironomids are frequently the cause of problems in the mains throughout the world. In the U.S.A. Ingram and Bartsch (1960) quote the "blood red colour" as being distinctive in all cases of infestation presumably because these species were conspicuous to the consumer rather than the absence of other types. An early infestation reported by Bahlman (1932) in 1930-31 describes chironomids emerging in considerable numbers from taps and in toilets due to an uncovered service reservoir.

Attempts to control chironomid infestations in the U.S.A. with copper sulphate and chlorine were reported to fail by Flentje (1945), but successful control was recorded using 1 p.p.m. D.D.T. and 3 p.p.m. pyrethrum. Silvey (1956) produced a list of concentrations of insecticides lethal to chironomids and found copper chlorine ammonia (4 p.p.m.) was successful contrary to previous reports. The standard method in use in water undertakings in the U.K. at the time of this study is to dose with pyrethrin or permethrin at levels which result in a lethal concentration for chironomid larvae and *Asellus* in the main, though in practice this level is rarely attained at the extremes of the system.

5.3.4) Identification of larvae present in the system

The larvae of the Chironomidae (Diptera) were frequently found in initial samples removed from sites in the system. Attempts to raise larvae through to adults and hence to determine species from adult characteristics failed in all trials. The heads of larvae were removed and mounted ventral side uppermost in D.M.H.F. or polyvinyl lactophenol, along with the body. Identification to genera was initially undertaken using the key to sub-families by Cranston and Reiss (1983) and then to genera (Cranston et al. 1983, Pinder and Reiss 1983, and Fittkau and Roback 1983) with reference to the keys by Cranston (undated) and Mason (1968). No attempt was made to take the identification to species (except in the case of the genus *Corynoneura* Winnertz, using the key in Cranston (1982) since the larval characters are variable and identification further may be erroneous. A total of 21 genera were found in the study area and are listed below with those most abundant indicated by *:

sub-family Tanypodinae:
genus: *Ablabesmyia* Johannsen
Macropelopia Thienemann
*Procladius** Skuse (sub-genus: Holotanypus)

sub family Chironominae:
tribe: *Chironomini* (*Harnishchia* complex):
genus: *Parachironomus** Lenz
tribe: *Chironomini:*
genus: *Chironomus** Meigen
genus: *Endochironomus* Kieffer
genus: *Dicrotendipes** Kieffer
genus: *Microtendipes* Kieffer
genus: *Glyptotendipes* Kieffer
genus: *Polypedelium** Kieffer
tribe: Tanytarsini:
genus: *Paratanytarsus** Thienemann and Bause
genus: *Cladotanytarsus* Kieffer
genus: *Tanytarsus* v.d. Wulp
genus: *Micropsectra* Kieffer

sub-family: Orthocladiinae:
genus: *Corynoneura* Winnertz (some individuals identified as the species *Corynoneura scutellata* Winnertz)
genus: *Psectrocladius** Kieffer (sub-genus P.*(Psectrocladius)*)
genus: *Cricetopus** v.d. Wulp

Notes on each genus present in the system are included in the sections on sub-families and tribes below. All the larvae present tend to be generalist forms, inhabiting still or moving water in natural conditions. The Tanypodinae are predatory (though not neccessarily obligate), and the remainder appear to be 'scrapers' or 'grazers', many of which occur naturally in 'aufwuchs'. *Corynoneura scutellata* may be a filter feeder (Cranston 1982), which may be a valuable preadaptation enabling this species to exploit a vacant 'niche' in the community of the distribution system (see below).

5.3.5 Tanypodinae

Ablabesmyia is characterised by subdivision of the maxillary palp and the possesion of 1-3 dark claws on the posterior parapods (Fittkau and Roback 1983). Larvae inhabit small and large standing and flowing waters and may reach 11mm long.

Macrolepia larvae are up to 7mm long with a characteristic pseudoradula (though this was difficult to distinguish in the two specimens obtained from the mains). Larvae live in fine sediments in cool water bodies (Fittkau and Roback 1983).

Procladius larvae are 6-11mm long, distinguished by pigmentation of the ligula, large mandibular basal tooth and a small accessory blade on the antenna. The structure of the paraligula on specimens where it could be clearly distinguished follows that used to distinguish the sub-genus *P.(Holotanypus)* Roback. The larvae tend to frequent the muddy substrata of standing or slowly moving water bodies, though some species are found in the profundal zones of deep lakes.

5.3.6 Chironominae

The two tribes of the Chironominae found in the system are treated separately during the course of this study since the genus *Paratanytarsus* contains parthenogenetic species which occur in the system and will be affected by different factors to the chironomini.

5.3.6.1 Chironomini

Parachironomus reach up to 12mm long and are characterised by the pecten epipharyngis, a wide toothed transparent plate. Generally, the larvae occur in both standing and flowing waters.

Chironomus larvae are up to 60 mm long, easily distinguished by two pairs of ventral tubules, mandible and mentum structure. Larvae generally graze on detritus or filter feed in soft sediments of standing water. Pinder and Reiss (1983) suggested they rarely occur in flowing water.

Endochironomus larvae were identified from characteristic pecten

epiphayrngis, since the form of the first labral seta (S1) was unclear in the specimen found during this study. Pinder and Reiss (1983) state that the larvae occur in 'aufwuchs' of living or dead substrata in all types of still water.

Microtendipes larvae are up to 15mm long with a characteristic number of antennal segments, mentum and mandibular structure. This genera is commonly found in 'aufwuchs' and in littoral and sublittoral sediments of standing water bodies, occasionally occuring in flowing water (Pinder and Reiss 1983).

Dicrotendipes are up to 11mm long. Commonly found in littoral sediments of standing (occasionally in flowing) waters. They are also sometimes found in 'aufwuchs'. Characterised by a pit on the frontal apotome (not visible in mounted specimens) and the mentum and pecten epipharyngis which has 5-7 broad teeth.

Glyptotendipes are up to 18mm long. Three species groups exist, the largest (larvae up to 18mm long inhabit 'aufwuchs', the other groups being leaf miners and species of unknown habit. The genera is thought to be paraphyletic and the larval characters can be heterogeneous. Only one individual was identified as being from this genus during the study.

The genus *Polypedelium* was one of the most numerous of all the genus present in the system, certainly the most frequently occurring on a site by site basis. Larval size varies between 5 and 14mm long and the characteristic *Polypedelium* mentum tooth arrangement was the main feature used to identify the genus. The mentum has one pair of high inner median teeth, a pair of outer medians which are low, and then a high first lateral tooth (Pinder and Reiss 1983). The genus is heterogeneous in character and occurs in all kinds of still and flowing waters (except artic and alpine habitat), being associated particularly with sediments.

5.3.6.2 Tanytarsini

Paratanytarsus larvae are up to 7mm long characterised by the pecten ephipharygis, antennal structure (with sessile Lauterborn organs) and bifid premandible. A eurytopic genus. The species *P.iniquilinus* is parthenogenetic as a pharate adult (Langton 1974; Appendix to Williams 1974).

Tanytarsus reach up to 9mm long and are distinguished from the genus *Micropsectra* (below) by the bifid premandible (visible in few mounted specimens, being generally obscured by the mandible) and the arrangement and number of claws on the posterior parapods (see below). The genus is found in all types of freshwater.

Micropsectra larvae are up to 8mm long and characteristic of muddy deposits in slack regions of streams. Distinguished from *Tanytarsus*

(above) in both specimens identified by the large number of small claws on the posterior parapod arranged in a series of rows (not few large claws in a single row as found in *Tanytarsus*).

Cladotanytarsus larvae are up to 5mm long, with a characteristic wedge shaped antennal segment 2 bearing large lauterborn organs on short pedicels, and with some claws on the posterior parapods finely serrated on their inner margin. Larvae have been found in streams, large rivers, lakes and ponds.

5.3.7) Orthocladiinae:

Corynoneura larvae are up to 3mm long, distinguished by the length of their four segmented antennae. Found in all types of aquatic habitats, standing water and ditches to mountain streams. The species *C.scutellata* is parthenogenetic (Burfield and Williams 1975). Cranston (1982) suggested *C.scutellata* is found in lentic habitats, and that in lotic habitats the larvae are associated with eroding substrates, often found in small fissures in stony substrates. Cranston (1982) also stated the structure of the mouthparts may be indicative of filter feeding. The species therefore has a number of preadaptations to a lifestyle of filter feeding from within corroded pipes, though the parthenogenesis has not developed to the degree found in *Paratanytarsus inquilinus*.

Psectrocladius larvae reach up to 11 mm long. Characterised by having a beard, palmate first labral seta (S1), a simple premandible and spurs on the procercus. The two subgenus *P.(Psectrocladius)* and *P.(Monopsectrocladius)* are distinguished by the form of the median teeth of the mentum. Paired, and single with a median projection respectively. A few individuals identified tentatively as *P.(Monopsectrocladius)* could not be confirmed as this genus, since the first labral seta appeared bifid on the one specimen where they could be distinguished (V.Smith pers. comm.), and procercal spurs were absent. Some species of this sub-genus do have three lobes on the S1, but whether this individual had a bifid or three lobed S1 could not be accurately determined. These animals were not possible to key out using the available keys and remain refferred to as Orthocladiinae: unidentified genus A.

Cricetopus larvae are up to 8mm long. Characterised by setal tufts on at least the first six abdominal segments and a bifid or single SI. Three different types of mentum were found in those specimens attributed to this genus, but no attempt was made to take identification further. The larvae of *Cricetopus* have been found in all types of standing and flowing freshwater.

5.3.8) Chironomid Pupae in the distribution system

During the course of this study a number of pupae were found of the genus *Paratanytarsus*, *Cladotanytarsus* and two members of the Orthocladiinae, *Psectrocladius* and *Cricetopus* (identified using the key by Wilson and McGill 1982). These were generally in poor condition and identification to species was not possible. From the samples removed from mains during June 1987, a number of pupal exuviae of *Paratanytarsus* sp., some containing eggs, were removed from the mains. A number of this type were confirmed as *Paratanytarsus inquilinus*, but many appeared to lack some of the features attributed to this species. All had the presence of a pearl row and 'nose' on the wing sheaths, found in *P.inquilinus* (Langton 1984 and Anon 1983) but the presence of a 'median point patch' of spines on the fouth abdominal segment was not confirmed in some pupae containing eggs, and the paired lateral point patches on segment four of the abdomen were absent or much reduced. These latter forms are likely to be members of the species complex containing *P.inquilinus* or *Paratanytarsus boiemicus* Keiffer. It appears therefore that despite pyrethrin treatment, and air-scour programmes, the Pitsford Supply Zone has become contaminated with a parthenogenetic species of *Paratanytarsus* (probably only *P.inquilinus*, which originated in the Grafham system).

5.3.9) Gut contents of chironomid larvae present in the study area

Procladius guts removed from animals in the distribution system contained remains of oligochates (*Nais* sp.), harpacticoids (*Bryocamptus pygmaeus*), chydorids (*Graptoleberis testudinaria* and *Alona* sp.), cyclopoids and ostracoda as well as smaller chironomid larvae. It is unlikely that Tanypodinae larvae are obligate predators (Oliver 1971), which explains the presence of large quantities of sediment but no animal remains in some *Procladius* guts examined during the course of this study.

Evidence from examination of the guts of *Polypedelium*, *Chironomus*, *Endochironomus*, *Paratanytarsus* and other Chironominae and Orthocladiinae taken from the distribution system suggest that ingestion of sediments is the foraging method in use, either by filter feeding or direct feeding. All the animals investigated had guts containing the red/brown iron stained sediments characteristic of the system, and none of those guts dissected from the above species have shown any animal remains.

5.3.10) Variation in the size of chironomid larvae during the course of the study

As the study continued, the overall size of chironomid larvae removed from the mains decreased. During 1986, at the first sites sampled, individual *Chironomus* sp. were frequently over 20 mm long. By June and

October 1987 animals which could be collected from the sample on a 1 mm mesh were rare. This may have been due to dosing of the system in 1986 which killed off all the chironomids, or to the installation of a sprinkler system at treatment halting the penetration of larvae and eggs. Small chironomids were still present, often in large numbers (particularly of *Paratanytarsus* sp.) after pyrethrin dosing, though this may simply be the recovery of a parthenogenetic mains population.

5.4) Other insects

Many other insects have been found in the distribution systems as reported by English (1958), Smalls and Greaves (1968), Collingwood (1966), and Ingram and Bartsch (1960).

In the system under consideration during this study, riffle beetle larvae (Elmidae) were present in two flushes from Charwelton. One very small trichopteran was also found in a sample from Chapel Brampton. These appeared to be isolated cases of penetration by fauna which would be unable to complete their life cycles in water. Elmidae require the presence of an air space in order to pupate, and Trichoptera require an air space for emergence prior to reproduction. Similar problems relating to emergence prior to reproduction meant Diptera larvae other than chironomids (Empididae, Ceratopogonidae, and *Chaoborus*) present in the study system would never complete their life cycle. Empiididae and Ceratopogoinidae were never present in considerable numbers but did ocuur at more than one site. *Chaoborus* were found during September, October and November 1987 at four sites (at two on two occasions), three of which were fed by Ravensthorpe slow sand filter. At three sites, Ravensthorpe, Guilsborough and Creaton, *Chaoborus* were found in association with *Sigara concinna* (which were dead and fragmented in some cases). Samples from the Ravensthorpe and Guilsborough sites during May 1988 (the next sampling occasion) were found to contain filamentous algae of the genus *Spirogyra* suggesting that a breakdown of the slow sand filter was ocurring. If this break was sufficient to allow penetration of *Chaoborus* and *Sigara* it is almost certain that smaller organisms including chironomid larvae would have been able to penetrate.

5.5) Isopoda

The two genera of Isopoda which are commonly found infesting mains are *Asellus* and *Gammarus*, though *Crangonyx* is also known to occur (Collingwood 1966, Smalls and Greaves 1968 and Sands 1969).

Gammarus are not difficult to remove from mains since they are active swimmers rather than crawlers and can be flushed easily from the system. *Asellus* are known to attach to the sides of the main and to both move

away as the flow velocity increases and take refuge in any crevices available (Turner 1956). Hence, *Asellus* are considerably more difficult to remove than other infesting taxa.

5.5.1) The life cycle of Asellus aquaticus

Collingwood (1964) produced a life cycle for *Asellus aquaticus* which indicates that temperature is an important factor in growth and reproduction. In natural populations in the River Trent (Aston and Milner 1980), where power stations raised the temperature to higher than normal, the mean length of male, immature female and non-ovigerous female *Asellus* was found to be temperature related. The life cycle was also found to shorten from 1 year to 4-7 months with increasing temperature. Whether the lack of severe temperature changes in the mains will enable the *Asellus* in the pipes to modify their life history is not known, but Adcock (1979) showed that if sufficient size has been attained, the spring cohort will reproduce in the autumn in natural conditions. If a lack of severe winter temperatures, and relatively higher spring temperatures enables two reproductive periods in the pipes as well as an increased survivorship over the winter, the potential for a rapid build up of *Asellus* is present.

The female holds eggs in a brood pouch (marsupium), where development appears related to the number of days above 4°C (Andersson 1969). It has been generally accepted in the water industry that eggs will not survive outside the brood pouch (Holland 1956, Collingwood 1964), but Rossi *et al.* (1975) (cited in Holdich and Tolba (1981)), show that 34% of ovigerous females in wild populations shed 40% of embryos from the marsupium and that these are able to survive, development depending upon the temperature and water quality. Thus some 13% of eggs in a population are released from the marsupium. Holdich and Tolba (1981) found that eggs in clean water developed more rapidly than those in polluted water, but that in clean water, eggs from polluted water have a better survival rate than those from clean water. This suggests that the shedding of eggs is likely to be a means of dispersal, and if the egg is in any way resistant or tolerant of treatment, infestation could easily recur.

5.5.2) The Diet of *Asellus* and *Gammarus*

Both *Asellus* and *Gammarus* are detritus feeders, though evidence suggests that *Gammarus* may not require fungi as part of their diet. Sutcliffe *et al.* (1981) found that animals grow faster on leached leaves than on fungal culture. In rivers diatoms make up 80% of the ingested flora of both genera, and algae overall was found to be a regular and relatively important part of the diet (Moore 1975). Willoughby and Marcus

(1979) found that *Asellus aquaticus* initially find and attach to the largest particle present when released (perhaps requiring a refuge and anchorage as prerequisites to feeding). They maintained a population on actinomycetes with the larval stages feeding on adult faeces. These faeces are found to provide a substrate for two particular species of hyphomycetes which exist with little or no competition. Rossi and Vitagliano-Tadini (1978) found that feeding on these two fungal species, larvae increased survival rates to 90% and tripled body lengths relative to controls on plant detritus. Rossi and Fano (1979) put forward the hypothesis that different genotypes of *Asellus aquaticus* exist that have different trophic needs satisfied by the different characteristics of fungi present in the environment. Since actinomycetes are present in the mains this is a likely source of food for the animals once established. Filamentous bacteria, which are also present are not highly nutritive food for *A.aquaticus* (Marcus and Willoughby 1978).

Prus (1971) found that *A.aquaticus* has different assimilation efficiency and consumption rate depending on the reproductive state for the individal and the density of the population. Thus at high densities the assimilation efficiency increases but the consumption rate does not, enabling an increase in the chances of survival

5.5.3) Asellus aquaticus in distribution systems and its control

Considerable research has been carried out in the past with regard to *A.aquaticus*, since it has been the major cause of consumer complaints in the water industry in the U.K. and Europe. Problems have occurred in Holland (Van Heusden 1948); Germany (Klapper 1956) and France (Boët 1984).

Early studies of the behaviour of *A.aquaticus* within the distribution system (Holland 1956) considered their survival under conditions of food stress, oxygen stress, pressure and temperature variation (2 - 25°C). Turner (1956) found that *A.aquaticus* orientates with increasing flow rates, and Holland (1956) stated that *A.aquaticus* show negative chemotaxis to a chlorine gradient. The much-quoted theory proposed by Holland (1956) that a chloramine residual in the system would inhibit pre-copulatory behaviour in *Asellus* was refuted by Collingwood (1964).

Turner (1956) suggested that a possible method of control was the use of ultrasonic sound, applied to the pipe, which would detach animals and render the pipe surface unattractive. Whether any further work was undertaken on this method is unknown.

Asellus are not affected by chlorine or chloramine treatment at concentrations which are acceptable to the consumer. Flushing has little effect on populations of *Asellus*, due to their ability to cling to the

inside of pipes. Smalls (1965) found that flushing removed only 38% of *Asellus* using flushing and then flushing after pyrethrin treatment. Abram, Evins and Hobson (1980) reported permethrin, a synthetic pyrethroid (Evins 1981), removing 90% of *Asellus*; the sampling methods used are unclear.

Pyrethrins have been used successfully to treat infestations of *Asellus* (Oliver 1961, Hart 1957), but often problems arise following treatment. It appears that *Asellus* is so well pre-adapted to the water distribution system that it excludes other competing species from the community. Phillips (1966) found *Asellus* control led to an infestation of *Nais* worms, Smalls (1965) found control of *Asellus* led to an increase in the numbers of most other species, and Crowther and Smith (1980) found *Asellus* control led to complaints about large numbers of "scavenging mites".

It appears therefore that *Asellus* control will not neccessarily remove complaints, since the removal of the species which is established at competitive equilibrium will enable other species to increase in numbers. Both Collingwood (1966) and Hart (1957) suggest that it is possible that *Asellus* populations in the mains may in fact be benefiting the supply, reducing complaints of taste and odour problems, by feeding on actinomycetes, the main source of these complaints.

5.5.4) Isopods in the Study area

In the system studied for this project *Asellus* were found on only three occasions. *Gammarus* were not recorded though the genus appeared after chironomid removal in a supply zone outside the study area. *Asellus* were common in the past, reported to reach levels of 2 or 3 in a glass of water in heavily infested areas in Corby (Anon 1978). During this period (1970 - 1975) no *Asellus* was present in the Ravensthorpe Supply Zone which was operating a slow sand filter rather than the rapid gravity filters used in the rest of the system. The *Asellus* problem was so severe that pyrethrin dosing was carried out in several zones and has continued on an irregular basis with recent dosing during 1985, 1986 and 1988.

The three records of *Asellus* from the system under study came from two water towers at West Haddon and Upper Weedon, and from a main at Crick, following pyethrin dosing during 1986. The two animals from Crick were dead, but those from both water towers were alive. All specimens showed head patterns suggesting *A.meridianus* Racovitza, and this identification was confirmed by examining the pleopods as described in the key by Hynes, Macan and Williams (1960). The presence of *A.meridianus* rather than *A.aquaticus* was of interest, but unfortunately no records exist as to whether the *Asellus* previously recorded in the system was

either species. If the infesting species was *A.aquaticus*, it seems likely these are isolated populations since *A.aquaticus* tends to dominate in communties when both species are present. *A.meridianus* may be the species present in Pitsford Reservoir and hence would be the species which caused complaints in the past, but this is not known. Hynes and Williams (1965) found that *A.aquaticus* and *A.meridianus* compete when both species are present. Their study suggests that *A.aquaticus* may predate *A.meridianus* when both inhabit the same area and compete for resources. Certainly their evidence shows *A.meridianus* is more successful on its own than with *A.aquaticus*.

5.6) Oligochaeta

Oligochaete worms from four families have been recorded from mains in the U.K., though those which appear to cause the main problems are from the families Naididae and Tubificidae (probably because of their size).

5.6.1) Life cycle and diet of oligochaetes

The feeding of *N.variablis* and other oligochaeta is discussed in a review of the biology of British naids by Learner *et al.* (1978). It is suggested that the ingestion of sediment particles enables the ingestion of microflora associated with the particle as described by Meadows and Anderson (1966). Harper *et al.* (1981), considered the retention time of bacteria in the gut of *N.variabilis* relative to the density of bacteria present in the top centimetre of sediments (where the worm is commonly found in riverine habitats). They produced a model which suggests that there is more than enough bacteria to support high densities of worms, despite a reduction of viability of 82% of bacteria that pass through the gut of the worm. It appears that *N.variabilis* and other oligochaetes may be important grazers upon naturally occuring bacteria in riverine sediments, and this is the likely situation in the mains. Like *Asellus*, the removal of bacteria by oligochaetes may be benificial rather than detrimental to the water supply. Meadows and Bird (1974) found that *N.pseudobtusa* Piguet ingests detritus but were unable to determine whether microflora or detritus is assimilated. *N.pardalis* Piguet was found to select the substrate size ingested, and ingests the sediments at a regular rate.

In natural conditions naids are generally most abundant during the the summer, with asexual budding increasing with temperature, though Piguet (1906) (reported in Learner *et al.* 1978) found higher proportions of *N.communis* Piguet budding during the period November to April. However Learner *et al.* (1978) presented evidence showing peaks of both *N.variabilis* and *N.communis* populations in summer (July and October).

Collins (1958) found that the asexual life cycle predominates in the distribution system. This is difficult to confirm using flush samples since oligochaetes frequently fragment during sampling, though animals which were in the process of budding were found in some samples.

The ability of these worms to rapidly infest any system if food is available has been shown by laboratory studies by Collingwood (1966) who found that 1 worm could give rise to 1000 individuals per month by asexual budding.

5.6.2) Oligochaetes in the distribution system and their control

In Osaka, a total of 20 species of Oligochaete were identified as present in the water-works plant of the city (Masayoshi 1936). The worms were present throughout the treatment works, in the filters, underdrains and filtered water.

N.variabilis and *N.communis* are both animals which are common in sand filters and hence penetration will not be difficult. *N.communis* has been found in large numbers infesting water supply reservoirs in Denmark (Wesenberg-Lund 1938).

Infestations by naids and tubificids are easily controlled by chlorination. Edwards and Learner (1963) found differences in the toxicity of copper to *N.variabilis* and *N.communis* in soft and hard water, but that both species were killed by 1% saline and by chlorine. This work also suggested that if worms are not totally destroyed in the system by chemical treatment, they are able to regenerate and hence reinfest the system.

Kelley (1955) used 2 p.p.m. chlorine to remove an infestation of *Nais* worms in the Norwich system, and Jobling (1964) used copper after chlorine dosing at 20 p.p.m. had failed to solve the problem. An infestation at Faringdon was contolled using 0.5 p.p.m. chlorine. Hart (1957), and Crabhill (1956) found that copper-chlorine-ammonia was a successful means of *Nais* control. It appears that chlorine residual does affect *Nais* worms, as found by Collins (1958), (5 p.p.m.) in laboratory tests. However, the wide discrepancies in the success of different concentrations suggest that the internal conditions of the main must play a part in determining any effect of the residual. Edge and Finch (1987) found that the number of complaints due to *Nais* dropped when they raised chlorine residuals in part of the system to remove bacteria.

It is likely that in many systems oligochaetes are held in check by the presence of larger invertebrates such as *Asellus* and chironomid larvae. Once the principal infesting animal has been removed, the oligochaetes are able to utilise the available food and increase populations to such an extent that infestation levels are attained.

Phillips (1966) reports an infestation of *N.variabilis* that occurred at Great Yarmouth following the control of an infestation of *A.aquaticus*. A record of *Nais* worms replacing chironomids as the infesting animal is referred to by the Anglian Water Regional Research Team (Anon 1978).

5.6.3) Oligochaetes in the study area

Worms were revoved from samples and mounted in polyvinyl lactophenol (with chlorazol black) or D.M.H.F. and identified under x400 and x1000 magnification using the key by Brinkhurst (1963).

Aeolosomatidae were found in the Ravensthorpe supply zone, but only in low numbers. The genus *Aeolosoma* has been found in distribution systems in the U.K. previously (Collingwood 1966). Enchytraeid worms were also found, but only in the Pitsford supply zone. These have also been found in other systems. The tubificids which have been found commonly in the U.K. are *Tubifex tubifex* Müller (Collingwood 1966) and tubificids were found in one area at the extreme of the Pitsford supply zone. These were not mature adults and identification to genus was not possible.

The most frequent oligochaetes in the study area were Naididae. The species found were identified to mainly *Nais* sp. of which the majority were of the *Nais variabilis / communis* type. These two species are easily confused (Learner 1979) since *N.variablils* can differ in form depending on habitat and season and is similar to *N.communis* and some *N.pardalis* forms. Since no living animals were stimulated to swim, the inference is that the animals in question were *N.communis* rather than *N.variabilis*. However, the identification of the naids was not taken any further than genus since it was felt any attempt to take the group to species would be unreliable. Individuals of *N.barbata* Müller and *Stylaria lacustris* Linn. were found in the Pitsford supply zone. Niad worms from the system were observed (in an aquarium) moving across the substrate surface inside tubes of fine sediment, presumably formed by mucus secretion.

5.7) Copepoda

The copepod fauna present in the mains consists of benthic species which preseumably originate from the benthos of the source water or from the filter beds. Representatives from each group of copepoda have been found in mains sampled in the U.K. (Collingwood 1966, English 1958, Smalls and Greaves 1968).

5.7.1) Cyclopoid copepod life history and diet

Cyclopoids are thought to be active feeders, either carnivores or herbivores. DeMott (1986) found that *Acanthocyclops bicuspidatus* could determine the difference between flavoured and unflavoured spheres and

actively select the former. This suggests that not only carnivorous but also herbivorous (in the case of the distribution system, detritivorous) cyclopoids are able to select material from the substrate, rather than ingesting large quantities of sediment, and obtaining whatever microflora or microfauna is attached. This is supported by the absence of quantities of sediment in the guts of all cyclopoids examined during the course of this study, in contrast to chydorids or oligochaetes. This could be explained if herbivorous cyclopoids are actively selecting bacteria and or fungi from the surface of the substrate, though there is no direct evidence for this.

The life history of cyclopoids, involving six naupliar stages and six copepodite stages (stage six being the male or female adult) leads to differences in strategy from those of chydorids. Cyclopoids must undergo mating to reproduce, and though the female can store sperm for future reproduction, cyclopoids are never able to dominate the community in the numbers that chydorids are able to maintain. Studies of the life histories of benthic cyclopoids in natural conditions by Smyly (1952 and 1957) show that numbers are never very high and do not peak and trough to such a degree as limnetic species, also cyclopoids in the benthos of lakes tend to be present throughout the year with no resting stages (unlike chydorids).

5.7.2) Penetration of treatment by cyclopoid copepods

The likely source is from benthos associated with the draw off tower (at Pitsford), or from the filter beds (at Ravensthorpe). Tinson and Laybourn-Parry (1986) investigated the littoral and profundal zone of Esthwaite water in the lake district and found that *Paracyclops fimbriatus* Rehberg, *Megacyclops viridis* (Jurine), *Acanthocyclops bicuspidatus* Claus and *Eucyclops agilis* (Koch) all disappear from the profundal zone with anoxia. *A.bicuspidatus* shows resting stages in the profundal zone but none of the species studied migrate to the plankton, implying a lateral migration of the remaining species into the littoral zone during conditions of anoxia. In laboratory studies Tinson and Laybourn-Parry (1985) found that females of the migrating species could survive anoxia for 5 hours and males (being smaller) for a while longer. *Paracyclops fimbriatus*, *Eucyclops agilis* and *Megacyclops viridis* all sit in the bottom of tanks in fully oxygenated water, but as the water becomes stratified, these animals concentrate near the surface. When concentrating at the surface these animals prefer to remain in contact with a substrate, a fact that would enable numbers to increase at the draw-off tower during times of stratification in the reservoir, hence increasing the potential for uptake of cyclopoid stages in the raw water.

5.7.3) Cyclopoids in distribution systems and their control

Smalls (1965) found that, both carnivorous and herbivorous species of *'Cyclops'*, and *'Canthocamptus'* were present in most systems including systems fed by underground sources.

Control of copepods has been carried out using both copper (English 1958) and copper-chlorine-ammonia (Crabhill 1956), and adults have been killed by 1.0 p.p.m. chlorine residual with sufficient contact time (Crabhill 1956). However, reinfestation can be rapid due to the ability of eggs to remain viable on leaving the egg sacs and their resistance to chlorination during treatment. At Indianapolis, Crabhill (1956) found 22 eggs per square inch of filter surface, and egg sacs were deposited on the filter continuously for 10 weeks. Since nothing has been found that can penetrate the egg sac and prevent it from hatching, this is a severe source of infestation.

5.7.4) Cyclopoid copepods in the study araa

The groups which were found in the supply zones of Ravensthorpe and Pitsford Treatment works are described below. Animals were identified by dissection and mounting in polyvinyl lactophenol and chloroazol black, using the keys of Harding and Smith (1960) with reference to Gurney (1933) for cyclopoids, and Dussart (1967), Stratton Wilson and Yeatman (in Edmundson [ed.] 1963) and Gurney (1932) for harpacticoids.

Though present in many samples, egg sacs were normally separated from the copepods during flushing or sample processing, with only three of the regularly sampled, 'disturbed' sites (all sites sampled more than once) having animals with eggs attached. In January female *P.fimbriatus poppei* were found carrying eggs, and in May, female *M.viridis*.

5.7.5) *Acanthocyclops*

Three species of the genus *Acanthocyclops* were collected, *A.robustus* Sars (*A.vernalis americanus*); *A.vernalis* Fischer; and *A.bisetosus* Rehberg. The *A.vernalis-robustus* group has been a source of considerable debate in the past, discussed in Fryer (1985a) and reviewed by Smith (1988). Various features have been used to distinguish the species, notably the spine formulae, setae, and anterior corners of the genital segment. The feature used in this study to distinguish *A.robustus* from *A.vernalis* was the relative length of the inner and outer apical spines on endopodite III of leg IV, where the inner apical spine is longer than the outer and approximately 80% of the length of the segment (as described by Smith 1988).

According to Fryer (1985a), *A.vernalis* is a benthic species, never being found in the plankton, while *A.robustus* can be either benthic or

limnetic. Only one record of a single *A.vernalis* occurred during the course of this study. This is likely to be a feature of density in the storage reservoirs rather than a consequence of penetration. It is probable that a species in the plankton (such as *A.robustus*) will be more likely to be in the raw water than one in the benthos. However, the presence of benthic species such as *Paracyclops fimbriatus* (see below) in considerable numbers suggests that penetration is possible despite mode of life in the storage reservoir.

A.robustus was more commonly found in samples from the Pitsford supply zone (20.5%) than Ravensthorpe (2.9%) and occurred in only 12.5% of all 'previously undisturbed' samples taken (first samples at sites used in chapter 7 and all samples taken in Chapter 6). *A.robustus* was described by Fryer (1985a) as a possible carnivore, and *A.vernalis* as predatory. Archbold and Berger (1985) found that *A.vernalis* adults and nauplii capture ciliates (*Halteria grandinella*) when provided with the prey species. Dissection of the guts of a number of adult *A.robustus* did not provide any evidence of predation and it would appear that either this species is a predator feeding by sucking body fluids from its prey or is feeding on bacteria and fungi removed from sediments or the water in the system.

The penetration of treatment by cyclopoids is of some significance since during the summer, when densities are high in the raw water, penetration can be considerable (Chapter 10). This input of copepods is important as a means of seeding the distribution system or as an input of organic material.

The other species of *Acanthocyclops* present in the system, *A.bisetosus*, is easily distinguished by distinctive 'pitting' of the furcal rami and the position of the lateral setae on the furcal rami. Roy (1932), cited in Gurney (1932), found *A.bisetosus* was usually unaccompanied by other cyclopoids and chydorids, and had an inability to survive with other copepods. In this study the appearance of *A.bisetosus* coincides with the change to final water from the slow sand filter at Ravensthorpe Treatment Works, though the species only occurs at sites where the flushing regime is high (Chapter 7) possibly where competing species are removed.

A.bisetosus was described by Fryer (1957a) as a herbivorous cyclopoid and hence is assumed to be feeding on bacteria in the distribution system. Dissection of the guts of a number of individuals produced no remains of any other animals.

5.7.6) *Megacyclops*.

The *Megacyclops gigas-latipes* complex is another area of difficult taxonomy in the cyclopoida. Einsle (1988) used electrophoresis to determine species of *Megacyclops*. Einsle found *M.viridis* was distinguished from *M.gigas* Claus by the length to width ratio of the furcal branches ; the ratio of seta 1: seta 4; the ratio of seta 1 : length of furca; and body length.

The *Megacyclops* isolated from the supply zones studied have all been identified as *M.viridis* using the key of Harding and Smith (1960). Identification relied on the following characteristics: ratio of length: breadth of the furcal rami, the length of the inner apical setae and to a lesser extent, the lengths of the outer apical setae. *Megacyclops* sp. are easily distinguished from other cyclopoid species by their large size. This species would undoubtedly be visible to the consumer in a glass of water. The presence of stage 5 copepodites is also detectable on the basis of size alone though these cannot be identified further than *Megacyclops* sp.

M.viridis is an active carnivore. Fryer (1957a) found that the presence of oligochaetes, non-chydorid cladocerans and algal material (which he presumed had been taken by mistake) in gut preparations. The related species *M.gigas* will swallow small animals such as nauplii whole (Fryer 1957a), but leaves behind parts of copepods. *M.gigas* also predates animals by suction of soft tissues after capture (which would leave no detectable trace in the gut). All the *M.viridis* from the system examined for prey species during this study contained the chaete of naids in their guts.

The predatory action of *M.viridis* has been described by Fryer (1957a), whereby the cyclopoid 'loops' over the substrate until the prey is detected by 'bumping' into it, whereupon the prey is seized and the various methods of feeding can be employed.

M.viridis is long-lived with a life span of 740 days (female at 8°C) (Smyly 1980) and the life span is inversely related to temperature. From his studies in Lake District tarns, Smyly (1952) found *M.viridis* numbers peaked in summer, but only when a large peak of *C.sphaericus* preceded this event. In a second tarn where prey numbers remained low, there was no peak during the year but numbers remained relatively constant.

Einsle (1988) found that a seasonal variation in size occurred in the population of *M.viridis* he studied, with larger individuals present in the winter and spring, often appearing as an intermediate type between *M.viridis* and *M.gigas* but identified to species by electrophoresis.

5.7.7) *Paracyclops.*

Paracyclops fimbriatus (Fischer) was found in approximately 23% of all disturbed samples removed from the system and was frequently present in large numbers. This species has two forms; *P.fimbriatus* (*sensu stricto*) (hereafter referred to as *P.fimbriatus*) and *P.fimbriatus poppei* (*P.poppei* Rehberg as referred to by Fryer 1985b). *P.fimbriatus poppei* is distinguished in the female by a long ridge of teeth on the furcal rami, and a difference in ratio of length to breadth of the furcal rami.

Both forms were found at approximately the same frequency in samples from undisturbed sites, but at disturbed sites both types are more common in the Ravensthorpe Supply Zone. *P.fimbriatus* occurring in 23.1% and 31.4% in Pitsford and Ravensthorpe Supply Zones respectively, and *P.fimbriatus poppei* in 15% and 29% respectively. When the two types of female where found together, there was no evidence of different male types, when found separately there did not appear to be any obvious difference between the associated males.

The ratio of the furcal rami of all individuals was measured and considered to see if any difference existed between the male populations found with each type of female when they occurred alone, females being distinguished by a different length to width ratio of the furcal rami (Table 5.1). Unfortunately the data was somewhat biased towards large numbers of males with female *P.fimbriatus poppei* and nothing could be determined from the small sample size other than the difference between females of each type. Fryer (pers. comm.) suggested that *P.fimbriatus* and *P.poppei* should be treated as species because there appears to be a distinction between the two types, with only one or the other being found in natural conditions. This is not the case in the limited number of samples where this species occurs in the distribution system (Chapters 6 and 7), where both species occurred at the same sites. This study has follows the convention of Gurney (1932) calling the two types sub-species, though each is treated separately in subsequent analyses.

5.7.8) *Eucyclops.*

Eucyclops agilis (Koch) is a very common cyclopoid in natural conditions and the most frequently occurring cyclopoid copepod in samples from undisturbed sites (27%). This species can be distinguished by a characteristic line of teeth along the outer margin of the furcal rami and the presence of only 12 segments in the antennule. Fryer (1985b) listed *E.agilis* as a benthic detritivore/herbivore. *E.agilis* was reported to take ciliates by Archbold and Berger (1985), and is known to remove 'aufwuchs' from submerged stones which suggests it will be able to feed in the mains.

Table 5.1) Length : Width Ratio of Furcal Rami in *Paracyclops sp.*

	Percentage occurence in each ratio (length/width)				Number of individuals	Number of sites
	5:1	4:1	3:1	2:1		
female:						
P.fimbriatus	16	27	33	24	122	24
P.fimbriatus poppei	0	11	77	12	293	30
male						
P.fimbriatus	0	0	61	38	6	3
P.fimbriatus poppei	0	1	28	72	103	14

5.7.9) Harpacticoidea.

Three species occurred in the supply zones studied, *Nitocra hibernica* (Brady), *Bryocamptus pygmaeus* (Sars) and *Atheyella crassa* (Sars), identified from the keys in Gurney (1932). *Atheyella crassa*, an uncommon species (Gurney 1932) was only found on one occasion (a single individual) at Weedon, while the other two species were frequent. At the majority of sites where both males and females were present, females frequently had eggs or carried spermatophores. During October 1988, a sample at Watford was found to contain numerous pairs of male and female *N.hibernica*, with the males clasping the terminal setae of the female with their antennules (pre-copulatory behaviour). Male harpacticoids clasp subadult females and remain in contact until the female moults into adulthood. Hicks (1988) suggested that in the marine meiobenthos of New Zealand, harpacticoids change their normal behaviour pattern and swim away from the substrate before clasping takes place, perhaps because detection of other harpacticoids is best accomplished in three dimensions rather than two. This may affect the appearance of harpacticoids in water from taps, though these animals are small and unlikely to be readily noticed.

Nitocra hibernica included members of the variety *N.hibernica hyalina* Jakubiasiak, which was originally found in water pipes of Poznan (Jakubisiak 1929, cited by Gurney 1932). Gurney (1932) also found this type, with short furcal rami, each with two spine rows on the dorsal surface, in Hickling Broad, Norfolk and stated it is not a 'bottom form' but is 'characteristic of weedy margins of clear, unpolluted waters'.

Bryocamptus pygmaeus is found in almost every type of water (Gurney 1932) and has been found relatively independant of climate (Donner 1928 cited in Gurney 1932), reproducing in all months of the year but with particular abundances in March, June and October - November. Female *Bryocamptus pygmaeus* were found carrying egg sacs in samples taken during June 1987. Gurney (1932) suggested that *B.pygmaeus* may be the commonest British species of harpacticoid.

Harpacticoid copepods were frequently found in samples taken from disturbed sites (*Bryocamptus pygmaeus* 41%) though less frequent at undisturbed sites (6.3%). *Nitocra hibernica* is more frequent in undisturbed sites than *Bryocamptus*.

5.8) Cladocera

The cladoceran species of the mains community can be divided into two types, those which penetrate treatment and die in the mains and those which maintain a population in the system. Generally, chydorids are

pre-adapted to live in the system while daphnids and similar groups tend to die. Krishnamoorthi (1976) found that *Daphnia* were present and breeding in a distribution system in India, a situation that is possible providing there exists sufficient non-living seston and bacterioplankton in the water flowing in the system (Nadin-Hurley and Duncan 1976).

5.8.1) The life history and habit of Cladocera

Under natural conditions, overwintering females or resting eggs (ephippia) develop into mature females and usually breed by parthenogenesis. Eggs are retained in the carapace until developed females emerge. The parthenogenetic cycle continues until such time as overcrowding or some environmental stimulus leads to the production of male eggs. Sexual reproduction then takes place and resting eggs (ephippia) are produced.

Chydorids are non-selective feeders (DeMott 1986), filtering specific sized particles depending on the size of their filtration apparatus. *Chydorus sphaericus* (Müller) is described by Geller and Müller (1981) as a "high efficiency bacteria feeder". Chydorids produce considerable quantities of fine 'frasse' material which (if colonised by actinomycetes, fungi or bacteria) can be used as a feeding substrate by larger animals such as oligochaetes and chironomids.

5.8.2) Cladocera in the distribution system and their control

Cladocera, particularly chydorids, were reported as present in systems in the U.K. in studies of infestation problems by Hart (1957), Kelly (1955), and Phillips (1966). In the U.S.A., Crabhill (1956) found that they were controlled by copper-chlorine-ammonia treatment of the mains. Mitcham and Shelley (1980) found that *Alona* and *Chydorus* were removed for a total of 37 weeks following permethrin dosing, after pyrethrins had failed to control numbers on a previous occasion.

These species are unlikely to cause complaints from consumers, unless present in vast numbers, but Smalls and Greaves (1968) found that dirty water complaints (from iron stained carapaces) are frequently associated with this group of animals.

5.8.3) Cladocera present in the study area

The species of chydorid found in the supply zones studied all occur in the benthos of water bodies and their requirements are outlined in Smyly 1958, Fryer 1985b and Fryer and Forshaw 1979. Chydorids were found in almost every sample removed from the mains during this study. Individual carapaces of the genus *Bosmina* and *Daphnia* occurred infrequently during the study, but always in low numbers and rarely with

animal remains inside the carapace. On one occasion a living *Bosmina* was removed from the Pitsford Contact Tank. A single individual of the species *Macrothrix laticornis* (Jurine) was found on one occasion during the study. *Macrothrix laticornis* is described by Scourfield and Harding (1958) as frequenting the margins and bottoms of ponds and lakes, and therefore is likely to be able to establish a population in the mains.

Chydorid ephippia were never observed during the three years of this study which implies the chydorids in the distribution system are never facing severe conditions, and the populations are below the carrying capacity of the environment. Identification of cladocera was undertaken using the keys by Scourfield and Harding (1958) and by Amoros (1984).

5.8.4) *Alona*

Four species of *Alona* were present in the mains populations, *A.quadrangularis* (Müller), *A.affinis* (Leydig), *A.rectangula* Sars and *A.guttata* Sars. The two larger species were characteristic of undisturbed sites with large quantities of sediments, and were easily distinguished by examination of the cephalic pores as descibed by Frey (1959, 1962) with two pores in *A.affinis* and three in *A.quadrangularis*.

Alona affinis was infrequent and was not found with eggs present in any samples from disturbed sites. *Alona quadrangularis* was only found on five occasions in samples from disturbed sites and eggs were found present during September 1987. *A.affinis* was only found in the Ravensthorpe Supply Zone, while *A.quadrangularis* was only removed from the Pitsford Supply Zone during the sampling of disturbed sites.

The two smaller species, *A.rectangula* and *A.guttata* were similar and were difficult to identify owing to the fact that *A.guttata* is described in the keys available as being without lateral squamae on the postabdomen, while some individuals collected during this study did appear to have this feature. *A.rectangula*, recently redescribed by Frey (1988) is distinguished by having a striated carapace, a rounded distal postabdomen with well developed lateral squamae and 7-9 pairs of marginal denticles or corresponding setal bundles. The species identified as *A.guttata* (confirmed by Fryer pers. comm.), never had a striated carapace, and had a postabdomen that taperered distally rather than becoming 'swollen' as is the case in *A.rectangula*. The end of the post-abdomen was not rounded, but 'cut back' sharply towards the claw and freqently had an indentation between the end of the post-abdomen and the claw.

Eggs were found in *A.guttata* during January and all the months sampled between April and January, without any obvious peak in numbers. *A.rectangula* showed a similar pattern, with reproductive animals

occurring in samples from every month sampled except March during the sampling period. *A.rectangula* had a higher percentage of reproductive animals in April to May and November. All these samples were removed from sites where the animals in question were colonising new sites, which may have affected the percentage of reproductives in the population.

Fryer (1968) found that *A.affinis* feeds by scraping material from the substratum (sometimes ingesting large inorganic particles) and has antennae used for scambling through detritus. *A.guttata* is tolerant of a wide range of physico-chemical conditions provided detritus or other substrate is present while *A.rectangula* is better adapted to muddy bottoms (Fryer 1968).

A.protzi, a species commonly found in distribution systems (Smalls and Greaves 1968), but very rare in natural conditions in the U.K. was not found from any of the supply zones in the study, but did occur in samples from a tap at the University of Leicester (Severn-Trent Water Authority Area).

5.8.5) *Chydorus*

Chydorus sphaericus (*sensu stricto*) Müller was the most common of all the Cladocera found during the survey, occurring in the greatest densities of any animal found in the mains in all samples taken over the study. Eggs were present in all months sampled (every other month) except March (as in the case of *A.rectangula* and *A.guttata* above), with the greatest percentage of females carrying eggs during May and September. Females from the same sample were found to carry one or two eggs, though frequently eggs were lost from the carapace during sample processing.

The spherical shape of *C.sphaericus* is suggested by Fryer (1968) to provide protection from predation because of its ability to withstand stress and not damage or break. This observation is supported by the fact that the chydorids found in the guts of Tanypodinae larvae examined (section 5.3.9), were *Alona* and *Graptoleberis*, although *C.sphaericus* was present in large numbers at the locations from which the predators were taken.

C.sphaericus 'scrambles' amongst the fine sediments from the pipe (pers.obs.) and Fryer (1968) states that feeding involves scraping of surfaces, including those where very small amounts of attached material (microorganisms) are present.

5.8.6) *Graptoleberis*

Graptoleberis testudinaria (Fischer) was a surprising member of the mains community, since it is more often associated with submerged plants (Fryer 1968). Various workers (Smyly 1958, Chengalath 1987 and Fryer and

Forshaw 1979) have found the species in areas with no plants, where it presumably feeds by gliding over the substrate and removing 'aufwuchs'. The carapace of *Graptoleberis testudinaria* is modified and has a protective function similar to a gastropod shell, with the ventral carapace margins forming a headshield. Fryer (1968) found that *Graptoleberis* collects food by scraping with the second pair of trunk limbs, and that individuals can feed whilst stationary on a substrate. It is possible that bacteria which adhere to the particularly small particles ingested by this species form part of the diet (Fryer 1968) and feeding is only possible when the animal is attached to the substrate.

In the mains it is likely that this is also the lifestyle, though there will be no phytoplankton in the 'aufwuchs'. It may be that *Graptoleberis* is able to use the surface of the pipe as a feeding substrate in a manner unlike other chydorids, because of its hugely modified carapace.

The greatest density of eggs was found in May, but a sample containing reproductive animals was also taken in November. *Graptoleberis* was only found at one of the ten disturbed sites, which was only sampled infrequently. In a study of *C.sphaericus* and *G.testudinaria* the percentage of *Chydorus* with two eggs decreased (and the percentage of individuals with one egg increased) as *Graptoleberis* numbers increased, a possible indication of low food resources due to competition between these species (Keen 1973). Keen found that in this association with *Chydorus sphaericus*, *Graptoleberis* halted parthenogenesis and produced resting stages during August and September, while *C.sphaericus* overwintered as parthenogenetic females.

Graptoleberis may not be as infrequent in the system as originally percieved, as it was found in more regions of the system during the tap survey work (Chapter 9).

5.9) Ostracoda

Ostracoda were infrequent, occurring in only 6% of all samples, and of those, 4% of 'disturbed sites'. They occurred in particular at disturbed sites at Chapel Brampton and Guilsborough. Individuals were identified to the genus *Candona* Baird, using the key by Tressler (1963) in Edmundson [ed.] (1963).

5.10) Acarina

The Acarina associated with the mains community were found to be of three different groups; the Halacaridae; Hydracarina (Hydrachnida or Hydrachnellae, as defined by Gledhill 1985. The term Hydracarina is used throughout this study.), and the Tyroglyphidae. Of these groups, the

Halacaridae were the most significant, occurring in almost all the samples removed during the study. A general review of the water mites and their life histories was undertaken by Gledhill (1985).

5.10.1) Halacaridae

These mites were identified using the key by Green and Macquitty (1987). Three species from two subfamilies were recorded, *Soldanellonyx monardi* Walter, (subfamily Limnohalacariae); *Lobohalacarus weberi* (Romijn & Viets) and *Porohalacarus alpinus* (Thor), (subfamily Porohalacarinae). These species are all small (less than 1 mm length), non-swimming mites which crawl in and on the substrate. Adults of *L.weberi quadriporus* (Walter) are often found in the sand of slow sand filters (Teschner 1963). Teschner found up to 40 animals per litre of sand at Bremen where they often occurred deeper than one metre in the filter column, a feature which suggests that penetration of the filter by these animals is very likely.

Most species have separate sexes (Green and Macquitty 1987), but mating behaviour has been observed in only one (marine) species of the family. Larvae are distinguished by having only three pairs of legs, while the nymphal stages (protonymphs; deutonymphs and tritonymphs) and adults have four pairs. Both multivotine and univoltine life histories have been found, but no information is available on the species found during this study. Univoltine species tend to overwinter as adults and lay eggs in spring. *L.weberi quadriporus* was found by Teschner (1963) to complete its life cycle in six months at an optimum temperature of 17°C with a good food supply, adults appearing in July.

Juvenile stages have different configuration of plates to the adults and also lack some of the distinguishing setae on the limbs, characteristic of species in the adults. The nymphal stages of the three species found during the course of this study were sufficiently different from each other to be identified and included with the adult forms. Confirmation of the identification of these nymphal stages was provided by Green (pers.comm.). *Lobohalacarus weberi* takes about six months to complete its life cycle under favourable conditions, and Teschner (1963) found that high temperature had the effect of reducing the extent of life stages and low temperature stimulated oviposition.

The mouthparts of these species are adapted for piercing and sucking (Green and Macquitty 1987) and *L.weberi quadriporus* has been found to predate both nematodes and oligochaetes (Teschner 1963) as well as scavenge. Teschner also found that mites of this species could survive for eight months without feeding.

5.10.2) Other Acarina

Two groups of Acarina occurred infrequently in the samples taken from the system. The Hydracarina occurred in only 3.6% of samples from the distribution system.

Also present in the samples were mites of the order Sarcoptiformes; family Tyroglyphidae (Acaridae), identified tentatively as the genus *Schwiebea* (Green pers.com.). These are frequently found in leaf litter though Türk and Türk (1957) found a *Schwiebea* species in groundwater, and the presence of these animals was considered initially to be contamination from the hydrants. However, animals were found to occur in all three samples in a sequence from a sampling site (Chapter 2) and mites of this type were also found in samples removed from taps (Chapter 9), implying that they do indeed exist in the main. This was confirmed when three individuals were removed from the gut of a Tanypodinae larvae from the distribution system. This led to their inclusion in the various analysis procedures applied in chapters 6 and 7.

5.11) Mollusca

Both bivalve and gastropod molluscs cause problems in distribution systems. Reviews of the situation in the U.S.A. and elsewhere (Ingram 1956, Morton 1976) show the principal problem in the U.S.A. is *Bythinia tentaculata* (L). (the faucet snail) which gains access as eggs via treatment (Ingram and Bartsch 1960). This snail is part of the British freshwater fauna, but there have been no records of its presence in the distribution systems of the U.K.

Krishnamoorthi and Rajagopalan (1967) found a total of 4 species of bivalves and 10 gastropod molluscs present in water supplies of India (from treatment works and slow sand filter beds), particularly the bivalve *Modiolus striatulus* Henley, which was present in great numbers. Four mollusc species were found to be of 'nusiance value' in the distribution systems of Calcutta and Bombay (Krishnamoorthi *et al.* 1976).

In Singapore, Ingram (1956) found the snail *Melania tuberculata* Müller is present in large numbers but only in parts of the system where the organic load of the water was high after passage through rapid gravity filters.

In Britain the major problems in distribution are caused by the gastropod molluscs *Hydrobia (Potamopyrgus) jenkinsi* Smith and *Limnaea pereger* Müller, though *Valvata cristata* Müller (Smalls 1966) and *Planorbis* spp. have also been recorded as present in supply systems.

5.11.1) Bivalvia

In the U.S.A. a fresh water clam, *Rangia cuneata* Sowerby was found by Counts (1980) in an industrial water supply. The water in the pipes had a chlorine residual of 3 p.p.m. which suggests that if penetration occurs (in this case thought to be due to a breakdown of chlorination in the past), larvae can establish themselves in the system and adults can survive high chlorine residuals.

In the U.K., the bivalve, *Dreissensia polymorpha* (Pallas) appears to be held back by treatment, but Clarke (1952) found larvae could survive in 10 p.p.m. chlorine for 1 hour and thus could be a problem should filtration fail. Greenshields and Ridley (1957) confirmed this, showing the problems caused by this bivalve in raw water mains. Control of *D.polymorpha* is possible using chlorination of the pipelines in question over a one week period.

Greenshields and Ridley (1957) found *Dreissensia polymorpha* tended to occur in pipes running between reservoirs and filtration works. The mains remained unaffected and Greenshields and Ridley suggested this may be due to chlorination. Seven day chlorination will kill adult mussels but this treatment will also kill the filter fauna, and so the use of double pipelines in all cases of flow is advised.

Clarke (1987) showed that bivalves cause associated problems by providing a habitat for other infesting animals. *Sphaerium corneum* (L.) was found in a storage tank where chlorination occurred during treatment. Within one year (since a cleaning operation) the floor of the tank was 150mm deep in *S.corneum* (Clarke 1987). Only about 5% of the animals were found to be alive but the presence of a deep layer of organic substrate in the tank provided a substrate for bryozoans, *Asellus*, chironomid larvae and ostracods.

5.11.2) Gastropoda

Limnaea can be controlled using chlorine (1.0 p.p.m.) (Oliver 1961), but *Hydrobia (Potamopyrgus) jenkinsi* Smith, being both parthenogenetic and ovoviparous is less easily controlled since reinfestation can occur from a single individual surviving treatment. If molluscs are not removed from the system following their control, it is widely believed that unpleasant tastes and odours result from their decay within the system.

Gastropods found in the two supply zones were typically at the extremes of the system and there is some evidence (A.Longhurst pers.comm) that the location of infestations may be due to the site of the original infestation, with animals spreading along the system. In the past it has been possible to state that snails can be found at specific areas of the system, but not outside these areas. *Hydrobia jenkinsi* is known to be

able to move upstream on gravel (Heywood and Edwards 1962) at 5.4 cm per day (on average) and so ought to be able to spread through the system if conditions are ideal.

Both *Hydrobia jenkinsi* and *Planorbis crista* (L.) were present in the system but were rarely found together, and when this did occur, it was in low numbers of both species, suggesting that competition may be in effect at high densities. *Planorbis crista* removed from the system had shells of a different form to that described in the key by Macan (1960). Many shells were uncoiled spirals and all had thick ridges present rather than slight ridges.

5.12) Microturbellaria

Microturbellaria were present in the system though never in large numbers or at many sites. These animals suffered considerably on collection and preservation of samples and were not sufficiently well preserved to allow any attempt at identification. The knowledge of this part of the fauna is not good and it is very unlikely that identification would have been possible in any case. The animals are Rhabdocoels and as such predate other species. The fact that the occasions when this group was present coincided with high densities of oligochaetes is an indication that oligochaetes may be the main prey species.

5.13) Tardigrada

Tardigrada are the smallest members of the mains fauna that are collected by the mesh size used to sample at the hydrant (142 µ), and then only the very large individuals tend to be collected. Ocasionallly small animals and ciliates were caught in the sediments but normally such animals were lost during sampling. The tardigrades are present in quite a high proportion of samples, but are frequently so small that they can be overlooked. The size of individuals suggests that their presence will never be a problem regarding consumer complaints. The animals found proved to be of the genus *Macrobiotus*, identified using the key by Morgan and King (1976). These animals are predators, actively taking ciliates and bacteria.

5.14) Nematoda

Nematodes were collected in many samples, but their size indicated that only large animals were captured in the hydrant net (George et al. (1964) used a membrane of 0.45 µ to collect worms). No attempt was made to identify these animals further.

Nematodes are the only organisms known to be present in the distribution system studied which may have an indirect effect on public

health. Chang *et al.* (1960) showed that bacteria can pass through chlorination within the gut of a nematode that penetrates treatment, but no viable bacteria have been shown to be voided. The probability of a worm passing through treatment and containing pathogenic bacteria which remain viable is very small indeed.

Control of nematodes has been effected by Crabhill (1956), using copper-chlorine-ammonia treatment. However, Collins (1958) found that though 1% saline and 20 p.p.m. chlorine (150 minutes contact time) would kill both adult and juvenile *Trilobius gracilis* in laboratory conditions, nothing could be done on a large scale to control nematodes in the distribution system. Chang *et al.* (1959) found that the two common taxa isolated from the distribution system of Ohio, *Monhystera* and *Diplogaster* were unaffected by chlorine at 24 p.p.m. for 100 minutes.

Various authors (Mott *et al.* 1981, Tombes 1979) have found that the density of nematodes in finished water coincide with periods of high rainfall, as nematode numbers increase in raw water. This is not any cause for concern unless the raw water 'draw-off' is situated downstream from any site where nematodes carrying pathogenic bacteria could enter the raw water.

Mott *et al.* (1981) found that 55 to 75% of live nematodes can pass through a rapid sand filter, though only 2 to 4% of dead nematodes penetrate treatment. This 55 to 75% penetration can therefore be halted by heavy prechlorination prior to filtration. In India, George *et al.* (1964) and George (1966) found that nematodes did not settle out in storage reservoirs and found a high proportion of mobile worms in the final water indicating the lack of effect of the normal chlorine dose used (less than 2.0 mg l^{-1}).

5.15) Other animals known to occur

Numerous other animals are known to occur at various times within the distribution system, and lists of taxa that have been removed in samples can be found in English (1958); Ingram and Bartsch (1960); Collingwood (1966); and Krishnamoorthi (1976).

In the system under study, the only other animal that occurred was a single dead leech, *Erpobdella*. The response to an inquiry for information from other water undertakings produced a number of other animals, particularly insects, but generally none which would be able to establish populations in the mains. Of the vertebrates, both eel and lamprey are still included in the mains fauna of some undertakings.

PART III) EXPERIMENTAL WORK

III.A) THE DISTRIBUTION SYSTEM

CHAPTER 6) CORRELATION OF COMMUNITY STRUCTURE WITH ENVIRONMENTAL AND OPERATIONAL PARAMETERS

6.1) Introduction.....130
6.2) Sampling Methods.....130
6.3) Sampling Sites.....132
6.4) Data Analysis Methods.....132
6.5) Kendall's Correlation Coefficient: Results and Discussion.....141
6.5.1) Environmental parameters and operational characteristics.....141
6.5.2) Effect of measured conditions in the main on the community.....144
6.5.2.1) Chironomidae.....144
6.5.2.2) Copepoda.....144
6.5.2.3) Chydorids.....147
6.5.2.4) Acarina.....147
6.5.2.5) Other Taxa.....148
6.5.3) Investigation of relationships between taxa.....148
6.6) Analysis using Hierarchical Cluster Analysis: Results and Discussion.....150
6.6.1) Taxonomic characterisation of clusters.....150
6.6.2) Characterisation of clusters using environmental and operational parameters.....154
6.7) Clustering using environmental and operational parameters.....160
6.8) General Discussion.....165

CHAPTER 6) CORRELATION OF COMMUNITY STRUCTURE WITH ENVIRONMENTAL AND OPERATIONAL PARAMETERS

6.1) Introduction

Preliminary samples removed from sites at Nether Heyford, Church Brampton and Chapel Brampton during 1986, indicated that adjacent pipes at the same site did not carry similar faunas, though pipe lengths fed off the same leg did sometimes appear similar. It was presumed that the operational characteristics of pipe lengths determine, either directly or indirectly through their effects on environmental characteristics, the fauna present in any length of pipe.

After two years of working with this system, it was possible to make an educated guess as to the nature of the community infesting pipes at various locations in the system, from knowledge of the location in the pipe network and pressure. It was intended that pipes with different environmental and operational parameters would be sampled by flushing a number of sites at a similar point in time, throughout the system. This would enable the environmental and operational factors influencing the community in the pipe to be determined.

Most operational characteristics affect sedimentation, carbon availability, oxygen levels and other 'environmental factors' and hence animal distribution within the system. Using cluster analysis to group flush samples on the basis of the similarity of animal community found therein, it was possible to determine whether pipe lengths with similar community structure were affected by similar operational characteristics. Any relationships between taxa in the mains community would become apparent.

Flush samples were grouped on the basis of faunistic similarity and classified using measured environmental variables. This determined whether any operational or environmental factors played an important role in determining the animal community. Similar analysis using operational characteristics of the system as the classification enabled the operations most likely to produce low levels of animals to be determined; where particular problem communities appeared; and what factors in the distribution system produced the environment in which they are able to maintain a population.

6.2) Sampling Methods

The methods chosen were based on the method outlined in Chapter 2. Sites were chosen with the assistance of the Inspectors in each District, to ensure the minimum of disruption to supply. Sites consisted of series of pipe lengths fed from a large diameter feed which could be flushed

through with clean water to a dead end, or locations where a single flush would clean a small diameter pipe fed from a large diameter feed.

Each hydrant was flushed three times to produce a sample, the first flush being timed so as to flush at least twice the volume of water contained in the pipe section. Ideally both the second and third flush flushed twice the pipe volume through the hydrant. At sites with low rates of flow, or where difficulties existed with drainage, this rarely occurred. In practice, the first flush allowed twice the pipe volume to be removed, and the second and third flush sampled at least the volume of the pipe, ceasing to flush as soon as the water ran clean after the pipe volume had been sampled.

Samples were collected in 142 μ mesh hydrant nets (1 m and 2 m long nets were used at sites where a large length of pipe was to be flushed, ensuring the bags would not burst due to a large quantity of sediment.), and returned to the laboratory where they were preserved in 70% I.M.S. and stored for later sorting. Subsampling and counting followed the procedure outlined in Chapter 2.

At many sites, the rate of flow was found to be lower than the 6 l s^{-1} to 7 l s^{-1} reccomended as a minimum flushing rate for quantitative measures of animals in mains to be accepted (Chapter 3). In order to accomodate these sites, two different analyses were carried out on the data (section 6.4).

At each site, the following variables were measured. (Methods of estimation and classification are described in Chapter 4):

Environmental Parameters:

pH	measured in the field
temperature	measured in the field
oxygen level	measured in the field
chlorine level	measured in the field
P.O.C.	measured in the laboratory
D.O.C.	measured in the laboratory
Sediment Dry weight	measured in the laboratory
Sediment Organic Content	measured in the laboratory

Operational Characteristics:

Consumption rate of water in main	calculated from 1:2500 plans
Pressure	measured in the field
Rate of flow	measured in the field
Pipe material	from 1:2500 plans
Pipe diameter	from 1:2500 plans

Travel time of water
from treatment — from Watnet III network analysis

6.3) Sample sites

A surplus of sites was chosen on the basis of 1:2500 plans and the locations in the system examined in the field to ensure correct drainage was possible. These sites were then discussed with Operations Staff and were reduced in number on the basis of ease of sampling and minimisation of disruption to the system. (There are some areas in the system where the mains are particularly weak and may not cope with the pressure changes relating to flushing.) In some instances, where consumers would face interruptions to supply, it was necessary to card warn (notify affected customers in writing at least 24 hours prior to the disruption to supply) properties. This was carried out by the District Inspectors concerned and where possible Anglian Water staff also assisted to ensure correct road signing and drainage on major roads. Two sites were lost during the sampling program due to neccessary operations (such as dirty water complaints which required immediate air-scour). A number of hydrant samples were also lost because of faulty hydrants or drainage problems, which led to the cessation of flushing prior to sample collection.

The sampling program was carried out in two phases, in May/June and October 1987, and the sites are listed in Table 6.1, with the number of samples (hydrants flushed) at each site and sample code.

The general location of these sites and their codes (Table 6.1) are indicated on Figures 6.1 a, b, c, d, and e. More detailed diagrams of the pipe networks at these sites and the hydrants sampled are included as Appendix V.

Each site consisted of either a small diameter main fed by a large diameter main, or a small diameter network fed by a large diameter main. If the site consisted of a network with a number of hydrants in series, clean water was pulled through the system from the large diameter main in order to maintain drift levels at each hydrant and to ensure that no consumers would be left with dirty water resulting from the sampling process.

6.4) Data Analysis Methods

Investigation of the relationship between environmental parameters, operational characteristics and taxa was undertaken by calculating Kendall's correlation coefficient (Kendall 1970) calculated as *tau-b* by the SPSSx (version 3.0) statistical analysis package available at University of Leicester. The animal densities at each site are included

Table 6.1) Site and flush samples removed during May/June and October flush sampling with rate of flush and sample code

	HYDRANTS	<7.0 l s^{-1}	Code
May/June:			
West Haddon	1	0	WH-SC
Watford Locks	1	0	WS-A5
Winwick	5	5	WI-H3 TO H7
Hollowell	1	0	HO-OC
Haslebech	3	3	HA-H1 TO H3
Watford	4	4	WA-H1 TO H4
Brackmills	2	0	BR-OC/-PC
Guilsborough	4	3	GU-NO/-H1/-H2/-PC
Brampton Lane	6	4	BL-H2/3/4/6/7/8
Canons Ashby	1	0	CA-H1
Weedon	1	0	UW-TR
Borough Hill	2	0	BH-HM/-HR
12 sites	31 total	19 total	
	HYDRANTS	<7.0 l s^{-1}	CODE
October:			
Charwelton	4	3	CH-H3 TO H6
Badby	3	0	BA-H1 TO H3
Woodford Halse	5	2	WH-H1/2/4/5/6
Arthingworth	6	0	AR-H1 TO H6
Creaton	1	0	CR-TL
West Farndon	4	1	WF-H2 TO H5
Newnham	3	0	NE-CR/-MA/-MO
Glassthorpe	2	0	GL-H1/H2
Weedon Bec	1	0	WB-RD
Cavalry Hill	4	1	CV-H1 TO H4
10 sites	34 total	7 total	
Total 22 Sites	65 total	26 total	

Fig.6.1a) Sketch Map of Ravensthorpe Supply Zone showing sample sites

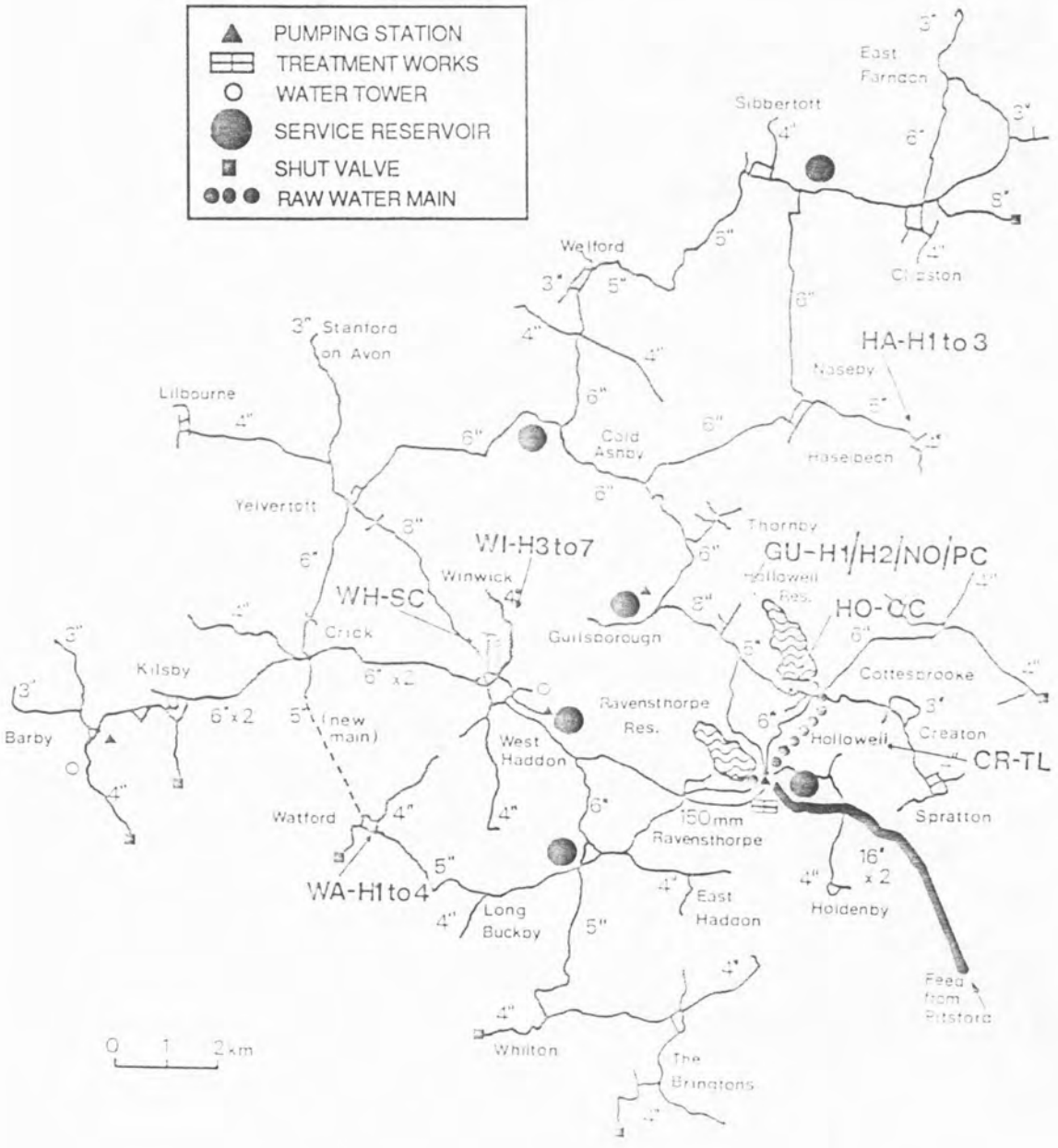


Fig.6.1b) Sketch Map of Wing Supply Zone (Area within Market Harborough District only) showing sample sites

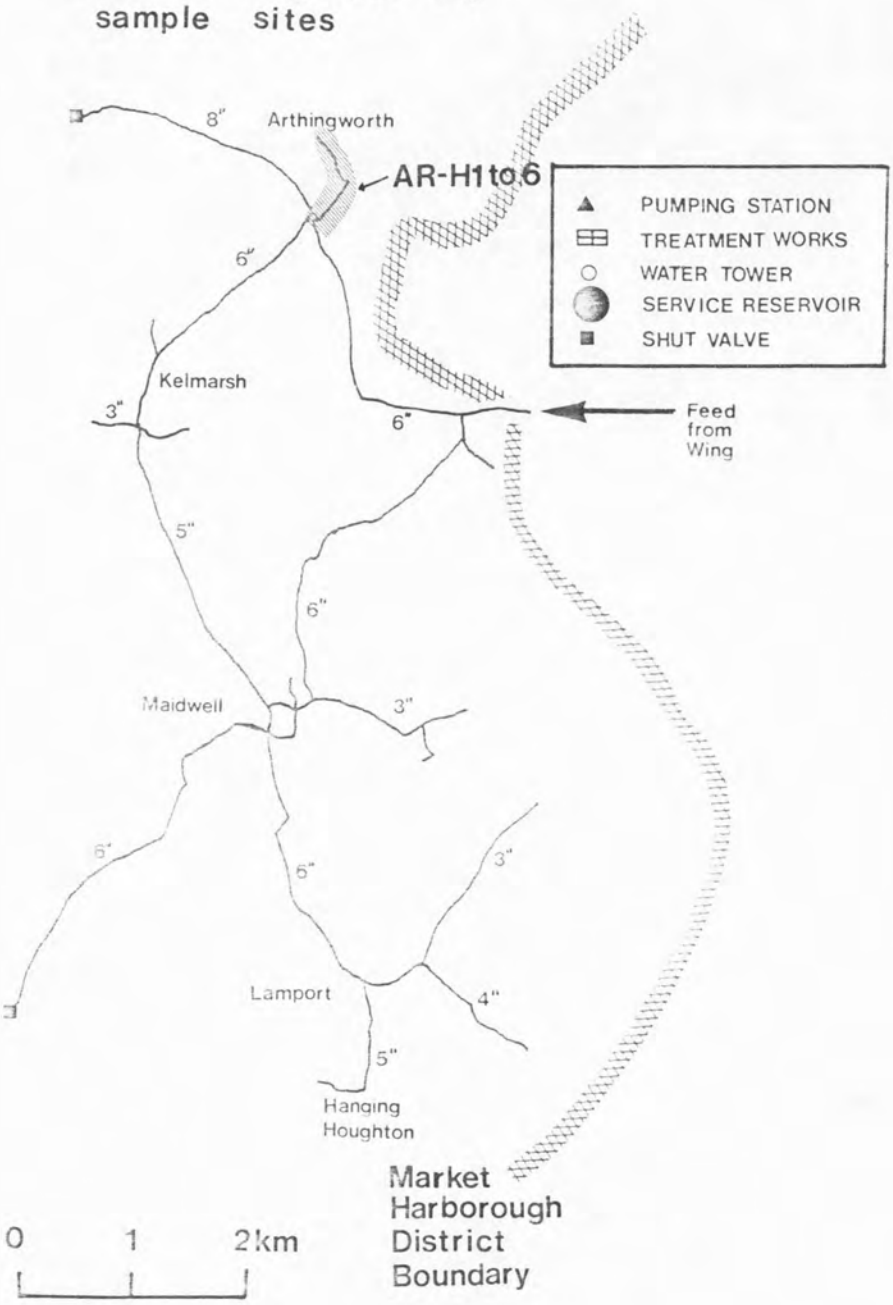


Fig.6.1c) Sketch Map of Northampton Supply Zone showing sample sites

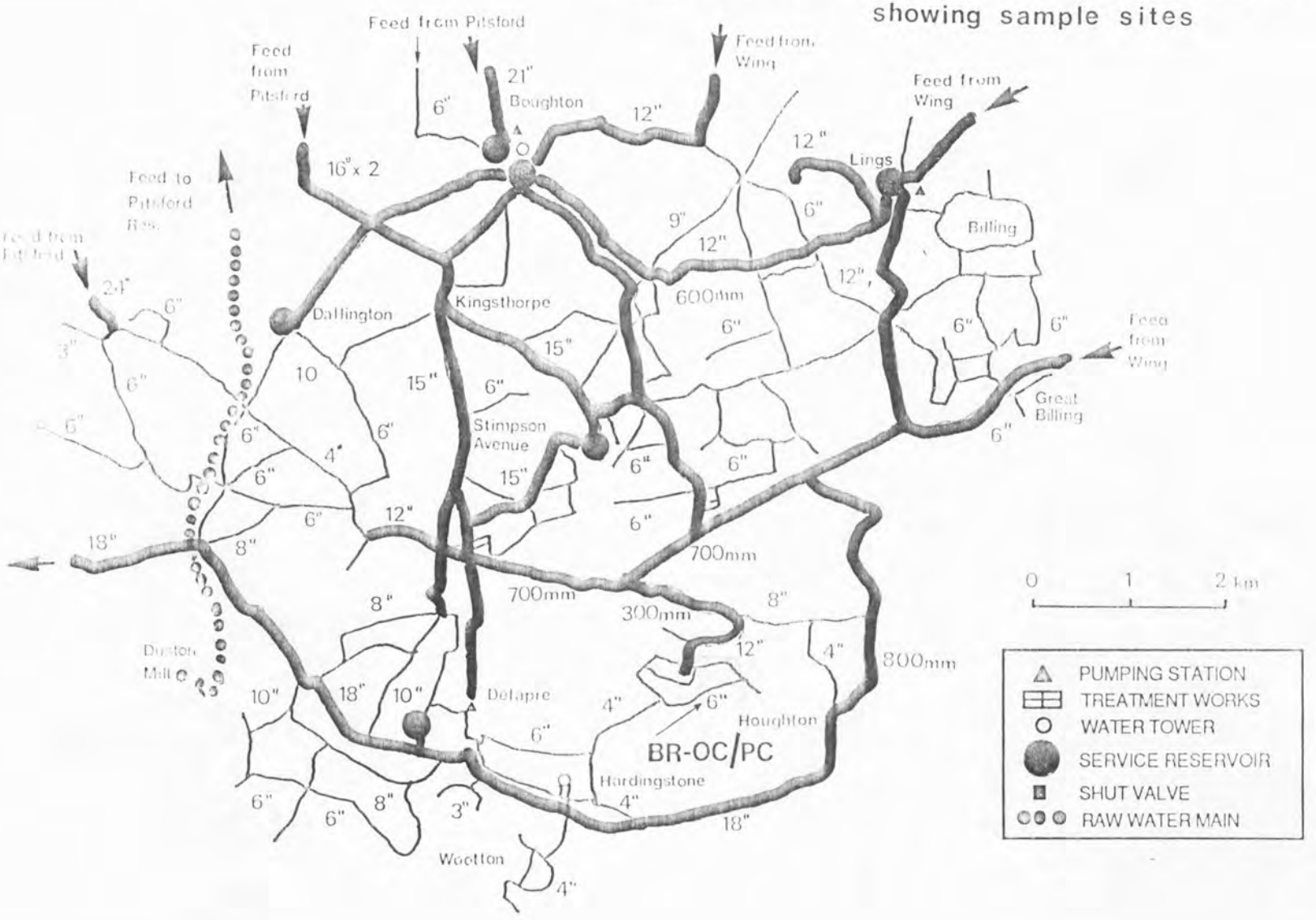


Fig.6.1d) Sketch Map of Pitsford East Supply Zone showing sample sites

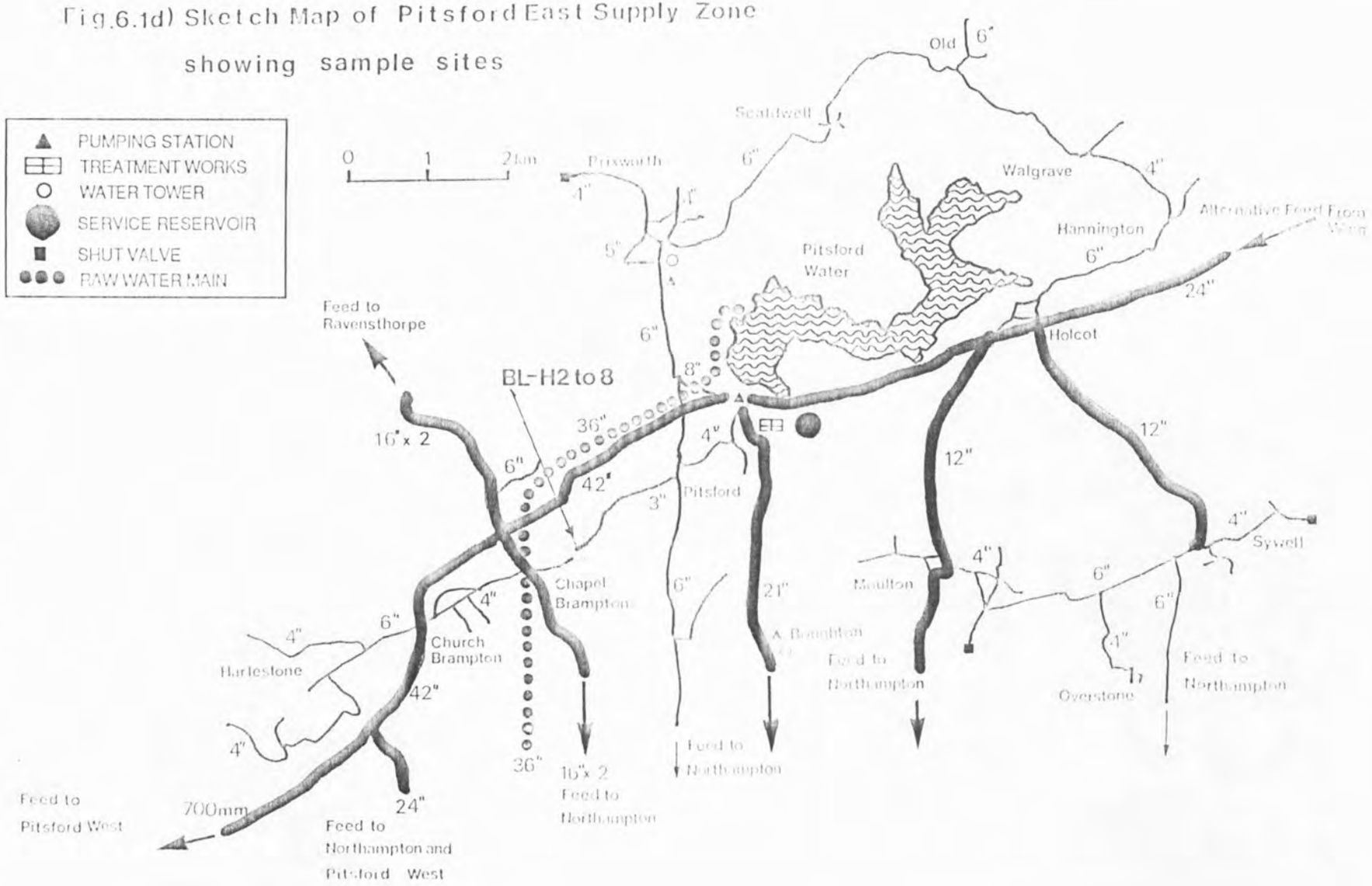
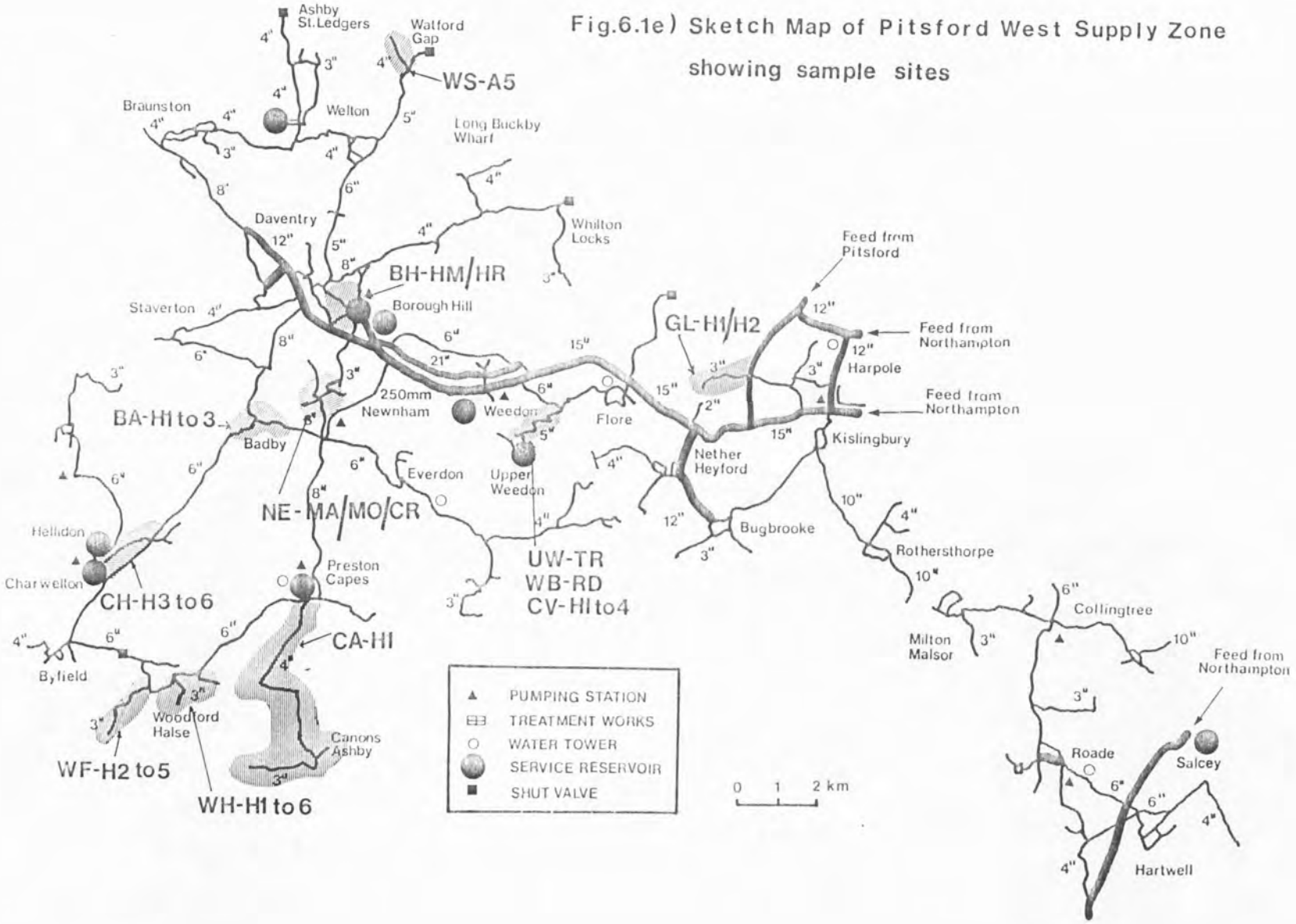


Fig.6.1e) Sketch Map of Pitsford West Supply Zone showing sample sites



as Appendix VI, and the environmental parameters as Appendix III.

Bullock (1971) examined the relative merits of similarity indices and concluded that of the rank correlation indices, Kendall's rank correlation coefficient is preferable to Spearman's *rho* because it is an arithmetic rather than geometric function. Being geometric, Spearman's *rho* will be biased towards sites with large differences between ranks. This is a feature of the data used in this study and therefore Kendall's *tau-b* was used in the analysis.

In his discussion, Bullock (1971) considered the effect of inclusion or exclusion of zero values. The exclusion of double absences was advised, since there is no way of determining whether an absence is due to environmental conditions; a failure of the sampling method to capture the animal; or a seasonal effect. Bullock did advise the inclusion of absence in one sample and presence in the second, since these will include information about at least one sample. However, in the distribution system, there is the problem of sites where conditions may be ideal for a particular species, but this species simply has not colonised this area. Furthermore, the large number of sites included in this analysis and the large number of taxa produced a situation where relatively few sites occur where two species are both present. If animal densities are plotted against each other, the spread of values along the axes where one or the other of the taxa is zero can be considerable and can lead to a failure to determine real relationships where both taxa are present. In this study, analysis of relationships between taxa was undertaken using only occasions when both variables were recorded, excluding both double absences and single absences from the analysis.

Each environmental parameter and operational characteristic of each sample was assigned to the groups described in chapter 4 prior to analysis (was scored on the basis of ranks 1 to 4). Since some sites were flushed at rates below the suggested 7.0 l s^{-1}, it was not possible to accurately determine the density of the taxa under investigation at each site. However, a relative estimate was possible and each taxonomic group was assigned to one of five (logarithmic based) groups relating to the density within the pipe:

$0 = 0$

$0 > 1 \leq 10$

$10 > 2 \leq 100$

$100 > 3 \leq 1000$

$1000 > 4 \leq 10000$

$10000 > 5 \leq 100000$

The taxonomic groups involved in the analysis were as follows:

Chironominae; Tanytarsini; *Corynoneura* sp.; Orthocladiinae; Tanypodinae; *Nitocra hibernica*; *Bryocamptus pygmaeus*; *Paracyclops fimbriatus*; *Paracyclops fimbriatus poppei*; *Acanthocyclops robustus*; *Acanthocyclops* copepodites (species undetermined); *Eucyclops agilis*; *Megacyclops viridis*; *Chydorus sphaericus*; *Alona guttata*; *Alona rectangula*; *Alona quadrangularis*; *Graptoleberis testudinaria*; *Soldanonellyx monardi*; *Lobohalacarus weberi*; *Porohalacarus alpinus*; Tyroglyphidae; *Naididae*; Nematoda; Ostracoda; *Planorbis crista*; *Hydrobia jenkinsi*;

Investigation of the environmental and operational variables was carried out using all the data from all sites, to determine whether these factors were linked. Each taxonomic group was correlated with each measured variable and each taxa was correlated with every other taxa (using only data for sites where both taxa occurred, since in many cases the number of zero values would distort any relationship).

The cluster method used was Ward's minimum variance method of cluster analysis (Ward 1963). This is a hierarchical grouping procedure, which commences with a set of *n* members, grouped as *n* groups with one member each. This becomes *n-1* groups following a pairing, then all the groups, including the new paired groups are paired and the 'objective function' is compared for each pairing, the optimal objective function determining the pairing that produces *n-2* groups, and so on. The optimal objective function in this instance is the minimum possible 'error sum of squares' (the sum of the squared derivatives about the group mean). Whichever pairing produces this minimum value is chosen to reduce the number of groups.

Ward's method involved the calculation of the squared Euclidean distance between sites, where the squared Euclidean distance is the distance calculated in the matrix of similarity between sites.

Four different dendrograms were constructed:

i) A dendrogram using data for taxonomic density per 10 metres of pipe from all sites flushed at over 7.0 $l\ s^{-1}$. This investigated whether density could produce clusters that related to measured conditions in the pipe.

ii) A dendrogram using data from every site, regardless of flushing rate, transformed to produce a relative measure (the ranks

described above). This enabled a large data set to be investigated.

iii) A dendrogram using data for taxonomic density as in i) (above) but log transformed such that:

$$f(x) \rightarrow \log(x + 1)$$

(since data did not conform to normal distribution and had many zero or near zero values). This was used to assess the accuracy of the clustering in ii).

iv) A dendrogram using data for environmental and operational variables (untransformed). This investigated whether clustering was in any way similar to that based on the community structure.

In every cluster based upon community structure, a 5% frequency of occurence was allocated as the minimum requirement for a taxon to be included in the analysis.

6.5) Kendalls Correlation Coefficient: results and discussion

Of the 37 taxa identified during this study, a total of 27 occurred at 5% or more of sites and were included in the analysis. The independant variables tested were organic content of sediment; dry weight of sediment; D.O.C.; P.O.C.; pressure; total chlorine; 'age' of the water since treatment; consumption rate (index of the residence time in the pipe); iron levels from the parish in question; turbidity from the parish in question; and dissolved oxygen. Each variable was ranked (using the classifications described in Chapter 4) prior to analysis. The variables temperature and pH were not included in this analysis since it was assumed that temperature (range 11.0 - 16.0) was approximately constant as was pH (range 7.2 - 7.8).

6.5.1) Environmental parameters and operational characteristics

A total of 13 variables were correlated, leading to 66 analyses of which 12 were significant at $p < 0.05$ (Table 6.2). (Table 6.3 shows the limits (classified 1 to 4) of each variable.) This number of tests would yield four apparently significant results from random values. Hence, some relationships appear to exist between the variables. There are strong correlations between iron levels and turbidity and strong correlation between organic content and dry weight of sediment.

The rate of flushing at each site, which indicates the distance from a trunk main, shows positive correlations with iron and turbidity, being high when the latter are low; and with age of water, decreasing as the age of water increases.

Oxygen concentration also shows significant correlations with both

Table 6.2) Significant correlations between measured variables

Variable 1	Variable 2	Kendall's tau-b	N	significance
Turbidity	Iron	0.6719	64	0.000 ***
	Rate	0.3526	64	0.003 **
	O_2	0.2514	63	0.043 *
Iron	Rate	0.3096	64	0.007 **
	O_2	0.3500	63	0.004 **
	Pressure	0.3815	62	0.002 **
	Organic weight	0.3263	63	0.005 **
Rate	Age	0.2940	48	0.022 *
Cl	O_2	0.2473	63	0.039 *
	D.O.C.	-0.3436	59	0.006 **
O_2	Pressure	0.4099	61	0.001 ***
Dry weight	Organic weight	0.7266	63	0.000 ***

Table 6.3) The classification of variables used in correlation tests (see also Chapter 4 and Appendix III)

Environmental Parameter	Classification 1	2	3	4
Org.weight (g)	$x < 5.0$	$10.0 > x > 5.0$	$20.0 > x > 10.0$	$x > 20.0$
Dry weight (g)	$x < 50.0$	$100.0 > x > 50.0$	$200.0 > x > 100.0$	$x > 200.0$
D.O.C. (mg l^{-1})	$x < 5$	$10 > x > 5$	$20 > x > 10$	$x > 20$
P.O.C. (mg l^{-1})	$x < 2$	$4 > x > 2$	$8 > x > 4$	$x > 8$
pressure (bar)	$x > 4$	$2 < x < 4$	$1 < x < 2$	$x < 1$
Cl (mg l^{-1})	$x > 1.0$	$0.5 < x < 1.0$	$0.1 < x < 0.5$	$x < 0.1$
age (hours)	$x < 12$	$12 > x < 24$	$24 > x < 48$	$x < 48$
consumption (l day^{-1})	$x > 55090$	$24397 < x < 55090$	$7870 < x < 24397$	$x > 7870$
iron (mg l^{-1})	$x < 0.05$	$0.05 < x < 0.1$	$0.1 < x < 0.2$	$x > 0.2$
turbidity (J.U.)	$x < 0.4$	$0.4 < x < 0.1$	$1.0 < x < 4.0$	$x > 4.0$
rate (l s^{-1})	$x > 12$	$8 < x < 12$	$6 < x < 8$	$x < 6$
O_2 (percent saturation)	$x < 80$	$40 < x < 80$	$20 < x < 40$	$x < 20$

iron and turbidity, increasing as they decrease. Oxygen also increased with both pressure and total chlorine levels. These may be related to distance from treatment works, producing higher levels of all three variables which drop off as samples are removed from further away in the distribution system. Chlorine shows a negative correlation with D.O.C., such that actual levels increase together.

6.5.2) Effect of measured conditions in the main on the community.

A total of 25 taxa and 12 variables were analysed. The taxa included zero values since measured variables were known to range from 1 to 4 so bias on both axis was not possible. Of 150 tested correlations, 45 showed a significance of $p < 0.05$ (8 cases would be expected to be significant by chance). These are given in Table 6.4 along with the percentage frequency of occurence of each taxonomic group in the 64 samples.

6.5.2.1) Chironomidae

The larvae of the chironomidiae were investigated in five groups, the Orthocladiinae (excluding *Corynoneura* sp.); Chironominae (excluding Tanytarsini); *Corynoneura* sp.; Tanytarsini; and Tanypodinae. Chironomidae occurred in less than 5% of samples while Orthocladiinae and *Corynoneura* did not show any significant correlation with the independant variables tested.

Tanytarsini show a postitive correlation with consumption rate and iron. This suggests that these animals are found at greater densities at sites with a low rate of consumption of water and at sites that have a high level of iron colouring the mains, possibly indicative of older parts of the system where tuberculation and encrustation of the pipe is extensive.

Tanypodinae show a strong positive correlation with the dry weight of sediment and organic material in sample sediment. The link between this predatory group and the organic content of sediment is not surprising, since a high organic load in the system suggests the presence of a high biomass, which would explain the presence of greater numbers of Tanypodinae larvae. This group also shows positive correlation with iron levels and pressure, suggesting that low pressure and high iron content of water characterise the sites where this group is numerous.

6.5.2.2) Copepoda

The harpacticoid copepod *Nitocra hibernica* is positively correlated with consumption rate, which suggests that it occurs at greater densities at sites where the rate of consumption is low. *N.hibernica* also shows a negative correlation with particulate organic content of the water. This

Table 6.4) Correlation between measured variables and taxa

Taxa	Frequency	Variable	Kendall's tau-b	N	Significance
Tanytarsini	40.6	Cons.	0.4124	61	0.000 ***
		Iron	0.3022	61	0.012 *
Tanypodinae	15.6	Iron	0.3336	64	0.006 **
		Pressure	0.6237	62	0.000 ***
		Dry weight	0.3157	64	0.010 *
		Org.weight	0.3543	63	0.003 **
Nitocra	17.2	Cons.	0.2470	64	0.035 *
		P.O.C.	-0.2712	58	0.030 *
P.fimbriatus	23.4	Turbidity	-0.3743	63	0.002 **
		Rate	-0.4756	63	0.000 ***
		Age	-0.4599	47	0.001 *
P.f.poppei	23.4	Rate	-0.4394	63	0.000 ***
		Age	-0.3866	48	0.004 **
		Org.weight	-0.2416	62	0.041 *
E.agilis	26.6	Age	0.5382	47	0.000 ***
A.robustus	12.5	Rate	-0.2505	62	0.035 *
		Cl	-0.3038	61	0.015 *
		Age	-0.2966	47	0.033 *
		Org.weight	0.3492	61	0.004 **
A.guttata	12.5	Age	-0.2687	64	0.005 **
A.quadrangular.	14.1	Rate	-0.2468	63	0.047 *
Soldanonellyx	45.3	Rate	-0.3678	62	0.001 **
Lobohalacarus	18.8	Turbidity	-0.3095	63	0.013 *
		Iron	-0.2403	63	0.047 *

(Table 6.4 continued)

Taxa	Frequency	Variable	Kendall's tau-b	N	Significance
Porohalacarus	12.5	Cons.	0.2902	64	0.015 *
		Age	0.3422	48	0.012 *
		Org.weight	-0.2723	63	0.023 *
Tyryoglyphidae	26.6	Rate	-0.2601	63	0.023 *
		Cl	-0.3047	62	0.011 *
		Age	-0.4011	47	0.003 **
Naididae	45.3	Cons.	0.2329	59	0.047 *
		Turbidity	0.2960	59	0.016 *
		Iron	0.3102	59	0.010 *
		Rate	0.3799	59	0.001 **
		Age	0.2849	44	0.033 *
		O_2	0.2360	58	0.036 *
Nematodes	7.8	Cl	-0.2433	48	0.003 **
Ostracoda	6.3	Rate	0.2733	64	0.020 *
		P.O.C.	0.2846	58	0.026 *
		Age	0.4084	48	0.003 **
Hydrobia	9.4	Iron	0.5303	64	0.000 ***
		O_2	0.3503	63	0.004 **
		Bar	0.6729	62	0.000 ***
		Org.weight	0.2327	63	0.049 *

might be a feature of sites where colonisation is underway and this species can survive with litle or no sediment while others cannot (see Chapter 7). Harpacticoids appear in the majority of drift (third) samples from mains when the community had been removed.

The benthic cyclopoid copepods, *Paracyclops fimbriatus* and *Paracyclops fimbriatus poppei* both show negative correlations with rate of sampling and age of water. *P.fimbriatus* also shows a negative correlation with turbidity and *P.fimbriatus poppei* a positive correlation with organic content of sediment. These suggest *Paracyclops* sp. are found at similar sites relatively close to trunk mains, where the water is 'young'.

Eucyclops agilis, the other common benthic species shows a positive correlation with the age of water. The two genus, *Eucyclops* and *Paracyclops* were never found together at any of the sites in this study.

Acanthocyclops robustus is also probably benthic in this system and there was no evidence from gut analysis of individuals from the system studied to suggest it is predatory. This species is positively correlated with the organic content of sediment but negatively correlated with rate and age, suggesting like *Paracyclops* an affinity for 'young' water and the proximity of trunk mains. This is not surprising since this species is known to penetrate through treatment (Chapters 9 and 10), and obviously is able to adapt to the benthic life style required in order to maintain a population in the pipes. Perhaps the correlation with organic content is an indication that it can only colonise under particular conditions. A negative correlation with chlorine indicates that low chlorine levels characterise sites where this species is abundant.

6.5.2.3) Chydorids

Only two species of the chydorids found in the system appear to be correlated with any of the parameters tested. *Alona guttata* and *Alona quandrangularis* show negative correlation with age and rate respectively, implying that they occur in greater densities at different types of site; *A.guttata* closer in time to treatment and *A.quadrangularis* further away from trunk mains.

6.5.2.4) Acarina

Soldanonellyx monardi occurs frequently in samples from this study and shows a negative correlation with rate, suggesting it is more common away from trunk mains, in the dead ends of the system. *Lobohalacarus weberi* was negatively correlated with iron and turbidity and occurred nearer to 'clean' water. *Porohalacarus alpinus*, the least common halacarid is positively correlated with consumption rate and age,

suggesting it is more abundant at sites where water flow is low in the extremes of the system. However, a negative correlation with organic matter in sediment suggests otherwise, since few sites at the extremes of the system have low levels of organic material. This latter correlation may be an artifact since *P.alpinus* occurred in samples from only eight hydrants at three sites.

The Tyroglyphidae are negatively correlated with total chlorine, rate and age. Those sites with a high total chlorine concentration will tend to be near treatment (unless contamination leads to unnatural high levels at some sites) and it may be that tolerance to a high total chlorine concentration enables these mites to exploit a niche otherwise vacant. This is supported by the negative correlations with age and rate.

6.5.2.5) Other taxa

Of the remaining groups tested, the naid worms occurred at 45.3% of sites sampled and showed positive correlations with consumption rate; iron; turbidity; age; rate and oxygen concentration. All are characteristic of sites at dead ends at the extreme of the distribution system. A low through-flow of water; high iron and turbidity levels in the water; 'old' water; a low flushing rate and low oxygen concentration characterise the sites where the greatest densities of naids were found.

Nematodes, Ostracods and *Hydrobia jenkinsi* all occurred at low frequencies 7.8%, 6.3% and 9.4% of 64 sampled hydrants repectively, and therefore analysis included a large number of zero values. The significant relationships shown in Table 6.4 must therefore be treated with caution.

6.5.3) Investigation of relationships between taxa

Since many of the taxa present in the distribution system studied were not widespread but occurred at low frequency in the 64 samples removed from the system, analysis to determine whether relationships existed between taxa was carried out after removal of all pairs of data containing zero values. Correlations which exist between taxa are likely to appear when both taxa are present and will not be distorted by a large number of sites on one or other axis, or a large number of sites at the origin.

A total of 33 taxa were included in the analysis of which 111 of a possible 528 correlations had sufficient data to allow calculation. Of these 111, only 5 were significant with $p < 0.05$ (Table 6.5). This is less than would be expected by chance (5% of 111 is 5.55) and therefore none of these can be considered as valid statements about relationships between taxa. Future work should attempt to obtain a larger data set such

Table 6.5) Significant correlations between species

Taxa 1	Taxa 2	Kendall's tau-b	N	Significance	
Tanytarsini	Orthocladiini	1.0000	13	0.000	***
Tanytarsini	Corynoneura	1.0000	5	0.046	*
Tanytarsini	Graptoleberis	0.8058	7	0.033	*
Chydorus	Lobohalacarus	0.9045	6	0.034	*
Graptoleberis	Soldanonellyx	0.7701	8	0.034	*

that more co-occurrences of taxa were present.

6.6) Hierarchical Cluster Analysis: Results and Discussion

From the sampling flow rates during the two sampling periods, it was apparent that of 64 hydrants sampled, 26 had flow rates of less than 7.0 litres per second. This leaves a total of 38 which can be investigated on a quantitative basis to determine the similarity between sites numerically. This meant a number of sites were not included in the 'density cluster analysis' because of their low flow, so a second analysis of site similarity was carried out by log classification of species density (a relative or semi-quantitative measure), using all the 64 sites in question. The classification used was as follows:

0	-	no animals present
0.5	-	animals present but sample equation failed
1	-	animal density in the range > 0 to 1
2	-	animal density in the range > 1 to 10
3	-	animal density in the range > 10 to 100
4	-	animal density in the range > 100 to 1000
5	-	animal density in the range > 1000 to 10000

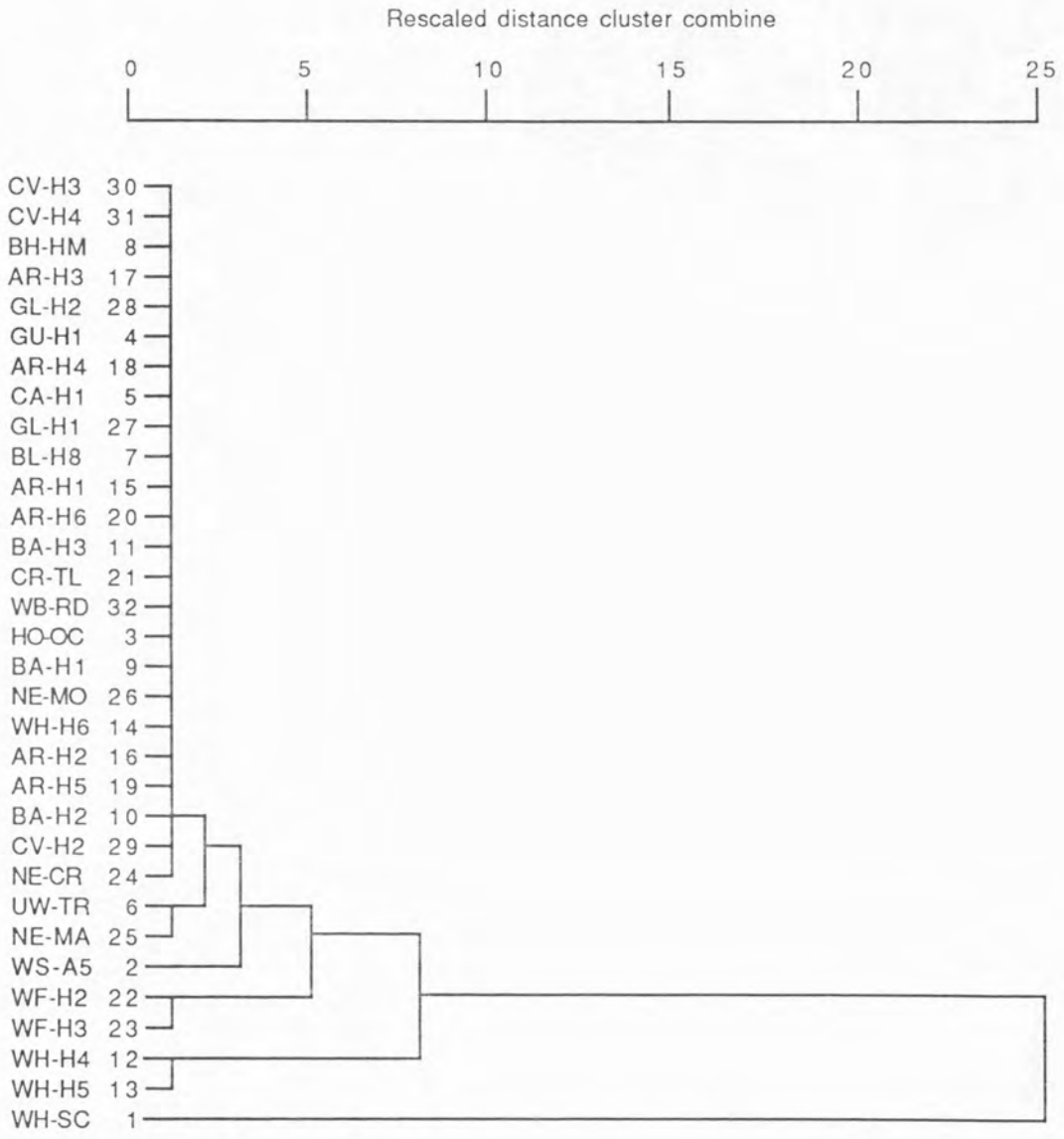
The dendrogram for the 'density cluster' (Figure 6.2, cluster sequence Appendix VII: Table 6.6), using only those sites where samples were removed at over 7.0 l s^{-1}, proved to be unsuitable for any form of subjective analysis, since the clusters are nested, and there is a very low 'cluster distance' between the points where clusters split (most sites being in one very similar cluster). The large data set of log classified density of animals (Figure 6.3, and Appendix VII: Table 6.7), produced five clusters A to E at a high level of dissimilarity.

A dendrogram (Fig. 6.4, Appendix VII: Table 6.8) of the log transformed data included in the 'density cluster' (all sites sampled at over 7.0 l s^{-1}) indicates clusters in the log transformed analysis coincide with clusters in the log classified analysis (Fig. 6.3), though A and C split at a higher level of similarity (A lower distance value, A' and C', Fig. 6.4) and cluster E separated into two (E'_1 & E'_2, Fig. 6.4). This similarity suggests the relative measure used to produce the dendrogram from all the data (Fig. 6.3) is valid. One complete group (set B, Fig. 6.3) is unrepresented in Figure 6.4 (set B' is absent). None of the sites in this group (set B) were sampled at rates over 7.0 l s^{-1}.

6.6.1) Taxonomic characterisation of clusters

Since the cluster is based on the similarity of sites using 30 taxa identified from the system, it was expected that the sites within each of the five clusters would show some degree of similarity of

Fig. 6.2) Dendrogram of cluster analysis based on animal densities at sites sampled at over 7 litres per second, showing site codes and cluster numbers



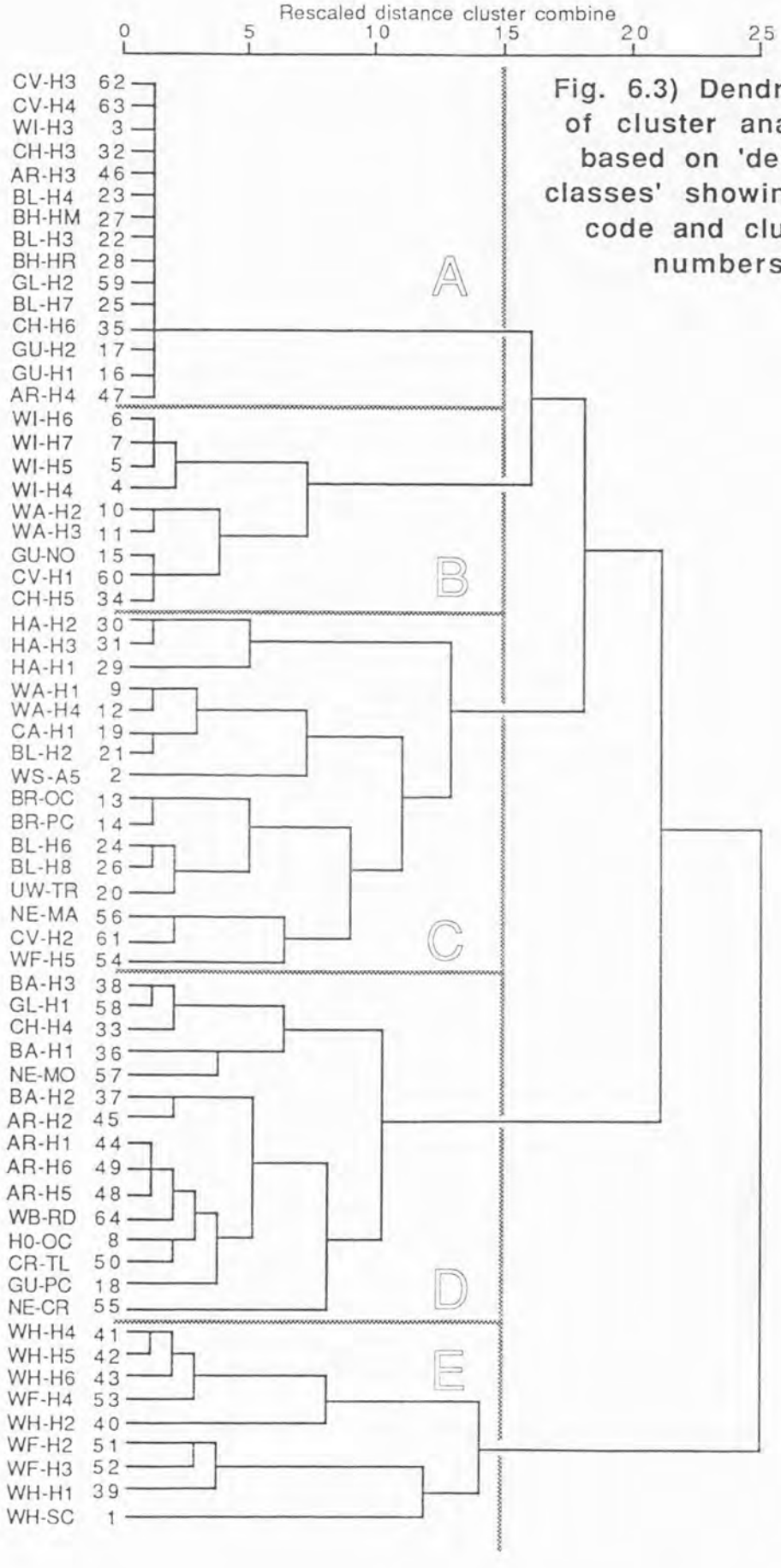
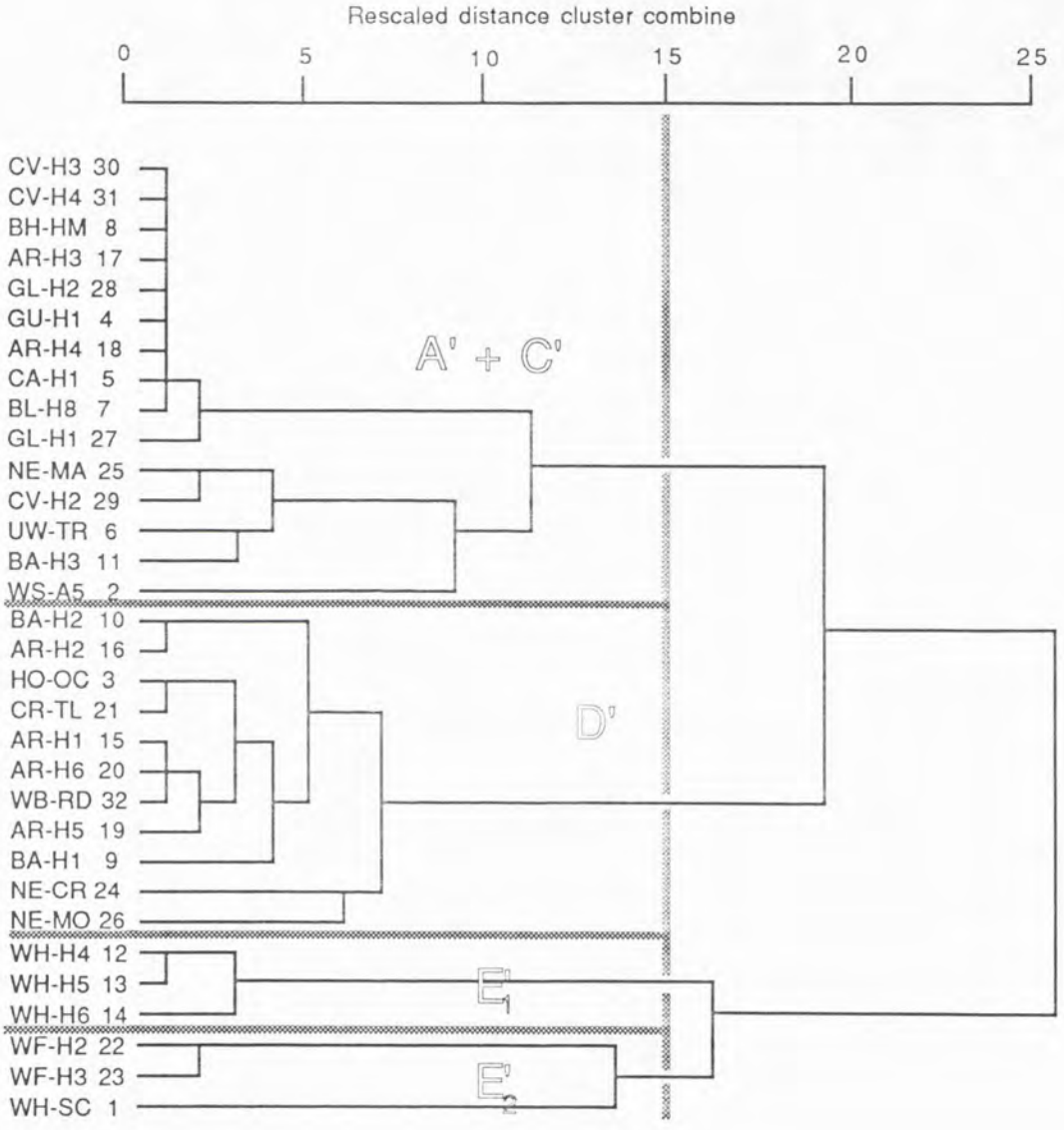


Fig. 6.3) Dendrogram of cluster analysis based on 'density classes' showing site code and cluster numbers

Fig. 6.4) Dendrogram of cluster analysis using Ward's method based on log animal densities from hydrants sampled at over 7 litres per second showing site codes and cluster numbers.



'classification' of the various taxa. Indicator taxa (notably taxa that cause complaints) were used as identifiers for the sites to determine whether the analysis had indeed produced clusters which linked certain communities with particular species. (Figs. 6.5 to 6.7)

Total chironomid larval density is high only in cluster E, suggesting that high chironomid density only occurs at a specific type of site (Fig. 6.5). *Hydrobia jenkinsi* occurs at sites in cluster B and C, but Figure 6.5 shows the infrequent occurence of this species.

The chydorid *Chydorus sphaericus* occurs in high densities only in cluster C (Fig. 6.6), while *Graptoleberis* only occurs in high densities in cluster E (though this is almost certainly because it ocurred at few samples, four of these being hydrants from Woodford Halse).

Eucyclops agilis occurs only at sites in cluster E, showing an absence at sites where *Paracyclops* occur (Fig. 6.7). The genus *Paracyclops* occurs almost exclusively in cluster D, with both *P.fimbriatus* and *P.fimbriatus poppei* also occuring at low density at two sites in cluster A. *Paracyclops* sp. occurred in the same pipe lengths, unlike natural conditions (Fryer pers. comm.) and have the same correlations with environmental parameters. This suggests a lack of ecological separation in the distribution system which calls their taxonomic separation into question. Naid worms, an important problem group tend to occur at high densities in clusters B and E (Fig. 6.7), and at low densities in clusters A, C and D.

Cluster A is therefore indicative of sites with few infesting species; cluster B has naids and low densities of chironomids; cluster C has high numbers of *Chydorus sphericus*; cluster D *Paracylops*; and cluster E, high densities of chironomid larvae, *E.agilis* and naids or *Graptoleberis*.

6.6.2) Characterisation of clusters using environmental and operational parameters.

The dendrogram using 'log classification' was examined using the classes for each environmental parameter (described in chapter 4). None of the parameters tested showed sufficient difference between clusters to warrant classification of any of the clusters A to E by any parameter.

However the number of service reservoirs and towers through which water must pass did produce high values in cluster E (Fig. 6.8), which could be linked with chironomid larval density. The quantity of sediment (dry weight removed by sample) shows no large values in clusters B or D (Fig. 6.9). Similarly, the 'age' of water and consumption rate show no apparent link to the clusters in this dendrogram (Fig. 6.10).

Pipe material, which incorporates the presence of scrape-and-reline

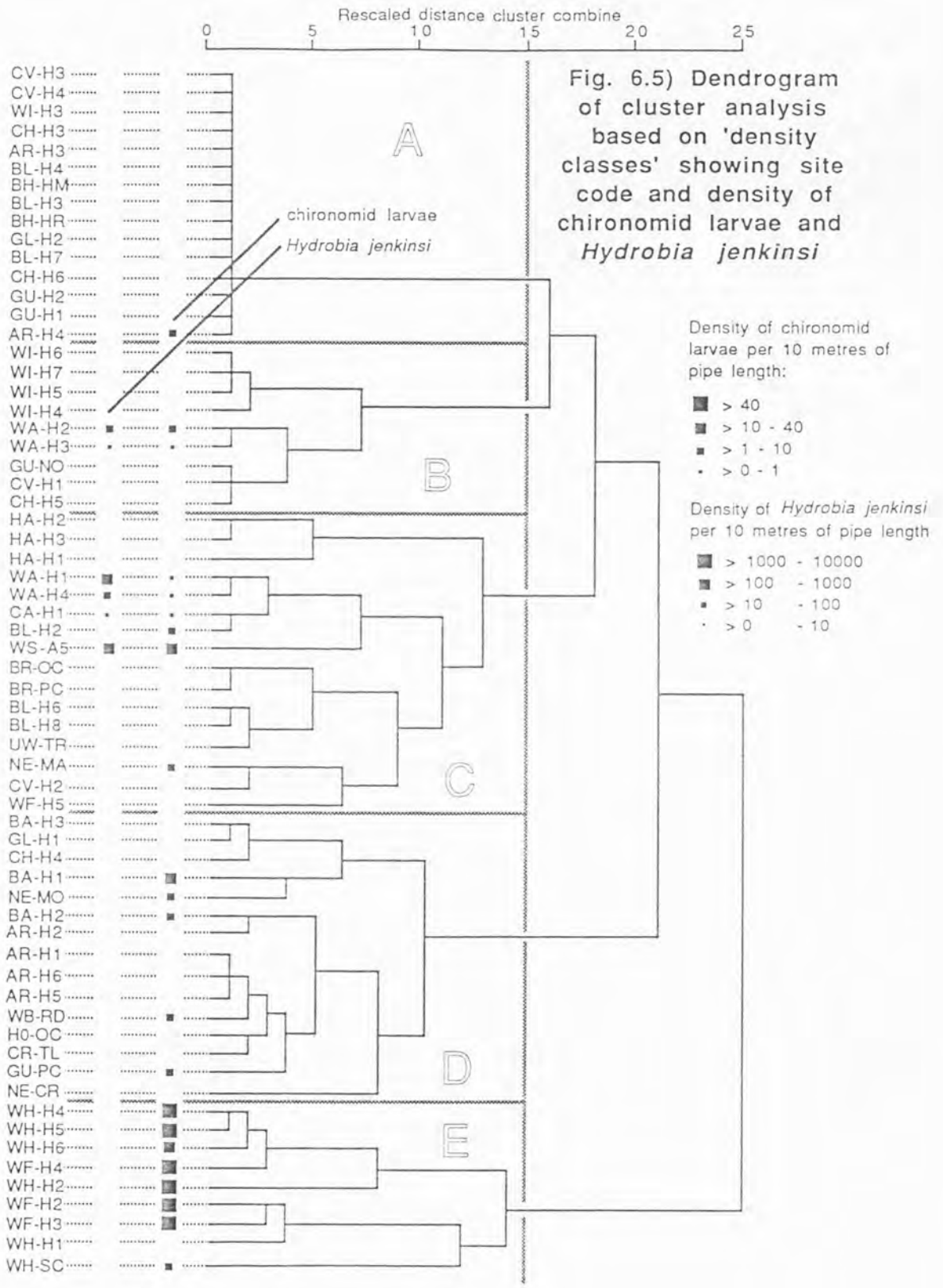


Fig. 6.5) Dendrogram of cluster analysis based on 'density classes' showing site code and density of chironomid larvae and *Hydrobia jenkinsi*

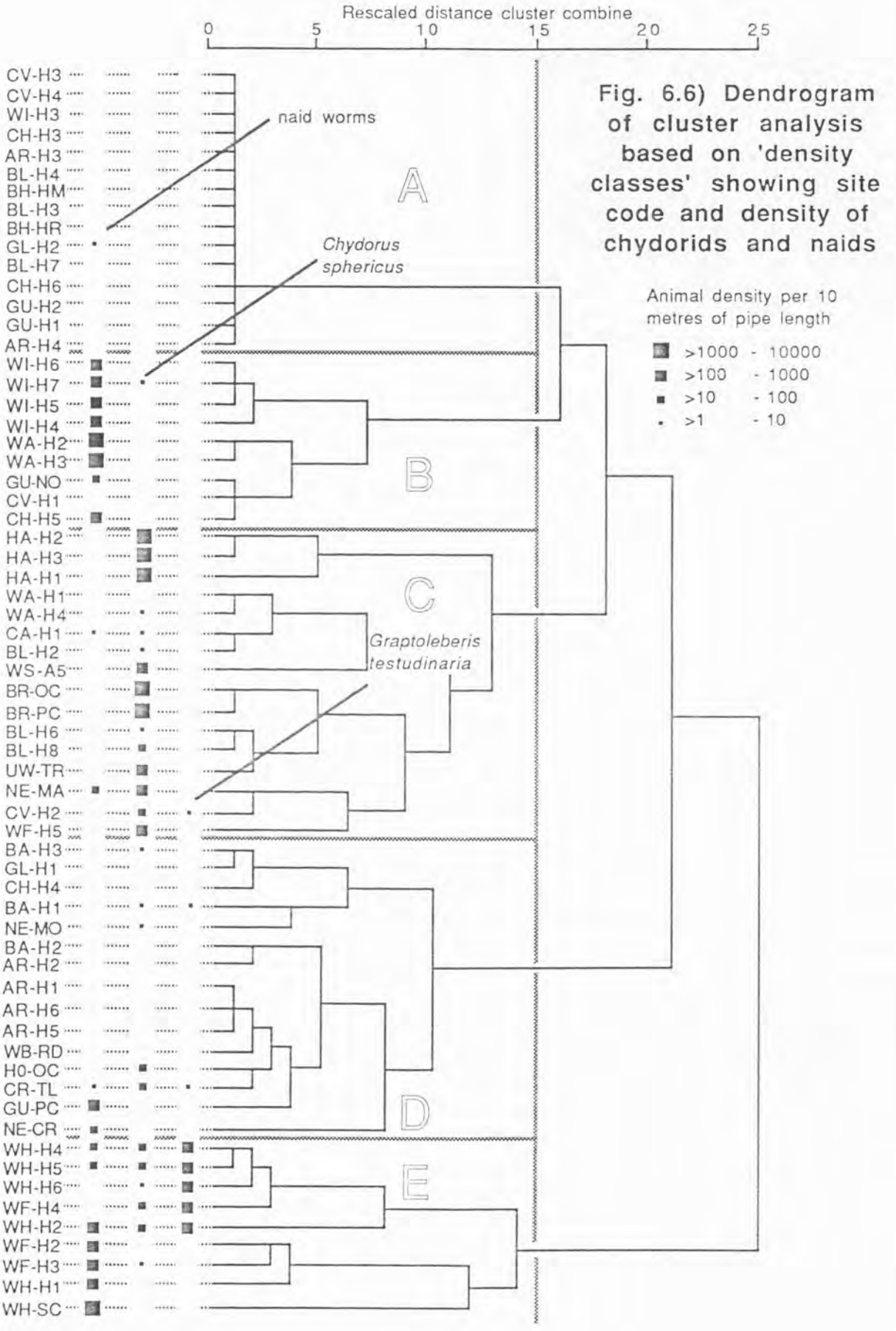


Fig. 6.6) Dendrogram of cluster analysis based on 'density classes' showing site code and density of chydorids and naids

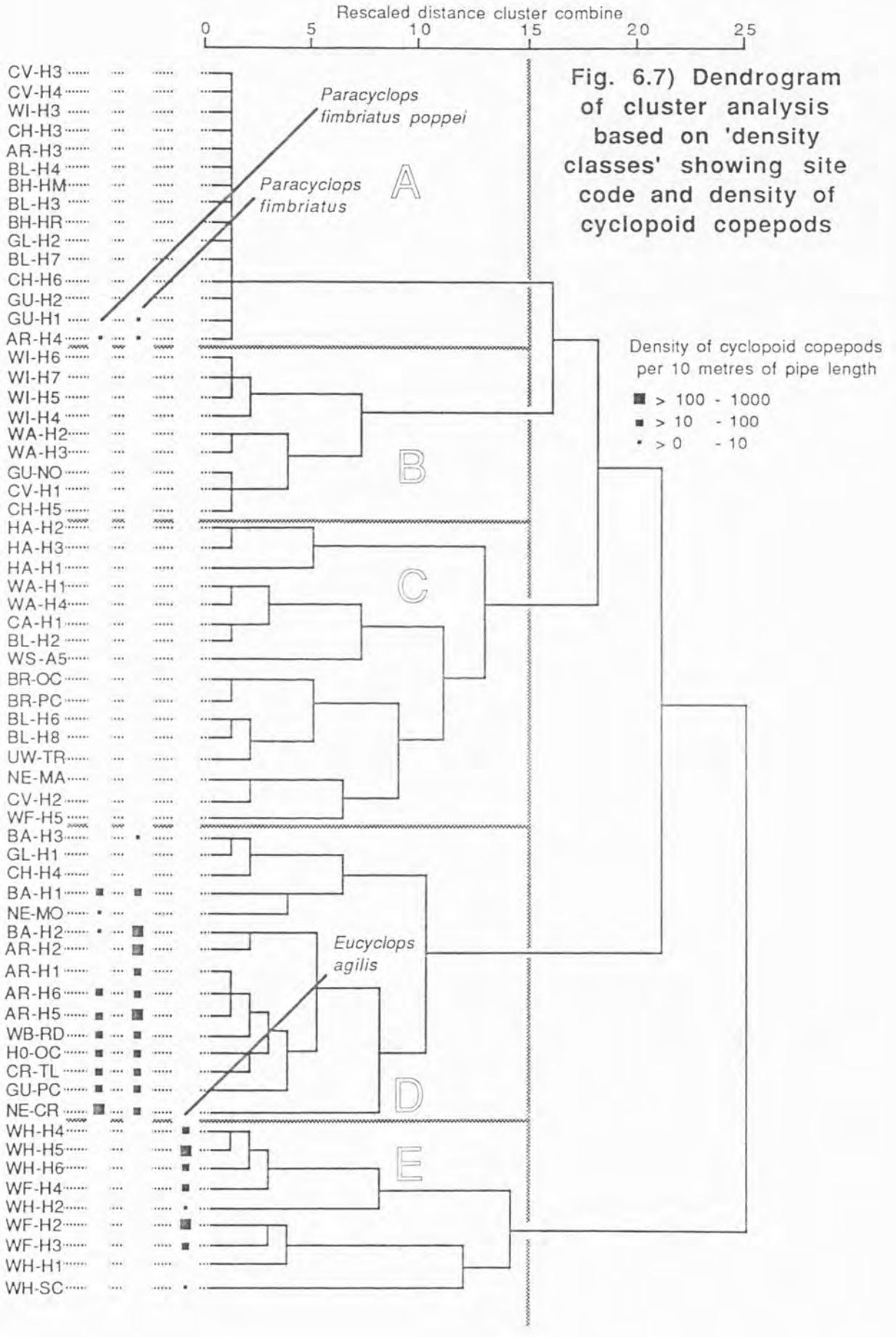


Fig. 6.7) Dendrogram of cluster analysis based on 'density classes' showing site code and density of cyclopoid copepods

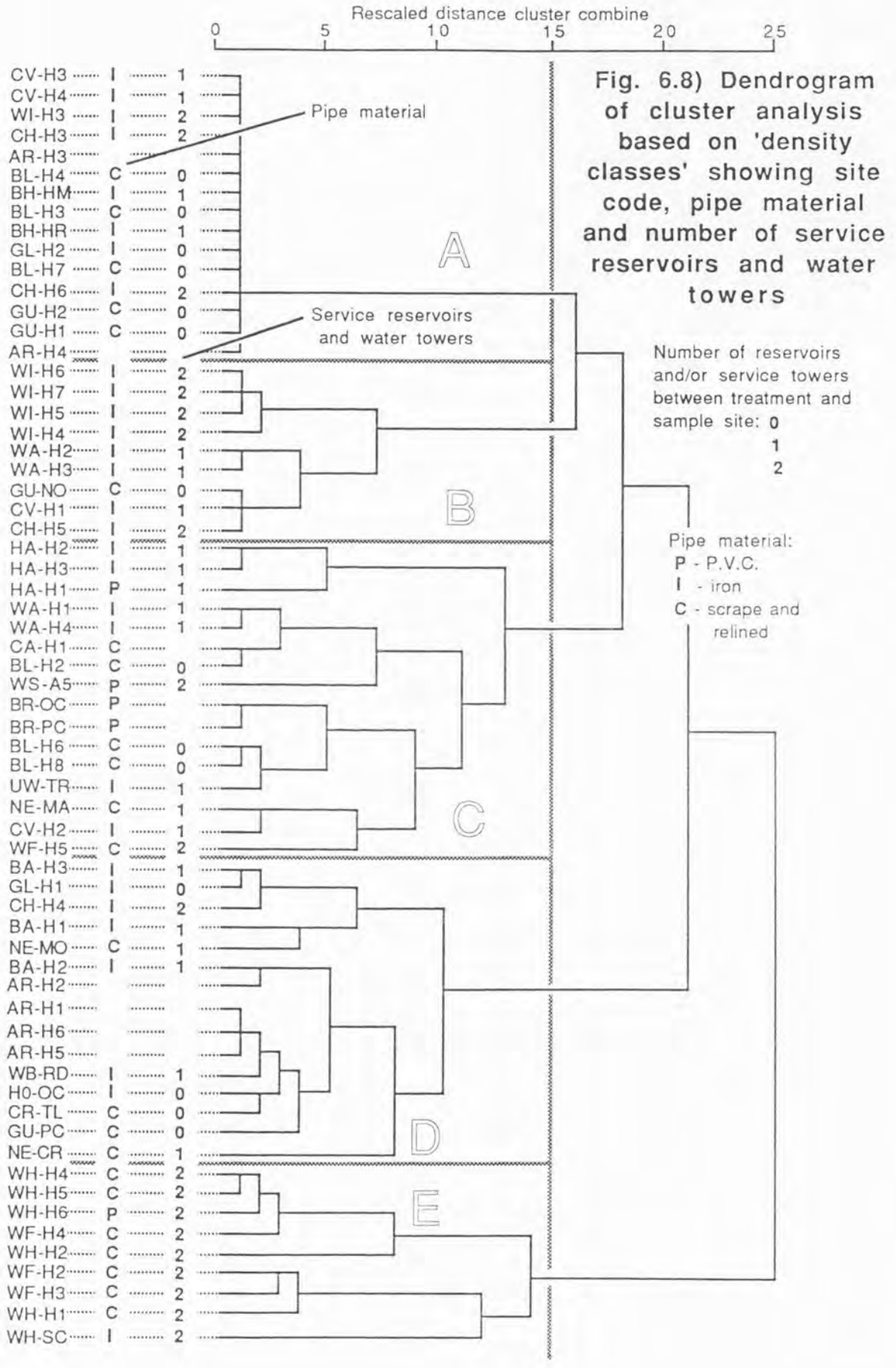


Fig. 6.8) Dendrogram of cluster analysis based on 'density classes' showing site code, pipe material and number of service reservoirs and water towers

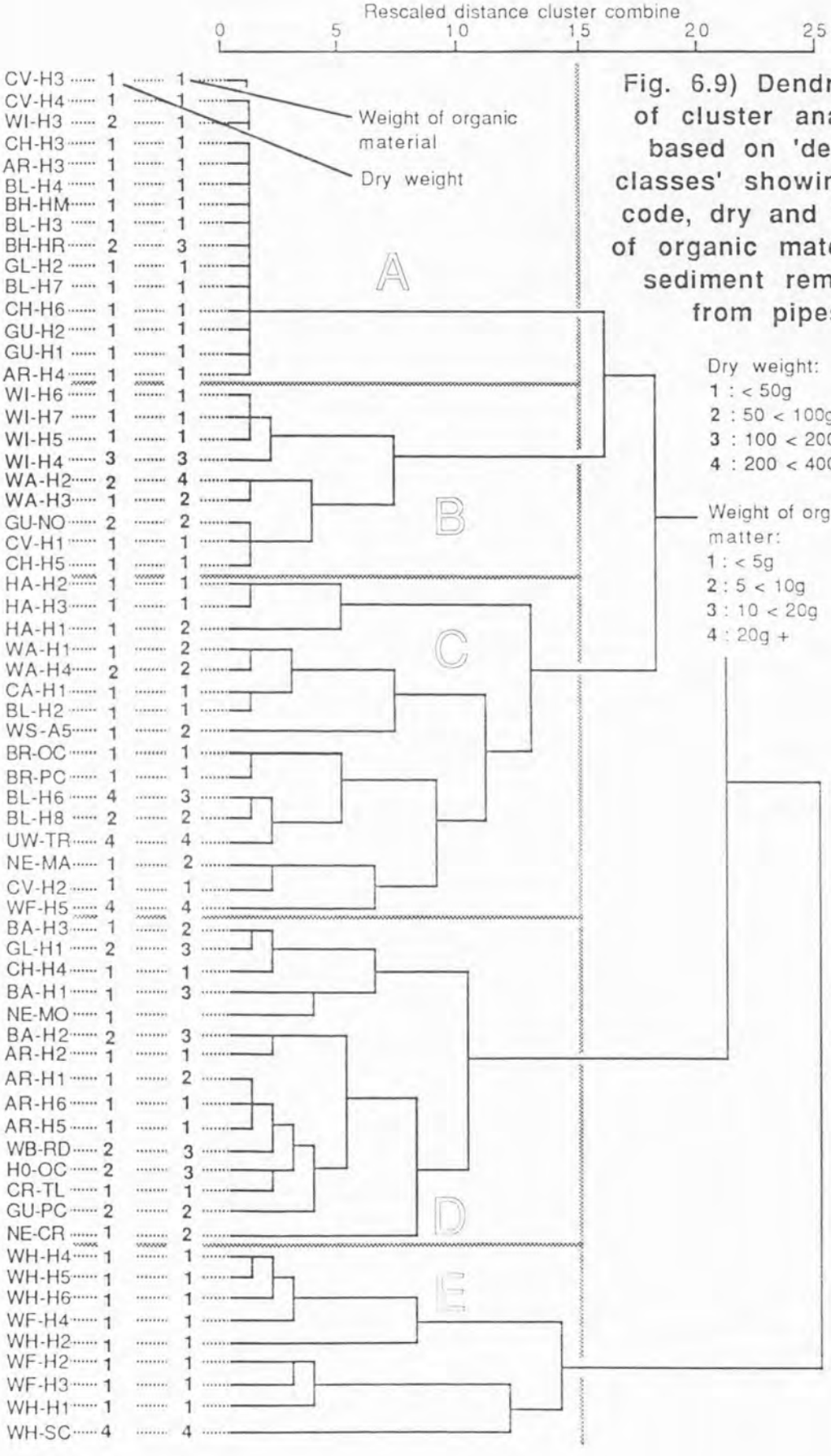


Fig. 6.9) Dendrogram of cluster analysis based on 'density classes' showing site code, dry and weight of organic material in sediment removed from pipes.

operations in the past did not show any obvious correspondence (Fig. 6.8) with the clustering, which suggests that scrape-and-reline does not remove the possibility of reinfestation within 5 years (the period all had been undisturbed since scrape-and-reline operations were carried out).

6.7) Clustering using environmental and operational parameters

The failure of any environmental parameters to coincide with the five clusters in the analysis carried out in section 6.5 led to an attempt to cluster the sites on the basis of environmental parameters rather than community structure. This led to a reduction in the number of sites available because of missing variables at some locations. A total of 41 sites were included in the cluster using all sites sampled and the variables rate; O_2; D.O.C.; P.O.C.; age; consumption rate; pressure at time of sampling; dry weight of sediment; and organic content of sediment. (Fig. 6.11, Appendix VII: Table 6.9). The dendrogram produced by this clustering process showed nesting and was not ideal for use as a means of assessing similarity between samples.

A second cluster analysis (Fig. 6.12, Appendix VII: Table 6.10) was carried out using only those sites sampled at over 7.0 l s^{-1}, with the same variables except that organic matter per 1000 litres flushed and dry weight per 1000 litres flushed were substituted for organic content of sediment and dry weight of sediment respectively. These measures of sediment were used because the greater rate of flow enables a more representative measure of sediment that corrects a source of error relating to the volume of water sampled (Chapter 4). This showed little nesting, but suffered from a reduction in the number of samples analysed.

Dendrograms were produced from the environmental parameters and labelled using total chironomid larvae, naid worms and *Hydrobia jenkinsi* (the three worst problem animals in infestations) (Fig. 6.13). At high densities, chironomid larvae (total density) values do appear to cluster together, but these high densities correspond to samples from hydrants at only two sites. The naids show no distinct pattern but *Hydrobia*, which only occurs at two of these sites is at a high density at 'WS-A5', which is quite separate from all other samples in the cluster on the basis of its environmental parameters and operational characteristics.

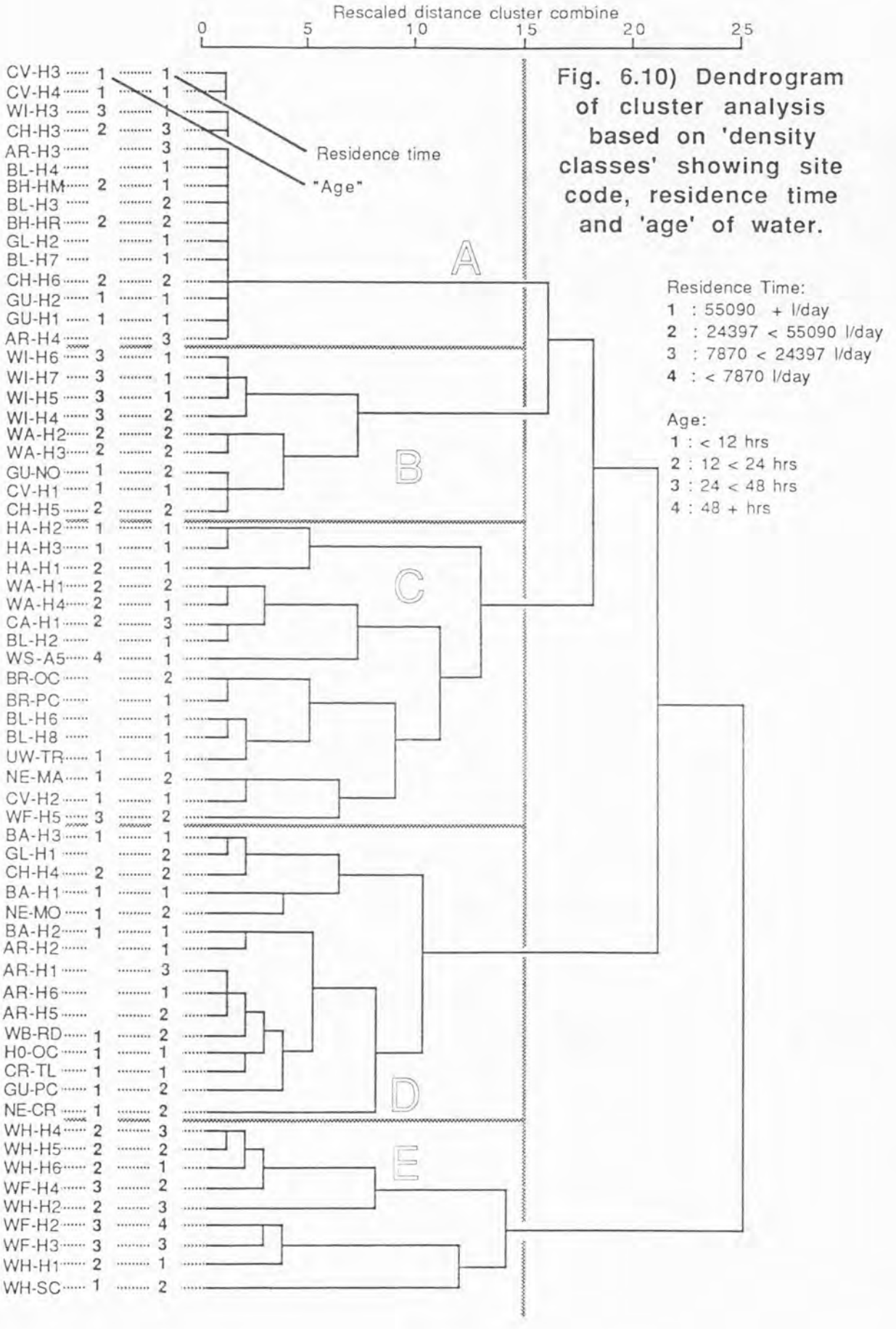


Fig. 6.10) Dendrogram of cluster analysis based on 'density classes' showing site code, residence time and 'age' of water.

Residence Time:
1 : 55090 + l/day
2 : 24397 < 55090 l/day
3 : 7870 < 24397 l/day
4 : < 7870 l/day

Age:
1 : < 12 hrs
2 : 12 < 24 hrs
3 : 24 < 48 hrs
4 : 48 + hrs

Fig. 6.11) Dendrogram of cluster analysis based on environmental and operational parameters showing site codes and cluster numbers.

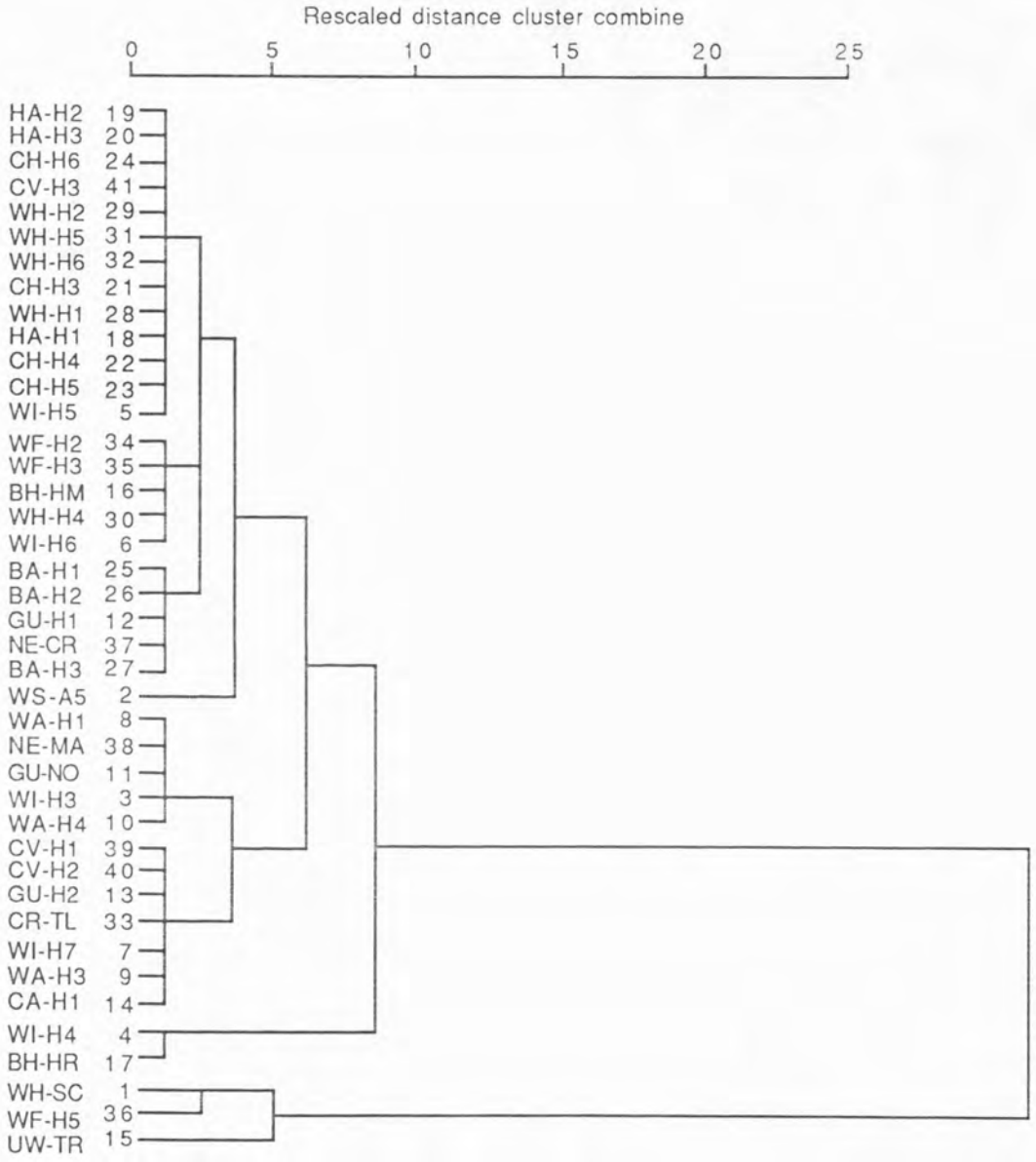


Fig. 6.12) Dendrogram of cluster analysis based on environmental and operational parameters at sites flushed at over 7 litres per second, showing site codes and cluster numbers

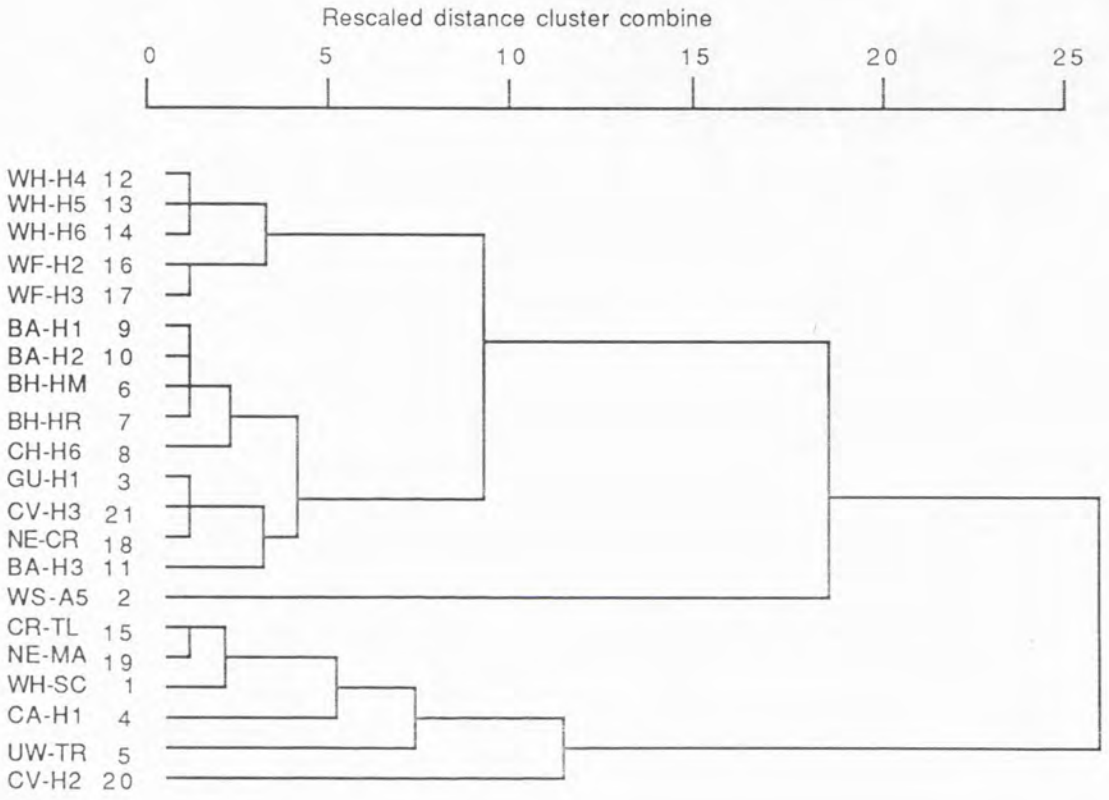
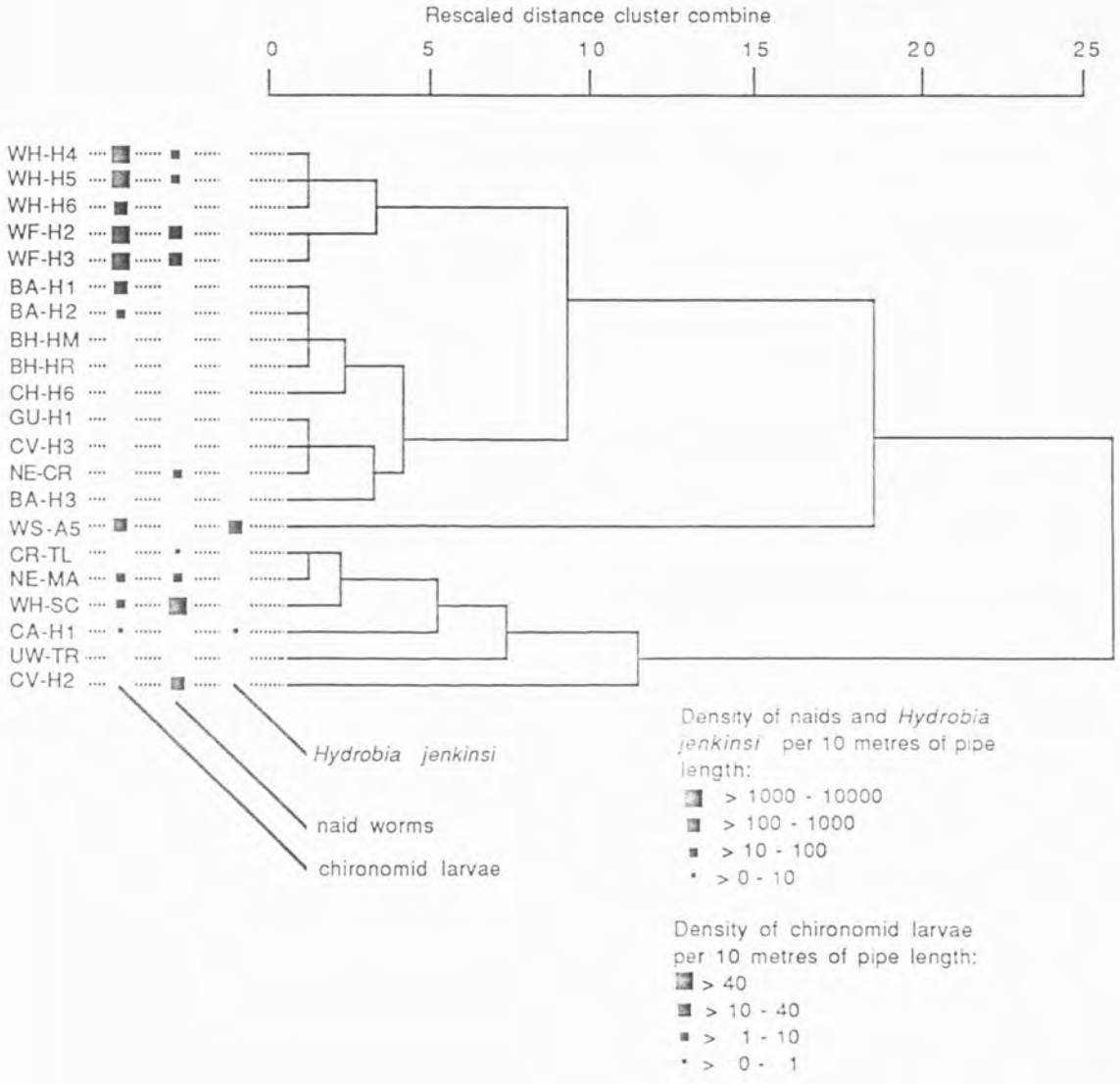


Fig. 6.13) Dendrogram of cluster analysis based on environmental and operational parameters at sites flushed at over 7 litres per second, showing density of problem animals.



6.8) General Discussion

From the two aspects of this work, the correlation analysis and the cluster analysis, there is little evidence to suggest that any of the environmental or operational parameters have a significant role that influences the structure of the community.

Consumption rate and age of water correlate with a number of species, an indication that 'distance from treatment' and flow in the pipe affect the density of some species. This is not surpising since it has long been held that the worst sites for infestations are dead ends at the periphery of the system, sites far from treatment with low flow in the pipe. The data used in chapter 7 from disturbed sites will provide a more accurate data set, but fewer variations of operational parameters since only 10 sites were used.

Many hydrants were sampled from the same pipe in the system which can lead to errors in areas of low pressure where clean water does not always appear during the third flush. Many of the low pressure pipes did show similar communities along a pipe, though as in the preliminary samples different pipes in the same area frequently supported different communities.

A number of distinct clusters on the basis of community structure indicated a distinct group of sites with high densities of chironomid larvae, a fact which is likely to be of use in future work. However, none of the environmental or operational parameters used in the dendrogram produced distinct clusters. It is likely that experiments in controlled conditions which would reduce the number of variables and lead to a clarification of those variables affecting the community structure. An idea of the microbiological state of the mains may be important in understanding differences between sites.

Any further work in the system should be designed to test specific features such as sediment rather than attempt to consider every variable possible. If sites known to be of a similar age of water, consumption rate and pressure are identified, the number of variables will be reduced. It may be that a larger system would be required to carry out such work, but to produce useful information from within the system the experimental design must be such as to reduce as many of the variables as possible, yet retain a fair sized number of sample sites.

CHAPTER 7) INVESTIGATION OF SUCCESSION AND RECOLONISATION UNDER DIFFERENT REGIMES OF FLUSHING.

7.1) Introduction.....168
7.2) Sampling Methods.....169
7.3) Site Choice.....169
7.4) Relationship between environmental parameters: Results and Discussion.....170
7.5) Site by Site Changes: Results and Discussion.....183
7.5.1) Sites sampled on a two-monthly basis.....183
7.5.1.1) Church Mount, Guilsborough.....183
7.5.1.1.1) Chironomidae.....183
7.5.1.1.2) Copepods.....185
7.5.1.1.3) Chydorids.....186
7.5.1.1.4) Mites.....186
7.5.1.1.5) Other Taxa.....197
7.5.1.2) Scott Close, Ravensthorpe.....197
7.5.1.2.1) Chironomids.....197
7.5.1.2.2) Copepods.....197
7.5.1.2.3) Chydorids.....198
7.5.1.2.4) Mites.....198
7.5.1.2.5) Other Taxa.....198
7.5.1.3) Berry Close, Rothersthorpe.....198
7.5.1.3.1) Chironomids.....199
7.5.1.3.2) Copepods.....199
7.5.1.3.3) Chydorids.....200
7.5.1.3.4) Mites.....200
7.5.1.3.5) Other Taxa.....200
7.5.1.4) Back Lane, Chapel Brampton.....210
7.5.1.4.1) Chironomids.....210
7.5.1.4.2) Copepods.....210
7.5.1.4.3) Chydorids.....211
7.5.1.4.4) Mites.....211
7.5.1.4.5) Other Taxa.....212
7.5.2) Sites sampled on a four-monthly basis.....212
7.5.2.1) West Way, Weedon.....212
7.5.2.1.1) Chironomids.....212
7.5.2.1.2) Copepods.....213
7.5.2.1.3) Other Taxa.....213
7.5.2.2) Stanford Close, Cold Ashby.....213
7.5.2.2.1) Chironomids.....213
7.5.2.2.2) Copepods.....220

7.5.2.2.3) Chydorids.....220
7.5.2.2.4) Mites.....220
7.5.2.2.5) Other Taxa.....221
7.5.3) Sites sampled on a six-monthly basis.....221
7.5.3.1) Brookside, Weedon.....221
7.5.3.1.1) Chironomids.....221
7.5.3.1.2) Copepods.....221
7.5.3.1.3) Chydorids.....222
7.5.3.1.4) Mites.....222
7.5.3.2) West Haddon Road, Cold Ashby.....222
7.5.3.2.1) Chironomids.....222
7.5.3.2.2) Copepods.....229
7.5.3.2.3) Chydorids.....229
7.5.3.2.4) Other taxa.....229
7.5.4) Sites sampled after periods greater than six months.....229
7.5.4.1) Park Lane, Watford.....229
7.5.4.1.1) Taxa present at Park Lane, Watford.....229
7.5.4.2) Parsons Close, Nether Heyford.....230
7.5.4.2.1) Taxa present at Parsons Close, Nether Heyford.....230
7.5.4.3) Wakefield Way, Nether Heyford.....230
7.5.4.3.1) Taxa present at Wakefield Way, Nether Heyford.....237
7.6) Discussion of species trends.....237
7.6.1) Chironomid larvae.....239
7.6.2) Harpacticoids.....240
7.6.3) Cyclopoid copepods.....241
7.6.4) Chydorids.....242
7.6.5) Mites.....242
7.7) General Conclusions.....243

CHAPTER 7) INVESTIGATION OF SUCCESSION AND RECOLONISATION BY EXAMINATION OF COMMUNITY STRUCTURE UNDER DIFFERENT REGIMES OF FLUSHING.

7.1) Introduction

This work was originally concieved as a means of assessing seasonal changes in the populations of animals inhabiting the distribution system. Since the sampling method used (Chapter 2) was destructive, aiming to remove the entire mains fauna at each sampling occasion, it was not possible to produce a measure of seasonal changes in population at any one site in the field. Preliminary observations at sites in the village of Church Brampton, Northampton indicated that even when close together within the system, the diversity and numbers of infesting animals in small diameter mains varied considerably. Any attempt to investigate seasonality by sampling a sequence of hydrants on a single leg sequentially in time, or a number of mains in the same town or village, would be subject to error, since there is no evidence to suggest that these pipe lengths would support similar communities. The sampling method described in Chapter 2 is unable to assess the effects of seasonality by sampling within the distribution system.

The possibilty of the construction of a pipe network to investigate seasonality was considered. A series of pipe sections fed by the same source, subjected to similar conditions in a controlled environment and seeded with the same initial community, would indicate the nature of seasonal effects within the mains. Providing these conditions are maintained as those in the distribution system, such a system could be used to provide information directly related to the mains, since the controlled environment would not differ from conditions in the pipes themselves. Unfortunately, the construction of such a system and maintaining the flow regimes and field chacteristics proved to be beyond the scope of this project.

A number of sites were chosen in the Western Area of Oundle Division and sampling regimes differing in flushing frequency designed. It was hypothesised that, following the initial disturbance of the first sampling occasion, the community within the pipe at each site (flushed on a regular basis) would always recolonise under similar conditions apart from seasonal changes.

Sampling was designed to show whether different intervals between flushes would show differences in the recolonising community over specific periods and thus indicate whether the distribution system has a discernible succession. In addition it was expected that any changes in density of animals over each period between flushes could also be

assessed at each site. Possible differences in reinfestation due to penetration of treatment and population growth could also be considered.

During the course of the sampling programme, a number of these sites changed from rapid gravity filter water from Pitsford Water Treatment Works to water from the slow sand filter at Ravensthorpe Treatment Works. This change allowed a direct comparison of sites under similar conditions being fed by two different water sources with differences in the final water quality.

7.2) Sampling Methods

Preliminary flushes after one month at sites at Nether Heyford, Northants. showed that animals were rarely at levels above the calculated drift, so a two month period was chosen as the shortest period during which the mains fauna may be able to develop beyond the level of the drift. Hence the regimes chosen were either two months, four months, six months or ten to fourteen months. The sampling regime was followed for an eighteen month period, and then all sites left for a further six months. The final flush, made six months after the eighteen month period, determined whether two-monthly sampled sites were able to recover from repeated regular flushing.

Each site was sampled following the methods outlined in Chapter 2. Subsampling followed the procedure outlined in section 2.6 and identification used the methods and keys referred to in each section of Chapter 5. The sites (Appendix VIII) were all small diameter pipes fed by large diameter mains and as such were able to produce quantitative samples at flushing rates over 6 l s^{-1}. At one site, Brookside, Weedon, sampling involved a preliminary flush of a feed leg before the main leg could be sampled (described in Appendix VIII). Samples were processed, quantified using the drift model and tested using analysis of variance. Any numerical anomalies between samples from a flush sequence were checked using a Q-Test.

The information expected from these sites will indicate the animals that penetrate the system at different times of year; animals that may recolonise the system from 'upstream', being carried in the drift; and animals that recolonise the system from the pipe itself, having not been removed by the flushing process.

7.3) Site choice

Sites which were sampled following the pyrethrin dosing in May 1985 were used as the main group of sites for the study, since all had been flushed initially during May and could be sampled on a regular basis without affecting the system. When it became known that Ravensthorpe

Reservoir water would be coming on-line during the study (originally scheduled for late 1986), it was decided to introduce a number of other sites so as to have an equal number of sites and flow regimes for each system. This would enable changes in the mains fauna brought about by the two different filtration methods to be detected. Water from Ravensthorpe water treatment works came on line, feeding the Ravensthorpe supply zone, during the first week of July 1987.

Some sites with a rate of flow of only slightly greater than 6 l s^{-1} had to be introduced at short notice, due to problems with drainage and variable rates of flow at these new sites. Tests on the data (ANOVA) produced at these sites did indicate a decline in animal numbers during the flush sequence. 'Ideal' sites (those with high flushing rates) were not common but detailed searches of site plans would have been time consuming and may not have produced sufficient sites in this system that could be repeatedly flushed.

The final sampling sites, regimes and rates of flow used to sample are indicated below and locations shown in Figure 7.1a - c. Outline plans of the sample sites and surrounding networks are included in Appendix VIII.

	Months Between Samples	Change To S.S.F.	Sample Flow Rates
Back Lane, Chapel Brampton	2		6-7 l s^{-1}
Berry Close, Rothersthorpe	2		16 l s^{-1}
Scott Close, Ravensthorpe	2	*	15 l s^{-1}
Church Mount, Guilsborough	2	*	15 l s^{-1}
Stamford Close, Cold Ashby	4	*	6-7 l s^{-1}
West Way, Weedon Bec	4		15 l s^{-1}
West Haddon Road, Cold Ashby	6	*	6-7 l s^{-1}
Brookside, Weedon Bec	6		15 l s^{-1}
Parsons Close, Nether Heyford	10		15 l s^{-1}
Park Lane, Watford	12	*	6-7 l s^{-1}
Wakefield Way, Nether Heyford	14		15 l s^{-1}

7.4) Relationship between environmental parameters: Results and Discussion

Investigation of the environmental parameters at each site showed that a number of parameters were related. The various parameters tested are listed below with their abbreviations (used in Tables 7.1 - 7.4) in brackets:

Fig.7.1a) Sketch Map of Ravensthorpe Supply Zone with repeated flush sites

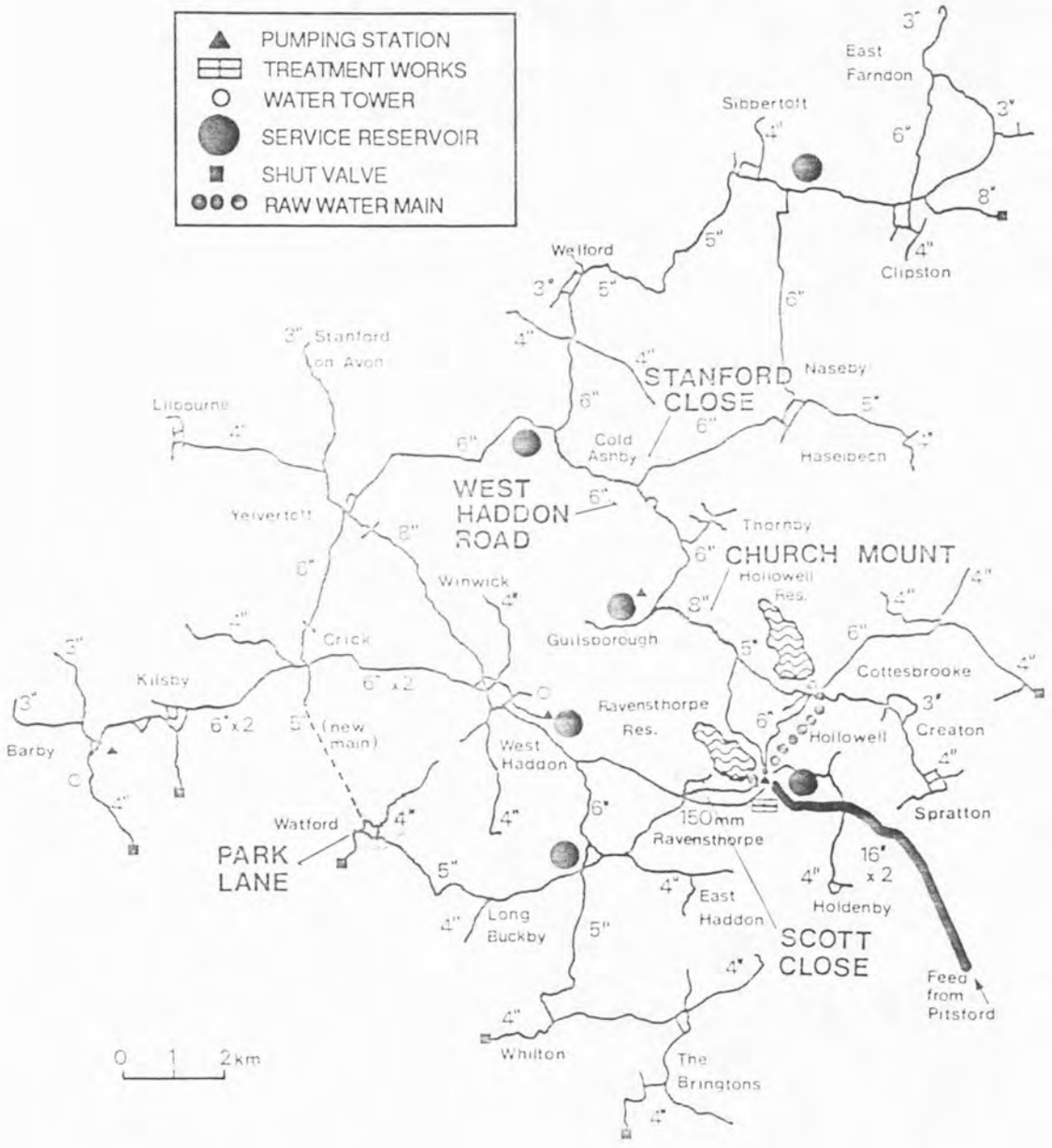


Fig.7.1b) Sketch Map of Pitsford East Supply Zone with repeated flush sites

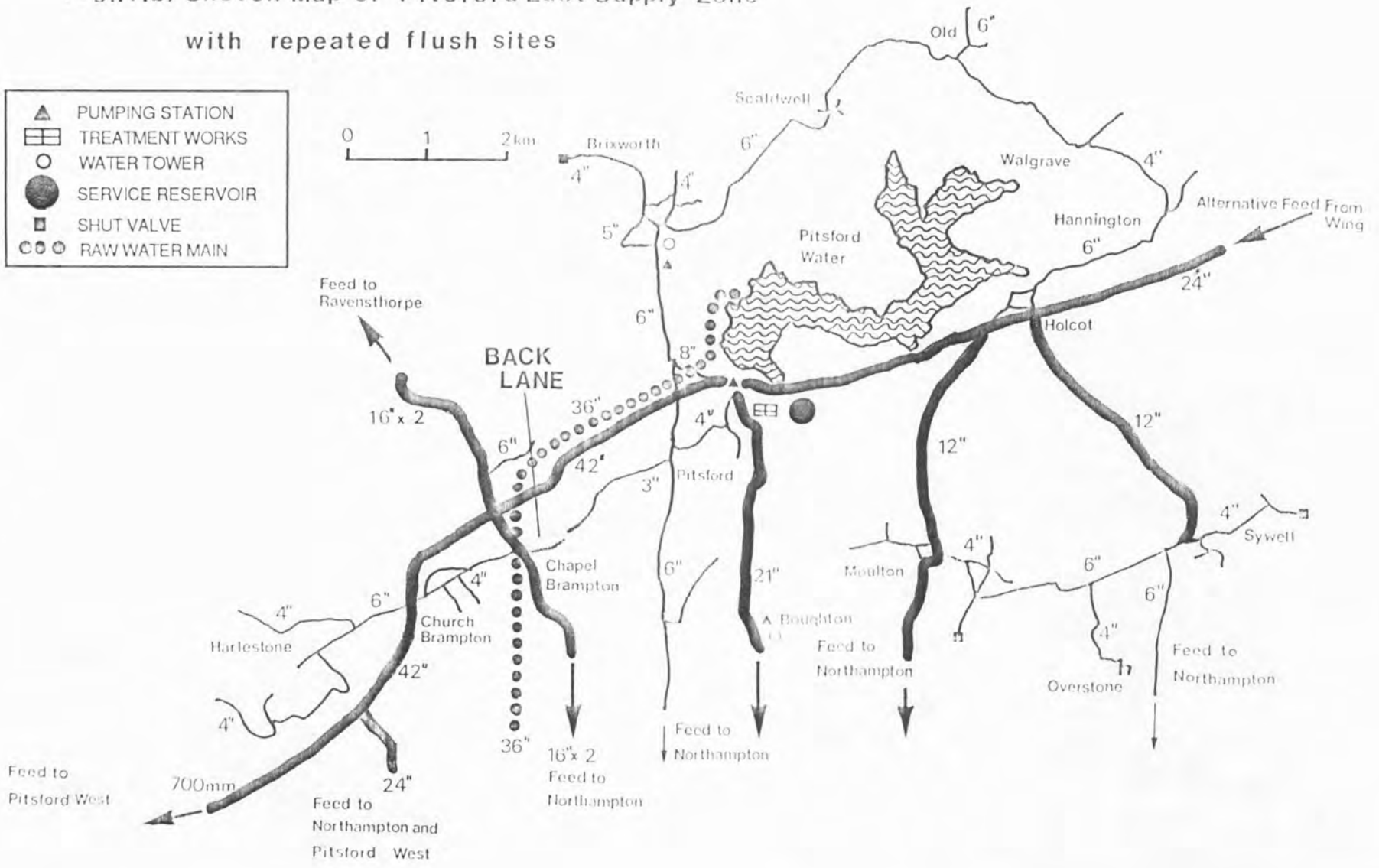
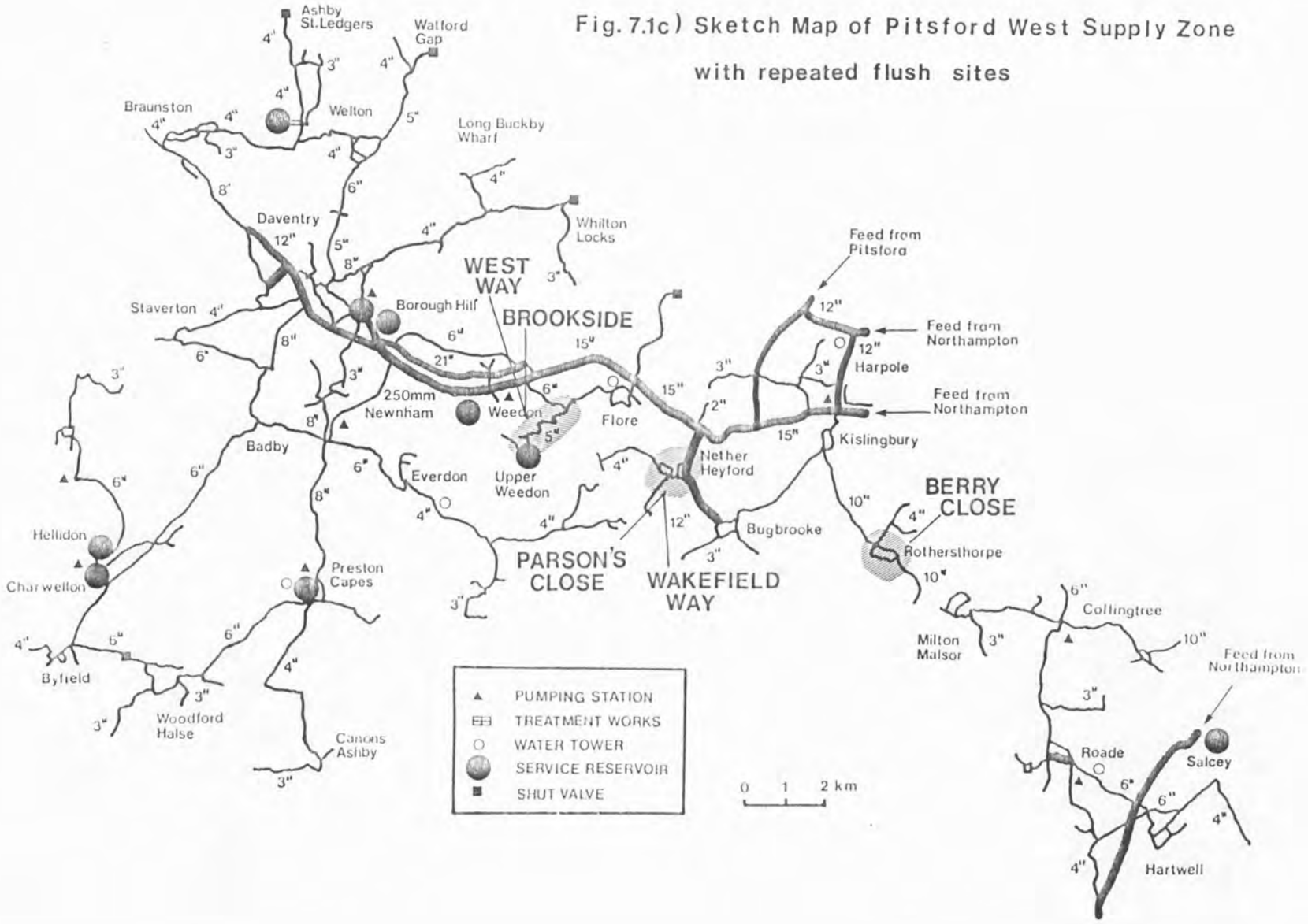


Fig. 7.1c) Sketch Map of Pitsford West Supply Zone with repeated flush sites



Time between flushes (F.Time)
Organic matter in sediment per 1000 litres flushed (OM/Vol)
Dry weight of sediment per 1000 litres flushed (DW/Vol)
Flush number (Flush)
Water temperature at time of flushing (Temp)
Oxygen saturation of water at time of flushing (Oxygen)
Pressure in the main at time of flushing (Press)
Total Chlorine concentration in main at time of flushing (Chlor)
Significant relationships determined by multiple regression analysis applied to all variables from all sites are shown in Table 7.1. Of these, four produce meaningful results when maximum and minimum values for the variables involved are applied to the equation.

The dry weight per unit volume showed a strong positive relationship with organic matter per unit volume (81% of the variation accounted for) and with D.O.C. (3%). P.O.C. also has a relationship with dry weight per 1000 litres of water flushed (the independant variable accounting for only 10% of the variation but with a significance of $P < 0.05$). D.O.C. is in turn linked with P.O.C. (again the percentage variation is low 7.5%, but significant at $P < 0.05$). It appears that all the carbon measurements are linked. On a site by site basis (Tables 7.2 a - g) organic matter and dry weight repeatedly show strong correlation particularly at the two-monthly sites (organic matter and dry weight of sediment show a similar relationship in Chapter 6).

At Back Lane, Chapel Brampton organic matter and dry weight show a high correlation (99% of the variation accounted for by the independant variable) and organic matter is affected by temperature (1%). The period between flushing has an effect on P.O.C. (92% of the variation) as does temperature (7%) which suggests that P.O.C. relates to the period over which sediment can build up in the pipe, and to a lesser extent, the seasonal variation of water quality. Berry Close, Rothersthorpe shows no significant regressions which are meaningful, but Scott Close, Ravensthorpe shows a strong relationship between the dry weight and organic matter (organic matter accounting for 98% of variation) and the time between flushes showing a small negative effect (accounting for 1%). At Church Mount, Guilsborough, dry weight and organic matter are again related (93% of variation accounted for) and P.O.C. is affected by temperature (68% of variation) supporting the Chapel Brampton data. West Way, Weedon is the only other site to show a meaningful relationship between variables, with organic matter accounting for 84% of the variation in dry weight. The remainder of sites had insufficient data to proceed with analysis.

It appears that at most sites, OM/Vol and DW/Vol are linked as are

Table 7.1) All sites: regression of environmental and operational parameters

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3	R^2	D.F.
[1]DW/Vol	-0.11932	6.16663	OM/Vol					0.8094	55
	-0.41112	6.09019	OM/Vol	0.04153	D.O.C.			0.8370	54
	-1.92286	6.01071	OM/Vol	0.04624	D.O.C.	0.01857	Oxygen	0.8520	53
[1]OM/Vol	0.07327	0.13126	DW/Vol					0.8094	55
	-0.07321	0.12361	DW/Vol	0.04589	Pressure			0.8451	54
[1]D.O.C.	6.09820	0.93898	P.O.C.					0.0751	55
[1]P.O.C.	0.94559	0.36401	DW/Vol					0.0968	55
Pressure	2.93682	1.80506	OM/Vol					0.1786	55
	2.89284	4.07797	OM/Vol	-0.36858	DW/Vol			0.2453	54
	3.28083	4.44148	OM/Vol	-0.34157	DW/Vol	-0.00460	F.Time	0.2986	53
Chlorine	0.22477	-0.01337	Flush					0.0858	55

[1] : indicates relationships referred to in the text.

Table 7.2a) Site by site regression of environmental and operational parameters
Back Lane, Chapel Brampton, Northants.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3	R^2	D.F.
[1]DW/Vol	-0.31332	8.86249	OM/Vol					0.9886	7
[1]OM/Vol	0.03661	0.11155	DW/Vol					0.9886	7
	0.11247	0.10008	DW/Vol	-0.00553	Temp			0.9953	6
D.O.C.	25.64106	-0.23760	Oxygen					0.4443	7
[1]P.O.C.	-1.32069	0.04142	F.Time					0.9162	7
	-2.46235	0.04112	F.Time	0.09958	Temp			0.9918	6
	-3.38035	0.04196	F.Time	0.10464	Temp	0.24942	Pressure	0.9971	5
Temp	14.53889	-19.58018	OM/Vol					0.6851	7
Oxygen	92.41176	-6.32353	P.O.C.					0.4848	7
Pressure	4.03890	-0.14167	Flush					0.5935	7

[1] : indicates relationships referred to in the text.

Table 7.2b) Site by site regression of environmental and operational parameters
Church Mount, Guilsborough, Northants.

Dependent variable	Intercept	B_1	Var_1	R^2	D.F.
[1]DW/Vol	-0.41116	20.55665	OM/Vol	0.9263	6
OM/Vol	0.02166	0.04506	DW/Vol	0.9263	6
[1]P.O.C.	-0.31429	0.07630	Temp.	0.6209	6
Temp.	6.72783	8.13747	P.O.C.	0.6209	6
Oxygen	94.88470	-21.85144	P.O.C.	0.5352	6
Pressure	3.48572	-0.22857	Flush	0.7413	6
Chlorine	0.79232	-0.01047	F.Time	0.5036	6

[1] : indicates relationships referred to in the text.

Table 7.2c) Site by site regression of environmental and operational parameters
Berry Close, Rothersthorpe, Northants.

Dependent variable	Intercept	B_1	Var_1	R^2	D.F.
DW/Vol	0.52506	1.17270	OM/Vol	0.6351	7
OM/Vol	1.26587	-0.01113	Oxygen	0.7796	7
Temp	53.64729	-8.70768	Pressure	0.5591	7
Oxygen	106.01121	-70.02883	OM/Vol	0.7796	7
Pressure	5.58533	-0.06420	Temp	0.5591	7
Chlorine	0.19222	-0.11667	Flush	0.5250	7

[1] : indicates relationships referred to in the text.

Table 7.2d) Site by site regression of environmental and operational parameters
Scott Close, Ravensthorpe

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	R^2	D.F.
[1]DW/Vol	-0.30184	8.13664	OM/Vol			0.9781	8
	0.32053	8.28479	OM/Vol	-0.00902	F.Time	0.9918	7
[1]OM/Vol	0.04187	0.12021	DW/Vol			0.9781	8
	-0.03713	0.11972	DW/Vol	0.00110	F.Time	0.9920	7

[1] : indicates relationships referred to in the text.

Table 7.2e) Site by site regression of environmental and operational parameters Brookside, Weedon, Northants.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	R^2	D.F.
OM/Vol	0.96400	-0.13400	Flush			0.9982	2
	1.01000	-0.14000	Flush	-0.10000	Chlorine	1.0000	1
D.O.C.	-2.13556	0.68444	Temp			0.9363	2
	-0.35859	0.58296	Temp	-0.45279	P.O.C.	1.0000	1
P.O.C.	18.32266	-0.17887	Oxygen			0.9070	2
Temp.	3.64568	1.36802	D.O.C.			0.9363	2
Temp.	0.61522	1.71537	D.O.C.	0.77670	P.O.C.	0.9999	1
Oxygen	101.7222	-5.07103	P.O.C.			0.9070	2
Chlorine	-4.04412	0.02353	F.Time			0.9412	2
	-5.11429	0.02857	F.Time	0.04286	Flush	1.0000	1

[1] : indicates relationships referred to in the text.

Table 7.2f) Site by site regression of environmental and operational parameters
West Haddon Road, Cold Ashby, Northants.

Dependent variable	Intercept	B_1	Var_1	R^2	D.F.
D.O.C.	56.11	-0.27926	F.Time	0.9982	1
Temp	177.00	-2.00000	Oxygen	1.0000	1
Oxygen	88.50	-0.50000	Temp	1.0000	1

[1] : indicates relationships referred to in the text.

Table 7.2g) Site by site regression of environmental and operational parameters
West Way, Weedon, Northants.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3	R^2	D.F.
[1]DW/Vol	-1.96588	11.30244	OM/Vol					0.8369	3
OM/Vol	0.30623	0.02939	P.O.C.					0.9247	3
	0.27912	0.02791	P.O.C.	0.00248	D.O.C.			0.9927	2
	0.24058	0.02810	P.O.C.	0.00241	D.O.C.	0.00334	Temp	1.0000	1
P.O.C.	-9.08032	31.45983	OM/Vol					0.9247	3
Pressure	6.36000	-0.53000	Flush					0.8969	3
	7.95631	-0.70215	Flush	-0.73891	OM/Vol			0.9902	2

[1] : indicates relationships referred to in the text.

D.O.C. and P.O.C. These are in turn affected by the time between flushes, temperature and the 'flush number'. This suggests that carbon input varied with season, and with the period of time over which sediment is able to build up in the pipe between flushing operations.

7.5) Site by site changes: Results and Discussion

The data from each site was examined separately using multiple regression analysis, to determine relationships between the log transformed density of the species present at each site after the initial flush, and the possible relationships between species present and the environmental parameters at each site. The data used in this analysis is included as Appendix IV (environmental and operational parameters) and Appendix IX (animal density).

The data for various taxonomic groups are shown in Figures 7.2 to 7.12. The height of each column on Figures 7.2 - 7.12 indicates the total density of animals per 10 m of pipe, and is divided showing the density of each species within the group. Each column represents the density of animals removed from the relevant site on the date indicated by the upper horizontal limit of the column. The density of animals which are present at the beginning of each colonisation period, having been brought in as drift has not been taken into account. Flushing is unlikely to produce total removal, unless in a new or P.V.C. main, and some animals are present as drift, but levels tend to be near to zero (Table 7.3). The value for harpacticoids given in Table 7.3 is a result of two particularly high drift levels of 31 and 45 individuals per 10 metres recorded at Park Lane, Watford.

7.5.1) Sites sampled on a two-monthly basis

These sites are assumed to indicate initial stages of recolonisation of the mains following a flush or other physical (rather than chemical) control exercise. At each site taxa and environmental parameters were analysed to determine any relationships (Table 7.4 - 7.7).

7.5.1.1) Church Mount, Guilsborough

This site, situated close to treatment was fed directly from a high pressure main. Sampling was always undertaken at high rates of flow and removal was assumed to be high. Water changed from Pitsford to Ravensthorpe in July 1987.

7.5.1.1.1) Chironomids

Chironomini larvae (Fig. 7.2a) recolonised in high densities during the period June to September 1986, and again, in lower densities, during

Table 7.3) Mean density of animals estimated to remain in 10 metres of pipe after cessation of flushing.

taxa	n	mean density ± standard error
chironomid larvae (over 2mm)	37	0.5988 ± 0.3593
chironomid larvae (under 2mm)	47	0.1206 ± 0.0379
Harpacticoids	47	2.1096 ± 1.1548
Cyclopoids	51	0.3672 ± 0.1222
Chydorids	49	1.8223 ± 0.7954
Halacarids	56	0.9862 ± 0.3837
Oligochaetes	22	0.7147 ± 0.4123

March to May and May to June 1987. Multiple regression analysis of all variables and other taxa with Chironomini extracts *Paracyclops fimbriatus poppei* (accounting for 94% of variation) and then organic matter in sediment per unit volume (3%), and dry weight of sediment per unit volume (2%) (see Table 7.4a). This sugests an association between *P.fimbriatus poppei* and chironomini at this site, illustrated by coincident peaks in the first summer of sampling. Tanytarsini first appeared during June - September 1986, with maximum numbers in September - November 1986, and continued to colonise throughout the next four periods. Tanytarsini showed an association with the halacarid mite *Soldanonellyx* (85% of the variation), and were also related to the dry weight of sediments in the main (11%) and Orthocladiinae (3%). These links with sediments may be direct or it may be that a greater density of sediment occurs at the same time as high densities of chironomid larvae (during summer penetration of treatment). Tanypodinae larvae showed a relationship to the density of *Alona guttata*, but again this may be a seasonal coincidence. After July 1987, no chironomids recolonised this site. This change in the density of animals between the two summer periods may be due to the switch from R.G.F. to S.S.F. water from Ravensthorpe Water Treatment Works, since the temperatures each year are similar. The failure of any chironomid larvae to recolonise during the period May - June 1986 may be related to the dosing of the entire system with pyrethrin prior to the May flush.

7.5.1.1.2) Copepods

Bryocamptus pygmaeus (Fig. 7.2b) recolonised, but never attained its initial density, with peak recolonisation during September - November 1986. Density was always low relative to undisturbed levels and it failed to recolonise after the switch to Ravensthorpe water, when the only species that appeared was *Nitocra hibernica*, which occurred at low density in the six month recovery period (the six month period to May 1988).

The cyclopoid copepods (Fig. 7.2c) *Paracyclops fimbriatus* and *Paracyclops fimbriatus poppei* showed a maximum recolonisation in the June - September 1986 period, and appeared at a greater density than initially present in the pipe, when only *P.fimbriatus* was present. Both *P.fimbriatus poppei* and *P.fimbriatus* showed a relationship with *Alona rectangula*, (*A.rectangula* accounting for 97% and 96% of the variation respectively). The lower density in the May - July 1986 period may have be due to pyrethrin treatment. Fewer *Paracyclops* recolonised during September - November 1986, and numbers remained absent or low from this point onwards. In the period from May - July 1987, *Acanthocyclops bisetosus* colonised for the first time. This species occurred in all the

following periods, either in densities over drift levels or in the drift itself.

7.5.1.1.3) Chydorids

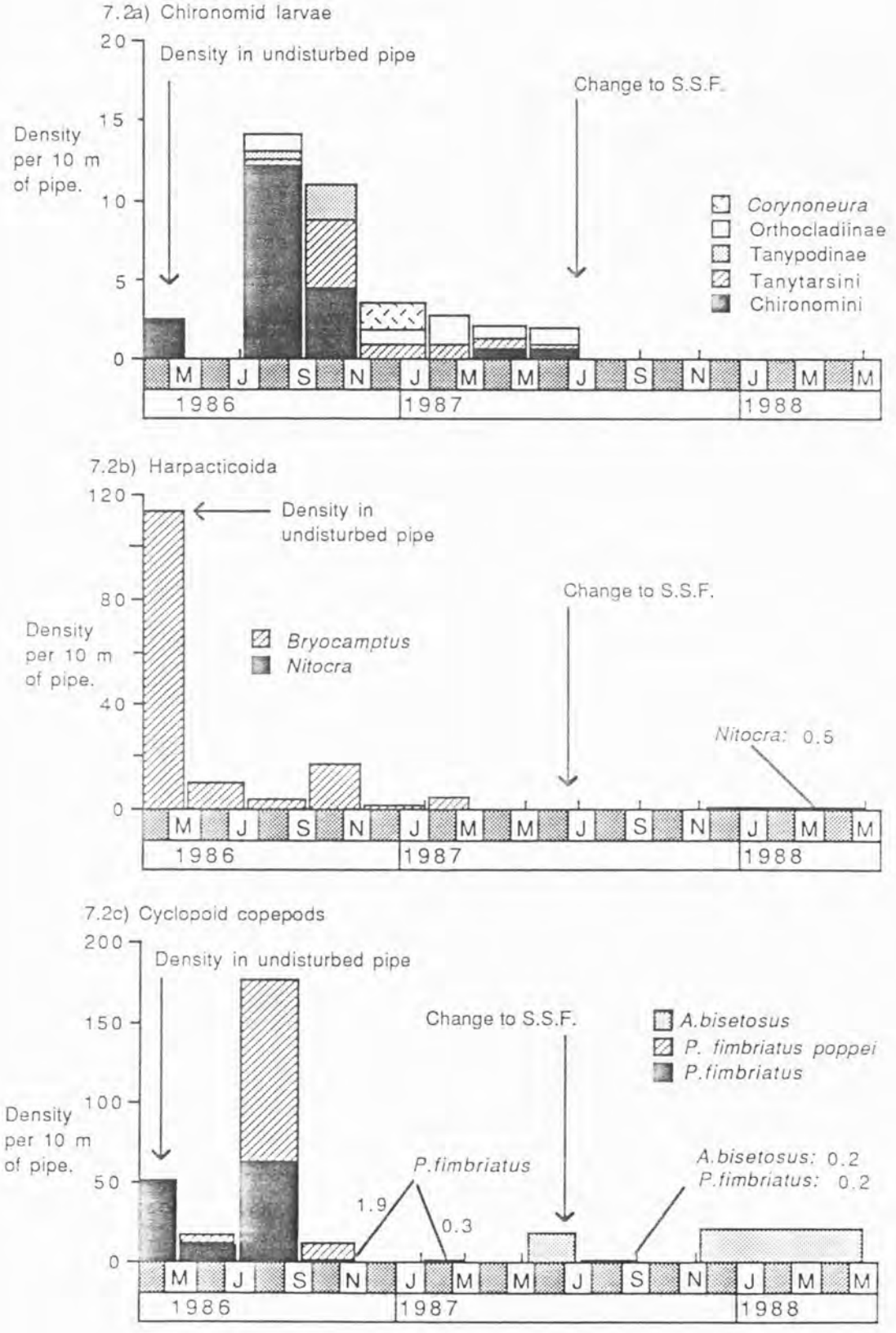
Chydorids failed to recolonise following pyrethrin treatment (Fig. 7.2d), but densities during July to November 1986 were greater than initially found in the system. *Chydorus sphaericus* numbers were low during the July - September 1986 period while *Alona rectangula* and *Alona guttata* both appeared in high densities. *A.rectangula* was dominant initially (July - September 1986) but then *A.guttata* had the greatest density of the three species. The July - September flush had 12.5% of *A.rectangula* and 6.3% of *A.guttata* reproductive, while in the September - November flush 42.5% of *A.guttata* were reproductive. Only *Chydorus* reappeared during the November - January 1987 period. This January record gave the lowest water temperature at this site (2°C), and no animals were found in the next period. *A.rectangula* showed a slight relationship with temperature of the water in the main (extracted as the second variable and accounting for 2% of the variation), which may indicate reproduction within the pipe was seasonal in this species. Following the switch to S.S.F., *A.rectangula* continued to recolonise at low densities, as did *Chydorus* during the recovery period. This suggests that at this site, *A.guttata* and *A.rectangula* either 'swamped' Chydorus numbers as they colonised, or were able to reproduce more successfully and establish a larger population. The failure to reach similar levels in 1987 may be due to the change in water source.

7.5.1.1.4) Mites

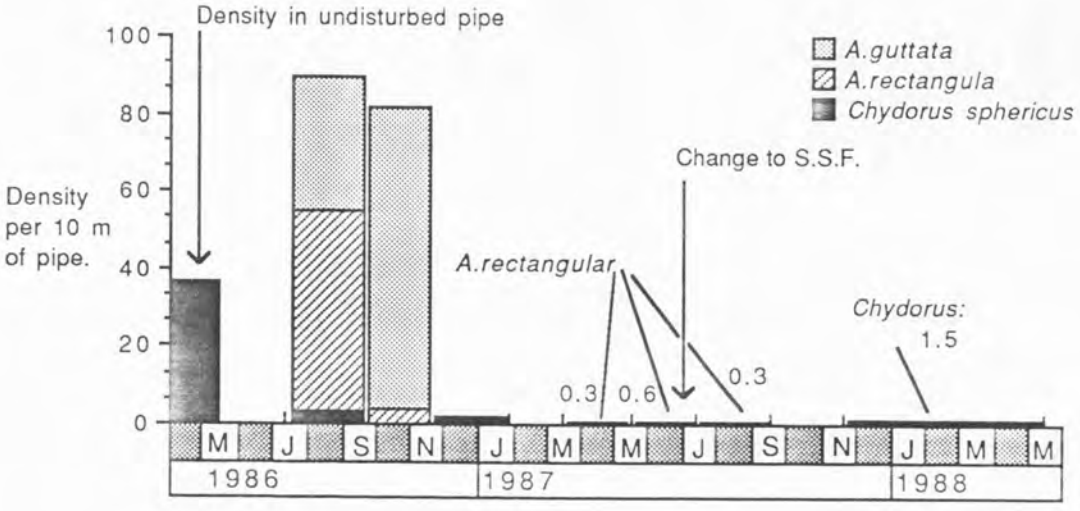
Soldanonellyx monardi and *Lobohalacarus weberi* were present in most samples taken at this site, which may be an indication of incomplete removal by flushing, or that penetration by these species was continuous (Fig. 7.2e). *Soldanonellyx* shows relationships with Tanytarsini (85% of variation); the dry weight of sediment (12%) and Orthocladiinae (2%); and a negative relationship with Tanypodinae larvae (1%). This indicates that substrate may be important for this species.

There was an initial failure to recolonise following the pyrethrin treatment in May 1986. Following the switch to S.S.F., the two species only occurred after six months in the main. Tyroglyphidae occurred infrequently following January 1987 and showed a negative relationship with chlorine level (numbers increasing as chlorine increased from 0.1 mg l^{-1} to 1.0 mg l^{-1}) at this site (accounting for 85% of the measured variation) and a negative relationship with the dry weight of sediment per 1000 litres of water removed from the pipe (a further 10% of the

Fig. 7.2) Animal density per 10 metres of pipe at Church Mount, Guilsborough, Northants.



7.2d) Chydorids



7.2e) Mites

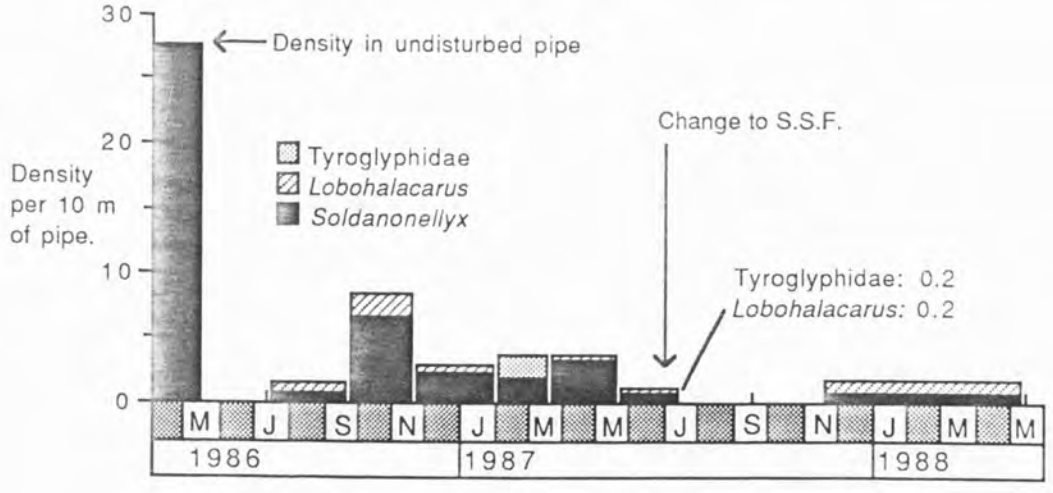


Table 7.4) Multiple regression of taxonomic groups and environmental variables at Church Mount, Guilsborough

[1] : indicates relationships referred to in the text.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2 / B_5	B_3	var_3 var_5	B_4 B_6	var_4 var_6	R^2	D.F.
[1]Chironomini	0.08102	0.52781	P.f.p.							0.93706	6
	-0.03812	0.57398	P.f.p.	2.38253	OM/Vol					0.97684	5
	-0.18725	0.61679	P.f.p.	8.62994	OM/Vol	-0.28749	DW/Vol			0.99460	4
	-0.22205	0.59224	P.f.p.	8.95267	OM/Vol	-0.28900	DW/Vol	0.08005	Bryoc	0.99949	3
[1]Tanytarsini	-0.02960	0.70063	Soldan							0.84820	6
	-0.01350	0.78681	Soldan	-0.10363	DW/Vol					0.96554	5
	0.02438	0.80731	Soldan	-0.10277	DW/Vol	-0.22680	Orthoc			0.99506	4
	0.01514	0.71332	Soldan	-0.08311	DW/Vol	-0.13494	Orthoc	0.19120	Tanyta	0.99944	3
	0.04679	0.74389	Soldan	-0.09512	DW/Vol	-0.11259	Orthoc	0.19592	Tanyta		
					/	-0.02115	Bar			0.99996	2
	0.04159	0.74674	Soldan	-0.09712	DW/Vol	-0.11480	Orthoc	0.18884	Tanyta		
					/	-0.02301	Bar	0.00018	Oxygen	1.00000	1
[1]Tanypodinae	-0.00427	0.20736	A.gutt							0.85209	6
	0.00000	0.37385	A.gutt	-0.19630	P.f.p.					1.00000	5
Bryocamptus	-0.88137	0.63609	Bar							0.72829	6
	-1.12350	0.80065	Bar	-1.74861	Coryno					0.91206	5
	-0.91608	0.61579	Bar	-1.51278	Coryno	0.65733	Tanyta			0.98612	4

Table 7.4) Church Mount, Guilsborough (cont.)

[1] : indicates relationships referred to in the text.

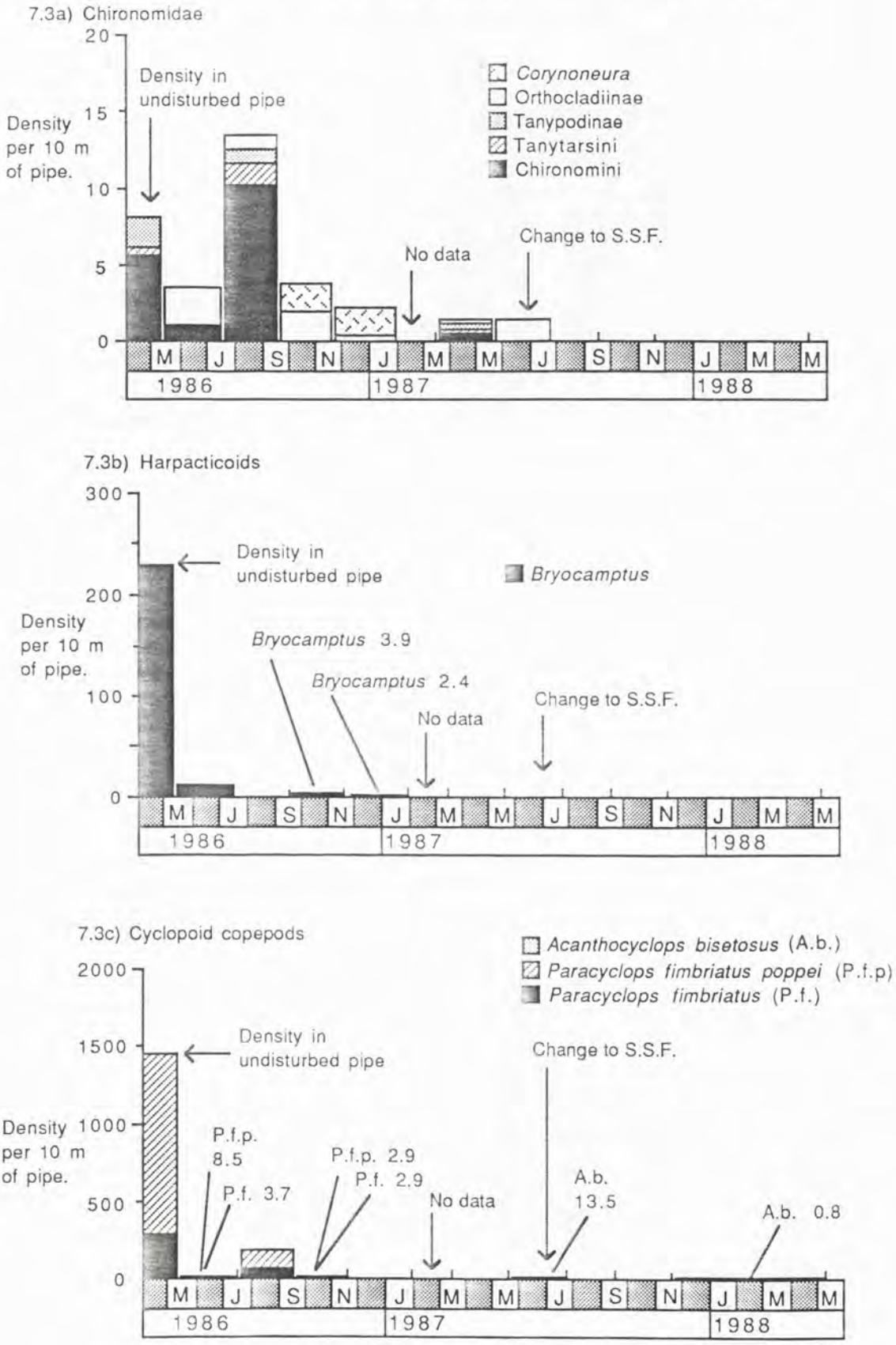
Dependent variable	Intercept	B_1	Var_1	B_2	var_2 / B_5	B_3	var_3 var_5	B_4	var_4 var_6	R^2	D.F.
[1]P.fimbriat	-0.05662	1.02221	A.rect							0.96095	6
	-0.01872	1.57859	A.rect	-0.82626	Chir					0.98367	5
	0.05406	1.76497	A.rect	-1.07410	Chir	-0.13018	P.O.C.			0.99530	4
P.f.poppei	-0.06271	1.26481	A.rect							0.97139	6
	-0.12595	1.16520	A.rect	0.25253	Bryoc					0.99077	5
A.guttata	0.08131	4.10917	Tanypo							0.85209	6
	0.00000	2.67490	Tanypo	0.52510	P.f.p.					1.00000	5
[1]A.rectangul	0.05834	0.76801	P.f.p.							0.97139	6
	-0.09192	0.75393	P.f.p.	0.01416	Temp					0.99029	5
	-0.05592	0.81367	P.f.p.	0.01172	Temp	-0.37958	Tanypo			0.99744	4
	-0.10539	0.79872	P.f.p.	0.01373	Temp	-0.61442	Tanypo	0.36226	Loboh	0.99950	3
	-0.12881	0.78967	P.f.p.	0.01431	Temp	-0.52057	Tanypo	0.32059	Loboh		
					/	0.09210	Ortho			0.99999	2
	-0.12832	0.79051	P.f.p.	0.01423	Temp	-0.51314	Tanypo	0.31054	Loboh		
					/	0.09252	Ortho	0.00197	DW/Vol	1.00000	1

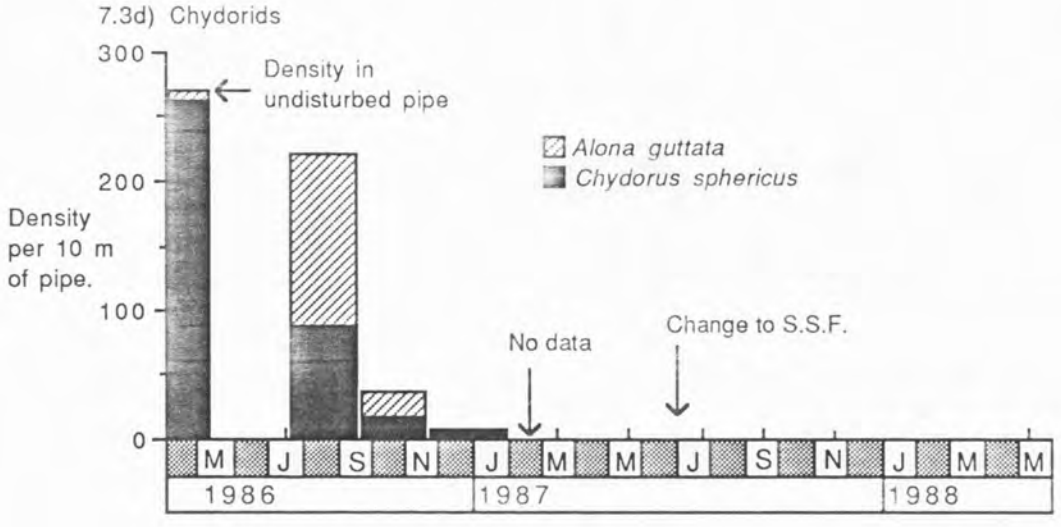
Table 7.4) Church Mount, Guilsborough (cont.)

[1] : indicates relationships referred to in the text.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2 /	B_3 / B_5	var_3 var_5	B_4 / B_6	var_4 var_6	R^2	D.F.
[1]Soldanonell	0.09189	1.21063	Tanyta							0.84820	6
	0.02741	1.22709	Tanyta	0.13125	DW/Vol					0.96890	5
	-0.02873	1.23255	Tanyta	0.12724	DW/Vol	0.28073	Ortho			0.99564	4
	-0.02119	1.39781	Tanyta	0.11671	DW/Vol	0.19094	Ortho	-0.26279	Tanypo	0.99937	3
	-0.06302	1.34386	Tanyta	0.12792	DW/Vol	0.15136	Ortho	-0.26303	Tanypo		
					/	0.02851	Bar			0.99996	2
	-0.05569	1.33915	Tanyta	0.13006	DW/Vol	0.15374	Ortho	-0.25288	Tanypo		
					/	0.03082	Bar	-0.00018	Oxygen	1.00000	1
Lobohalac	0.08002	0.78277	Tanypo							0.74530	6
[1]Tyroglyph	-0.14116	1.39550	Cl							0.84940	6
	-0.12109	1.46370	Cl	-0.06653	DW/Vol					0.95910	5
	-0.14337	1.52542	Cl	-0.06551	DW/Vol	0.07499	A.biset			0.99935	4

Fig. 7.3) Animal density per 10 metres of pipe at Scott Close, Ravensthorpe




7.3d) Chydorids
300
200
100
0
Density per 10 m of pipe.
Density in undisturbed pipe
Alona guttata
Chydorus sphericus
No data
Change to S.S.F.
M J S N J M M J S N J M M
1986
1987
1988

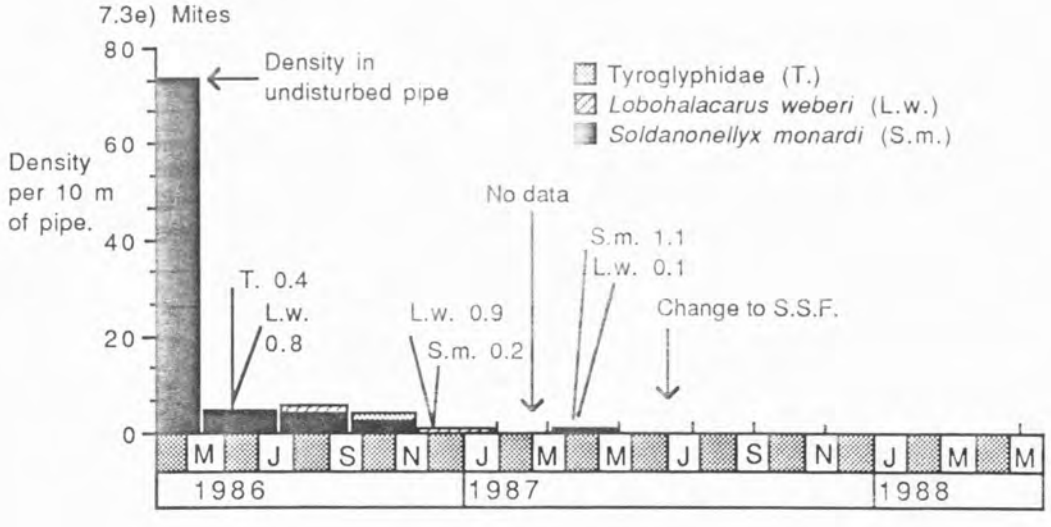

7.3e) Mites
80
60
40
20
0
Density per 10 m of pipe.
Density in undisturbed pipe
Tyroglyphidae (T.)
Lobohalacarus weberi (L.w.)
Soldanonellyx monardi (S.m.)
No data
S.m. 1.1
L.w. 0.1
T. 0.4
L.w. 0.8
L.w. 0.9
S.m. 0.2
Change to S.S.F.
M J S N J M M J S N J M M
1986
1987
1988

Table 7.5) Multiple regression of taxonomic groups and environmental variables at Scott Close, Ravensthorpe

[1] : indicates relationships referred to in the text.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3 /	B_4 / B_5	var_4 var_5	R^2	D.F.
Chironomini	0.02649	3.53608	Tanypo							0.91002	7
	-0.03428	3.62972	Tanypo	0.03327	DW/Vol					0.98558	6
	-0.02089	6.06622	Tanypo	0.03169	DW/Vol	-1.74050	Tanyta			0.99811	5
	-0.00561	6.16707	Tanypo	0.06703	DW/Vol	-1.83493	Tanyta	-0.29485	OM/Vol	0.99986	4
	-0.01437	6.17720	Tanypo	0.07065	DW/Vol	-1.84868	Tanyta	-0.33310	OM/Vol		
							/	0.00095	Temp	0.99999	3
[1]Tanytarsini	0.00603	1.40245	Tanypo							0.97154	7
[1]Tanypodinae	-0.00305	0.69275	Tanyta							0.97154	7
	-0.00473	0.48863	Tanyta	0.08552	Chiron					0.98769	6
	-0.00508	0.29688	Tanyta	0.16081	Chiron	-0.00508	DW/Vol			0.99993	5
	-0.00090	0.29825	Tanyta	0.16186	Chiron	-0.01086	DW/Vol	0.04779	OM/Vol	0.99995	4
	0.00232	0.29931	Tanyta	0.16187	Chiron	-0.01144	DW/Vol	0.05392	OM/Vol		
							/	-0.00015	Temp	1.00000	3
Orthocladi	0.55239	-0.05192	Flush							0.60088	7
	0.57117	-0.06153	Flush	0.28110	A.bise					0.83544	6
	0.45538	-0.04980	Flush	0.29673	A.bise	0.58437	Tyrogl			0.94795	5
	0.36199	-0.04054	Flush	0.28929	A.bise	0.62174	Tyrogl	0.01839	DW/Vol	0.99271	4

Table 7.5) Scott Close, Ravensthorpe (cont.)

[1] : indicates relationships referred to in the text.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3 /	B_4 B_5	var_4 var_5	R^2	D.F.
Corynoneu	0.43998	-0.02570	Temp							0.48273	7
	0.43463	-0.03449	Temp	0.57208	Orthoc					0.80126	6
	0.84869	-0.03427	Temp	0.64492	Orthoc	-0.00553	Oxygen			0.94248	5
Bryocamptus	0.86585	-0.09266	Flush							0.51296	7
	1.21791	-0.12605	Flush	-2.15518	Tanyta					0.92283	6
[1]P.fimbriatus	0.02799	0.79934	P.f.p.							0.98005	7
	0.02630	0.67283	P.f.p.	0.13844	A.gutt					0.99032	6
	0.02391	0.62819	P.f.p.	0.11231	A.gutt	0.50446	Tanyta			0.99592	5
	0.00036	0.62021	P.f.p.	0.02858	A.gutt	1.00000	Tanyta	0.44959	Tyrogl	1.00000	4
[1]P.f.Poppei	-0.02621	1.22608	P.fimb							0.98005	7
	-0.11276	1.17256	P.fimb	0.12653	P.O.C.					0.99012	6
Chydorus	1.29992	0.85798	A.gutt							0.83762	7
	0.03835	0.79736	A.gutt	1.13698	Coryno					0.92893	6
	0.04774	0.87550	A.gutt	1.76709	Coryno	-1.65303	Tyrogl			0.98613	5
	-0.00000	0.66865	A.gutt	2.03169	Coryno	-1.69752	Tyrogl	0.25371	P.f.p.	1.00000	4
A.guttata	-0.06460	0.97627	Chydor							0.83762	7

Table 7.5) Scott Close, Ravensthorpe (cont.)

[1] : indicates relationships referred to in the text.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3 /	B_4 B_5	var_4 var_5	R^2	D.F.
[1]Soldanonell	0.78257	-0.08121	Flush							0.77910	7
Lobohalacar	0.04486	0.45884	Chiron							0.71927	7
Tyroglyphid	-0.13627	1.37503	Chlorine							0.50342	7
	-0.16271	1.21959	Chlorin	0.18922	Bryocam					0.80774	6

variation).

7.5.1.1.5) Other taxa

Other taxa include Ostracoda, which were present initially at this site never but never reappeared during the sampling period. In the July - September 1987 period the sample removed from this site contained individuals of *Daphnia* (carapaces) and *Chaoborus* sp.; September - November 1987 contained *Chaoborus* and *Sigara* sp.; and November - May 1988 contained numerous filaments of *Spirogyra*. Coupled with the presence of a *Chaoborus* from the village of Creaton (sampled during October 1987 - see Chapter 6) which was also fed by Ravensthorpe, this appearance suggested a potential problem with the filter. After consultation with Anglian Water Biologists, the presence of *Chaoborus* and *Sigara* was taken to indicate a break in the Ravensthorpe filter. The *Spirogyra* was also attributed to a problem with the filter rather than a continuous increase in organic input.

7.5.1.2) Scott Close, Ravensthorpe.

This site is situated near to the treatment works, and is fed directly from an 8" high pressure main. During the sampling programme, one period (January to March, 1987) was lost due to works carried out at the site, on the day prior to scheduled sampling, involving draining the main to replace a hydrant. The water at this site changed from R.G.F. to S.S.F. in July 1987.

7.5.1.2.1) Chironomids

As at Guilsborough, the Chironomini showed highest density in the period June - September 1986, with a general downward trend in numbers of all larvae removed as flushing continued (Fig. 7.3a). Unlike Guilsborough, this site did show recovery during the May - July 1986 period, perhaps the proximity to the feed from Pitsford may have enabled 'new' animals more rapid access than elsewhere. *Corynoneura* was present at this site, first occurring during the period September - November 1986, the period prior to their occurence at Guilsborough, suggesting that proximity to treatment may relate to occurence. The Tanypodinae larvae at this site show a significant relationship with Tanytarsini (accounting for 97% of the variation) and a positive correlation with Chironomini (1%) (see Table 7.5).

7.5.1.2.2) Copepods

The copepods at this site showed a similar trend to those at Guilsborough. *Bryopcamptus pygmaeus* (Fig. 7.3b) recolonised at low

densities after the initial clearing of the pipe, did not colonise during the winter nor when the switch to S.S.F. took place. *Paracyclops fimbriatus* and *P.fimbriatus poppei* density increased during June - September 1986 (Fig. 7.3c), but animals were present between May and July 1986, despite pyrethrin dosing. These two cyclopoids show a strong correlation, accounting for 98% of the measured variation. *Acanthocyclops bisetosus* appeared as the only cyclopoid copepod after the change from R.G.F. to S.S.F at Ravensthorpe, though rarely at levels above drift.

7.5.1.2.3) Chydorids

The chydorids *Alona guttata* and *Chydorus sphaericus* (Fig. 7.3c) failed to colonise after pyrethrin dosing in May 1986, appearing between July and November 1986. Reproductive animals were present in both periods at roughly equal percentages in both species, 15% in July - September 1986 and 3%, in September to November 1986. No *Chydorus* were found with eggs or young during the period November - January 1987 as was the case at Guilsborough. After S.S.F. water came on-line, these species did not reappear.

7.5.1.2.4) Mites

The Acarina present at this site (Fig. 7.3d) were the same species as those which occured at Guilsborough. Tyroglyphidae occurred infrequently during 1986, and *Soldanonellyx* and *Lobohalacarus* were both present at low densities until May - July 1987 (the onset of S.S.F.). The negative relationship between *Soldanonellyx* and the number of flushes suggests a failure to remove animals (as described by work in Chapter 3).

7.5.1.2.5) Other taxa

Other species occurring at this site included nematode worms which failed to reappear after initial sampling of the site. During the period of S.S.F. water sampled during July - September 1987 the remains of a *Hydra* were removed from this site; during September - November 1987, as at Guilsborough, *Chaoborus* were removed; and November - May 1988 recovery period produced considerable filaments of *Spirogyra*.

7.5.1.3) Berry Close, Rothersthorpe

This site is situated at the southern extreme of the sampling area, fed by a 12" high pressure main from Kislingbury. The village of Rothersthorpe can also be fed from a 12" main to the south, which delivers Grafham rather than Pitsford water. During the period of study, there was no switch of feed, though previously the site had been fed by Grafham for an unknown period.

7.5.1.3.1) Chironomids

Chironomid larvae were absent from the initial sample taken in July 1986 which may be a feature of the site or an effect of pyrethrin dosing (Fig. 7.4a). Chironomini and Orthocladiinae both showed their maximum density during July - September 1986. Lower densities of animals from these taxa occurred during November 1986. No larvae were present between November 1986 and March 1987, but in the March - May 1987 period both Chironomini and Orthocladiinae reappeared. Chironomini recolonised repeatedly, with maximum density again during the July - September period. Multiple regression analysis (Table 7.4) found Chironomini were related to *Acanthocyclops robustus* (56% of variation); chlorine levels (34%); Hydracarina (8%) and D.O.C. (3%). These two related species were linked particularly with the summer periods, when penetration from high densities of *A.robustus* in the storage reservoir was likely to occur (see below), and it may be that this was also a feature of Chironomini. Tanytarsini first appeared in the March - May 1987 period, recolonised during September - November 1987 and were the dominant species at the end of the recovery period, when chironomid larval density reached a maximum. Tanypodinae at this site were found to relate to D.O.C. (49% of variation) and the time between flushes (49%), though it is possible these two variables were related. Chironomid density did not decrease after July 1987 at this site, unlike Guilsborough or Ravensthorpe, supporting the evidence that a difference in water quality exists between the two water treatment works.

7.5.1.3.2) Copepods

Bryocamptus pygmaeus (Fig. 7.4b) density was initially low, but during November - January 1987 and January - March 1987, the density was greater than that found initially in the undisturbed pipe. March - May 1987 showed a drop in the density after which the species never reappeared. This may be linked with the low density of chydorids or lack of chironomid larvae, cyclopids, or Acarina. *Paracyclops fimbriatus* (Fig. 7.4c) appeared after the initial removal of animals from the site and then at low densities or not at all. Both *P.fimbriatus poppei* and *P.fimbriatus* had a maximum recolonisation density during September - November 1987, both present in greater numbers than in the undisturbed pipe. There was a close relationship between the two *Paracyclops* species (accounting for 86% of the variation). Only *Megacyclops viridis* occurred in the March - May 1987 sample and reappeared throughout the remainder of the study (as copepodites during September - November 1987 and November - May 1987), coinciding with the absence of harpacticoids. *Acanthocyclops robustus* colonised during July - September 1986; May - July and July -

September 1987. The highest recorded densities in the final water from Pitsford during 1986 and 1987 were 27 cyclopoids and 32 cyclopoids per m^3 respectively (from data made available by Anglian Water), corresponding with the period containing these peaks. There was no drop in cyclopoid numbers after July 1987 at this site as occured at sites which switched to S.S.F.

7.5.1.3.3) Chydorids

The chydorids (Fig. 7.4d) *Chydorus sphaericus*, *Alona rectangula* and *Alona guttata* were all present in the initial flush at this site. However, only *Chydorus* recolonised between July and November 1986. The period November - January 1987 showed the recurrence of the two *Alona* spp. and *Chydorus*. During this period, no *Chydorus* with eggs were found, unlike the two previous periods. Both *Alona rectangula* and *A.guttata* populations had females with eggs during this period (10.3% and 22.2% respectively). No animals recolonised between January and May 1987 and in July 1987 *Chydorus* (40.0% with eggs) and *A.guttata* reappeared. During September - November 1987, as during November to January 1987, *A.rectangula*, the more numerous species had the smaller percentage of females with eggs (4.5% compared to 45.4% in *A.guttata*). *A.rectangula* and *A.guttata* showed a significant relationship at this site with 80% of the measured variation accounted for (Table 7.6).

7.5.1.3.4) Mites

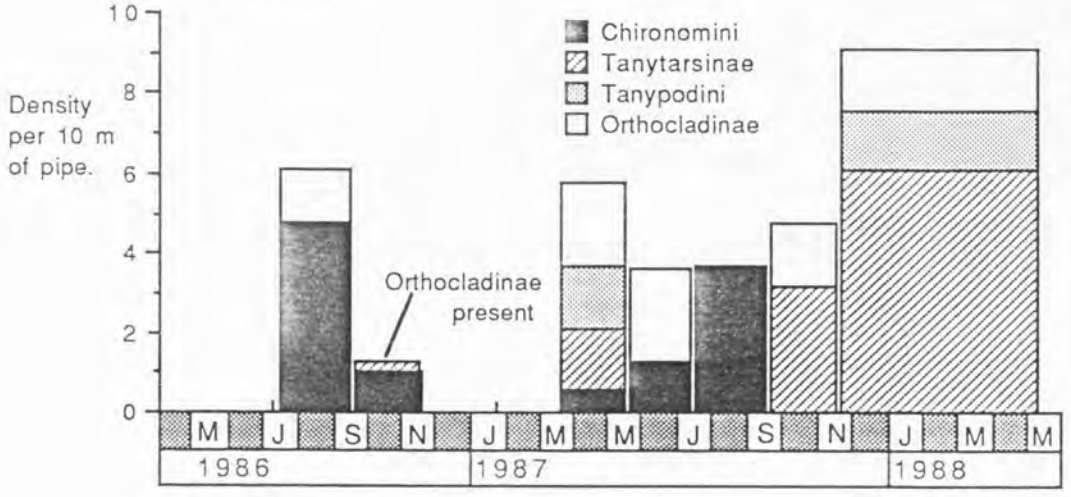
The mites at this site (Fig. 7.4e) show generally low densities, with only *Soldanonellyx* colonising during 1986, then recolonising in March - May 1987. The Hydracarina coincide with the maximum density of *Acanthocylops robustus* (Fig. 7.4c) and may be brought into the system on account of high densities in the raw water during this period. Tyroglyphidae occurred in every sample from from March 1987, and have a maximum density during July - September 1987. Tyroglyphidae at this site were found to have a positive relationship with the number of flushes, increasing as the study proceeded.

7.5.1.3.5) Other taxa

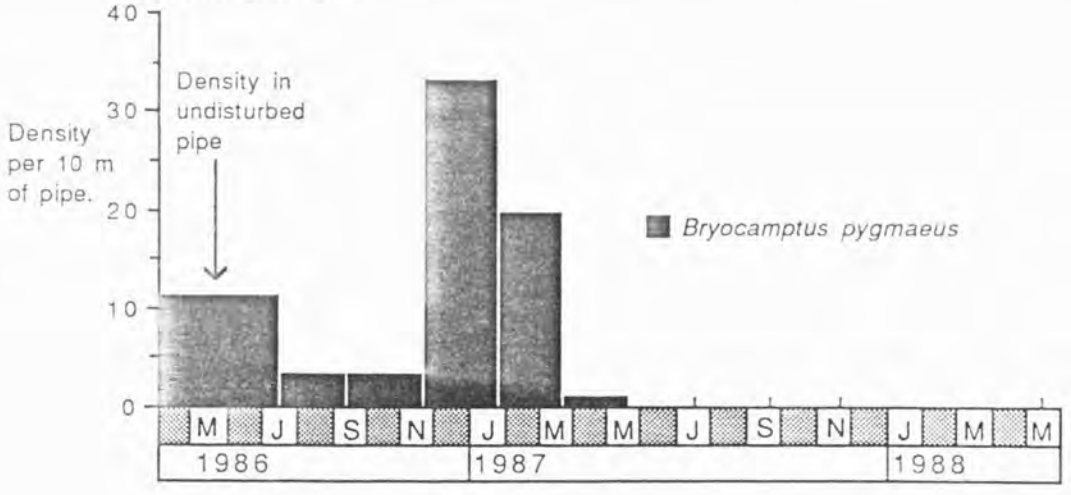
During November 1987, fragments of a *Sigara* were removed from this site (also present at both Ravensthorpe and Guilsborough above). There was no evidence of S.S.F. water getting to this site and no filamentous algae appeared during the recovery period (see also Chapel Brampton below).

7.4) Animal density per 10 metres of pipe at Berry Close, Rothersthorpe

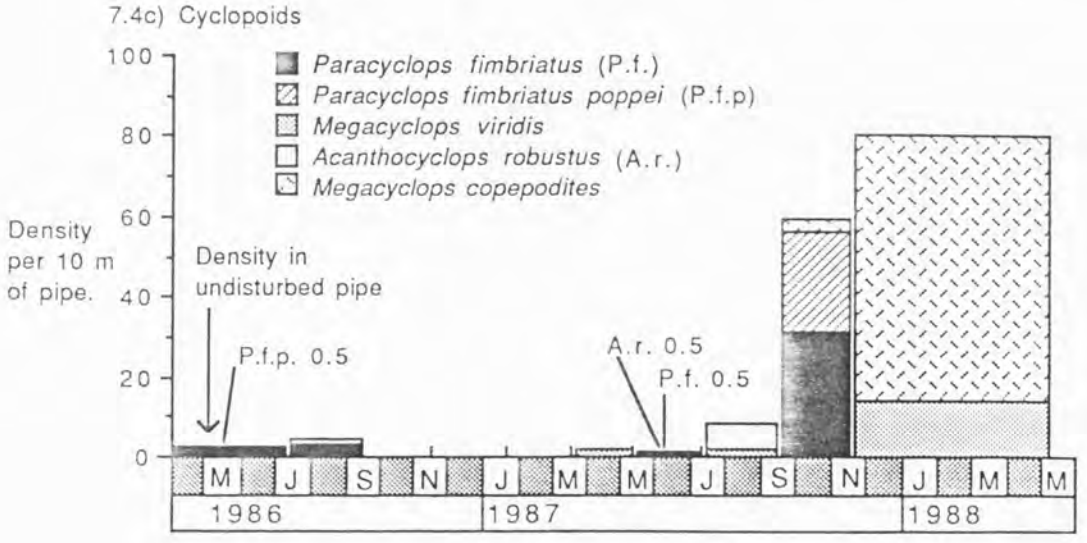
7.4a) Chironomidae

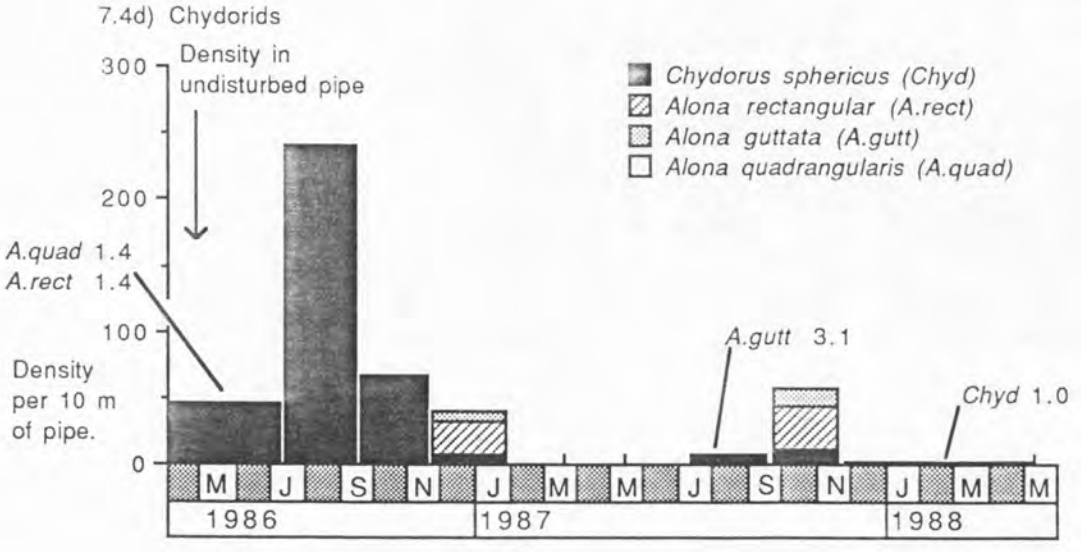


7.4b) Harpacticoids



7.4c) Cyclopoids




7.4d) Chydorids
Density in
undisturbed pipe
300
200
100
0
Density
per 10 m
of pipe.
A.quad 1.4
A.rect 1.4
A.gutt 3.1
Chyd 1.0
Chydorus sphericus (Chyd)
Alona rectangular (A.rect)
Alona guttata (A.gutt)
Alona quadrangularis (A.quad)
M J S N J M M J S N J M M
1986
1987
1988

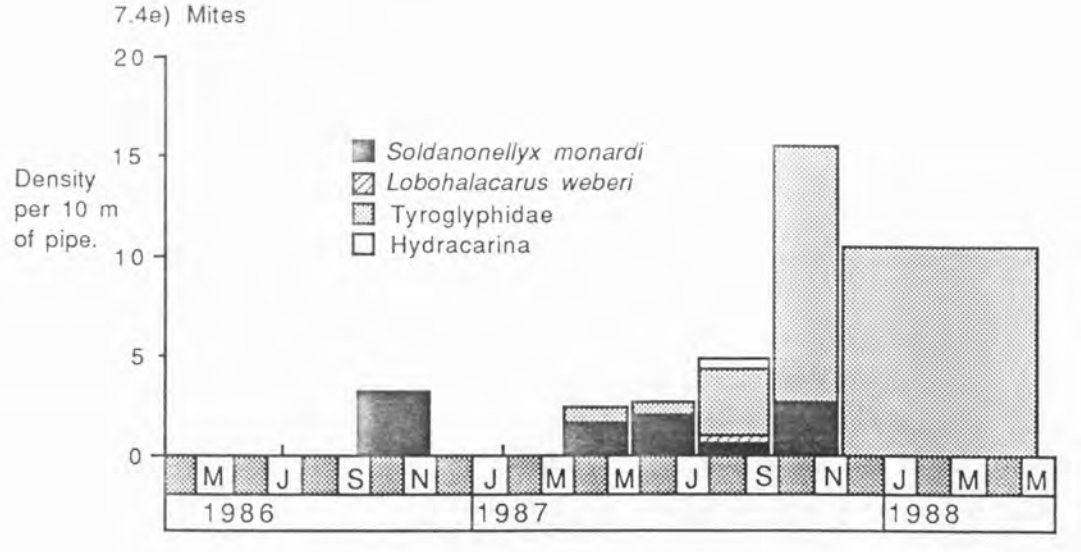

7.4e) Mites
20
15
10
5
0
Density
per 10 m
of pipe.
Soldanonellyx monardi
Lobohalacarus weberi
Tyroglyphidae
Hydracarina
M J S N J M M J S N J M M
1986
1987
1988

Table 7.6) Multiple regression of taxonomic groups and environmental variables at Berry Close, Rothersthorpe

[1] : indicates relationships referred to in the text.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3 /	B_4 / B_5	var_4 / var_5	R^2	D.F.
[1]Chiron	0.14212	0.74003	A.robu							0.56349	7
	-0.32168	0.75261	A.robu	3.77914	Chlor					0.87753	6
	-0.22464	1.67493	A.robu	2.65121	Chlor	-5.05437	Hydrac			0.96296	5
	-0.32751	1.77564	A.robu	2.74221	Chlor	-5.36617	Hydrac	0.01682	D.O.C.	0.99255	4
Tanytar	0.00244	0.57718	Tyrog							0.66608	7
	-0.03802	0.46234	Tyrog	0.91509	Tanypo					0.88642	6
	0.01817	0.51392	Tyrog	0.69612	Tanypo	-0.36549	A.robu			0.98401	5
	0.15464	0.66807	Tyrog	0.78142	Tanypo	-0.33582	A.robu	-0.03544	Flush	0.99875	4
[1]Tanypod	0.00792	0.38129	M.vir							0.69641	7
	-0.12608	0.32282	M.vir	0.02986	D.O.C.					0.96100	6
	-0.10628	0.33802	M.vir	0.02749	D.O.C.	-0.90326	Lobohal			0.99541	5
Bryocamp	-5.17255	1.16414	Pressure							0.75730	7
[1]P.fimb	0.10728	0.99078	P.f.popp							0.86409	7
[1]P.f.popp	-0.07219	0.87214	P.fimb							0.86409	7
A.robust	0.05686	7.47415	Soldan							0.88612	7
	-0.01535	5.99936	Soldan	0.35745	Chiron					0.97580	6

Table 7.6) Berry Close, Rothersthorpe (cont.)

[1] : indicates relationships referred to in the text.

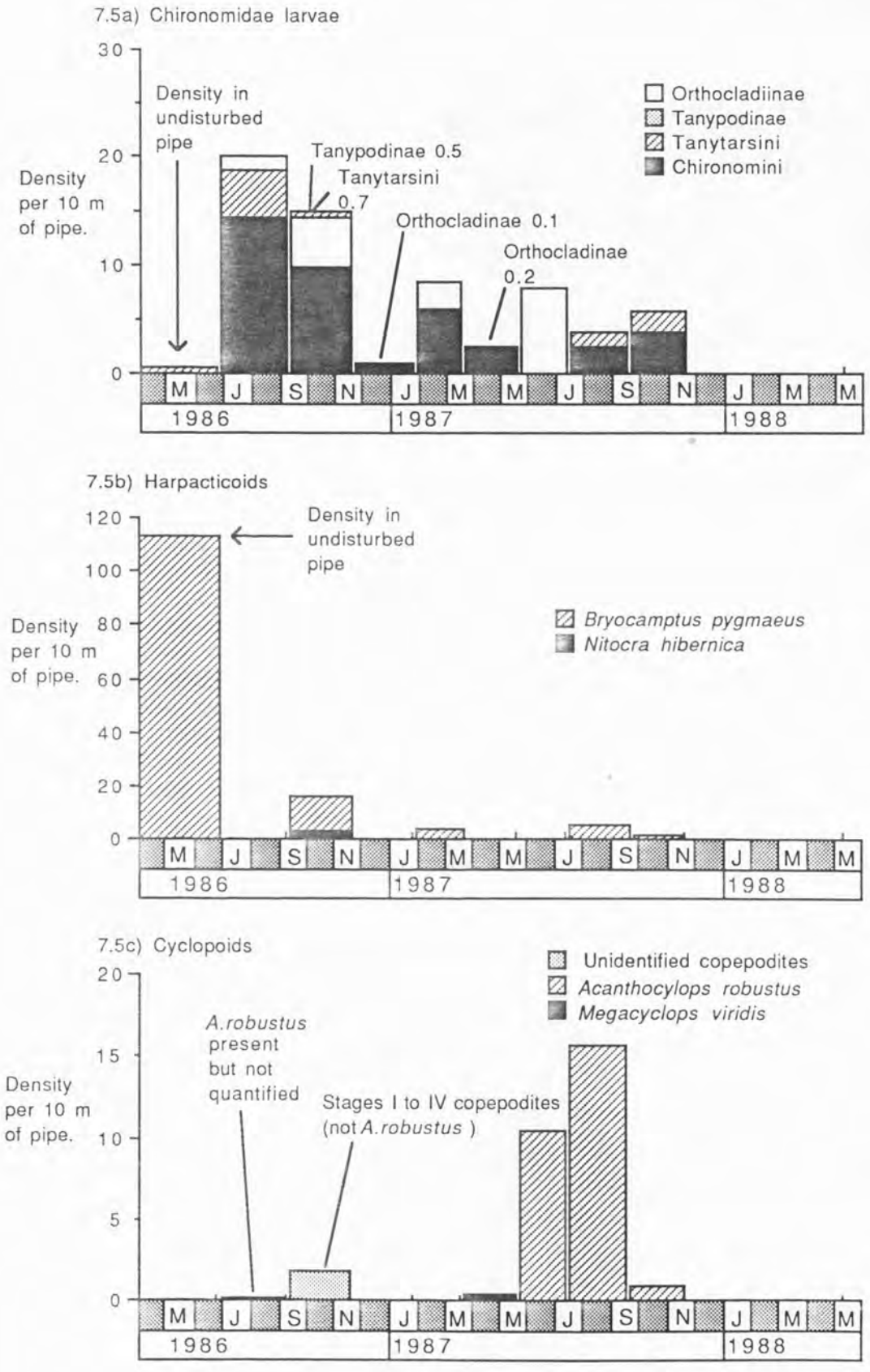
Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3 /	B_4 B_5	var_4 var_5	R^2	D.F.
M.viridis	-0.46757	0.00924	F.Time							0.79653	7
	-0.33991	0.00630	F.Time	0.99369	Tanyta					0.92211	6
	-0.37714	0.00617	F.Time	1.23312	Tanyta	2.79698	Soldan			0.99269	5
	-0.23407	0.00630	F.Time	1.08640	Tanyta	2.74300	Soldan	-0.00189	Oxygen	0.99759	4
	-0.25556	0.00638	F.Time	1.04209	Tanyta	2.44155	Soldan	-0.00222	Oxygen		
							/	0.00434	Temp	0.99984	3
Chydorus	-1.30056	17.04386	Chlor							0.76873	7
	-1.92550	20.16856	Chlor	0.82947	A.gutt					0.93634	6
[1]A.rectang	-0.04980	1.31494	A.gutt							0.80527	7
	-0.00005	1.49180	A.gutt	-8.02238	Loboh					0.99998	6
	-0.00000	1.48503	A.gutt	-7.98643	Loboh	0.00938	P.f.popp			1.00000	5
[1]A.guttata	0.08755	0.61239	A.rect							0.80527	7
	0.00004	0.67031	A.rect	5.37760	Soldan					0.99998	6
	0.00063	0.67339	A.rect	5.37797	Soldan	-0.00632	P.f.popp			1.00000	5

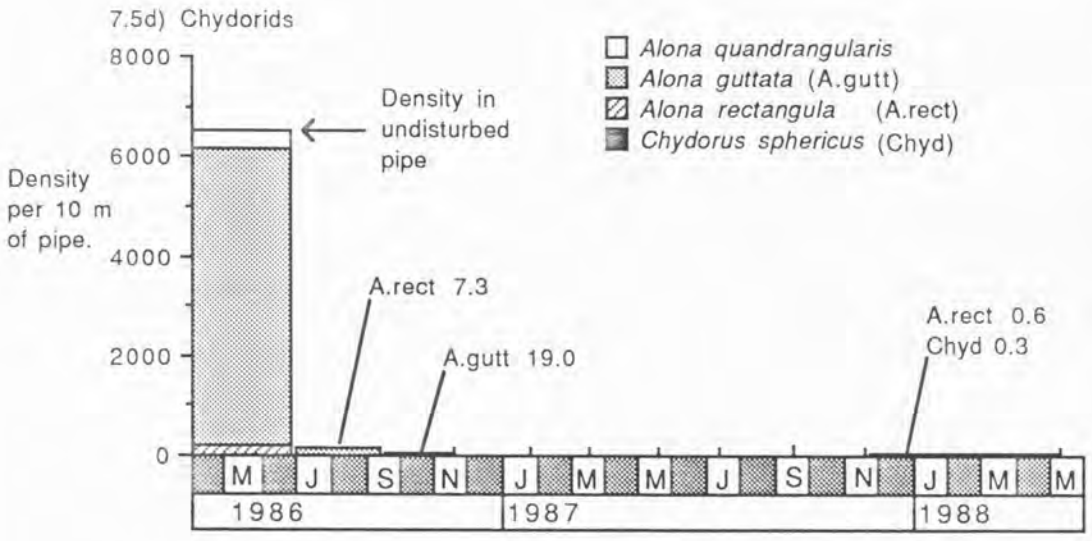
Table 7.6) Berry Close, Rothersthorpe (cont)

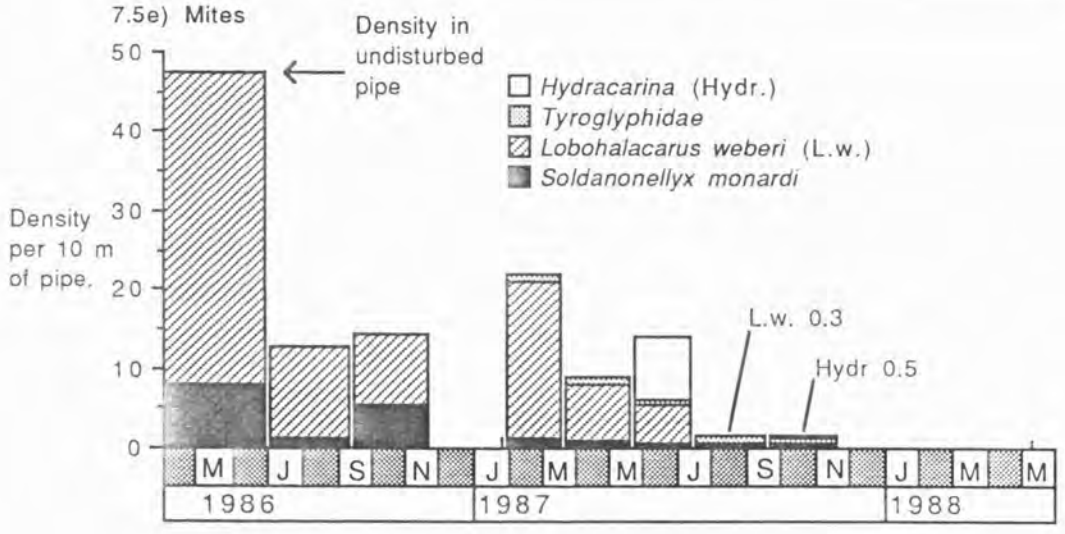
[1] : indicates relationships referred to in the text.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3 /	B_4 B_5	var_4 var_5	R^2	D.F.
Lobohalacar	0.00000	0.645707	Hydrac							1.00000	7
[1]Tryoglyphid	-0.55222	0.15328	Flush							0.80791	7
	-1.01328	0.19659	Flush	0.25710						0.96608	6
	-0.93682	0.21066	Flush	0.26848	Chydor	-0.01493	Temp			0.98778	5
	-0.92218	0.20749	Flush	0.26653	Chydor	-0.01939	Temp	0.22696	Orthoc	0.99696	4
	-0.99419	0.21193	Flush	0.28253	Chydor	-0.01899	Temp	0.16654	Orthoc		
							/	0.00882	D.O.C.	0.99932	3

Fig. 7.5) Animal desities per 10 metres of pipe at Back Lane, Chapel Brampton




7.5d) Chydorids
8000
6000
4000
2000
0
Density per 10 m of pipe.
Density in undisturbed pipe
Alona quandrangularis
Alona guttata (A.gutt)
Alona rectangula (A.rect)
Chydorus sphericus (Chyd)
A.rect 7.3
A.gutt 19.0
A.rect 0.6
Chyd 0.3
M J S N J M M J S N J M M
1986
1987
1988


7.5e) Mites
50
40
30
20
10
0
Density per 10 m of pipe.
Density in undisturbed pipe
Hydracarina (Hydr.)
Tyroglyphidae
Lobohalacarus weberi (L.w.)
Soldanonellyx monardi
L.w. 0.3
Hydr 0.5
M J S N J M M J S N J M M
1986
1987
1988

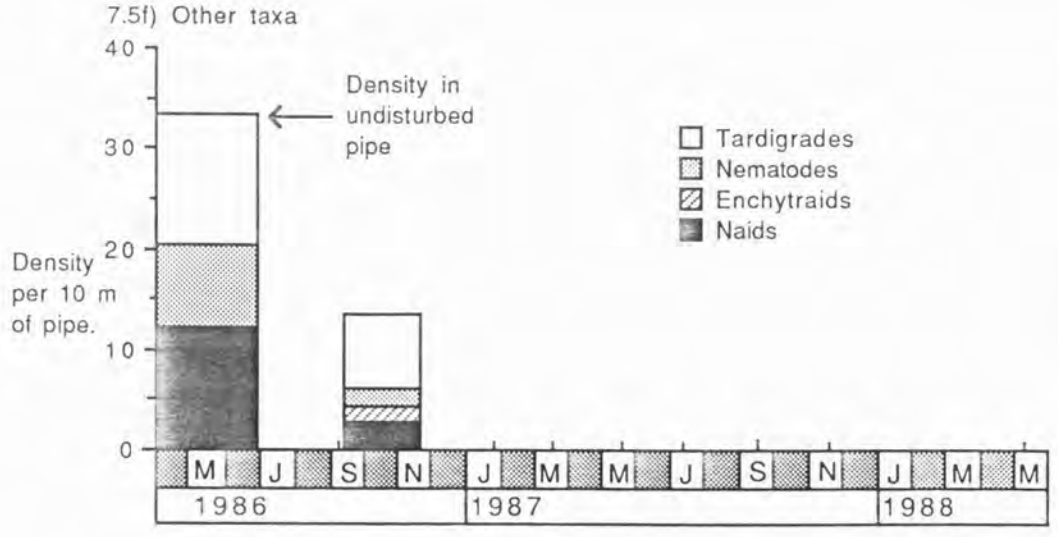

7.5f) Other taxa
40
30
20
10
0
Density per 10 m of pipe.
Density in undisturbed pipe
Tardigrades
Nematodes
Enchytraids
Naids
M J S N J M M J S N J M M
1986
1987
1988

Table 7.7) Multiple regression of taxonomic groups and environmental variables at Back Lane, Chapel Brampton

[1] : indicates relationships referred to in the text.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3 /	B_4 B_5	var_4 var_5	R^2	D.F.
[1]Chiron	0.40589	0.39154	A.gutt							0.54524	7
[1]Tanytar	0.11568	0.76676	A.rect							0.66834	7
	0.03553	0.86833	A.rect	1.25768	A.quad					0.88183	6
	-0.00295	0.84987	A.rect	1.41334	A.quad	2.56155	Chydor			0.99283	5
	0.00000	0.84666	A.rect	1.54747	A.quad	2.54747	Chydor	-0.15700	Nitocr	1.00000	4
Tanypod	0.00000	0.32366	Nitocr							1.00000	7
[1]Orthoc	0.03812	0.45325	Loboh							0.45711	7
	-0.03825	0.43786	Loboh	0.67810	Hydrac					0.80816	6
	-0.04847	0.36475	Loboh	0.74464	Hydrac	2.23114	Tanypo			0.92457	5
	-0.04188	0.59510	Loboh	0.81805	Hydrac	5.37716	Tanypo	-0.18374	Soldan	0.98088	4
	-0.02710	0.56403	Loboh	0.76430	Hydrac	4.30713	Tanypo	-0.79331	Soldan		
							/	-0.12318	M.vir	0.99682	3
[1]Nitocra	0.00000	0.92049	Naids							1.00000	7
Bryocamp	0.16741	3.19058	A.quad							0.59909	7
	0.40721	4.82180	A.quad	-0.05097	D.O.C.					0.80512	6
[1]A.robustus	-0.63708	0.07886	Temp							0.50948	7
A.quadrang	-0.00992	0.18777	Bryoca							0.59909	7
	-0.07414	0.16582	Bryoca	0.01116	D.O.C.					0.88722	6

Table 7.7) Back Lane, Chapel Brampton (cont.)

[1] : indicates relationships referred to in the text.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3 /	B_4 / B_5	var_4 / var_5	R^2	D.F.
A.rect	-0.05944	0.87165	Tanyta							0.66834	7
	-0.01548	1.00541	Tanyta	-1.34636	A.quad					0.87964	6
	0.00483	1.16587	Tanyta	-1.65340	A.quad	-2.98224	Chydor			0.99135	5
	0.00000	1.00018	Tanyta	-1.54775	A.quad	-2.26744	Chydor	0.06567	A.gutt	1.00000	4
[1]A.gutt	0.12512	2.06451	A.rect							0.63985	7
	0.05367	2.29108	A.rect	2.29197	Naids					0.96034	6
	0.00000	2.33272	A.rect	2.20116	Naids	-4.17887	Chydorus			1.00000	5
[1]Soldanonell	0.20317	1.02021	Naids							0.67876	7
	0.09108	0.84575	Naids	0.21615	Lobohal					0.88722	6
Lobohal	0.16593	1.50141	Soldan							0.46130	7
Naids	0.00000	3.35658	Tanypo							1.00000	7
Nematodes	0.00000	0.82188	Nitocr							1.00000	7

7.5.1.4) Back Lane, Chapel Brampton.

This site was unique amongst the four sites sampled on a two-monthly basis being fed from a 6" dead end main which was itself fed by a 42" trunk main from Pitsford. The pressure at this site was lower than at the other four and samples were removed at the lowest rates possible for the sampling model to operate (between 6 and 7 l s^{-1}). This site is also considerably closer to Pitsford Treatment Works than the other sites. The mains in this area appear older than the other four sites from the state of the hydrants. The only information to support this is that the houses at this site are older than the other sites. Initial samples were taken in June at this site rather than directly after pyrethrin sampling in May.

7.5.1.4.1) Chironomids

Initial chironomid larvae numbers at this site were low relative to the recolonising densities obtained during the study (Fig. 7.5a). Chironomini and Orthocladiinae ocurred throughout the periods between June 1986 and May 1987, with Chironomini reappearing during July - September 1987. The Chironomini and Orthocladiinae showed maximum recolonising densities during June - September 1986 and May - July 1987 respectively, as was the case at Rothersthorpe. Though chironomids were present after July 1987, there was no recolonisation during the recovery period. Multiple regression analysis (Table 7.7) showed that Chironomini were related to *Alona guttata* density (accounting for 54% of the variation) while Tanytarsini correlate with *Alona rectangula* (66%). Orthocladiinae density was linked with the density of *Lobohalacarus* (a predatory halacarid) and to the Hydracarina (a summer penetrator of filtration).

7.5.1.4.2) Copepods

Bryocamptus pygmaeus (Fig. 7.5b) numbers never recolonised to the density that was present in the undisturbed pipe. They were present at low densities in September - November 1986 along with *Nitocra hibernica*. Recolonisation remained low or did not occur for the remainder of the study, with no animals recolonising during the recovery period. *Nitocra* showed a high correlation with naid worms at this site with almost 100% of the variation accounted for, but naids only occurred on two sampling occasions.

The reinfestation by cyclopoid copepods that occured at this site was quite distinct from the other three sites sampled at this frequency (Fig. 7.5c). *Acanthocyclops robustus*, which occurred between May and November 1987, dominated the cyclopoids at this site. The cyclopoids

present (but not measured) during July - September 1986 were *A.robustus* (in low numbers) while those stage IV copepodites present during September - November 1986 appeared to be *Megacyclops* sp. No *A.robustus* occurred between November 1986 and May 1987, which suggests that density of recolonising animals may be linked directly to the penetration of filters by animals in the storage reservoir at Pitsford. This corresponds to the peaks in Pitsford final water discussed in section 7.5.1.3.2. At this site *A.robustus* is significantly related to temperature of the water (accounting for 51% of the measured variation). *Megacyclops viridis* also ocurred at this site, present in the March - May 1987 sample as was the case at Rothersthorpe.

7.5.1.4.3) Chydorids

Chydorus sphaericus occurred during only one period, September - November 1987, at low densities. However, three species of *Alona*: *A.quadrangularis*; *A.rectangula* and *A.guttata* were present in the undisturbed pipe (Fig. 7.5d). The *Alona* spp. never recovered to the high levels present in the undisturbed pipe - *A.quadrangularis* never recolonised the site. The period from June - September 1986 showed reinfestation by both *A.guttata* and *A.rectangula*, but only *A.guttata* reinfested during September - November. During both of these periods female *A.guttata* with eggs were present, the greatest percentage being June - September 1986 (52.6%). *Alona rectangula* is significantly related to the density of *A.guttata* (accouting for 64% of the measured variation for this species). No chydorids reinfested during the winter, and *A.rectangula* recolonised during the September - November 1987 period along with *Chydorus*. No recovery occurred during the final six months of the sampling period.

7.5.1.4.4) Mites

The mites *Lobohalacarus weberi* and *Soldanonellyx monardi* were present throughout, excepting November - January 1987 and November - May 1988 (Fig. 7.5e). *Soldanonellyx* density was related to naid worms (68% of the variation) and *Lobohalacarus* (21%) suggesting either a predatory role with naids as prey as is the case in *Lobohalacarus*, or that some requirement such as substrate is shared with naid worms. Naids occurred only twice at this site and hence the result from this regression analysis is of doubtful significance. Tyroglyphidae occurred only after January 1987, (one month earlier than Berry Close) and Hydracarina show a maximum density in 1987 which was likely to be linked with an increase in numbers at Pitsford Storage reservoir - corresponding to an increase in cyclopoid copepods in the raw water.

7.5.1.4.5) Other taxa

Naids, nematodes and tardigrades were present in initial samples but recolonised only during September - November 1986, then failed to recolonise at all (Fig. 7.5f).

During September - November 1987, the recovered sample contained a single *Chaoborus* larvae, (as at Ravensthorpe and Guilsborough). No *Spirogyra* occurred at this site during the final six months of the study which suggests that as zoning indicated there was no S.S.F. water at this site. This information leads to another possible explanation for the presence of *Sigara* and *Chaoborus* larvae in the pipes of two diferent supply zones. If either of these species had somehow entered Pitsford Contact tank which was near to the Reservoir itself, it would be possible for them to lay eggs. If this happened prior to the switch to S.S.F. water in July, the animals may have been developing within the contact tank or trunk mains until they finally reached the end of the system. There was no evidence as to whether the *Sigara* or *Chaoborus* were alive and it may be the *Sigara* had entered the contact tank and have been moving as dead adults down the main since then. *Chaoborus* may also be able to penetrate other service reservoirs or towers in the system in which case these may be isolated occurrences that appeared to be linked.

7.5.2) Sites sampled on a four-monthly basis

Densities of animals at these sites were expected to be higher than those sampled on a two-monthly basis, and these densities would reflect the animals which can survive and establish a population in the mains rather than those which may simply penetrate in high densities from the raw water. Multiple regressions are included as Tables 7.8 and 7.9.

7.5.2.1) West Way, Weedon

This site is fed from a 5" main and was at high pressure, always sampled at approximately 15 l s^{-1}. Unlike the other sites sampled in this part of the study, at West Way, the pipe runs uphill, which may affect the recolonisation process, as animals and sediment may settle out at the base of the pipe and be carried away by the feeder main.

7.5.2.1.1) Chironomids

Following the initial sample after pyrethrin dosing no chironomid larvae were present in the pipe (Fig. 7.6a), and none occurred during the corresponding period in 1987. Low numbers reinfested during September - January 1987, followed by maximum reinfestation density during January - May 1987. Chironomid larvae (including *Corynoneura*) did appear during the recovery period when Weedon remained on R.G.F. water. Tanypodinae larvae

showed a relationship with D.O.C. at this site (Table 7.8), but there were few samples and the degrees of freedom were low. Other regresssion analysis, though significant, did not relate particularly to the maximum and minimum data of the taxa involved. Chironomini were affected by the temperature at the time of flushing which may be an indication of seasonal changes in penetration of treatment. Tanypodinae and Tanytarsini also show a positive relationship, but the degrees of freedom for both of these regressions were low.

7.5.2.1.2) Copepods

Bryocamptus pygmaeus was present initially at this site but numbers were significantly higher in the drift than the first or second flush. No harpacticoids recolonised this site during the study period. They were present at drift levels in the pipe during May - September 1986 and January - May 1987.

Paracyclops fimbriatus poppei and *Acanthocyclops robustus* (Fig. 7.6b), both occurred during the May - September 1987 period which coincides with the peak of *A.robustus* in the storage reservoir at Pitsford (see section 7.5.1.3.2 above). *Paracyclops fimbriatus* did not appear until the final sampling period, when neither of the other two species occurred.

7.5.2.1.3) Other taxa

Chydorus sphaericus was absent from the initial sample and colonised during the September - May 1988 final sampling period. No egg bearing females were found on examination of this sample. Similarly, *Lobohalacarus* and *Soldanonellyx* reinfested only during the final sampling period (Fig. 7.6c), though both these species were present prior to the repeated sampling. Both Ostracoda (January - May 1987) and nematodes (September - May 1988) colonised at low densities (nether having been present in initial sample).

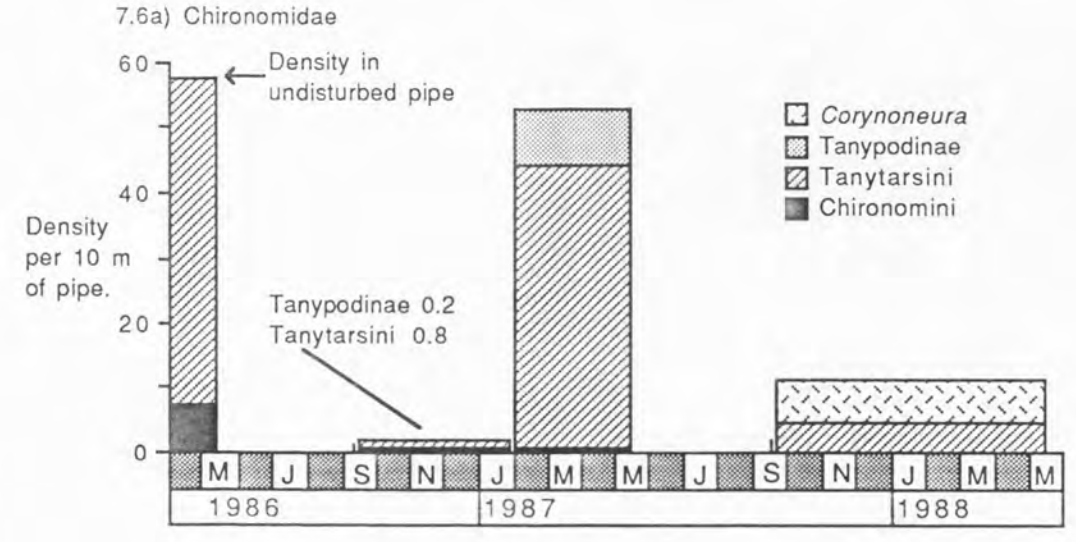
7.5.2.2) Stanford Close, Cold Ashby

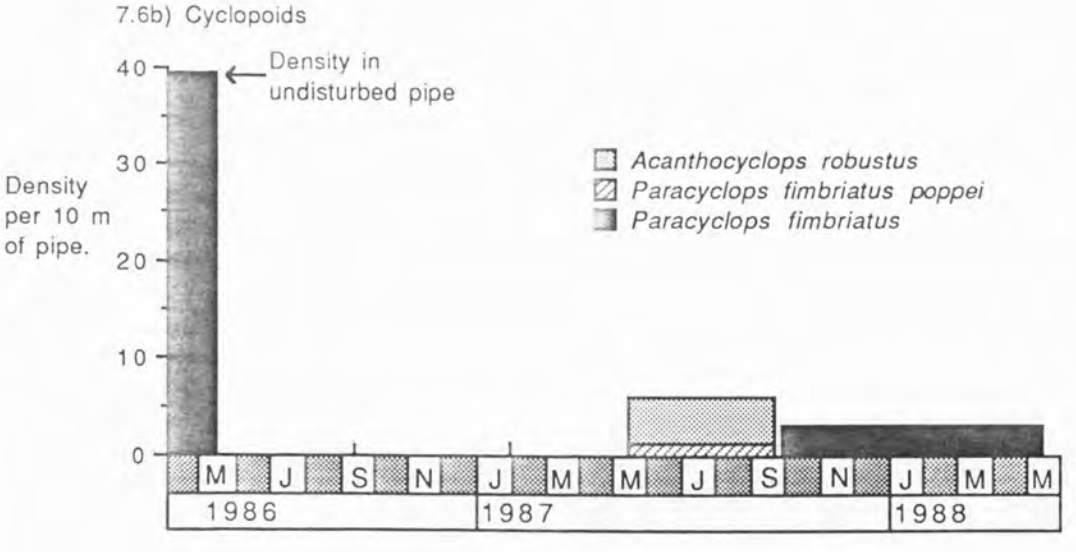
Stanford Close is fed from a main which does not carry water at particularly high pressure. Samples were taken at the lower limit of application of the sampling method 6 - 7 l s^{-1}. The feed main is a 6" from Guilsborough, not a large diameter trunk main. This site changed to S.S.F. water from Ravensthorpe during July 1987.

7.5.2.2.1) Chironomids

Chironomini larvae reinfested during May - July 1987 period (Fig. 7.7a). No animals recolonised during the winter months, and after

Fig. 7.6) Animal Density per 10 metres of pipe at West Way, Weedon





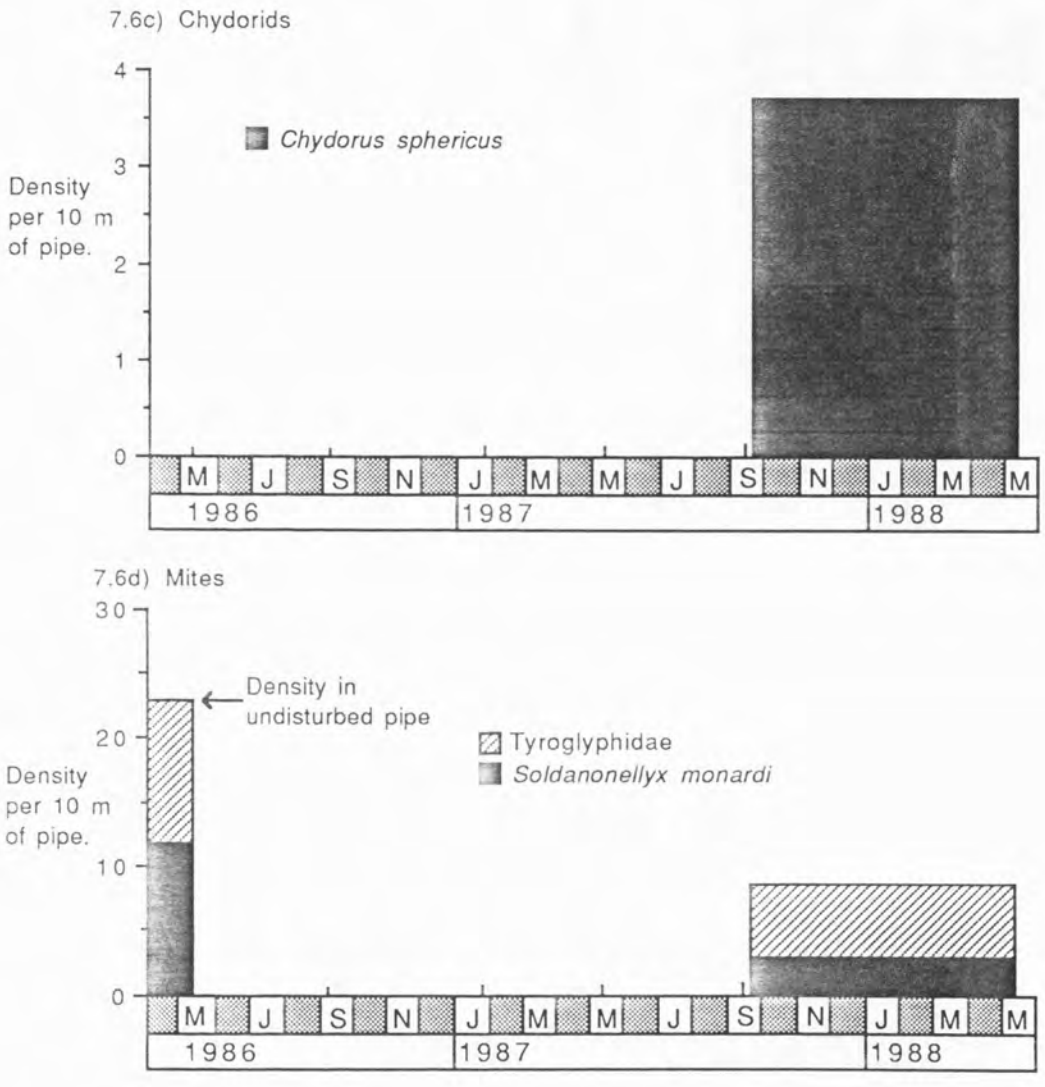
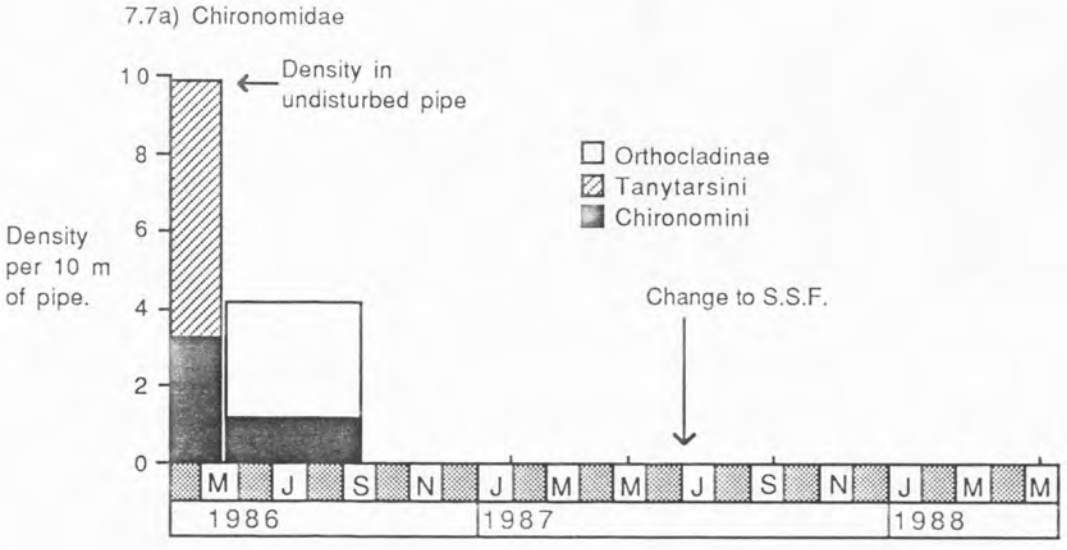

7.6c) Chydorids
Density per 10 m of pipe.
Chydorus sphericus
0
1
2
3
4
M J S N J M M J S N J M M
1986
1987
1988
7.6d) Mites
Density per 10 m of pipe.
Density in undisturbed pipe
Tyroglyphidae
Soldanonellyx monardi
0
10
20
30
M J S N J M M J S N J M M
1986
1987
1988

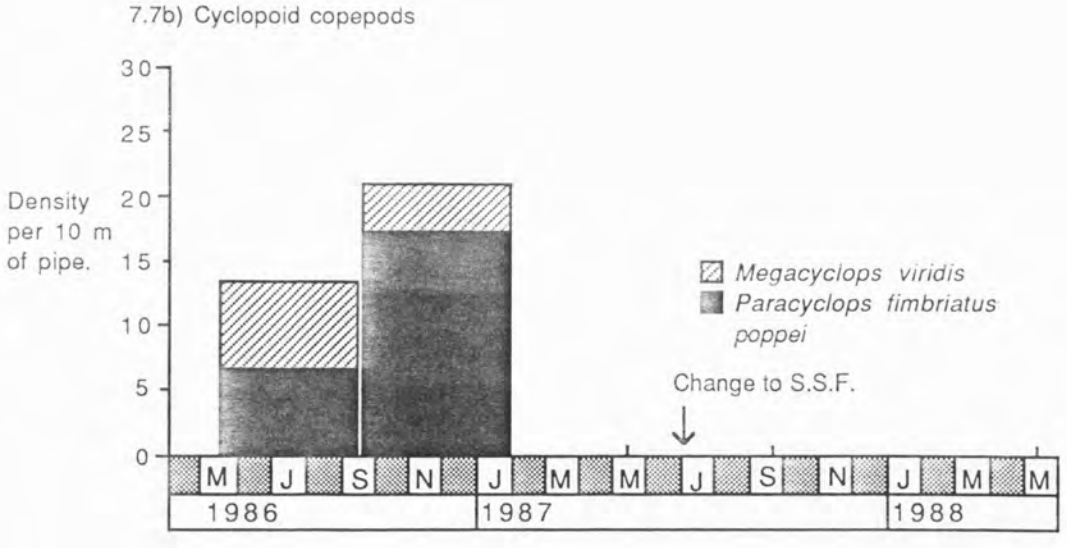
Table 7.8) Multiple regression of taxonomic groups and environmental variables at West Way, Weedon

[1] : indicates relationships referred to in the text.

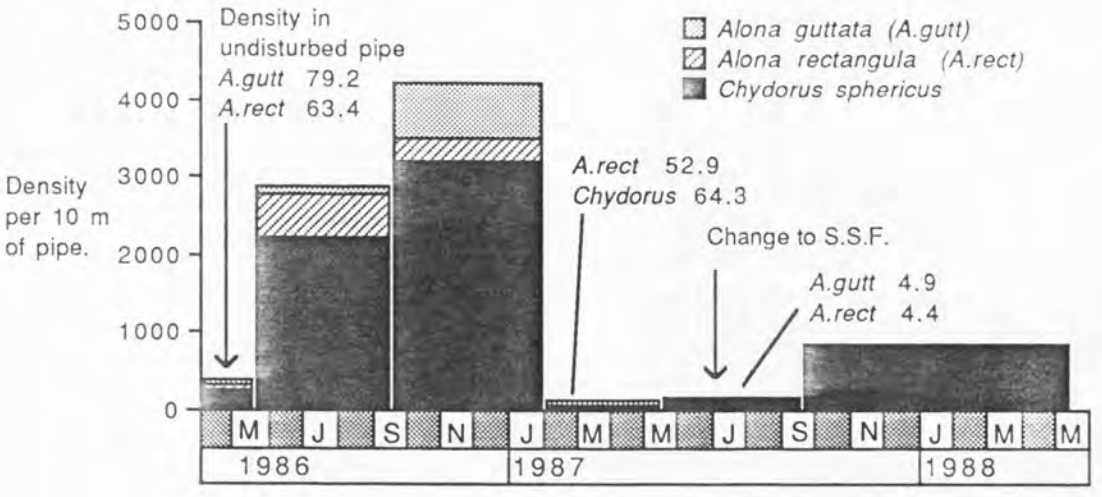
Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3	R^2	D.F.
[1]Chiron	0.25954	-0.01848	Temp					0.83990	3
	0.30411	-0.02471	Temp	0.37467	P.f.popp			0.99718	2
[1]Tanytar	0.22407	1.43708	Tanypo					0.80419	3
	-0.86867	1.79894	Tanypo	0.00695	F.Time			0.99861	2
	-0.82356	1.80386	Tanypo	0.00699	F.Time	-0.00460	Temp	1.00000	1
Tanypod	-0.07144	0.01839	D.O.C.					0.99524	3
Coryno	0.00000	1.46483	P.fimb					1.00000	3
P.fimb	0.00000	0.68267	Coryno					1.00000	3
P.f.popp	0.00000	0.45302	A.rob					1.00000	3
A.robust	0.00000	2.20743	P.f.popp					1.00000	3
Chydorus	0.00000	0.74875	Corynon					1.00000	3
Soldanon	0.00000	0.65847	Corynon					1.00000	3
Nematode	0.00000	0.60612	Corynon					1.00000	3
Ostracod	-0.03861	0.00784	D.O.C.					0.99556	3

Fig. 7.7) Animal density per 10 metres of pipe at Stanford Close, Cold Ashby

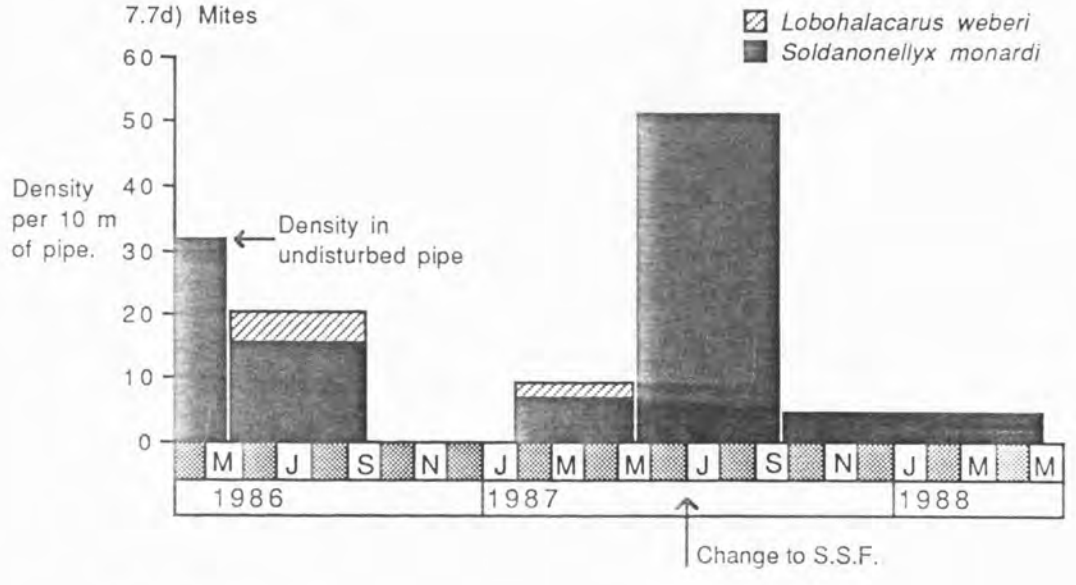




7.7c) Chydorids



7.7d) Mites



7.7e) Other taxa

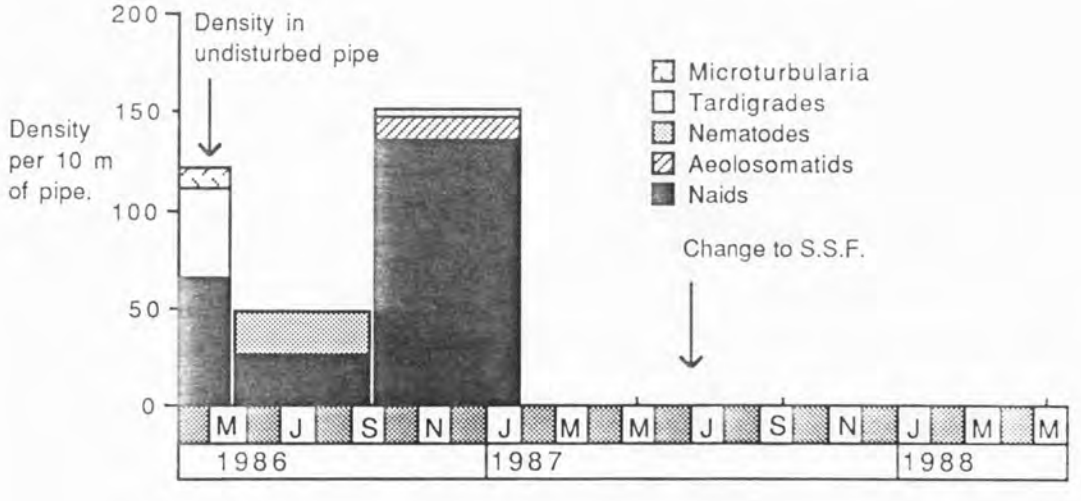


Table 7.9) Multiple regression of taxonomic groups and environmental variables at Stanford Close, Cold Ashby

[1] : indicates relationships referred to in the text.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3	R^2	D.F.
Chiron	0.00000	0.52583	Orthoc					1.00000	3
Orthoc	0.00000	1.90176	Chiron					1.00000	3
[1]P.f.popp	0.00403	0.60153	Naids					0.99874	3
	0.00000	0.59252	Naids	0.08499	Ortho			1.00000	2
[1]Chydorus	3.33963	-0.03905	D.O.C.					0.87589	3
	2.96278	-0.02859	D.O.C.	0.51442				0.99435	2
A.rect	4.44356	-0.72597	Flush					0.97224	3
	5.02856	-0.84297	Flush	-0.95466	Ortho			0.99749	2
	4.63526	-0.78678	Flush	-0.60803	Ortho	0.68520	OM/Vol	0.99999	1
A.gutt	0.24471	1.23092	Naids					0.94481	3
	1.78460	1.56560	Naids	-0.02408	Oxygen			0.99926	2
	1.74263	1.59299	Naids	-0.02427	Oxygen	0.00244	D.O.C.	1.00000	1
[1]Soldanon	-0.31811	0.11632	Temp					0.96388	3
	-0.47924	0.11844	Temp	0.09615	P.O.C.			0.99815	2
	-0.68235	0.13710	Temp	0.06316	P.O.C.	0.24187	Ostracods	1.00000	1
Lobohal	-0.12102	0.13710	Press					0.90090	3
Naids	-0.00579	1.66034	P.f.p.					0.99874	3
	0.00000	1.58856	P.f.p.	0.17155	Tard			1.00000	2

water treatment changed from R.G.F. to S.S.F. there was no further recolonisation.

7.5.2.2.2) Copepods

Both *Nitocra hibernica* and *Bryocamptus pygmaeus* were present in the undisturbed pipe but failed to recolonise, despite being present at drift levels on two occasions. *Paracyclops fimbriatus poppei* and *Megacyclops viridis* both colonised during May - September 1986 (Fig. 7.7b) and *Megacylops viridis* showed increased density during September - January 1987. *P.fimbriatus* shows some relationship with naids at this site, accounting for over 99% of the variation measured, but this may be a similar requirement in the pipe environment rather than any relationship between the taxa. Once the change from R.G.F. to S.S.F. occured, no cyclopoids were present in the pipe, (though *Paracyclops* sp. and *Megacyclops* occurred occasionally at drift levels) unlike Ravensthorpe and Guilsborough where *Acanthocyclops bisetosus* occurred.

7.5.2.2.3) Chydorids

The chydorids at this site showed an increase in population levels over those found initially in the undisturbed pipe (Fig. 7.7e). *Chydorus sphaericus* was present in high densities though numbers decreased during January - May 1987 as did those of *A.rectangula*. *Chydorus* numbers increased following this period, despite the change to the S.S.F. at Ravensthorpe. *Chydorus* density at this site was related to D.O.C. (87% of the variation, see Table 7.9). *Alona rectangula* and *Alona guttata* were present initially and reinfested during the May - September 1986 and September - January 1987 periods. On successive sampling occasions *A.rectangula* decreased as *A.guttata* increased. However, *A.guttata* failed to recolonise during January - May 1987. The period September - January had the greatest percentage of egg bearing *Chydorus* (46.7%); egg bearing *A.rectangula* decreased to 16.7% from the previous occasion (25.0%); while *A.guttata* increased from 20.0% to 50.0% which may explain the change in reinfesting density of *A.guttata* (increase) and *A.rectangula* (decrease) between the two occasions.

7.5.2.2.4) Mites

Soldanonellyx and *Lobohalacarus* were both present in the pipe during the sampling period (Fig. 7.7d). *Lobohalacarus* was not present in the initial sample and colonised during May - September 1986. *Soldanonellyx* failed to recolonise during September - January 1987 (as did *Lobohalacarus*) but reinfested during every following period. The variable temperature showed a relationship with *Soldanonellyx* at this site (96% of

measured variation), suggesting seasonal changes in the recolonising population of this species.

7.5.2.2.5) Other taxa

Naid worms recolonised during May - September 1986 and September - January 1987 (Fig. 7.7e), then failed to recolonise. If animals were not removed initially, numbers could have increased during May - September 1987, then a second failure to remove all the animals could have lead to the increase in density during the winter, since naid worms can reproduce during the winter period (Chapter 5). Nematodes, tardigrades and Microturbullaria were all initially present at this site but failed to recolonise.

7.5.3) Sites sampled on a six-monthly basis

The significant multiple regressions from these two sites were included as Tables 7.10 and 7.11, but are not discussed since the degrees of freedom are low.

7.5.3.1) Brookside, Weedon

Sampling this site involved two flushes of a branched pipe, since the first sampling occasion led to the bursting of a hydrant net on one branch. This meant, the sample from the second branch did not include the 'shared' portion of the leg (see Appendix VIII) and hence sampling always involved an initial flush of the first leg and shared leg.

The pipe length is at the same location as West Way, Weedon (section 7.5.2.1) only runs level rather than uphill. Pressure at this site was good and samples were always taken at high rates of flow.

7.5.3.1.1) Chironomids

Chironomid numbers at this site did not recover during the first two periods, May 1986 to May 1987 (Fig. 7.8a), despite being present as drift in both cases. During November - May 1987, chironomid larvae, including *Corynoneura*, reappeared with Tanytarsini dominant. The final six month period was dominated by Tanypodinae larvae (but at low density).

7.5.3.1.2) Copepods

Bryocamptus pygmaeus and *Atheyella crassa* did not recolonise at all during the sampling period. The cyclopoid copepods (Fig. 7.8b) showed a change in fauna, with *Eucyclops agilis* initially present, replaced by *Paracyclops fimbriatus poppei* and *A.robustus* during the May - November period following pyrethrin dosing in May 1986. After November 1986, no cyclopoids recolonised throughout the remainder of the study period.

7.5.3.1.3) Chydorids

This site was the only in this study to have *Graptoleberis* present. Initially, May 1986, *Graptoleberis* had a high proportion of females with eggs (31.8%), and showed a strong correlation with temperature (though the degrees of freedom for this regression were low). *Graptoleberis* and *Chydorus* both increased in density during May to November 1986 (Fig. 7.8c), but were not present during the following period November - May 1987. During May - November 1986, *Graptoleberis* had 9.3% of females with eggs. The May - November 1987 period showed that *Chydorus sphaericus* was replaced by *Alona rectangula*, and though *Graptoleberis* was still present with *A.rectangula*, it was less numerous. This period had no *Graptoleberis* with eggs but *A.rectangula* had 56.2% females with eggs. The final period, November - May 1988 showed low recolonisation density, *Graptoleberis* having 28.6% reproductive females, similar to the corresponding period during 1986/1987.

7.5.3.1.4) Mites

Soldanonellyx and Tyroglyphidae were present at this site (Fig. 7.8d). *Soldanonellyx* increased reinfestation density over initial levels during the first sampling period. *Lobohalacarus* only occurred during the November to May periods, when both species were at low densities of reinfestation.

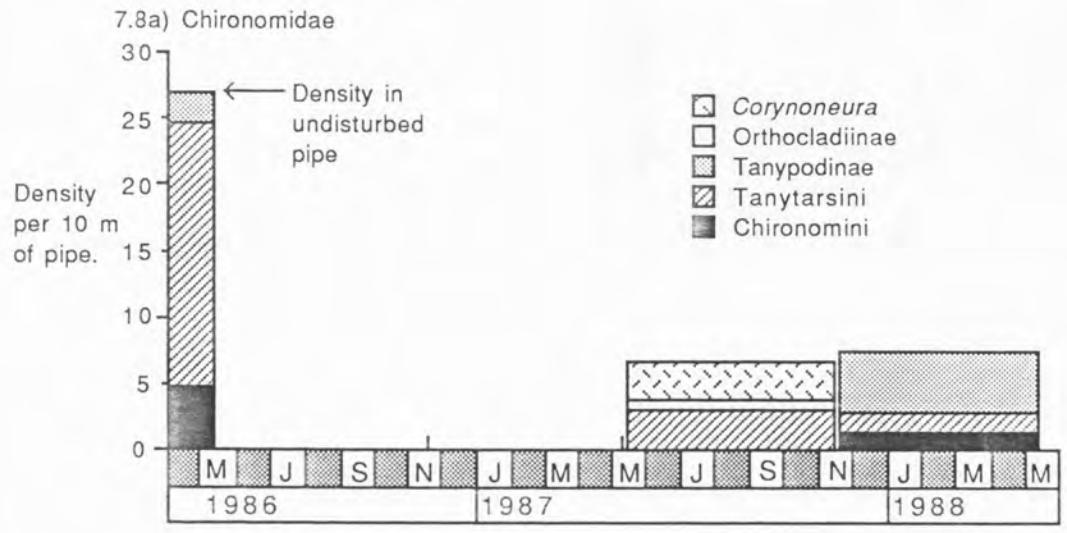
7.5.3.2) West Haddon Road, Cold Ashby

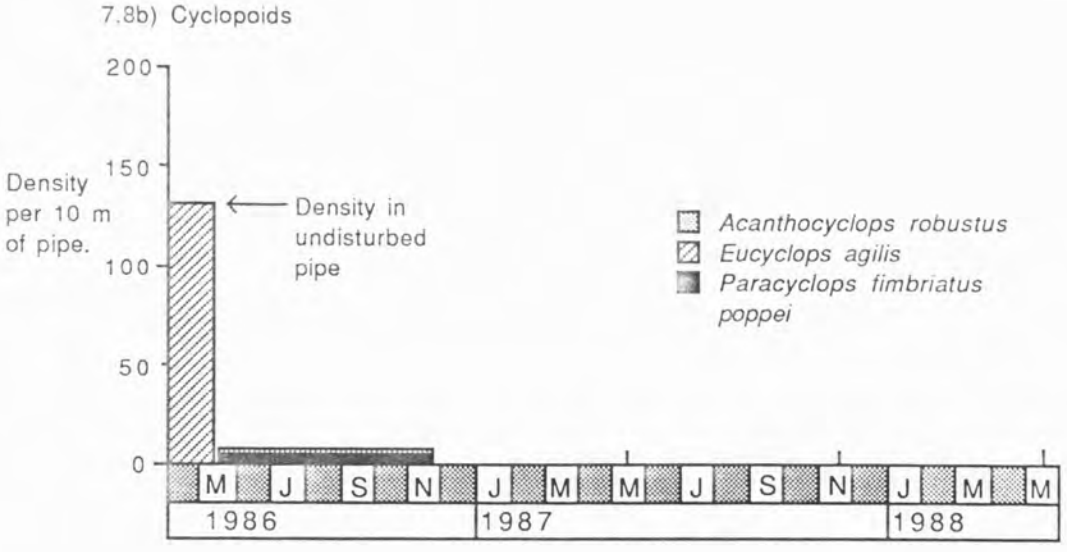
This site suffered from low pressure and was at the limit of flushing rate acceptable for the application of the sampling model to obtain quantitative data from each flush series. The feed at this site was the same as at Stanford Close, Cold Ashby (section 7.5.2.2). It became apparent from original plans after sampling had commenced that the hydrant at this site did not lie at the extreme end of the pipe, but had a 'dead space' beyond the hydrant from which reinfestation would be possible after any flushing of the pipe. This site changed to S.S.F. water during July 1987.

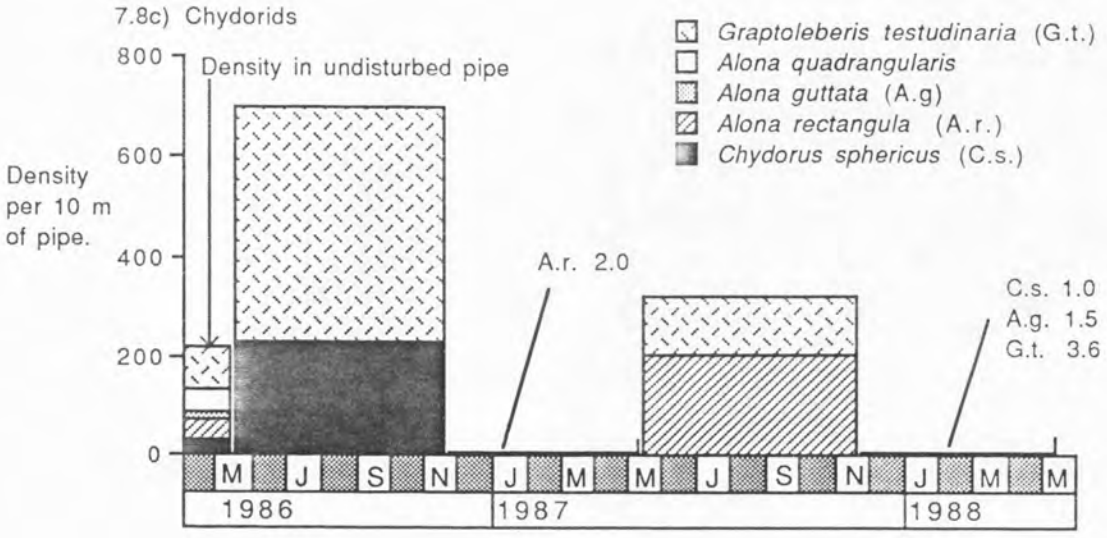
7.5.3.2.1) Chironomids

Only the larvae of Chironomini were present initially at this site (Fig. 7.9a). Orthocladiinae were present during May - November 1986, and Tanytarsini appeared between November and May 1987. The remaining two periods failed to produce any chirionomid larvae which may be a feature of the change from R.G.F. to S.S.F.

Fig. 7.8) Animal density per 10 metres of pipe at Brookside, Weedon






7.8c) Chydorids
Density in undisturbed pipe
Density per 10 m of pipe.
800
600
400
200
0
Graptoleberis testudinaria (G.t.)
Alona quadrangularis
Alona guttata (A.g)
Alona rectangula (A.r.)
Chydorus sphericus (C.s.)
A.r. 2.0
C.s. 1.0
A.g. 1.5
G.t. 3.6
M J S N J M M J S N J M M
1986
1987
1988

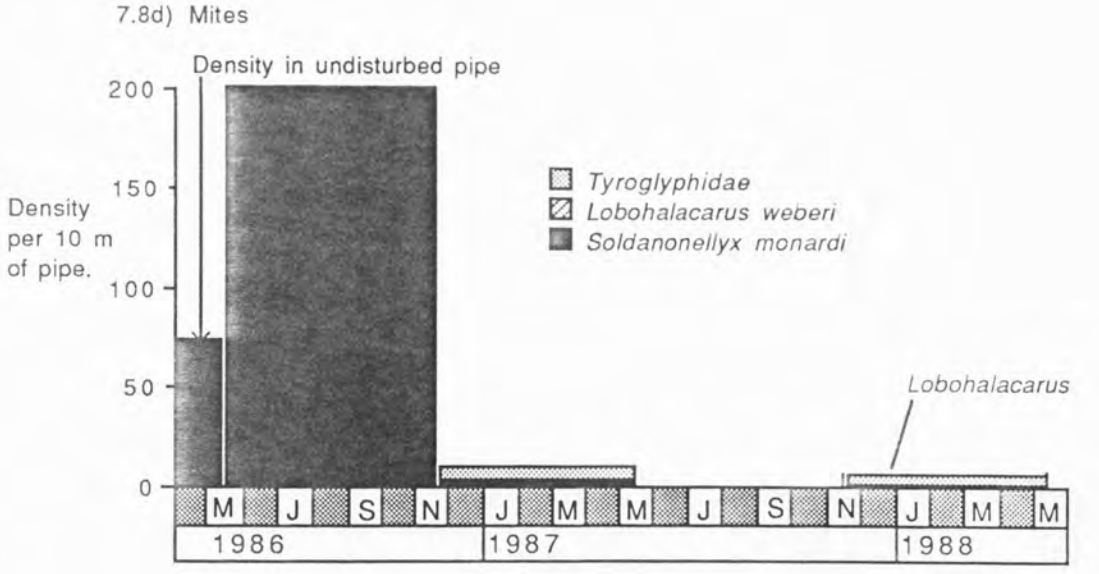
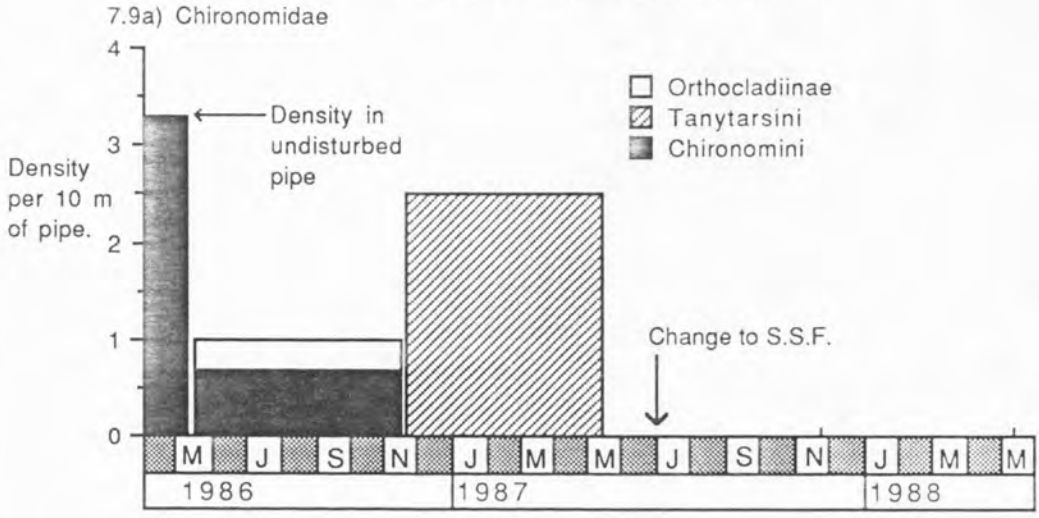

7.8d) Mites
Density in undisturbed pipe
Density per 10 m of pipe.
200
150
100
50
0
Tyroglyphidae
Lobohalacarus weberi
Soldanonellyx monardi
Lobohalacarus
M J S N J M M J S N J M M
1986
1987
1988

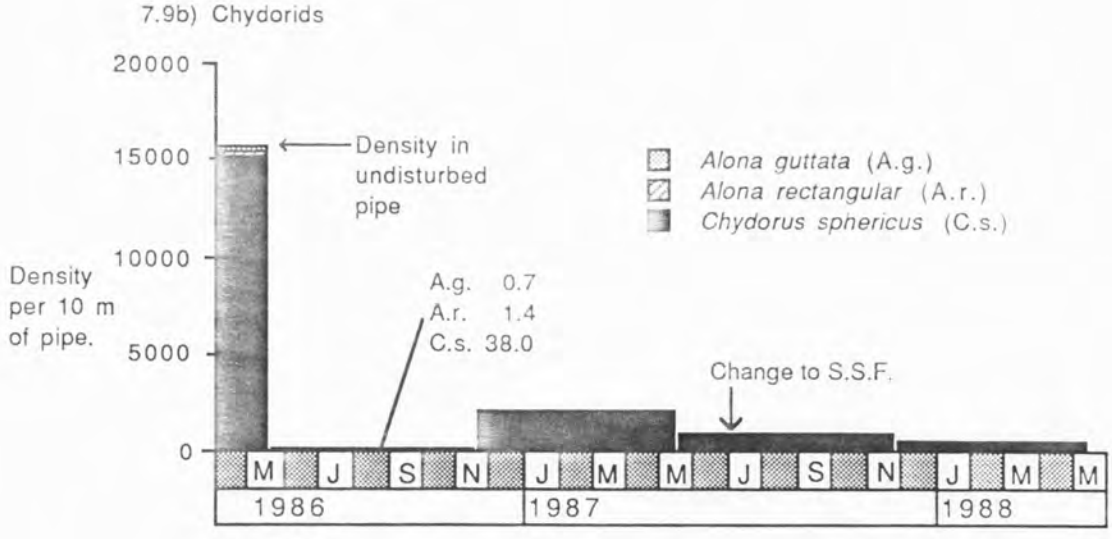
Table 7.10) Multiple regression of taxonomic groups and environmental variables at Brookside, Weedon

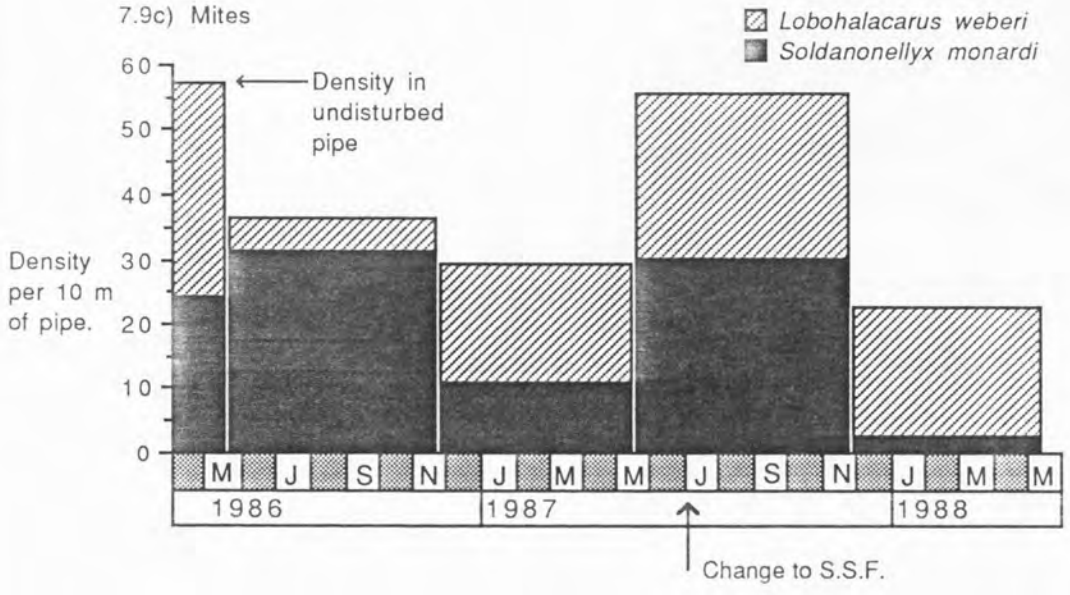
[1] : indicates relationships referred to in the text.

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	R^2	D.F.
Chiron	0.00000	0.50800	Tanypo			1.00000	2
Tanypo	0.00000	1.96780	Chiron			1.00000	2
Coryno	-0.03490	0.25737	A.rect			0.93759	2
P.f.popp	0.00000	1.42439	A.rob			1.00000	2
A.rob	0.00000	0.70205	P.f.pop			1.00000	2
Chydorus	-6.77136	1.69007	Press			0.99976	2
	-6.02060	1.50515	Press	0.31758	P.f.popp	1.00000	1
Grapto	6.81774	-0.48051	Temp			0.99491	2
	6.95166	-0.47400	Temp	-0.09306	DW/Vol	1.00000	1
A.gutt	0.00000	1.04663	Chiron			1.00000	2
A.rect	0.15904	3.72384	Corynon			1.00000	2
Soldanonell	0.31384	3.57097	A.rob			0.93038	2
	0.66126	3.41484	A.rob	-0.23688	P.O.C.	0.99999	1

Fig. 7.9) Animal density per 10 metres of pipe at West Haddon Road, Cold Ashby






7.9c) Mites
Lobohalacarus weberi
Soldanonellyx monardi
Density per 10 m of pipe.
60
50
40
30
20
10
0
Density in undisturbed pipe
M J S N J M M J S N J M M
1986
1987
1988
Change to S.S.F.

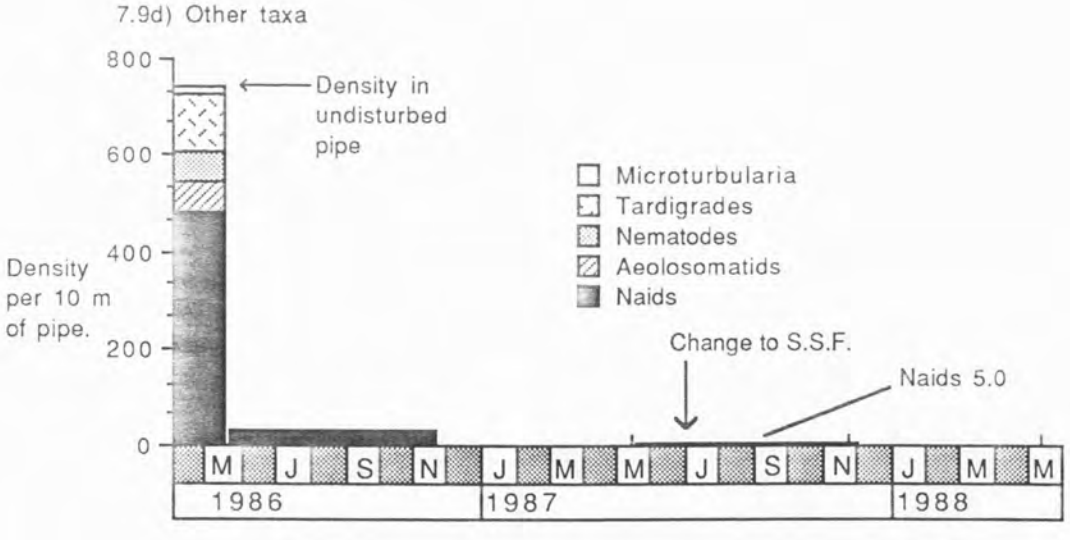

7.9d) Other taxa
Density per 10 m of pipe.
800
600
400
200
0
Density in undisturbed pipe
Microturbularia
Tardigrades
Nematodes
Aeolosomatids
Naids
Change to S.S.F.
Naids 5.0
M J S N J M M J S N J M M
1986
1987
1988

Table 7.11) Multiple regression of taxonomic groups and environmental variables at West Haddon Road, Cold Ashby

[1] : indicates relationships referred to in the text.

Dependent variable	Intercept	B_1	Var_1	R^2	D.F.
Chiron	0.00000	2.02249	Orthoc	1.00000	1
Orthoc	0.00000	0.49444	Chiron	1.00000	1
P.f.popp	-1.27845	0.14205	Temp	1.00000	1
M.vir	-0.62720	0.69688	Temp	1.00000	1
Chydorus	3.82145	-0.92192	Pressure	0.99555	1
A.rect	0.00000	1.64987	Chiron	1.00000	1
A.gutt	0.00000	1.00000	Chiron	1.00000	1
Soldanon	2.46324	-0.10647	Temp	0.99851	1

7.5.3.2.2) Copepods

Both species of harpacticoid copepod failed to recolonise this site, following the flush in May 1986. *Paracyclops fimbriatus poppei* and *Megacyclops viridis*, (present in the initial sample from this site along with copepodites which appeared to be *Megacyclops*) recolonised during the first winter, November - May 1987.

7.5.3.2.3) Chydorids

Chydorus sphaericus failed to recover to the densities initially present at the undisturbed pipe, but was present at each sampling occasion with a maximum reinfestation during the November - May 1987 period when 22.9% of females carried eggs or young (Fig. 7.9b). *Alona rectangula* and *Alona guttata* were both present initially and recolonised at low densities in the May - November 1986 period, but failed to re-establish in the mains after that time.

7.5.3.2.4) Other Taxa

Two species of mite, *Soldanonellyx* and *Lobohalacarus* were present in every sample taken from this site (Fig. 7.9c) and recover to levels close to initial levels during May - November 1987. The naids present initially at this site failed to recover to pre-flushing levels and did not occur during winter periods (Fig. 7.9d).

7.5.4) Sites sampled after periods greater than six months.

These three sites were sampled with slightly different periods between flushes, 10, 12 and 14 months. Those sites sampled at 10 and 14 months were flushed twice initially. None of these three sites were sampled enough times to consider multiple regression analysis of the data provided.

7.5.4.1) Park Lane, Watford

Park Lane is a small diameter dead end fed by a low pressure 5" main at the extreme of the Ravensthorpe Supply Zone. Samples were removed from this site at approximately 7.0 l s^{-1}, the minimum rate of flow for application of the sampling model. After the change from R.G.F. to S.S.F. the pressure at this site which was then fed from Ravensthorpe rather than Pitsford dropped slightly to 6 l s^{-1}, but have been included here as this rate was also found at other sites.

7.5.4.1.1) Taxa present at Park Lane, Watford

This site had no chironomid larvae present at any time during the sampling period. This was unexpected since the feed pipe was the same as

that which feeds West Haddon Road, Watford (Chapter 6) which is adjacent to this site where numerous Tanytarsini were present.

The harpacticoid *Nitocra hibernica* (Fig. 7.10a) was able to recolonise between flushes. The cyclopoid *Eucyclops agilis*, not initially present, colonised during the first 12 month period, and was present in the second period between flushes, but drift levels could not be determined. No other cyclopoids occurred at this site (Fig 7.10b).

Chydorus and *Alona affinis* colonised during the first period, but again, drift levels could not be determined. *Chydorus* reached a high density during the second period.

Soldanonellyx and *Lobohalacarus* both colonised during each period between flushes, though *Lobohalacarus* was not present in the initial sample from this site (Fig. 7.10c).

The remaining species present, naid worms and the gastropod *Hydrobia jenkinsi* occurred in the second and first periods between flushes respectively, though both were present at the undisturbed pipe.

7.5.4.2) Parsons Close, Nether Heyford

A small pipe leg, fed directly from a 12" high pressure main, this site was sampled at a high rate of flow, ensuring maximum removal of animals.

This site was sampled in April 1986 and the again in May 1986, before being left for a 10 month period and then a further 12 months.

7.5.4.2.1) Taxa present at Parsons Close, Nether Heyford.

During the second period May - June 1987, both Tanytarsisni and Tanypodinae were able to recolonise (Fig. 7.11a), along with *Bryocamptus pygmaeus* (Fig. 7.11b) and *Alona guttata* (Fig. 7.11c), None of the groups appeared in the first or third period between flushes.

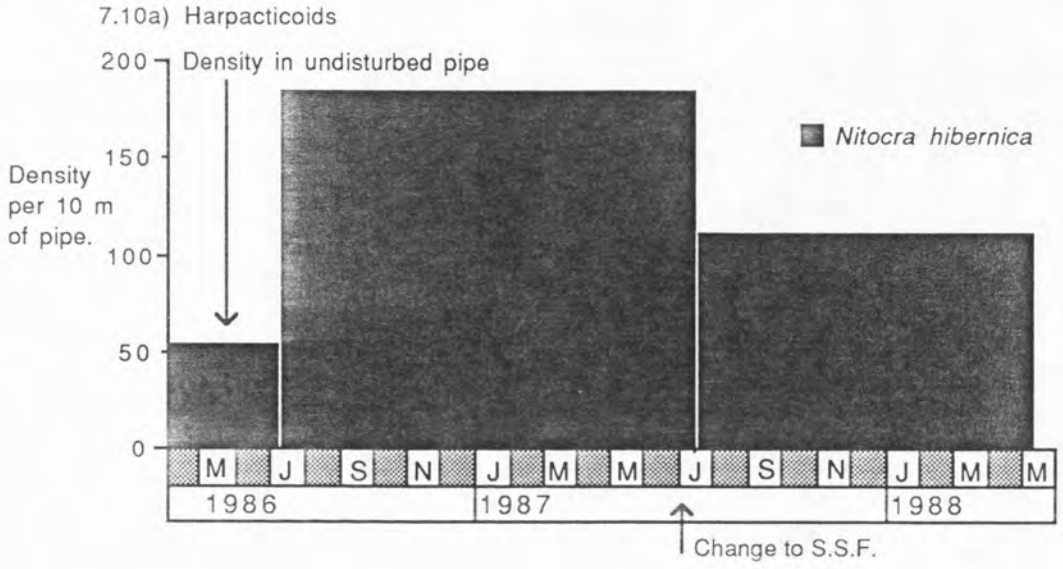
Soldanonellyx (Fig. 7.11d) colonised the main during this final period, but was not present initially. The other species present, both types of *Paracyclops* sp., failed to recolonise.

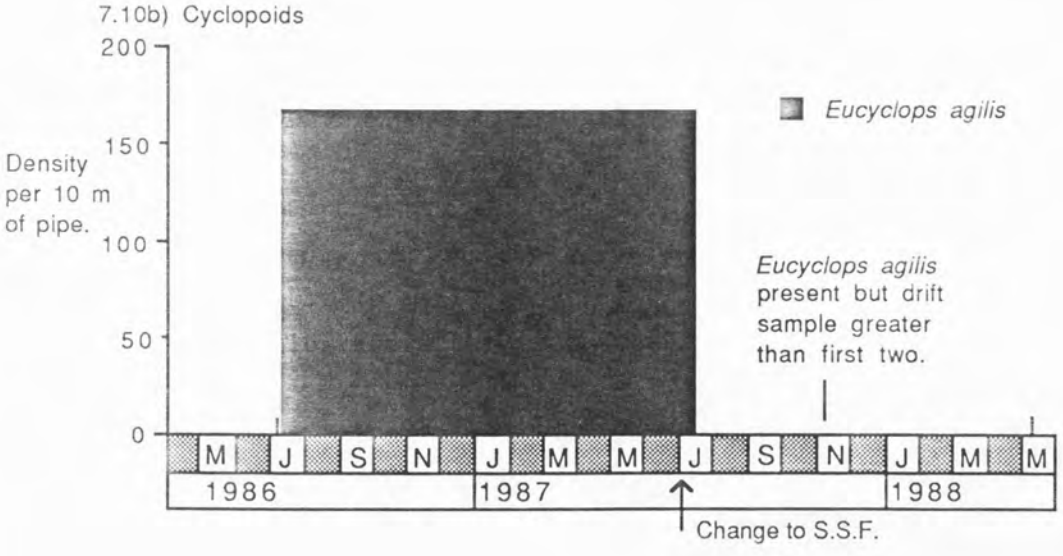
7.5.4.3) Wakefield Way, Nether Heyford

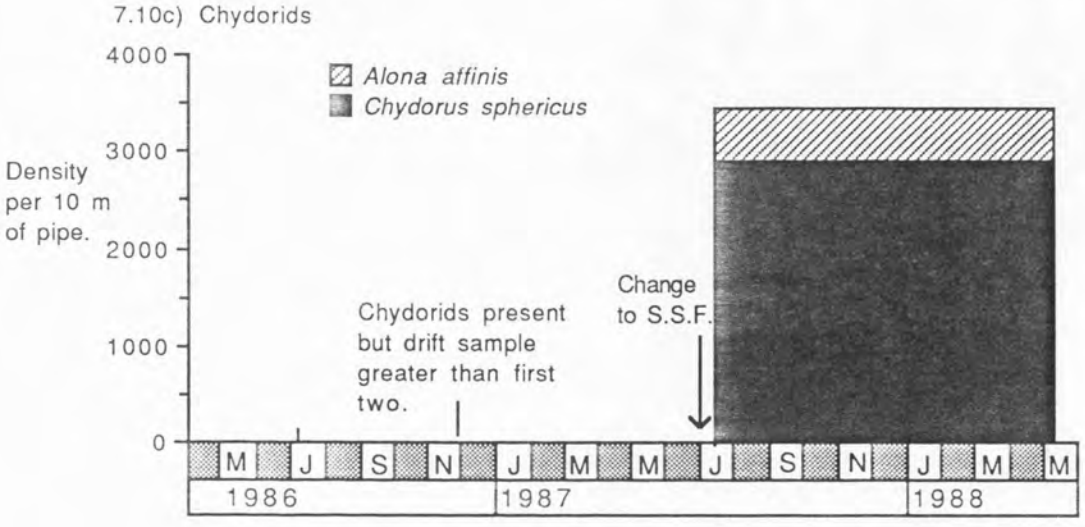
This site was flushed initially then after a 14 month period, a 10 month period and finally at the end of the study after a 6 month period.

The leg itself appeared to be fed directly from the 12" high pressure main, though two different plans show that at one time it was believed to be fed by an 8" main which ran from the 12". The former, direct feed was accepted by the Inspector responsible for this area and all the work assumes this was the case. Flush samples were removed from this site at high rates of flow enabling maximum removal of animals.

Fig. 7.10) Animal density per 10 metres of pipe at Park Lane, Watford






7.10c) Chydorids
4000
3000
2000
1000
0
Density per 10 m of pipe.
Alona affinis
Chydorus sphericus
Chydorids present but drift sample greater than first two.
Change to S.S.F.
M J S N J M M J S N J M M
1986
1987
1988

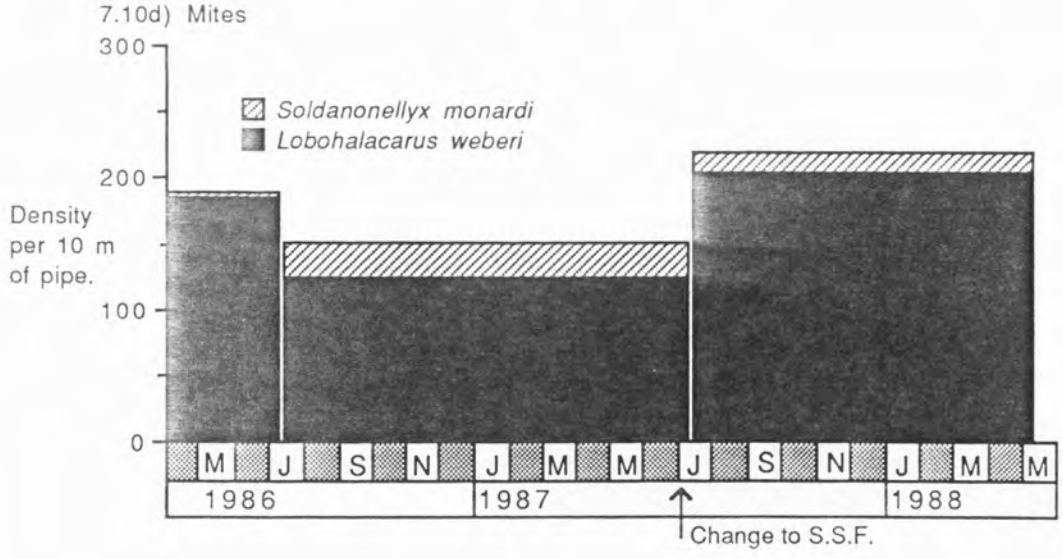
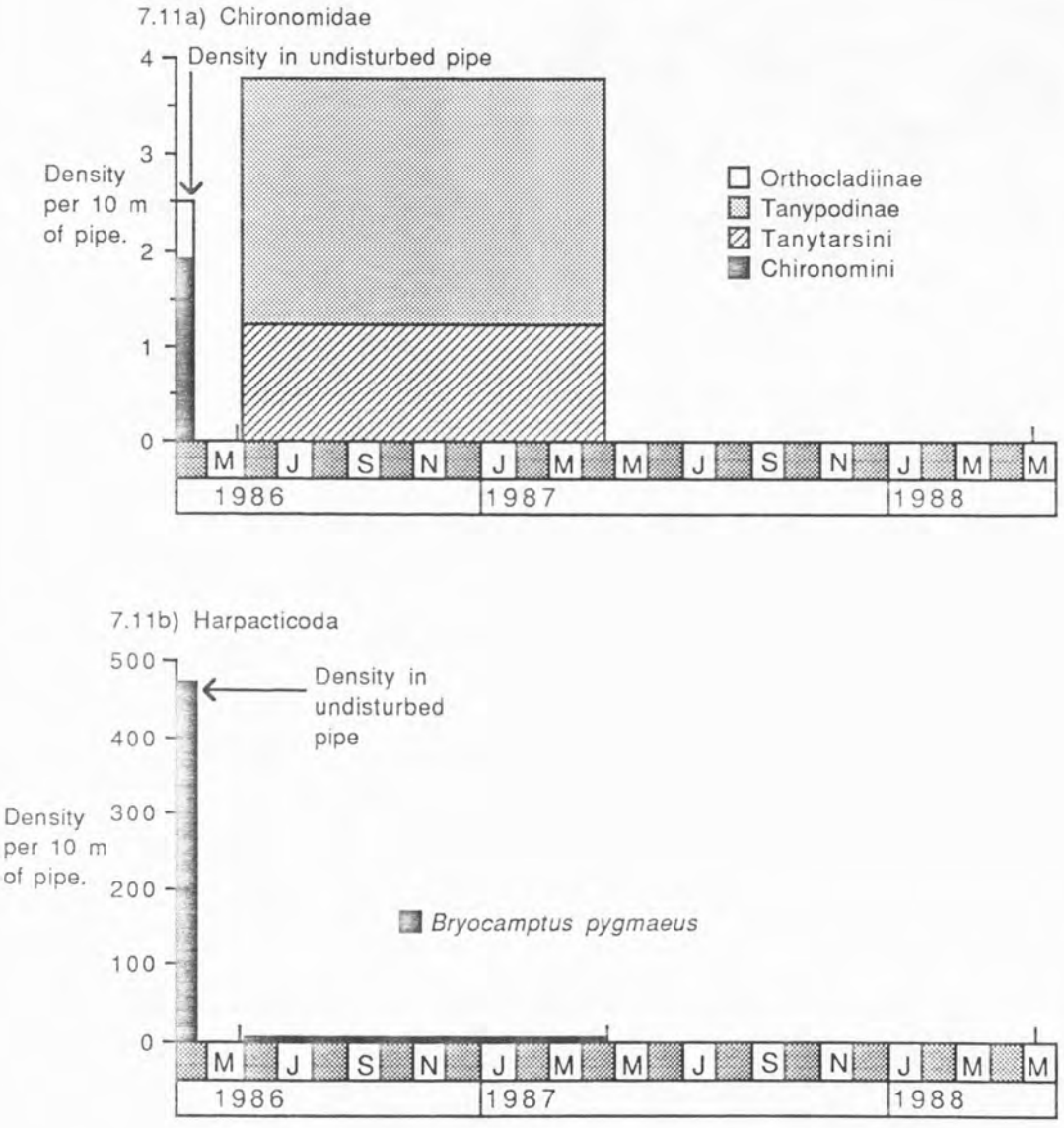
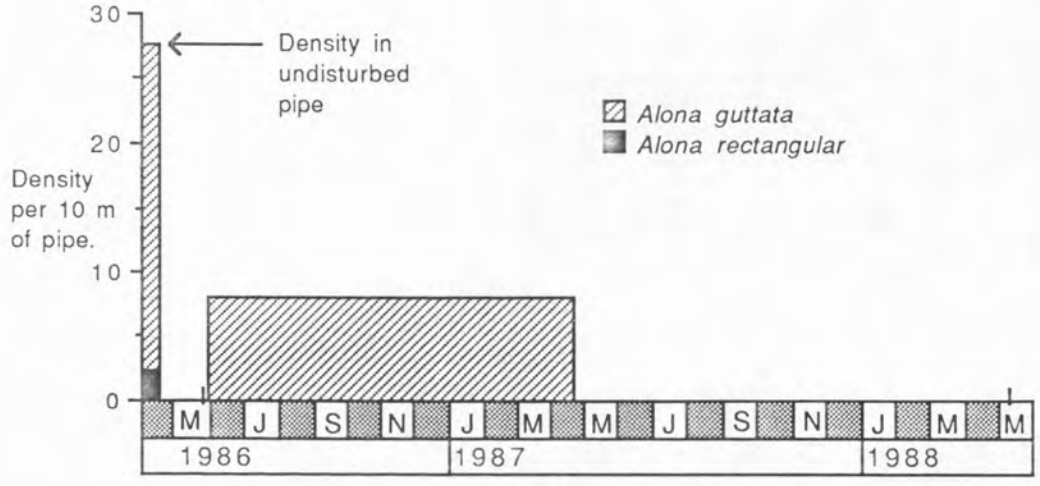

7.10d) Mites
300
200
100
0
Density per 10 m of pipe.
Soldanonellyx monardi
Lobohalacarus weberi
M J S N J M M J S N J M M
1986
1987
1988
Change to S.S.F.

Fig. 7.11) Animal density per 10 metres of pipe at Parsons Close, Nether Heyford



7.11c) Chydorids



7.11d) Mites

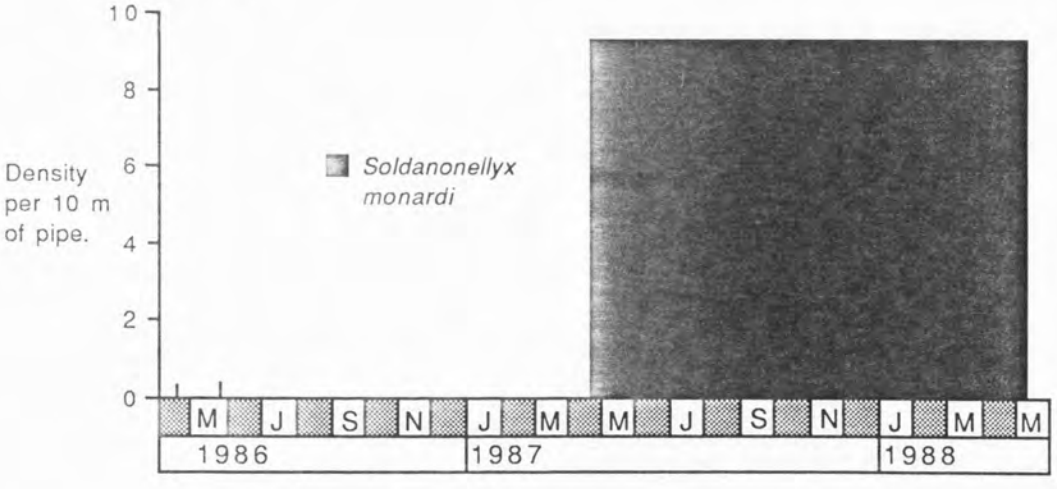
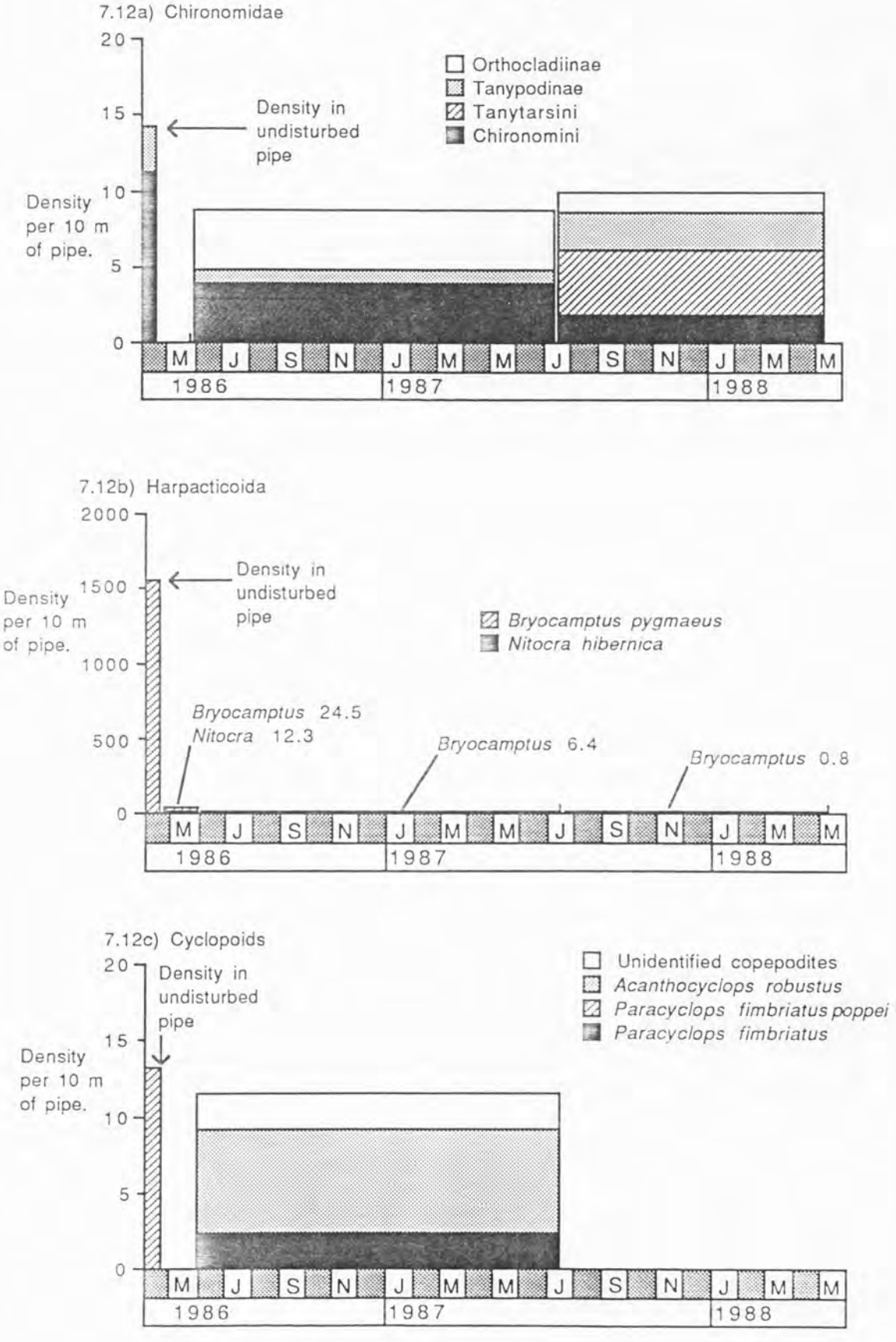
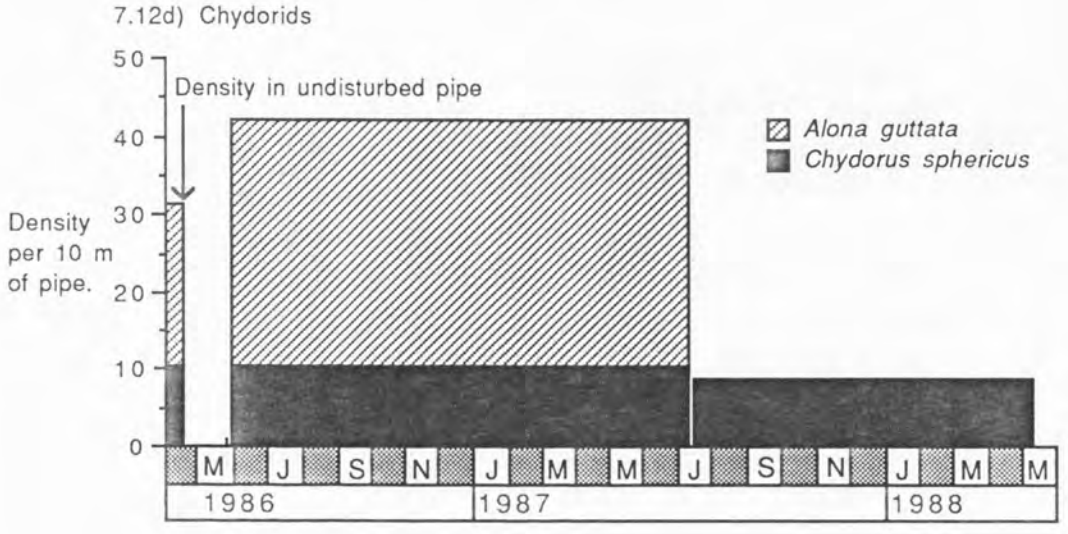
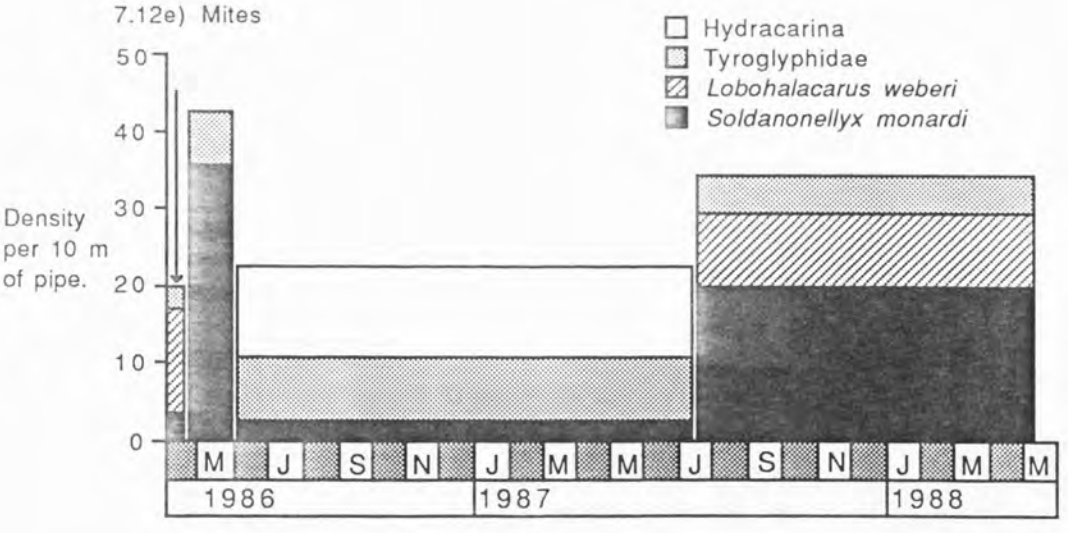


Fig. 7.12) Animal density per 10 metres of pipe at Wakefield Way, Nether Heyford




7.12d) Chydorids
Density in undisturbed pipe
Alona guttata
Chydorus sphericus
Density per 10 m of pipe.
50
40
30
20
10
0
M J S N J M M J S N J M M
1986
1987
1988


7.12e) Mites
Hydracarina
Tyroglyphidae
Lobohalacarus weberi
Soldanonellyx monardi
Density per 10 m of pipe.
50
40
30
20
10
0
M J S N J M M J S N J M M
1986
1987
1988

7.5.4.3.1) Taxa present at Wakefield Way, Nether Heyford

Chironomid larvae, Tanypodinae, Chironominae and Orthocladiinae appeared during both long sampling occasions, but Tanytarsini occurred only during the second period between flushes, at a high density (Fig. 7.12a).

Both species of harpacticoid were present in the 'undisturbed' site and recolonised during the initial one month sampling period. *Bryocamptus* also appeared at low densities in the remaining periods (Fig. 7.12b). The cyclopoids *A.robustus* and *Paracyclops fimbriatus* colonised during the second period but not during the third (Fig. 7.12c). *Paracyclops fimbriatus poppei* did not reinfest this site.

Both *Chydorus* and *Alona guttata* appeared in the second period (Fig. 7.12d), but only *A.guttata* occurred during the third period November to May.

Three groups of mites were present at this site. The halacarids, *Soldanonellyx* and *Lobohalacarus* (Fig. 7.12e). Tyroglyphidae were present in all samples from this site, and Hydracarina appeared during the second period but not the third, as was the case for *A.robustus*.

7.6) Discussion of Species trends

The log transformed density of each species or taxonomic group were analysed with both environmental and operational sites for all samples taken after the initial flush of each site. This examination of all sites in the same analysis gave an indication of the effects of operational parameters and also of flushing itself on the various animals present.

The regression analyses are shown in Table 7.12. Analysis was carried out without zero values for taxa to determine whether relationships held true when any two taxa were present and were not distorted by zero values on either axis or a large number of points through the origin.

Tanytarsini and Tanypodinae showed significant relationships with P.O.C. and D.O.C. respectively, with 44% of the variation in Tanytarsini accounted for by P.O.C. and 42% of the variation in Tanypodinae accounted for by D.O.C. It appeared that these two taxa were both affected by the amount of carbon in the system. Tanytarsini are tube dwelling chironomids that lie on the substrate ingesting material and high levels of P.O.C. may indicate a large quantity of 'loose' sediment for this group to feed on. The Tanypodinae density increased with the organic matter present in the system, and D.O.C. may be a means of obtaining a relative measure of the abundance of bacteria at the bottom of the benthic food chain. Orthocladiinae were affected by temperature (Accounting for only 19% of the variation) which suggests that in the Orthocladiinae recolonising

Table 7.12) All sites: regression of environmental and operational parameters with taxa, excluding zero values in analysis

Dependent variable	Intercept	B_1	Var_1	B_2	var_2	B_3	var_3	R^2	D.F.
[1]Tanytarsini	0.29853	0.11419	P.O.C.					0.44644	22
[1]Tanypodinae	0.27534	0.01203	D.O.C.					0.42859	11
[1]Orthocladiinae	0.14296	0.01902	Temp					0.19253	26
Corynoneura	0.26649	0.00232	F.Time					0.83104	3
[1]Chydorus	2.69374	-0.24507	Flush					0.28664	23
	3.57246	-0.23072	Flush	-0.28301	Pressure			0.52470	22
	2.78300	-0.15185	Flush	-0.29478	Pressure	2.66519	Chlorine	0.64467	21
[1]A.rectangula	0.53540	3.20591	Chlorine					0.44750	14
[1]Soldanonellyx	1.38475	-0.13938	Flush					0.30434	35
	0.92050	-0.10009	Flush	0.00228	F.Time			0.43660	34
	0.96495	-0.11131	Flush	0.00334	F.Time	-0.07330	DW/Vol	0.51670	33

[1] : indicates relationships referred to in the text.

density is seasonal, probably due to penetration of treatment. However, if this was the case the fact that Chironomini did not show a similar pattern must be considered.

Chydorus sphaericus was found to be affected by flush number (accounting for 29%) with numbers dropping as the number of flushes increased; pressure (23%) (low pressure linked with more *Chydorus*) and chlorine (11%). This suggests that *Chydorus* is most numerous at low pressure sites (where sediments will be more likely to settle out) and was hard to completly remove from the mains, but that repeated flushing of a site will eventually remove it. *Alona rectangula* shows greater density at high chlorine levels.

Of the mites, *Soldanonellyx*, like *Chydorus*, appeared to be hard to remove, levels decreased over the sampling period with the number of flushes. Tyroglyphidae levels increased with time between flushes as would be expected.

If one considers the significant regressions on a site by site basis, few were repeated throughout, though links between Orthocladiinae and Chironomini; Tanypodinae and Tanytarsini; *Chydorus* and *Alona guttata*; *Alona guttata* and *Alona rectangula*; and *Paracyclops fimbriatus* and *Paracyclops fimbriatus poppei* do appear more than once.

7.6.1) Chironomid larvae

The Chironomini peaked between June and September 1986 in all of the two-monthly sites, but following the switch to S.S.F. there appeared to be no recolonisation by any chironomid larvae. This change is supported by the four and six-monthly sites at Weedon and Cold Ashby, where no chironomid larvae appeared after the change to S.S.F. at the Cold Ashby sites.

The Orthocladiinae did not show any distinguishable pattern relating to all sites, but did show a positive relationship with Chironomini at Stanford Close, Cold Ashby and West Haddon Road, Cold Ashby.

The Tanypodinae and Tanytarsini show a positive relationship at Ravensthorpe which may be a link between predator and prey. However, if this link was strong, evidence of predation of Tanytarsini would have been expected in more Tanypodinae guts examined. It is more likely this is a coincidence, with both groups occuring at sites where biomass is high. Tanypodinae and *M.viridis* appeared during the same periods at Berry Close, Rothersthorpe. The Tanytarsini occured in periods between flushes at any time of year, with the greatest densities building up during the months January - March.

Corynoneura was infrequent in these sites, occuring only five times at four sites, and it was not possible to explain the presence at Weedon,

Guilsborough and Ravensthorpe other than to suggest that all the sites were near to large diameter trunk mains, while the other sites were not.

In summary, it appears that the change from R.G.F. to S.S.F. had a significant effect on the chironomid recolonisation of sites in this study. This suggests that the S.S.F. water contains considerably fewer chironomid larvae which have penetrated treatment, and that the chironomids that recolonised during the R.G.F. phase of the study were almost certain to be in the final water rather than penetrating at service reservoirs.

Chironomini and possibly Orthocladiinae showed seasonal variation with peaks of recolonisation in the summer, which linked with penetration peaks at treatment. However, Tanytarsini occurred at any time of year in low densities. The Tanytarsini group included both parthenogenetic and non-parthenogenetic species and therefore it was hard to determine any precise effects. There was no evidence to suggest that *Corynoneura* is a serious problem in this system.

The site at Park Lane, Watford was unique in never having chironomid larvae during the study. However, this site was at the extreme of the system and contained large numbers of naids, and *Hydrobia jenkinsi*, unlike any other site, and these may compete with chironomids for food if not removed by flushing.

7.6.2) Harpacticoids

At Watford, the harpacticoid *Nitocra hibernica* recovered to pre-flush densities and the change to S.S.F. had no effect whatever on its numbers. However, the other two year sites, Parsons Close and Wakefield Way, Nether Heyford, show that *Bryocamptus pygmaeus* failed to recover during any of the periods between flushes. Similarly at the four-monthly and six-monthly sampled sites, *Bryocamptus* failed to recolonise and *Nitocra* did not colonise.

The two-monthly sites showed some recolonisation but not to any great degree in the latter part of the study, and those sites which change to S.S.F. water appeared to have lower densities of recolonising animals.

It seems likley that *Bryocamptus* was present at most sites and penetrated treatment. This means it was always likely to be in the drift carried in the water flow. Thus recolonisation over a short period was possible (appearance in two-monthly sampled sites), but over longer periods, this species was unable to recolonise, suggesting conditions were still some way from those originally present in the pipe prior to flushing.

Nitocra hibernica was less common and the site where it occurred, Park Lane, Watford, appeared quite different from any other site in this

study. Being at the end of the system, it may be little influenced by sampling operations since its 'feed' main could be infested at as high a density as the pipe itself. This would account for the problems sampling this site where the third (drift) flush frequently contained a greater density than the first or second flush.

7.6.3) Cyclopoid copepods

The most common cyclopoids in the system, *Paracyclops fimbriatus* and *Paracyclops fimbriatus poppei* were associated at many of these sites (see also chapter 6). Significant regressions occurred at Ravensthorpe and Rothersthorpe. At the two-monthly sites both occurred at low density levels, though on some occasions (September - November 1987 Rothersthorpe and May - November 1988 Guilsborough), large numbers were removed. Whatever features enabled the genus *Paracyclops* to exist in the main appears to be shared by these two sub-species. Whether they are true species, sub-species or 'morphs', they exist at the same sites in this system.

Acanthocyclops robustus density in the pipes was linked with the R.G.F. water from Pitsford Storage Reservoir. Peaks only occurred at sites which were fed from Pitsford R.G.F. and only in the summer, the period of maximum penetration of treatment by cyclopoids (i.e. the greatest density of cyclopoids in the final water). These summer peaks did not however, appear at every site in both summers, and the differences in densities between the two years are unexplained. The site-by-site differences may be due to the proximity of large diameter feed mains, or service reservoirs. It is likely that this species maintained a population in the pipe and is 'boosted' in numbers every year.

After the switch to S.S.F., the species *Acanthocyclops bisetosus* appeared at the two sites nearest to Ravensthorpe Treatment Works. Ravensthorpe and Guilsborough both contained low densities of this species which was believed to be penetrating the S.S.F.. Other species occured at lower densities, so it appears the S.S.F. provided water with less animals. The failure to find *A.bisetosus* in the mains at Cold Ashby or Watford is assumed to relate to the distance between the sites, or perhaps to an effect of towers and reservoirs between these sites and treatment. Future study of the Ravensthorpe Supply Zone, would be of value to determine the speed of advance of this copepod through the system.

The cylopoid *Megacyclops viridis*, occurred particularly during March - May periods, but there is little information that can be deduced from the appearances of this species at sites during this study.

7.6.4) Chydorids

Alona quadrangularis occured in only undisturbed pipes during this study. This may be because this species only occurred in a 'climax community', or simply because it rarely penetrates treatment.

The two-monthly sites all seem to follow a similar pattern, with a large increase in density of animals during the first summer, which drops away over the winter of 1986/87, and little or no recolonisation during the summer of 1987. At each two-monthly site the species composition differs between flushes, but the recolonising species at each site were present during the previous period. This suggests that recolonisation is by animals left in the pipe after flushing rather than animals in the final water. Then as flushing progressed, the density of animals remaining in the pipe was reduced, and the 1986/87 winter flushes caused levels to drop to such an extent that recovery was not possible in the following summer.

Chydorids were the most numerous of all the taxa present in the mains, and densities were very large at sites left for a longer period than two months. Densities recolonising after the switch from R.G.F. to S.S.F. at two, four and six-monthly sites were lower, perhaps due to less organic material in better quality water from the S.S.F.

At Brookside, Weedon, *Graptoleberis* is present in the undisturbed pipe, but there is no dominant species unlike most other sites. *Graptoleberis* and *Chydorus* (and later *Alona rectangula*) all attained huge recolonising densities relative to numbers in the undisturbed pipe. This may be due to the failure of microturbellaria, tardigrades and nematodes to recolonise. If these taxa penetrate treatment only rarely or rarely survive passage through the system, a niche may be available for exploitation by rapidly colonising chydorids which were not removed by flushing and reproduce parthenogenetically from the beginning of the period between flushes.

7.6.5) Mites

Three of the two-monthly sites (not Berry Close, Rothersthorpe) show a similar pattern, with considerably lower numbers after the initial flush, which reduced as flushing continued. No animals occurred following the change to S.S.F. at the two-monthly sampled sites.

At sites sampled at regimes greater than two months, mites were able to recover despite the change to S.S.F. This may be a feature of lower pressure at these sites, which would lead to a low rate of flow when sampling and hence more animals were able to remain within the pipe following flushing.

Tyroglyphidae occurred during 1987 at these two-monthly sites and at Berry Close, Rothersthorpe, becomes the only species present following the six month recovery period.

7.7) General Conclusions

From the above results a number of features of the system can be defined.

1) Near to treatment or a large diameter feed, sites do not recover within four months to one year of flushing. Recovery does seem possible further from treatment at the extremes of the system because sites are fed through pipes with similar infesting communities.

2) Some chironomid larvae and *Acanthocyclops robustus* appear to be directly linked with penetration of treatment works and the density in the final water of the works.

3) Chydorids and mites appear to recolonise from animals remaining in the pipe rather than animals arriving in drift.

4) S.S.F. contains significantly fewer animals in the drift than R.G.F. and hence recolonisation is reduced.

5) The comunity generally decreases in 'recolonisation density' during the winter. This suggests that an ideal time to undertake control operations would be prior to any increase in animals during March onwards, when the animal density is relatively low.

CHAPTER 8) THE EFFECT OF FREQUENCY OF DISTURBANCE ON SPECIES RICHNESS, DIVERSITY AND DENSITY OF 'PROBLEM' TAXA.

8.1) Introduction.....245
8.2) Diversity and species richness: Huston's General Hypothesis of Species Diversity.....246
8.2.1) The relationship between taxonomic richness, diversity and environmental parameters at undisturbed sites.....248
8.2.1.1) Methods.....248
8.2.1.2) Results and Discussion.....249
8.2.2) Diversity and frequency of population reduction..249
8.2.2.1) Methods.....252
8.2.2.2) Results and Discussion.....252
8.2.3) The relationship between Diversity and taxonomic richness with likely measures of population reduction and population growth rate.....254
8.2.3.1) Methods.....254
8.2.3.2) Results and Discussion.....254
8.3) The relationship between particular problem species and the frequency of population reduction and environmental factors.....254
8.3.1) Methods.....254
8.3.2) Results and Discussion.....262
8.3.2.1) Chironomini.....262
8.3.2.2) Tanytarsini.....262
8.3.2.3) Orthocladiinae.....262
8.3.3) Conclusions.....263
8.4) Suggestion for work to determine whether animals in mains occur at random or in a predictable fashion.....263

CHAPTER 8) THE EFFECT OF FREQUENCY OF DISTURBANCE ON SPECIES RICHNESS, DIVERSITY AND DENSITY OF 'PROBLEM' TAXA.

8.1) Introduction

Much debate exists as to the nature of species richness and diversity and their effect on the stability of communities. One hypothesis, the 'conventional wisdom' as termed by Begon *et al.* (1986) was proposed by Elton (1958) - that more complex communities are more stable. The other view was proposed by May (1972) - that more complex communities are less stable. Begon *et al.* (1986) argue that complex and fragile communities will occur in stable and predictable environments while variable and unpredictable environments will support only simple robust communities.

The distribution system contains both locally stable and unstable environments. At the extremes of the system, sediment loading is higher and animals are less likely to be affected by pyrethrin treatment. Nearer treatment, pyrethrin will be at higher concentrations and animals are unlikely to have a substrate into which they can escape. Pyrethrin dosing, flushing and other cleaning operations can be assumed to be 'disturbances' rather than 'catastrophes' since there will always be a residual population to recolonise the available niches.

A successional sequence may exist in the pipes that leads to a stable community at 'predictable' sites (the ends of the system). Since these sites tend to be where severe infestation problems occur, the problem species may be associated with the later stages of any successional sequence. A more diverse community, one which is controlled by frequency of disturbance and population growth rates (as proposed by Connell 1978 and developed by Huston 1979) will lie between colonising stages and this climax community.

Whether diversity and taxonomic richness related to any environmental measure was determined by investigating the results from sites sampled for work described in Chapter 6. Sites sampled to investigate recolonisation (Chapter 7) provided a series of sites sampled at different frequencies of flushing. The general hypothesis of species diversity (Huston 1979) was considered as a model for the changes at these sites.

Changes in diversity and taxonomic richness over time indicated whether succession was taking place in the mains, or whether the recolonisation was a 'competitive lottery' as described by Begon *et al.* (1986). If succession ocurred, a decrease in diversity was expected at those sites with short intervals between flushing (flushing frequencies which prohibit from growth all but species with rapid rates of population increase). Sites flushed infrequently, at frequencies which allowed

species to compete, were expected to show little change in diversity. If a competitive lottery was taking place, all species would be able to recolonise and diversity was expected to maintain a constant level over time.

8.2) Diversity and species richness: Huston's General Hypothesis of Species Diversity

Huston (1979) assumed that ecosystems are not at equilibrium and that in this state, species richness and diversity have a predictable relationship with both the frequency of reduction and growth rate. Huston (1979) predicted the maintenance of a high level of diversity will take place when a reduced rate of competitive displacement allows a longer period of co-existence between competing species (assuming diversity to be related to the rate at which differences in competitive ability are expressed by different species). The rate of competitive displacement will be affected by two features of the ecosystem, the population growth rate and the degree of population reduction.

The population growth rate was defined by Huston as "a population specific intrinsic rate of increase". This is the rate at which a particular population of a species will increase in numbers and biomass in a particular environment. This "environmentally regulated potential rate of increase" will relate to the affect of parameters such as energy or nutrient availability in the system on the potential rate of increase of the species. Huston's model assumes that all competing species will react in the same way to such environmental parameters, and that the mean population growth rate will affect diversity in a predictable fashion (Fig. 8.1). Population growth rate will affect the rate of approach of the community to competitive exclusion since at low levels, competition is unlikely to occur because limiting factors will produce low densities of potentially competing species. At high population growth rates, competitive exclusion takes place and hence diversity will be reduced.

The term 'frequency of population reduction' was used by Huston to define "density independent, species independent reductions which affect the entire community being considered". If population reduction was density dependent, levels of diversity would be more likely to remain high, since the species with the greatest density would be reduced in numbers to a greater extent. This would reduce competitive displacement and allow populations of poorer competing species to survive. The factors which make up population reduction frequency can be biotic (such as predation) or abiotic (such as climate) and will have a predictable effect on diversity (Fig. 8.2). The severity of population reduction has a similar relationship with diversity, with increasing severity of

Fig. 8.1) The predicted relationship of diversity and population growth rate. (After Huston 1979)

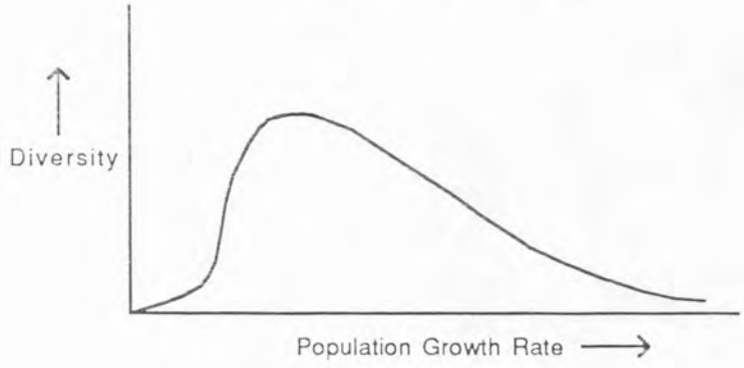


Fig. 8.2) Predicted relationship of diversity and frequency of population reduction (After Huston 1979)

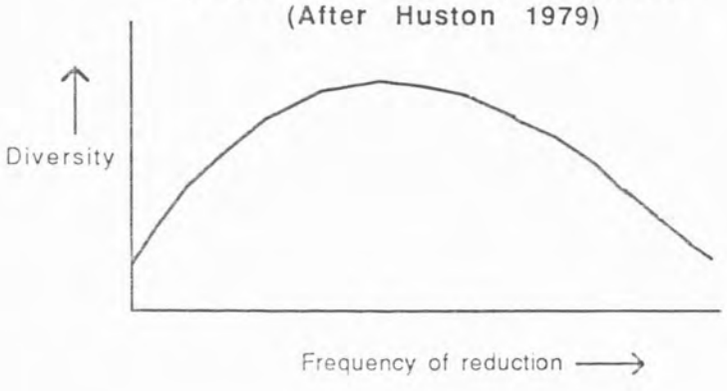
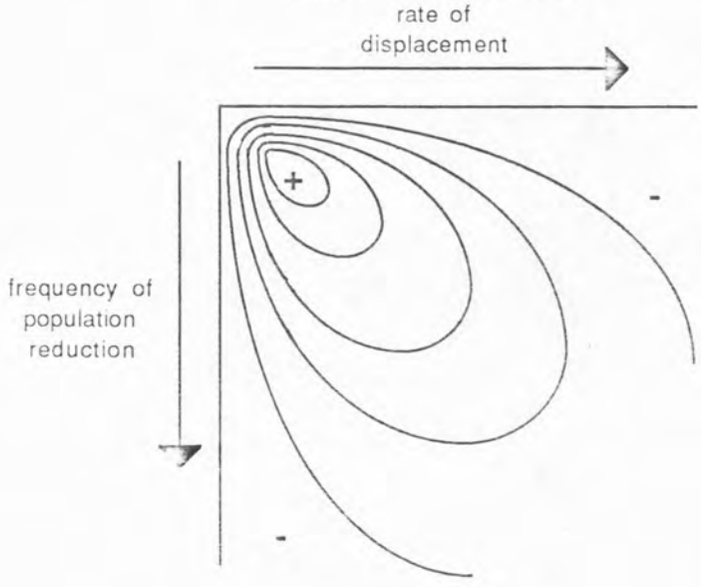


Fig. 8.3) Huston's Model of The General Hypothesis For Species Diversity (After Huston 1979)



reduction moving the graph to the right. Diversity will be at a maximum level when levels of population reduction are such that:

i) competitive exclusion is inhibited (unlike the situation at low levels of population reduction), and

ii) disturbance is not so frequent that recovery is not possible.

Huston (1979) combined these two parameters to produce the 'General Hypothesis' (Fig. 8.3, after Huston 1979), which predicts that diversity follows a pattern with the greatest diversity occuring at mean population growth rates just prior to competitive exclusion and when frequency of reduction does not lead to the loss of species because of harsh conditions.

Huston (1985) used this model to determine the reasons for a predictable depth gradient in diversity of coral reefs. In order to obtain the general model he assumed population reduction to relate to predation, wave and storm damage, sedimentation and tidal exposure, and population growth rates to be directly related to light availability. This work showed that actual measures of the axes used in the 'General hypothesis' are not required, if a measure of some parameter which directly affects these features of the ecosystem is available.

In the distribution system, various factors such as flow and pressure, chemical treatment, cleaning operations and predation will affect the extent of population reduction. In the work carried out in Chapter 7, the frequency of flushing at different sites was assumed to have the most influence on population reduction. The work carried out in chapters 6 and 7 did not produce any measure of population growth rate. However, if this is proportional to the density of taxonomic groups, then environmental parameters which affect this density (such as organic matter, P.O.C., D.O.C., age of water and temperature) can be used as the other axis for Huston's 'General hypothesis'.

8.2.1) The relationship between taxonomic richness, diversity and environmental parameters at undisturbed sites

8.2.1.1) Methods

By calculating the Shannon-Weiner index (as used by Magurran 1988) a measure of diversity can be determined.

$$\text{Shannon - Wiener Index: } H' = -\Sigma p_i \log p_i$$

where p_i is the proportion of all individuals in the ith species and is given by n_i/N. (n_i being the number of individuals of the ith species in

the sample and N the total number of individuals in the sample). This index produces a biased result compared to the complete formula for H' but Peet (1974) found that the error involved in using this simplified formula is rarely significant. If samples were known to remove the entire community from the pipe, the Brillouin Index would be a better measure of diversity (Magurran 1988), but since total removal is rare (removal coefficients (see chapter 3) of 0.9 being generally the maximum) the use of the Shannon - Wiener Index is justified.

The classification used in this work did not always relate to species. Chironomid larvae were only identified as far as tribe or genus, and other, less frequent, taxa to family. However, if all identification is standard throughout the samples, diversity relationships should still be apparent.

Various environmental parameters were considered to determine their relationship with diversity and taxonomic richness. The parameters examined were: organic matter in sediments, dry weight of sediments, temperature, age of water, D.O.C. and P.O.C. Examples of data used and values for taxonomic richness and H' are given in Appendix X.A.

8.2.1.2) Results and Discussion.

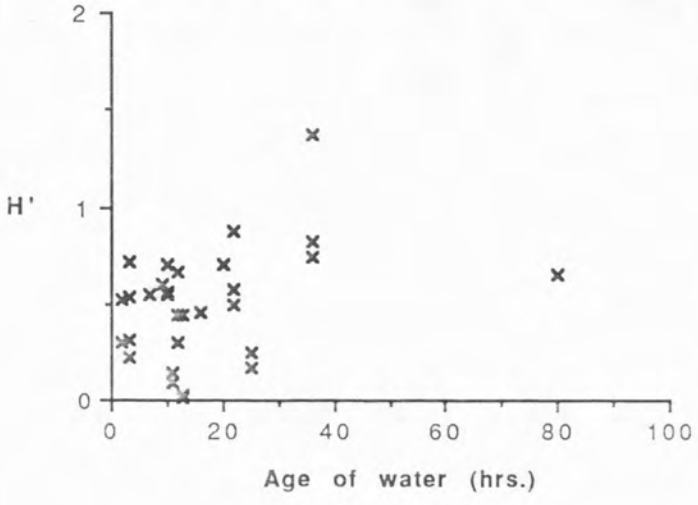
Figures 8.4 and 8.5 indicate the types of relationship found between diversity, taxonomic richness and environmental parameters. (Taxonomic richness is the number of taxa present as used in the analysis of Chapters 6 and 7.) Assuming age of water and organic matter reflect the population growth rate, there is no obvious link between the data from undisturbed sites (Chapter 6) (Figs. 8.4 and 8.5) and the prediction of Huston's model (Fig. 8.1). This may be an artifact of data being biased toward the lower end of the x axis for both variables. It is possible that none of the parameters examined are linked with mean population growth rates, or perhaps the model does not apply to this community.

8.2.2) Diversity and frequency of population reduction.

The sites used to consider recolonisation (Chapter 7) were taken to be a number of sites where 'disasters' (flushes) occurred at a particular frequency, and removed the majority of the population. The remaining animals and those introduced by drift could increase in number and the community recover, in which case Huston's model predicts the relationship shown in Figure 8.2. The severity of the disturbance has a similar effect on diversity as the frequency of disturbance, with the two axes being interchangeable (Huston 1979). The effect of flushing is severe, with population reductions of 90% common, and so diversity will tend to be shifted to the right of this graph.

Fig. 8.4) Relationship of Shannon-Wiener Diversity Index (H') with potential measures of population growth rate.

a) H' with age of water



b) H' with organic content of sediments

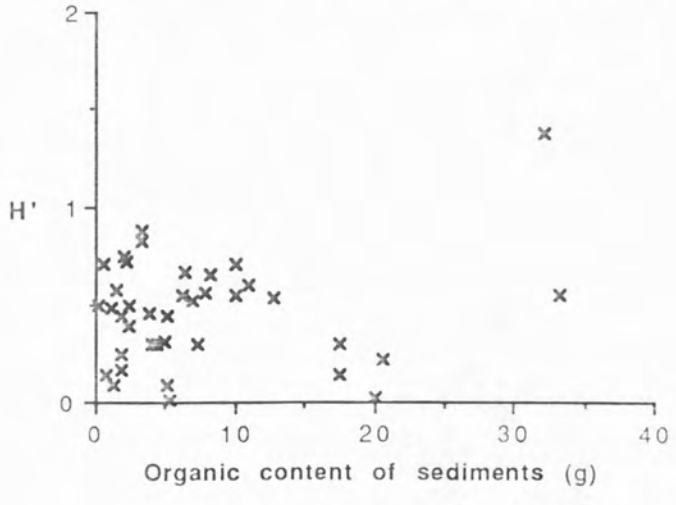
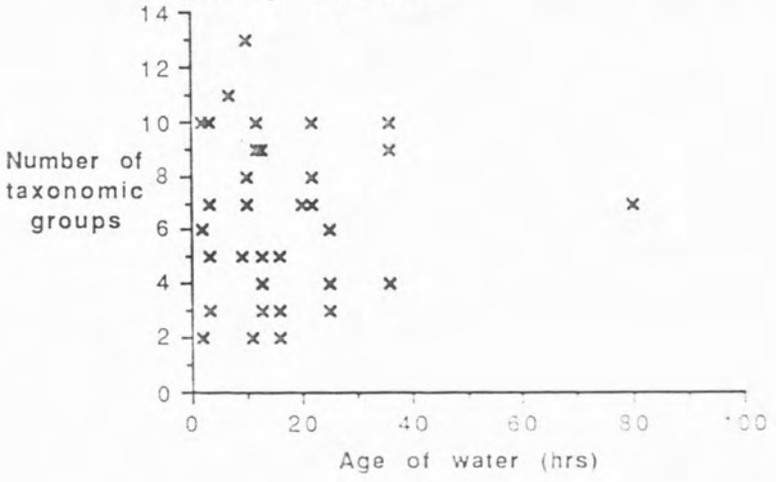
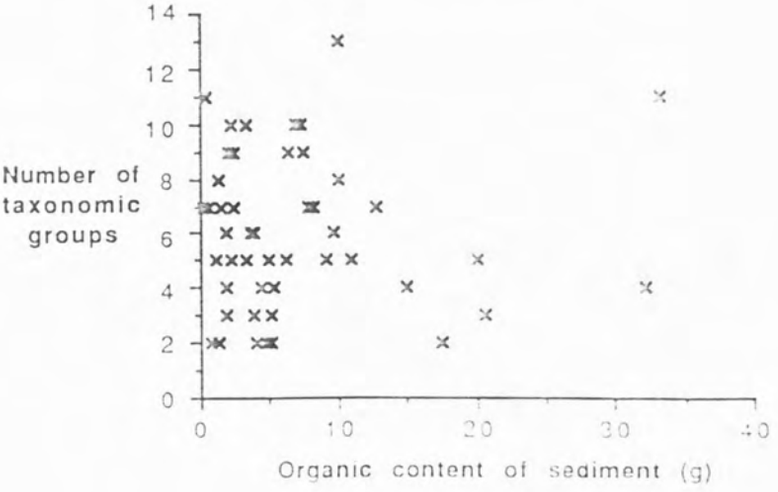


Fig. 8.5) Relationships of taxonomic richness with potential measures of population growth rate

a) Taxonomic richness with age of water



b) Taxonomic richness with organic content of sediments



8.2.2.1) Methods

The relationship between these measures of the community and the frequency of population reduction (in this case the time since the last flush) was examined using taxonomic richness and the Shannon - Weiner index for all sites after the first flush. Two measures of taxonomic richness were examined, the number of taxa used in the analyses for Chapter 7, and a more accurate measure of the taxonomic richness of the site based on the species groups present in the pipe (with chironomid larvae taken to genus) and the taxa present in the 'drift'. The time since last flush was inversely related to the frequency of population reduction and hence the expected relationship should be a reflection of Huston's prediction.

All S.S.F. sites (those which were fed by Ravensthorpe Treatment Works following the change in July 1987) were removed from this analysis since it is apparent from Chapter 7 that there is a difference in the density of animals penetrating treatment between this works and Pitsford.

Examples of data from disturbed sites (Chapter 7) used in this analysis are included as Appendix X.B.

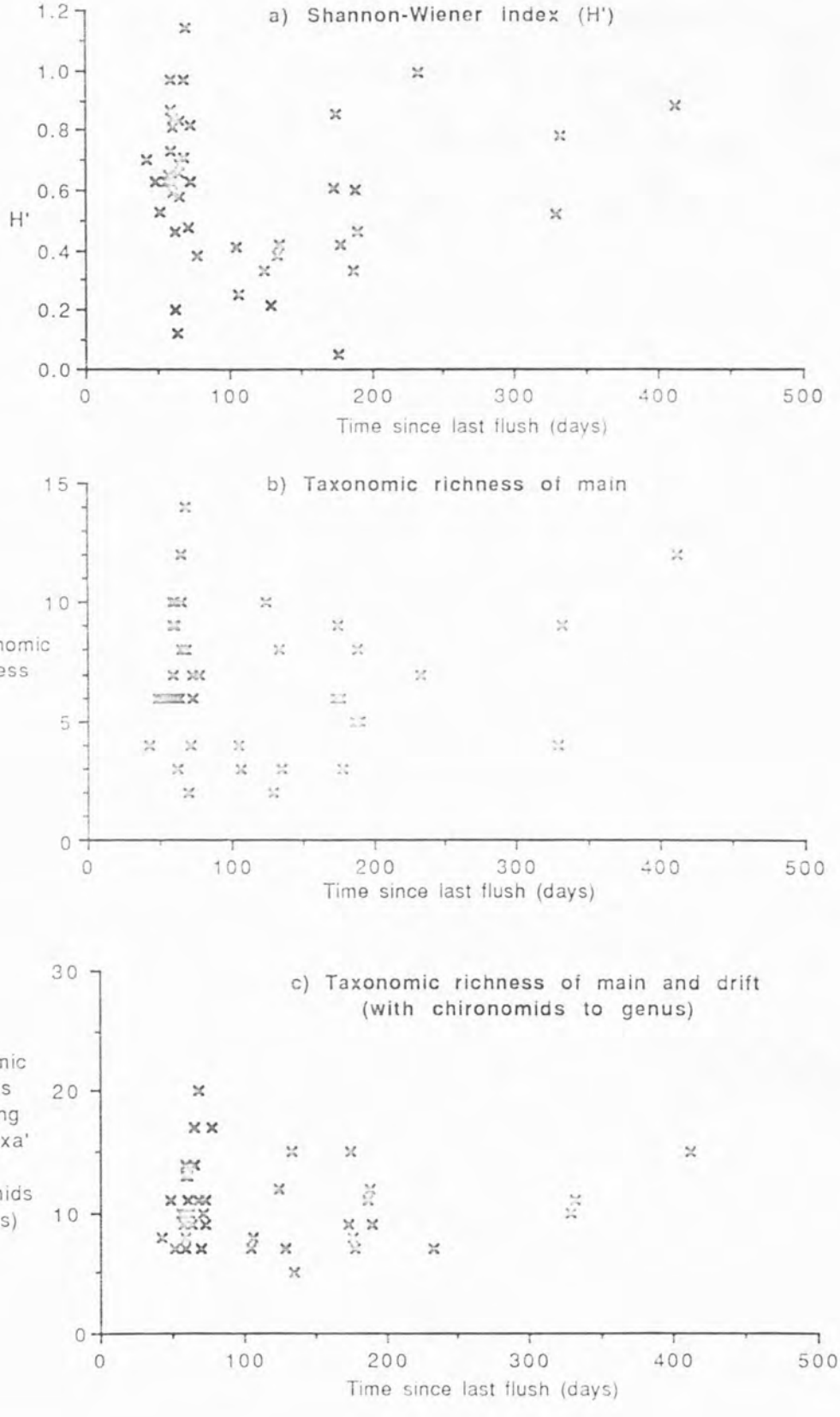
8.2.2.2) Results and Discussion

Neither taxonomic numbers nor diversity show the relationship with the frequency of population reduction predicted by Huston's model (Figs. 8.6a - c). The required time period to reach a stable community, where the community can recover between incidents of population reduction may be greater than the longest interval between flushes (14 months) used in this study. If this is the case, the data plotted in Figure 8.6a - c could represent the portion of the predicted relationship nearest to the origin.

Considerable variation about the predicted line should be expected with flush samples taken at different times of year and from sites where environmental parameters affecting population growth rates vary, and this is a possible explanation of the lack of coincidence with the model.

There may have been no sequence of succession and colonisation was completely at random. Alternatively, the initial assumption may be at fault and flushing may be too severe a method to allow recovery of the community, and might be descibed as a catastrophe rather than an disturbance. If the former is the case, the curve would not be expected to fit and the data would lie on a horizontal line, suggesting species are equally able to colonise available sites and hold their position at any site against other species until such time as another population reduction occurs.

Fig. 8.6) Relationship of taxonomic richness and diversity with frequency of population reduction in the main



8.2.3) The relationship between diversity and taxonomic richness with likely measures of population reduction and population growth rate

8.2.3.1) Methods

If succession did occur, values of taxonomic richness or diversity would produce contours as predicted by Huston's model when data points from disturbed sites (Chapter 7) were plotted on axes of assumed population reduction and possible measures of population growth rate.

8.2.3.2) Results and discussion

Neither age of water, nor organic matter in the sediment (per 1000 litres flushed) (Figs. 8.7 a and b) show the predicted relationship with diversity (shown in Fig. 8.3) or with taxonomic richness.

There is a bias in the data that may influence these results, with samples being more frequent in the two monthly region of the graph. Either the values being used to determine population growth rates and the frequency of population reduction are invalid, or there is no successional sequence taking place over the time scale used to assess recolonisation in Chapter 7.

Since the predicted relationships with population growth rate and frequency of population reduction did not occur, an alternative possibility, that of a competitive lottery must be considered.

8.3) The relationship between particular problem species and the frequency of population reduction and environmental factors.

The frequency of population reduction (the rate of flushing over the two year period) is a potential management feature of the distribution system. If problem species relate to the frequency of population reduction and measured environmental factors in the pipes themselves in a predictable manner, it will be possible to determine an ideal frequency of flushing to ensure infestation of those particular species does not occur.

8.3.1) Methods

By considering the flushing frequency in conjuction with different environmental variables, it may be possible to determine any relationship. The groups used to investigate possible relationships were Chironomini, Orthocladiinae and Tanytarsini.

The contour diagrams (Figs. 8.8 to 8.10) are transformed using the function:

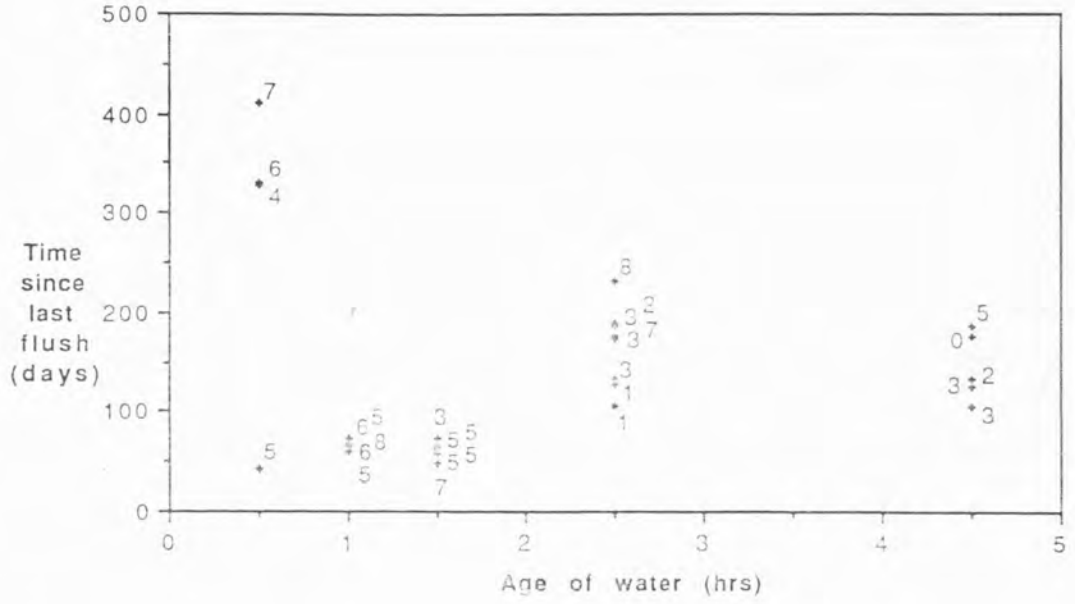
$$f(x) \rightarrow \ln(x + 1)$$

Fig.8.7) Contour diagrams of Shannon-Wiener Index (H') with time since last flush and environmental parameters assumed to represent population growth rate

Key for ranks of H':

0: 0.046 - 0.156	1: 0.156 - 0.265	2: 0.265 - 0.375	3: 0.375 - 0.484
4: 0.484 - 0.594	5: 0.594 - 0.703	6: 0.703 - 0.813	7: 0.813 - 0.922
8: 0.922 - 1.032	9: 1.032 - 1.141		

a)



b)

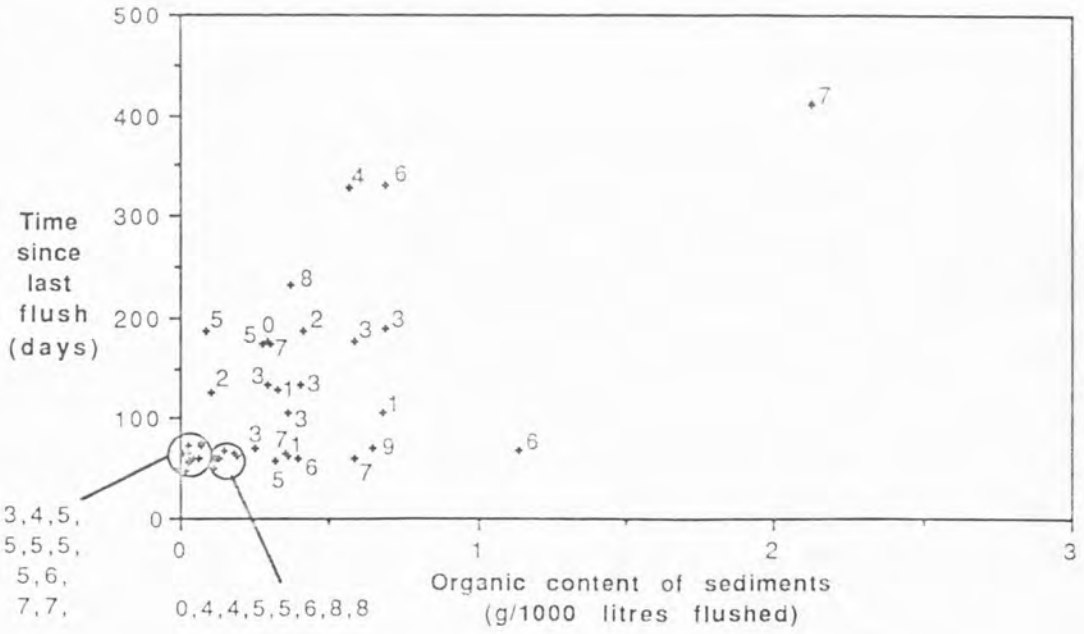


Fig. 8.8) Contour Diagrams of Chironomini Density with ln frequency population reduction and ln population growth rate measures.

Density of Chironomini:

0: 0.00 - 1.40	1: 1.40 - 2.80
2: 2.80 - 4.20	3: 4.20 - 5.60
4: 5.60 - 7.00	5: 7.00 - 8.40
6: 8.40 - 9.80	7: 9.80 - 11.20
8: 11.20 - 12.60	9: 12.60 - 14.00

Fig. 8.8a) Chironomini with time since last flush and age of water

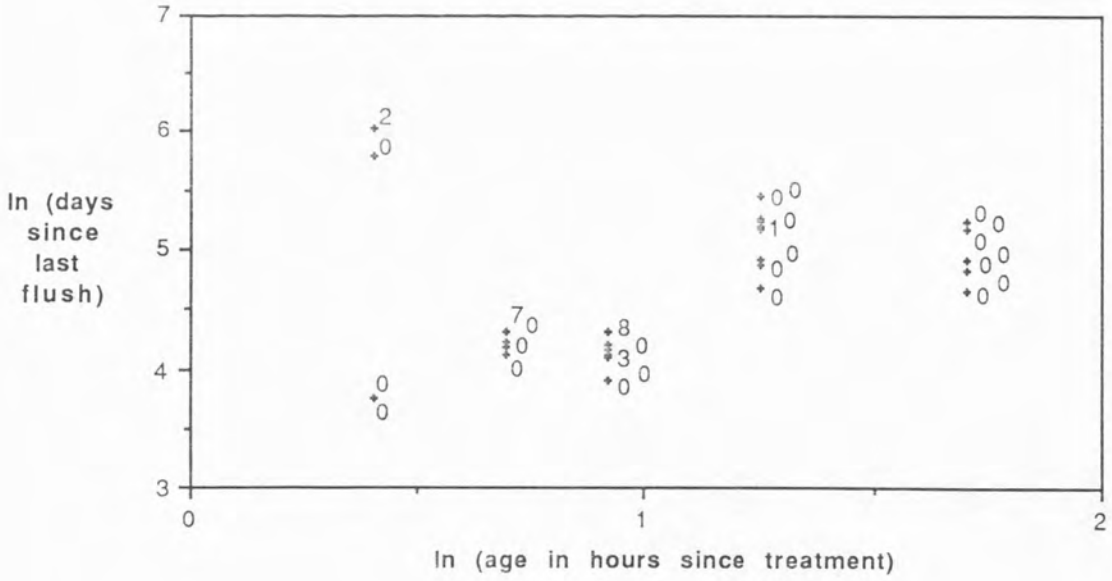


Fig. 8.8b) Chironomini Density with time since last flush and weight of organic matter in sediment per 1000 litres flushed during sampling

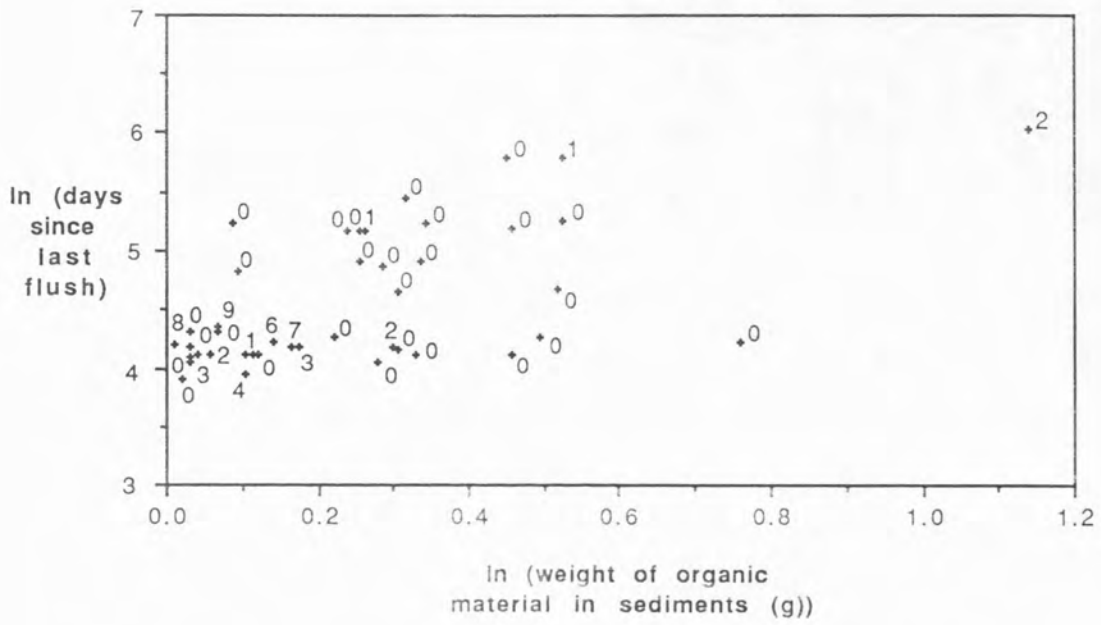


Fig. 8.8c) Chironomini Density with time since last flush and water temperature in the main.

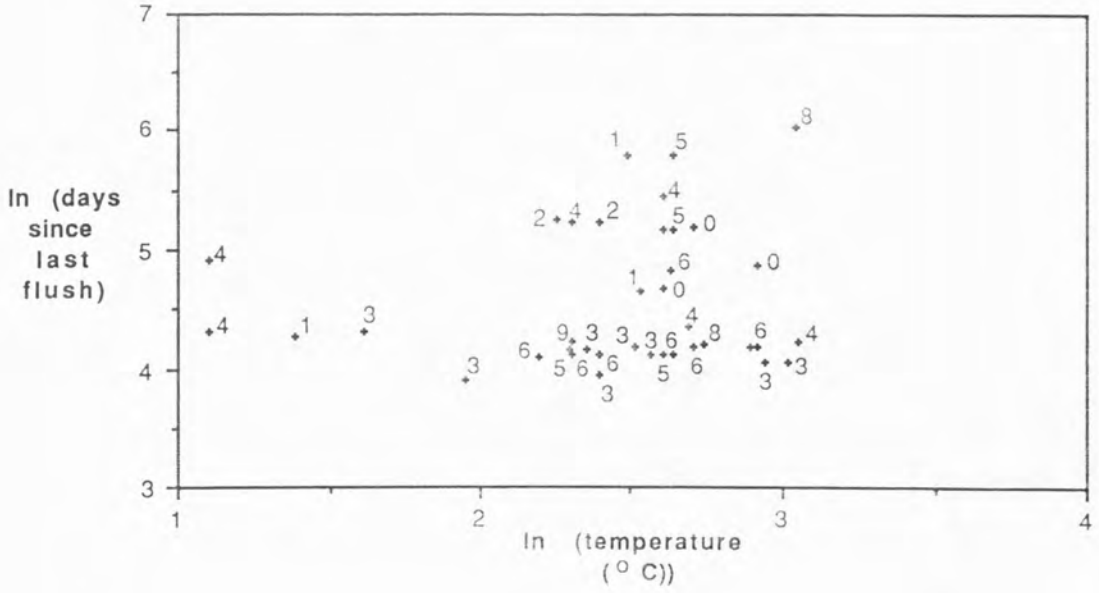


Fig. 8.9) Contour Diagrams of Tanytarsini Density with ln frequency population reduction and ln population growth rate measures.

Density of Tanytarsini:

0: 0.00 - 2.00	1: 2.00 - 4.00
2: 4.00 - 6.00	3: 6.00 - 8.00
4: 8.00 - 10.00	5: 10.00 - 12.00
6: 12.00 - 14.00	7: 14.00 - 16.00
8: 16.00 - 18.00	9: 18.00 - 50.00

Fig. 8.9a) Tanytarsini Density with time since last flush and age of water

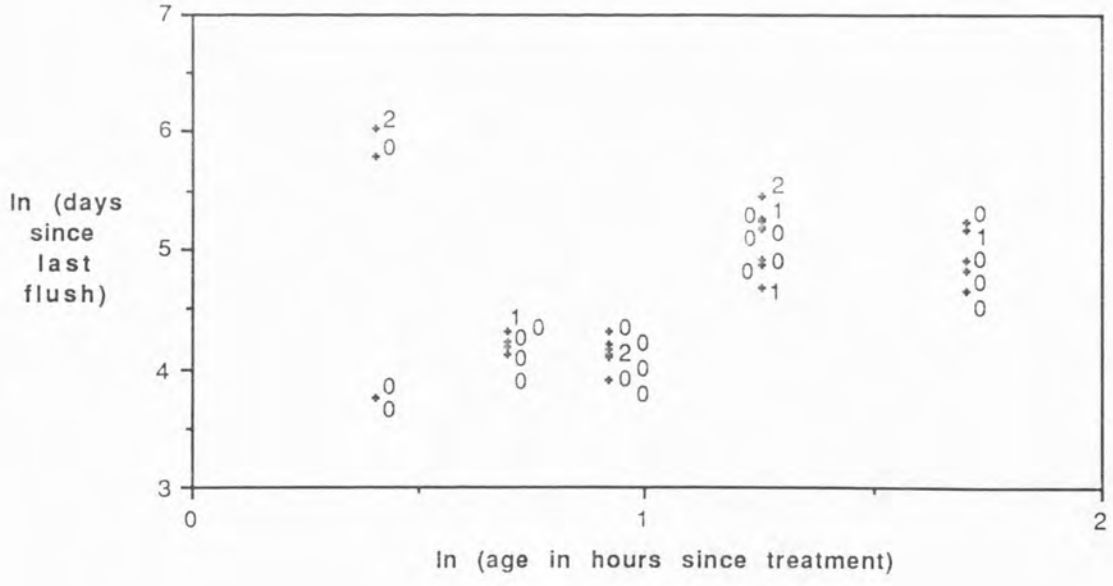


Fig. 8.9b) Tanytarsini Density with time since last flush and weight of organic matter in sediment per 1000 litres flushed during sampling

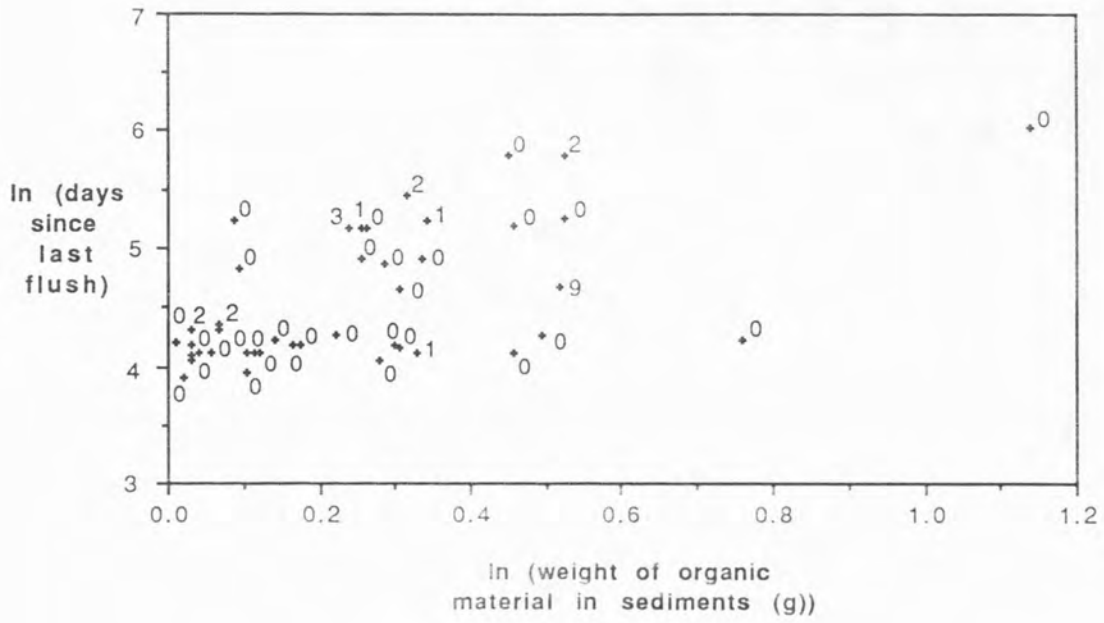


Fig. 8.9c) Tanytarsini Density with time since last flush and water temperature in the main.

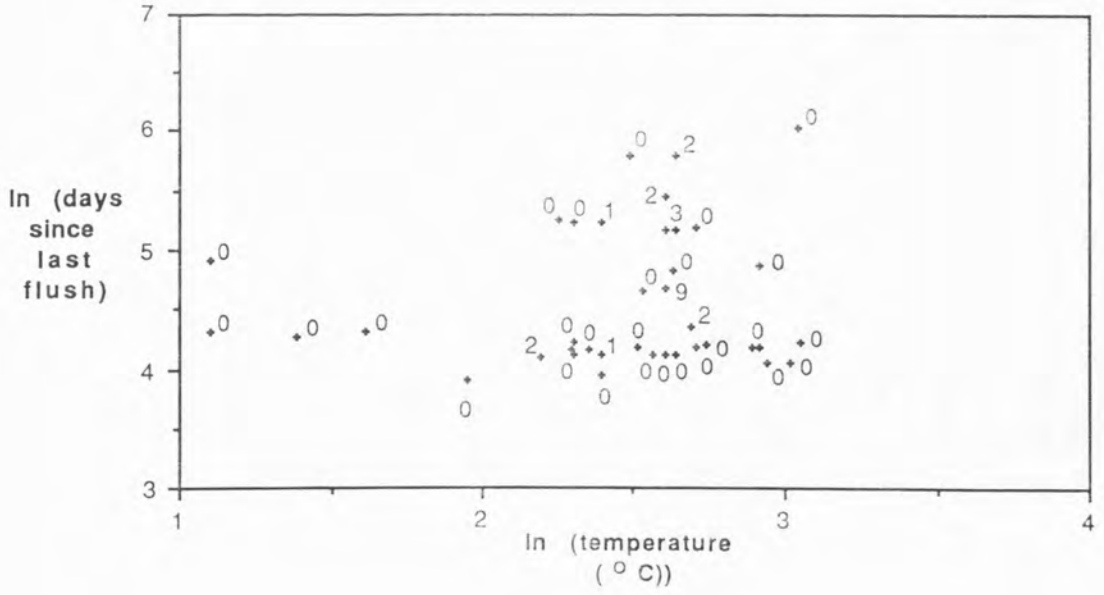


Fig. 8.10) Contour Diagrams of Orthocladiinae Density with ln frequency population reduction and ln population growth rate measures.

Density of Orthocladiinae:

0: 0.00 - 0.78	1: 0.78 - 1.56
2: 1.56 - 2.34	3: 2.34 - 3.12
4: 3.12 - 3.90	5: 3.90 - 4.60
6: 4.60 - 5.46	7: 5.46 - 6.24
8: 6.24 - 7.02	9: 7.02 - 7.80

Fig. 8.10a) Orthocladiinae Density with time since last flush and age of water

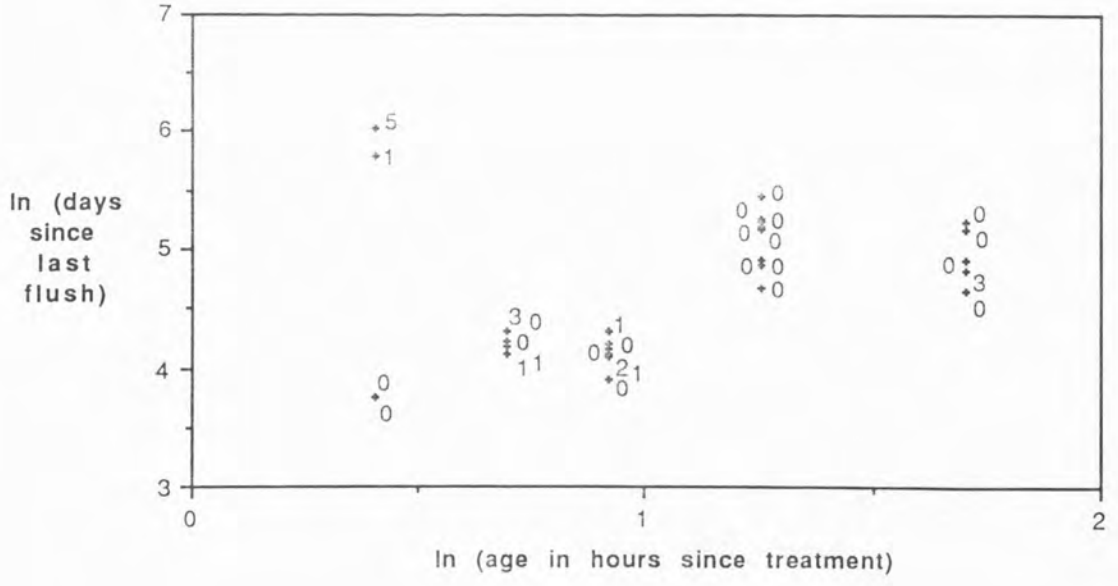


Fig. 8.10b) Orthocladiinae Density with time since last flush and weight of organic matter in sediment per 1000 litres flushed during sampling

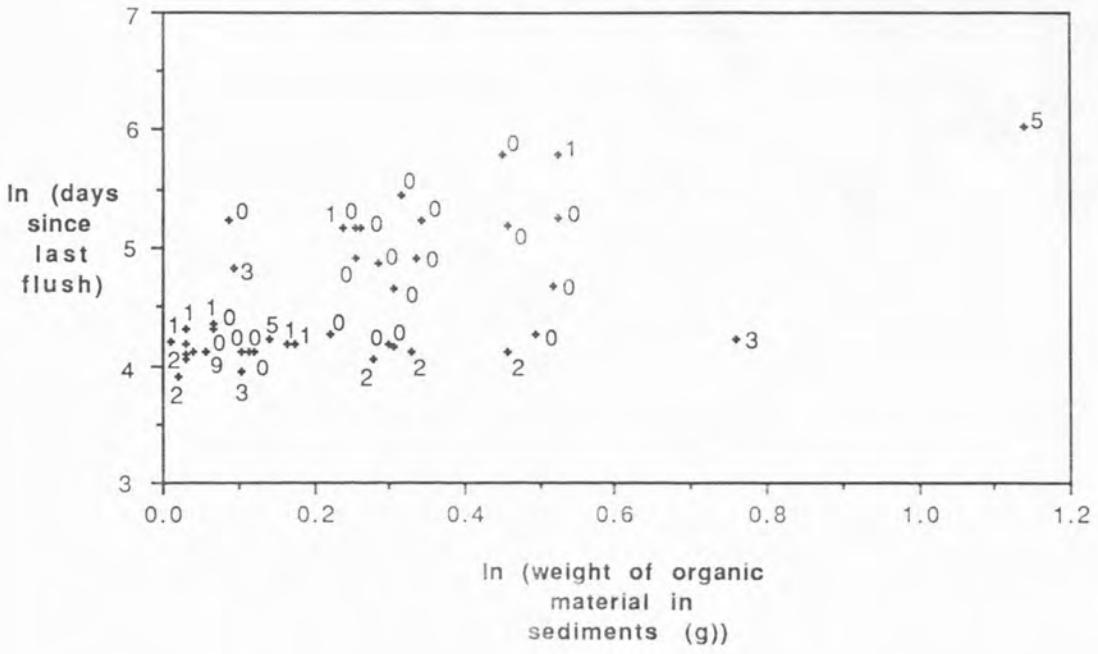
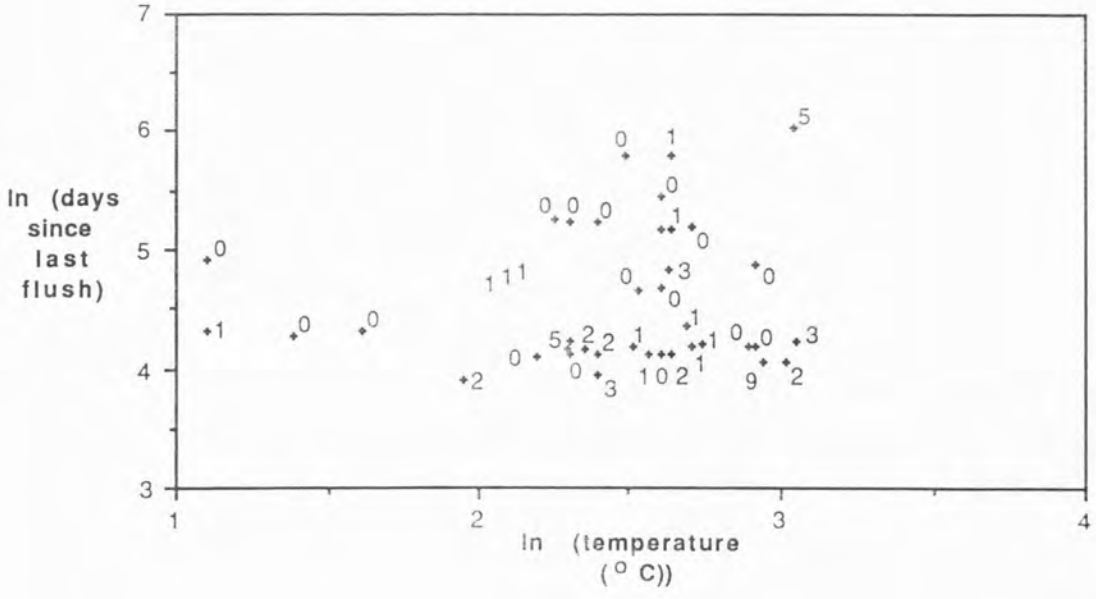


Fig. 8.10c) Orthocladiinae Density with time since last flush and water temperature in the main.



to enable the points to be distinguished more easily and density values to be inserted.

8.3.2) Results and discussion.

The contour diagrams, Figures 8.8 to 8.10 suffer from the same problem apparent from section 8.2 (above) - that the data is clustered in one region of the plot and thus the interpretation of the contour plot is limited to a restricted range for the variables. The Figures show information from time since flushing with organic material; age and temperature, but dissolved organic carbon and particulate organic carbon were also tested resulting in no obvious relationship with any of the taxa.

8.3.2.1) Chironomini

Chironomini show no obvious relationship with age of water, though densities were generally lower at distance from treatment (Fig. 8.8a). Figure 8.8b suggests that Chironomini appeared at greatest densities where the quantity of organic matter in the sediment was low and the time between flushes was short. These two factors were linked, frequent flushing resulting in low levels of sediment. It may be that Chironomini require an absence of other species to become established in the main - though this suggests succession rather than a competitive lottery. However, this relationship may be an artefact of the sampling strategy, with more sites sampled at high frequency of flushing during the summer, when chironomids were penetrating treatment at their greatest density (Fig. 8.8c).

8.3.2.2) Tanytarsini

There is no apparent differences between densities at different age of water (Fig. 8.9a), suggesting Tanytarsini were not related to distance from treatment. the relationship with organic matter and time since last flush (Fig. 8.9b) also shows no apparent contours of density, but time since last flush and temperature (Fig. 8.9c) indicates higher densities were found at higher temperatures.

8.3.2.3) Orthocladiinae

It appears that like Chironomini, Orthocladiinae were found in greater densities closer to treatment, when age is low (Fig. 8.10a). The contour plot using organic matter and time since last flush (Fig. 8.10b) indicates that sites with a short period between flushes and low organic matter had higher densities of Orthocladiinae. Again this may be a fault

in the design of the experiment, with more samples taken at this type of site during the summer period when Orthocladiinae were occurring at greater densities than at lower temperatures (Fig. 8.10c).

8.3.3) Conclusions

The results support the conclusion of Chapter 7 that Chironomini and Orthocladiinae are penetrating treatment and that Tanytarsini are influenced by the mains conditions. No predictable relationship was found between density of the taxa of chironomid investigated, time since the last flush and any of the five environmental variables tested.

8.4) Suggestion for work to determine whether animals in mains occur at random or in a predictable fashion.

The way ahead for this part of the study is to consider a series of controlled experiments where communities are introduced to pipes with known conditions which can be accurately monitored. This would involve the construction of a model system where sampling regimes can be varied as required without restrictions produced by working in the field.

If enough information can be obtained from a series of pipes that cover the range of conditions which could occur in the distribution system, it will be possible to determine:

> i) whether succession does occur, albeit over a long time period and
> ii) whether animal groups have a predictable relationship with the frequency of flushing and measures of population growth rate.

The latter would enable any Water Undertaking to classify the 'type' of supply zones present in a distribution system by measuring the relevant environmental parameter, such as organic loading; different seasons; and different age of water zones. Once this is measured, the model can be used to determine a flush frequency which will maintain these populations at levels which will not cause consumer complaints (see Chapter 9).

PART IIIb) ANIMALS AT THE CONSUMERS' TAP

CHAPTER 9) THE RELATIONSHIP BETWEEN ANIMALS IN THE DISTRIBUTION SYSTEM AND ANIMALS EMERGING AT THE TAP.

9.1) The need for information about animals at taps.....265
9.2) Introduction.....266
9.3) Study sites.....266
9.4) Methods.....270
9.4.1) Tap filtration methods.....270
9.4.2) Laboratory techniques.....272
9.4.3) Index of emergence.....273
9.4.4) Degree of infestation 273
9.4.5) Mains sampling.....274
9.5) Results and Discussion.....275
9.5.1) Emergence index of species groups.....275
9.5.2) Emergence at Ravensthorpe and Pitsford.....275
9.5.3) Emergence index related to rate.....279
9.5.4) Variation in the emergence index at the tap.....279
9.5.4.1) Ratio of chydorids in the main and at the tap at Whilton.....289
9.5.5) Emergence index relative to animal density.....289
9.5.6) Degree of infestation at the tap.....293
9.5.7) Degree of infestation at the tap and in the main...293
9.6) General Discussion.....293
9.7) Conclusions.....296

PART IIIb) ANIMALS AT THE CONSUMERS' TAP

CHAPTER 9) THE RELATIONSHIP BETWEEN ANIMALS IN THE DISTRIBUTION SYSTEM AND ANIMALS EMERGING AT THE TAP.

9.1) The need for information about animals at taps

The project established a means of quantifying the infesting fauna of a pipe section in the distribution network, enabling accurate measurement of numbers. However it is also neccessary to produce a meaningful measure of infestation which can be related to consumer complaints. The relationship between the level of animal infestation in the main and the density of animals emerging at the tap would provide such a measure.

This is important because the level of infestation at which consumers might register a complaint is variable and as yet uncertain. An Anglian Water site at Whilton, Daventry District Office where operations staff work on a daily basis, was found to have chironomids emerging at a measured rate of approximately 8 per consumer day without being noticed.

Water undertakings will only be able to assess the requirements of potable water relative to animals ('animalcules' as defined by the D.O.E. circular on drinking water quality objectives, Anon 1984) by establishing a link between mains and taps. This will enable the derivation of a single value which can be quoted as the level of service to the consumer. Continuous monitoring will be possible within a supply zone in order to maintain the required level of service. Undertakings will be able to monitor mains or taps. Either

a) a series of mains flushes in an area will indicate where animals are emerging at undesirable rates from the tap or

b) a series of samples taken at the tap will indicate levels of emerging animals prior to an infestation level (in the main) which is considered undesirable. Thus by flushing control, the threshold of numbers which leads to consumer complaints will not be attained.

The choice of method will depend very much on the manpower and funding available to combat consumer complaints within an undertaking, and the relationship with the consumer (Section 9.6). Further work to establish precisely which animals give rise to complaints from the consumer will enable water quality objectives to be drawn up which relate directly to the consumer.

Ideally, the mains fauna will be quantified and manipulated by controlled flushing regimes (as in Chapter 7). This would enable measures of animals at taps to be related directly with the mains fauna. However, in this study, the location of tap sample sites was restricted.

9.2) Introduction

A number of taps at various Water Authority buildings in the Western Area of Oundle Division were fitted with Norgren filtration units (see below). These units were run for approximately 4 days each month over a period of 10 months. At the end of this period, the mains which supplied the taps were flushed to establish the fauna present. The animals emerging at the taps were compared with the mains fauna at the end of the tap run to determine any relationship between density of animals in mains and the numbers to exit at taps. Logistical problems prevented filter units from being located on consumer taps served by the mains already sampled during the major part of this study (Chapter 7).

An Index of emergence (I_e) was devised and a suggestion for a Degree of Infestation at the tap ($D.I._t$) was proposed (based on the method of Greaves and Evins (1972) modified in Williams *et al.* (1986)). This $D.I._t$ enables a site to be scored using a single number relating to the density of emerging animals and their ability to cause complaints. The emergence index was compared between sites, each site being sampled over a 10 month period to detect any seasonality. Each site was then considered using the $D.I._t$. In addition the possible effect of pyrethrin treatment during May 1988 was considered.

9.3) Study Sites

Sites were chosen in Daventry and Market Harborough Disticts, Oundle Division. Six sites were used throughout the system, four in the Pitsford supply zone and two in the Ravensthorpe supply zone (locations Fig. 9.1a, b and c). The sites are listed below, along with the conditions in the area in which they are located:

Ravensthorpe Supply Zone:

1) Ravensthorpe Treatment Works - final water from a large diameter main fed from a slow sand filter.
2) Watford Pumping Station - low pressure, small diameter main (far from treatment) with a slow sand filter feed.

Pitsford Supply Zone

3) Pitsford Treatment Works - final water from a large diameter main fed by a rapid gravity filter.
4) Whilton Sewage Works - low pressure, small diameter main (far from treatment) fed from a rapid gravity filter.
5) Brixworth Sewage Works - low pressure, small diameter main (near treatment) fed from a rapid gravity filter.

Fig.9.1a) Sketch Map of Pitsford West Supply Zone showing tap sampling sites

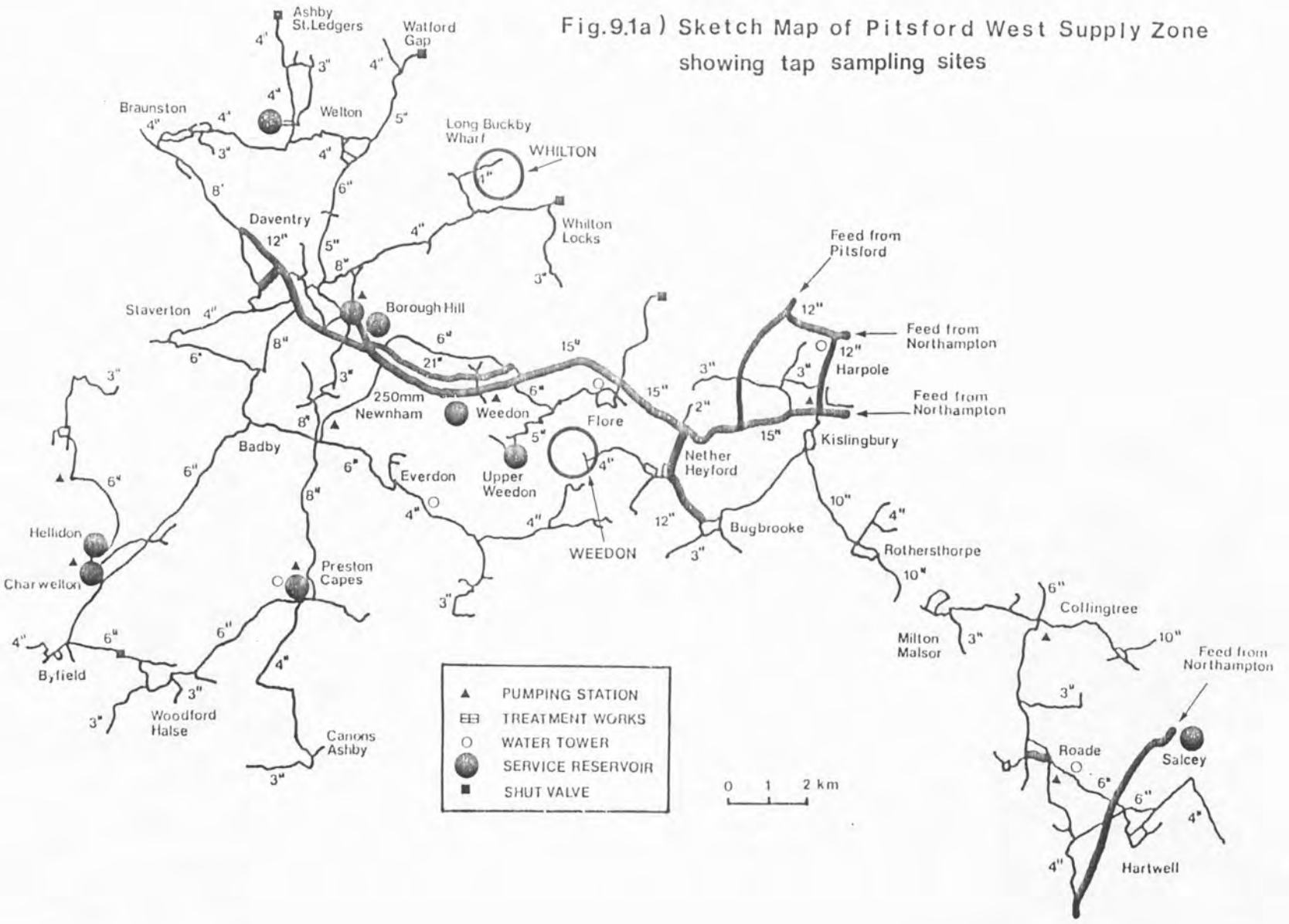


Fig.9.1b) Sketch Map of Ravensthorpe Supply Zone showing tap sampling sites

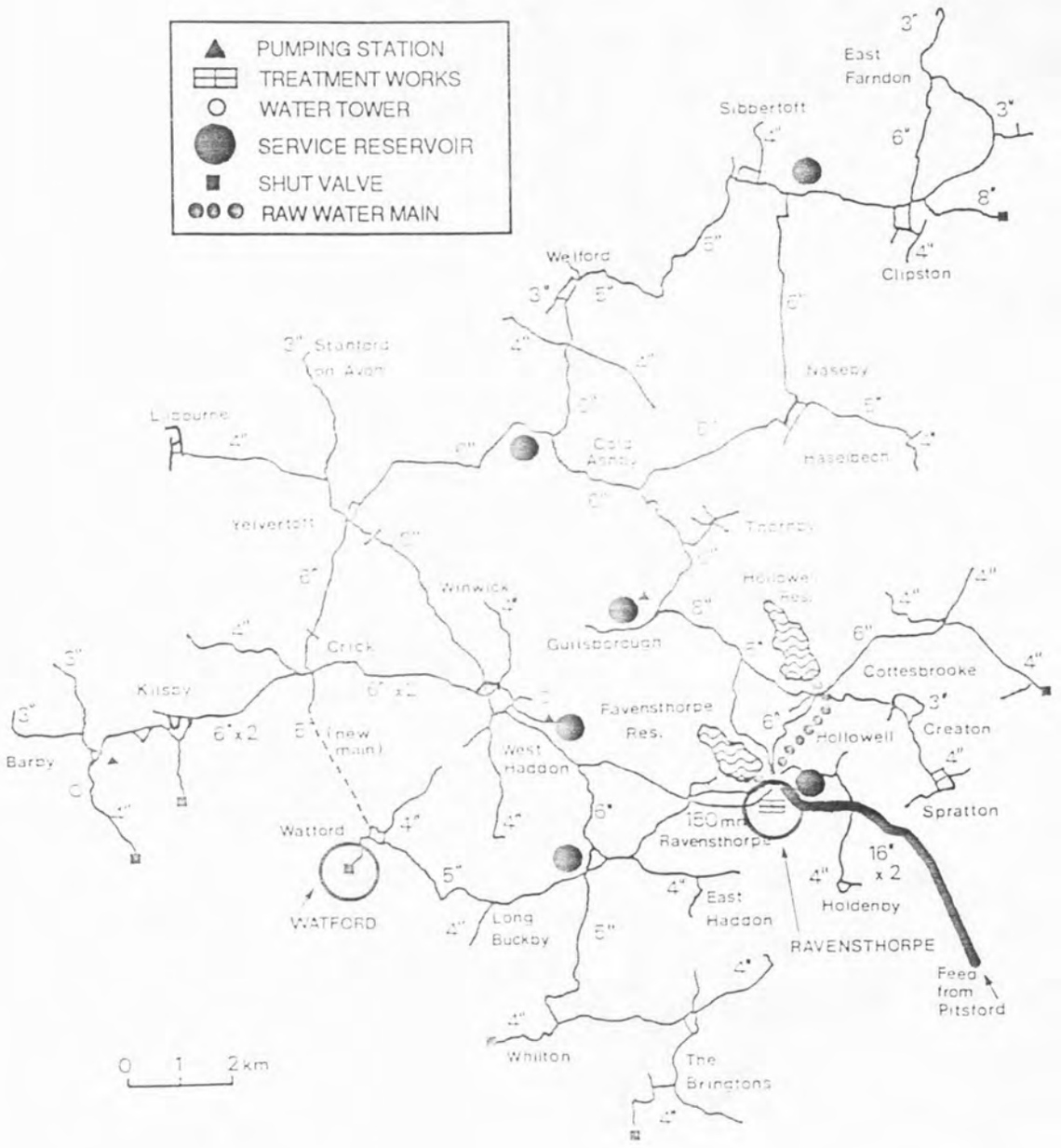
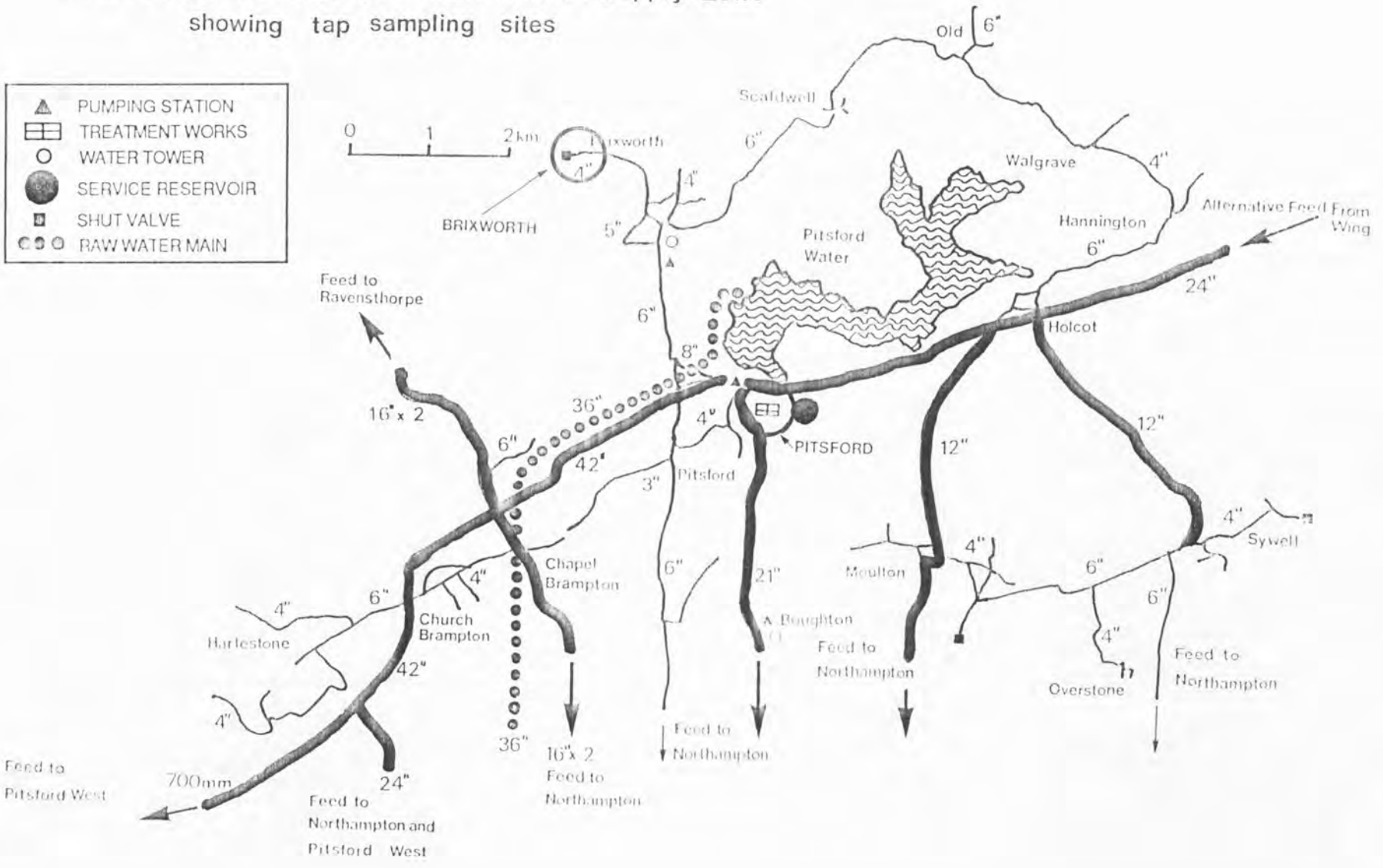


Fig. 9.1c) Sketch Map of Pitsford East Supply Zone showing tap sampling sites



6) Weedon Sewage Works - low pressure, small diameter main (far from treatment) fed by a rapid gravity filter.

These sites gave a comparison of slow sand filter and rapid gravity filter treatment, near to the treatment works (sites 1 and 3) as well as comparison of low pressure sites far from treatment (site 6), near to treatment (sites 4 and 5) and high pressure at treatment (site 3). The S.S.F. sites (Ravensthorpe Supply Zone) allowed comparison of high presure near treatment (site 1) and low pressure (sites 2 and 4) mains. Comparison between supply zones was also possible.

Plans to compare P.V.C. and Asbestos Concrete mains had to be abandoned in order for the work to commence early in 1988 due to the lack of available sites where taps could be fitted.

Sites 2, 4, 5, and 6 were fed by mains where sampling (using the method descibed in Chapter 2) was possible. This enabled the fauna in the pipe feeding each tap site to be quantified at these locations, though operational constraints restricted samples to a relative, rather than quantitative, measure. The two treatment works sites (1 and 3) were fed by mains without available hydrants.

Apart from the full-system dosing of pyrethrin in May 1988, the supply pipe at Whilton was air-scoured in February 1988. Sites at Whilton, Watford, Brixworth and Pitsford all suffered from disconnection of filter units and alteration of flow rate. This led to samples of an unknown rate but known volume being taken. Samples were taken every month between January and October 1988.

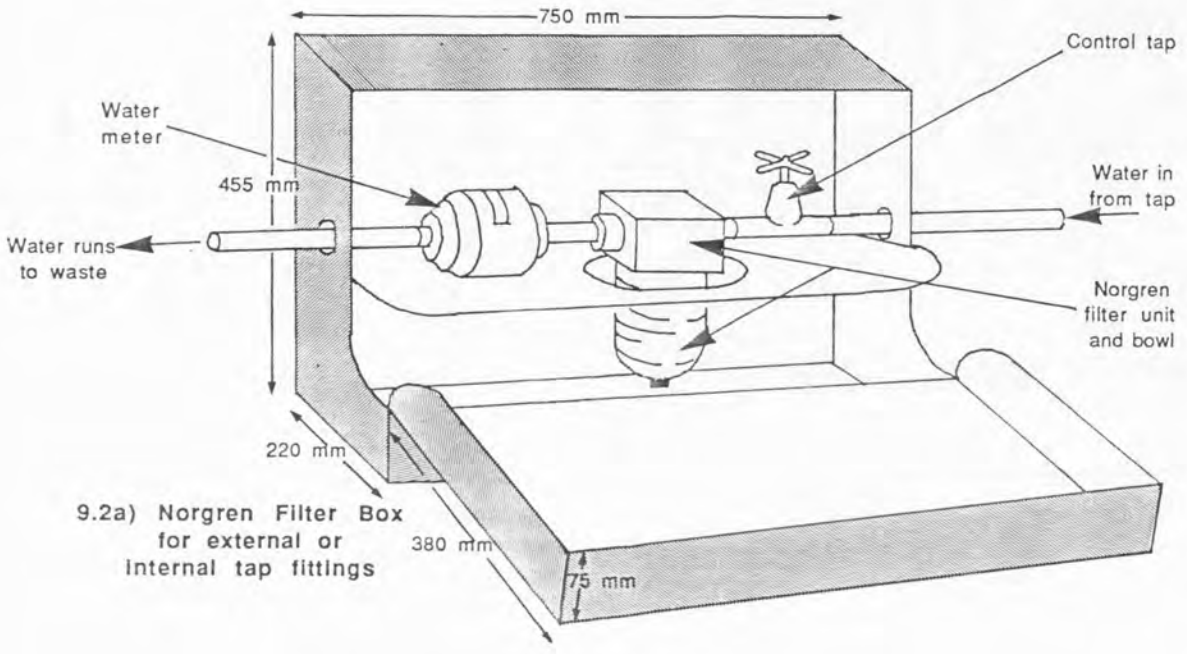
9.4) Methods

9.4.1) Tap filtration methods

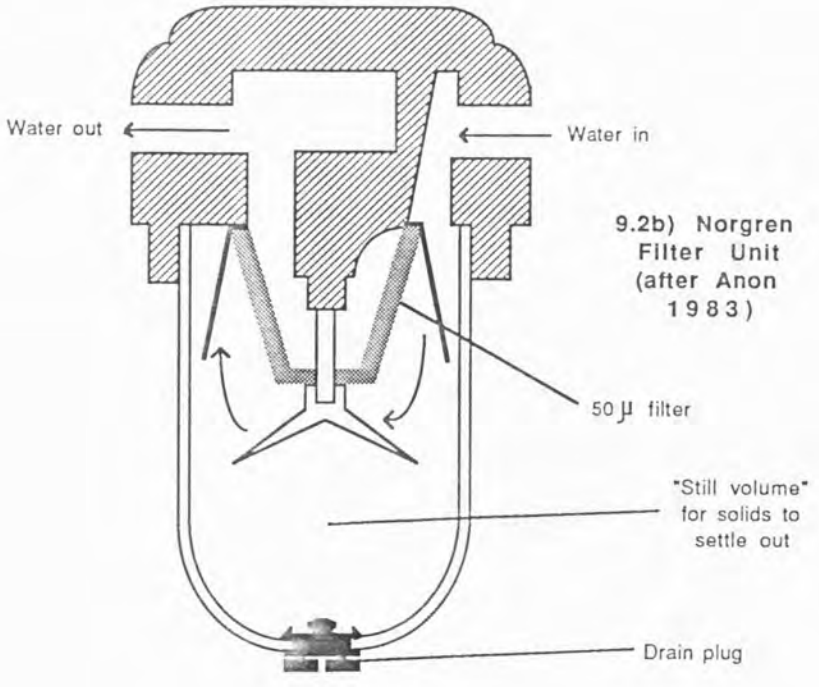
Each site was fitted with a Norgren Filter Unit (Fig. 9.2), on either an external or internal tap. These units were based on a previous unit designed by Anglian Water and built by A.W. staff at Daventry District Office, Whilton.

The tap filter unit consists of a wooden box 445 mm by 750 mm by 220 mm (Fig. 9.2a) with a hinged lid, enabling access to a water meter and the filter unit itself. An inlet hose runs from the tap to a Norgren filter system (Fig. 9.2b) obtained from B.L.Pneumatics Ltd. This is connected in line with a water meter which is connected to an outflow pipe that runs to waste. The filters used were plastic 50µ mesh which are equivalent to sintered bronze filters which have been used in the past (Barham 1985). The filters operate as shown in Figure 9.2b. Samples are collected by draining the water in the filter bowl into a plastic 2 litre

Fig. 9.2) Sketch of Norgren Filter Box and section through filter unit



9.2a) Norgren Filter Box for external or internal tap fittings



9.2b) Norgren Filter Unit (after Anon 1983)

bucket removing the bowl and filter and storing in the bucket with the drained water, until return to the laboratory for examination.

At each site the unit was connected and left to run for a minimum of 48 hrs, normally 72 or more. Initially an attempt was made to maintain the flow rate at the average rate of consumption per consumer for the Western Area of Oundle Division (35 litres per hour). However this proved impossible since taps were in use at some locations and needed to be disconnected and reconnected. It also appears that at these low rates of flow, the filters became clogged with material and the flow ceased. This appears to be due to fine material that breaks up and passes through the filter at high rates of flow.

It was decided to turn taps on at different rates, greater than the average rate of flow per consumer. Taps were turned on at a rate that would correspond with a tap in a hand basin run in regular use. Values of animal density were standardised by relating numbers to the avearge volume of water used by consumers per day (780 litres).

Rate of flow is a variable which can be considered in future studies by checking the flow with a flow gauge and ensuring that the tap was not used during the sampling period.

9.4.2) Laboratory Techniques

Samples were returned to the laboratory alive and the water from the bucket was poured through a filter constructed from a 140µ mesh plankton net. The Norgren filter was washed (using water filtered through a 140µ mesh to ensure no contamination from supply) into this net. All collected animals and particles were then examined in a Bogarov trough under a binocular microscope (x15 - x40 magnification).

Animal numbers (both living and dead) were counted and identified using a rough taxonomic classification. All intact animals were counted since the filter may cause the death of individuals of certain groups after a period, as may the processing of the sample in the laboratory. These dead animals were chydorids and to a lesser degree, cyclopoids. If these animals exit at the tap as dead individuals, these taxonomic groups (where movement plays a large part in their detection by the consumer) will be less likely to cause complaints.

Chydorid carapaces, cyclopiod fragments and particulate matter (both organic and inorganic) were each recorded as present or absent in the sample.

Where animals were present in a sample in large numbers, preliminary examination of the Bogarov trough was followed by preservation in 70% I.M.S. and subsampling. Subsamples were taken at dilutions that allowed at least 50 individuals of the taxonomic group in question to be counted.

9.4.3) Index of emergence (I_e)

For each site and taxonomic group, an index of emergence (I_e) was calculated:

$$(7) \qquad I_e = 1/n \; \Sigma(D.C/V)$$

where n = number of samples
D = density of animals
C = average consumption per consumer day
V = volume of water filtered

9.4.4) Degree of Infestation

To establish a degree of infestation at the tap ($D.I._t$) or in the main ($D.I._m$), each animal group was ranked with regards their potential to lead to consumer complaints, and a value relating to their frequency was produced.

Using major taxonomic groups, for speed of counting, each group was allocated a grade (R). This grading (R) will require future research regarding consumer complaints (discussed below), but for the purpose of this study, the groups were scored as follows:

group 1: animals which will never cause complaints
e.g. tardigrades, nauplii

group 2: animals which may cause complaints if they exit in large numbers e.g. ostracoda, mites, harpacticoids

group 3: animals which may cause complaints in low numbers by nature of their larger size and movement e.g. chydorids, small cyclopoids

group 4: animals larger than group 3 and possibly missed at low densities e.g. oligochates, flatworms, *Megacyclops* sp.

group 5: larger animals or animals that are mobile and hence single individuals are likely to cause a complaint e.g. snails, chironomid larvae, *Asellus*

The score system for each group is as follows:

Group 1:	0
Group 2:	1
Group 3:	2
Group 4:	4
Group 5:	8

The score system devised was geometric because there is an increasing likelihood of single animals causing complaints from each group.

The second aspect of the $D.I._t$ relates to animal density when emerging at the tap. $Log(I_e + 1)$ was used because as more and more animals emerge, complaints will not increase proportionally, but for example will relate to 10 animals to much the same degree as 20 animals. The addition of 1 to I_e removes the possibility of values being negative.
$D.I._t$ was thus calculated using every taxon:

(8) $D.I._t = \Sigma(R.\log(I_e + 1))$ for all species.

This can be extended to apply to a supply zone **(9)** by taking the mean of all samples in that zone such that:

(9) $D.I._{t(\text{supply zone A})} = 1/n(\Sigma(D.I._t)) = 1/n(\Sigma(R.\log(I_e + 1)))$

where n is the number of sampling sites within that supply zone.

The calculation of a single measure of infestation has been considered prior to this study (Greaves and Evins 1972, Evins and Greaves 1979, Ainsworth [ed] 1981 and Williams *et al.* 1986) and the method outlined above owes much to these previous ideas. However, scores and ranking of the likelihood of complaints is still based on qualitative information.

9.4.5) Mains sampling

The sites at Brixworth, Weedon, Watford, and Whilton were each sampled following the methods outlined in Chapter 2, and the degree of infestation of the main ($D.I._m$) was calculated to enable comparison between the mains and the taps.

Unfortunately the mains in question were not sufficiently close to large diameter pipes to make quantitative values possible. Since the clean water would need to come from some distance away, considerable disruption through loss of supply would have been neccessary, requiring card warning. Therefore, a relative measure of the animal density was used, by flushing all four sites at approximately the same rate for a fixed period of time.

This produced samples which were directly comparable in that the removal of animals at the same rate of flow is assumed to be constant, and the relative density was produced as the number of animals per 1000 litres flushed. Using the same grading outlined above for the calculation of the $D.I._t$, a degree of infestation in the main would be calculated:

(10) $D.I._m = \Sigma(R.\log(Q + 1))$

where R = the rank for each taxonomic group
and Q = the density of animals per 10 metres of pipe

However, this equation was modified **(11)** because of the relative nature of the sampling procedure in this instance:

$$(11) \qquad D.I._{m'} = \Sigma(R.\log(F + 1))$$

where F = the density of animals per 1000 litres flushed

9.5) Results and Discussion.

9.5.1) Emergence index of taxonomic groups

The numbers of animals collected in the Norgren Filters and the I_e for each sampling occasion are included as Appendix XI.A & B. Table 9.1 shows the emergence index (I_e) and frequency of occurrence in samples for each taxonomic group for all sites combined. The most frequently occuring taxonomic groups were harpacticoids, cyclopoids and chydorids. This was not particularly surprising as these were often the most numerous groups in the mains. They also had the greatest I_e, implying that the chance of a single individual emerging from a tap is high, particularly with cyclopoids and chydorids. Oligochaete worms did not appear in any tap samples, and *Hydrobia* had a low I_e.

9.5.2) Emergence at Ravensthorpe and Pitsford

Table 9.2 shows the I_e for each taxon at each site over the 10 month period. Final waters from both treatment works were compared by examination of tap samples from Ravensthorpe and Pitsford, where there was little chance to establish a community in the main. There was an apparent difference in the final water leaving the two treatment works. The animals present differed considerably in their emergence indices, particularly cyclopoid copepods. Generally, the Ravensthorpe samples were free of animals and particulate matter, while Pitsford samples contained numerous animals, sediment and organic particles. If the two raw waters show different levels of animals this will explain the difference in final waters. However, if no difference is apparent in the raw water, this difference in final water will be due to the efficiency of the two filter systems. Figure 9.3 shows the cyclopoid copepod levels in the raw and final water for the two treatment works, Ravensthorpe (slow sand filter) and Pitsford (rapid gravity filter) from data provided by Anglian Water (using Norgren filters as described by Barham 1985). The raw water values at Pitsford (Fig. 9.3a) are considerably higher during the period

Table 9.1) Index of emergence for all sampling occasions and frequency of occurrence in samples

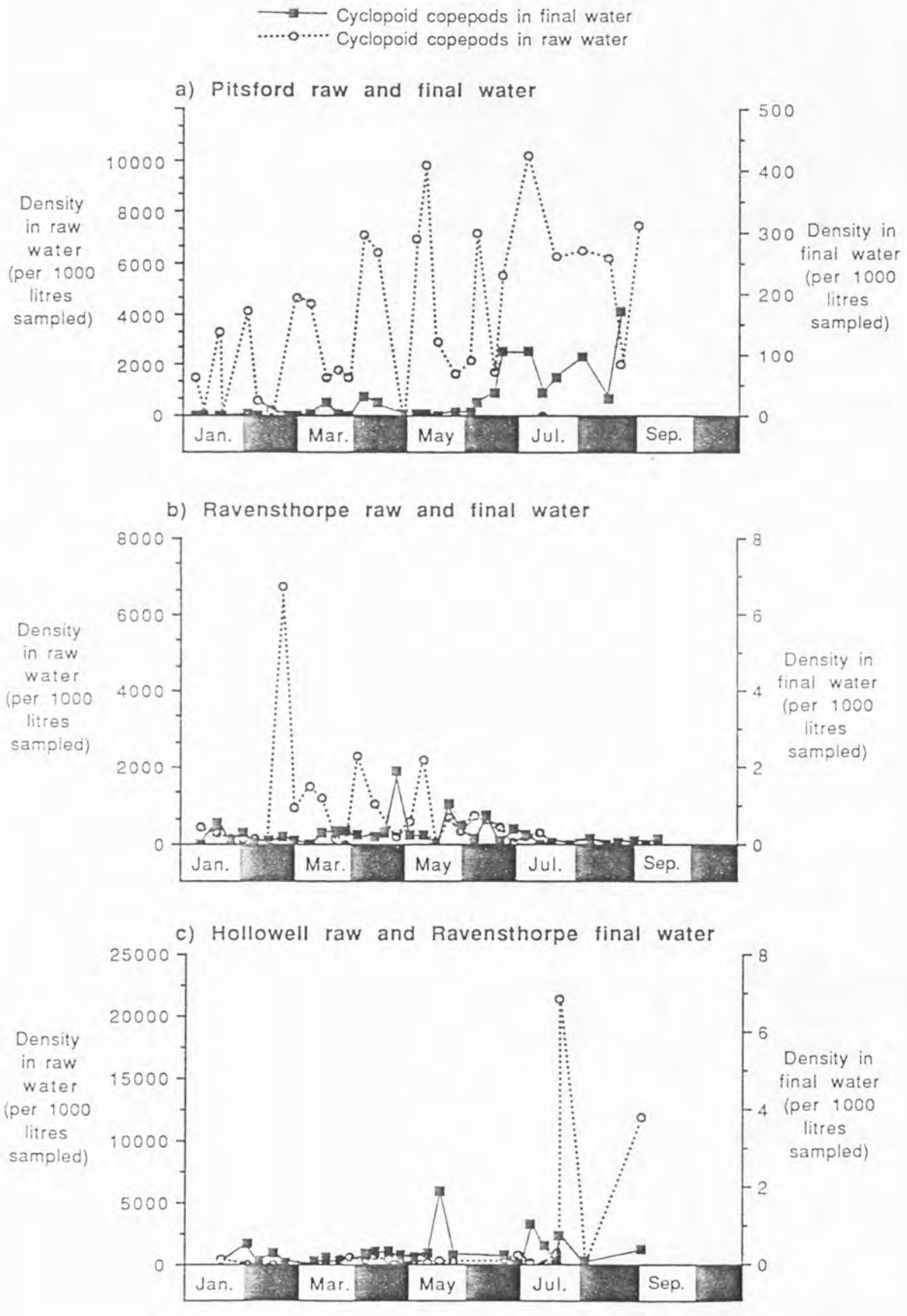
taxonomic group	I_e	% frequency (n = 53)
Chironomid larvae	0.21	22.6
Chironomid larval exuviae	0.08	18.9
Harpacticoids	0.27	30.2
Cyclopoids	2.50	39.6
Chydorids	1.28	39.6
Halacairids	0.15	18.9
Tyroglyphids	0.12	17.0
Hydracarina	0.10	15.1
Daphnia	0.01	5.7
Ostracoda	0.07	1.9
Tardigrada	0.00	5.7
Hydrobia	0.01	5.7

Table 9.2) Mean Index of emergence at each site over the sampling period

taxonomic group	Site Pi.	Br.	We.	Wh.	Ra.	Wa.
chironomid larvae	0.03	0.02	0.20	0.82	0.01	0.02
chironomid exuviae	0.11	0.11	0.18	0.04	0.00	0.05
harpacticoids	0.08	0.04	0.00	1.26	0.00	0.12
cyclopoids	17.00	0.22	0.02	0.10	0.01	1.08
chydorids	0.12	0.06	0.89	4.98	0.00	0.68
halacaridae	0.00	0.00	0.03	0.22	0.00	0.53
tyroglyphidae	0.00	0.19	0.01	0.01	0.48	0.09
hydracarina	0.74	0.03	0.00	0.01	0.00	0.01
(n)	7	6	11	10	9	10

Site Code:
Pi. - Pitsford
Br. - Brixworth
We. - Weedon
Wh. - Whilton
Ra. - Ravensthorpe
Wa. - Watford

Fig. 9.3) Cyclopoid penetration of treatment during 1988



of the tap study, though Hollowell (Fig. 9.3c) has the largest peak in numbers during July 1988. Ravensthorpe raw water also shows a single peak which is comparable in density to the Pitsford peaks. It appears that Ravensthorpe Treatment Works is subjected to peaks of cyclopoid numbers in the raw water comparable to Pitsford, but not over such a prolonged period.

If the two types of treatment had a similar efficiency, then numbers in the final water at Ravensthorpe following the peaks in the raw water would be similar in density to numbers at Pitsford. However, as can be seen from the final water data in Figure 9.3, the density of copepods in the final water at Ravensthorpe never exceeded three animals per 1000 litres, while at Pitsford, the density exceeded 100 animals per 1000 litres on four occasions. As far as cyclopoid copepods are concerned, it appears that rapid gravity filtration at Pitsford is not as efficient as slow sand filtration at Ravensthorpe, and this fact is apparent from the animals removed at the taps at these two locations.

9.5.3) Emergence index related to rate

Each sampling occasion involved the use of different flow rates, so the rate of flow and I_e were plotted for each taxon. The results for chironomid larvae, cyclopoids, harpacticoids and halacarid mites (Figs. 9.4 - 9.7) suggest that the flow rate did not have a relationship with the density of animals exiting per consumer day, with animals removed at high densities at low rates of flow. The relationship between chydorids and rate of flow however (Fig. 9.8) suggests rate may have had an effect on this taxon, but the data were found not to be significant (Fig. 9.9) with occasions when no chydorids were present removed.

This lack of relationship between rate and emergence index suggests that some other feature must control the exit of animals at the tap (presumably the density of animals in the main), and that the variation in rate of flow during the sampling period will not have a significant effect on the data.

9.5.4) Variation in the emergence index at the tap

Table 9.3 shows the temperature changes in the system over the period of the study. These data are a mean value from four service reservoirs sampled each each month during the same week as the tap samples were collected. Possible temperature effects linked with the effects of pyrethrin dosing are discussed below.

Figure 9.10 shows the I_e levels for chironomid larvae at each site over the sampling period. Of all the taxa considered during this study, chironomid larvae and associated larval exuviae are of the greatest

Fig. 9.4) Chironomid larvae emergence index: variation with rate of flow

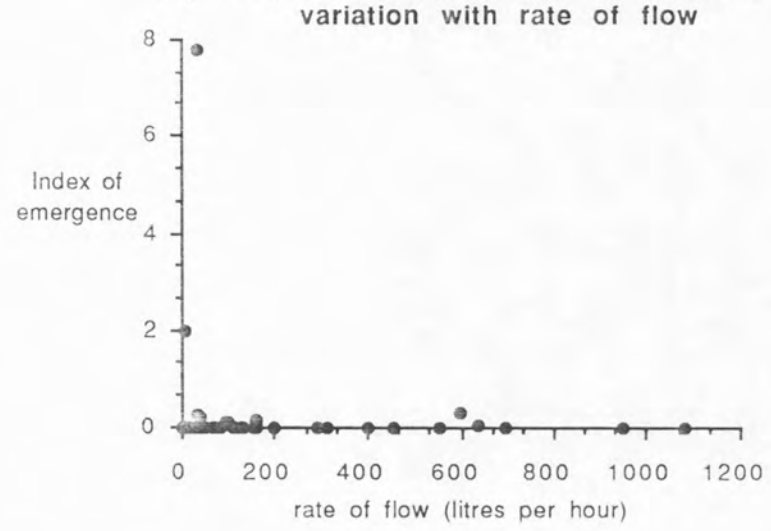


Fig. 9.5) Cyclopoid emergence index: variation with rate of flow

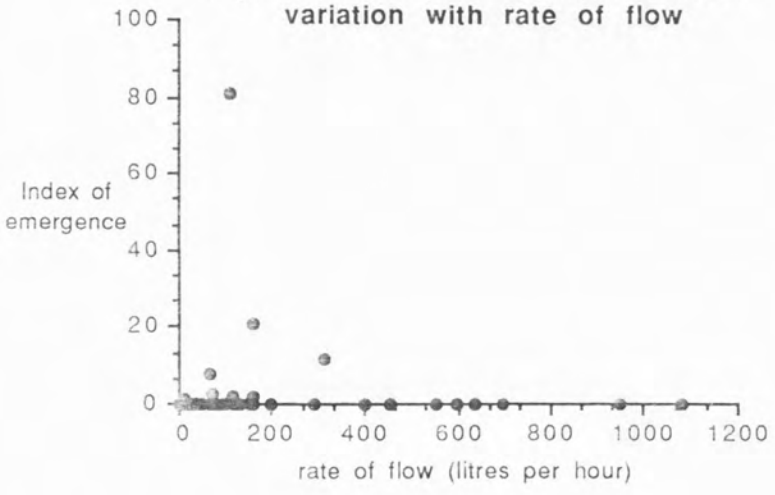


Fig. 9.6) Harpacticoid emergence index: variation with rate of flow

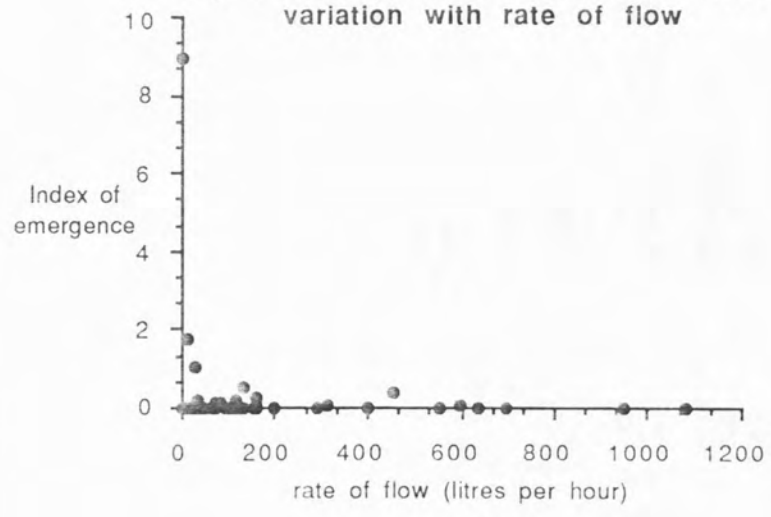


Fig. 9.7) Halacarid emergence index: variation with rate of flow

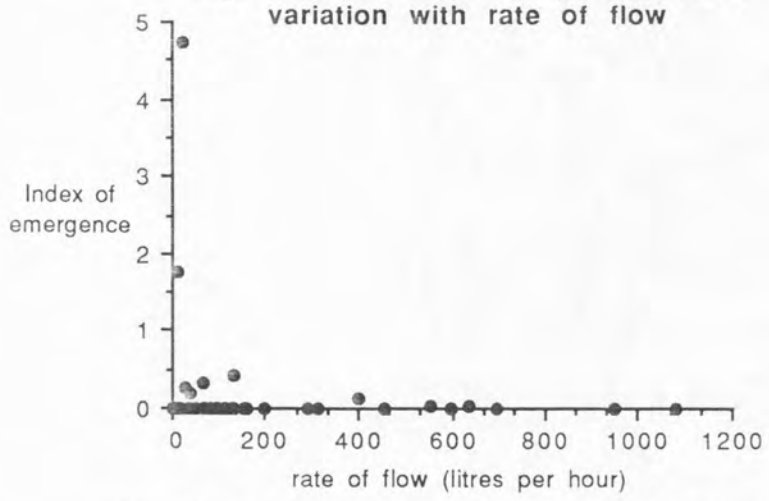


Fig. 9.8) Chydorid emergence index: variation with rate of flow after removal of zero values

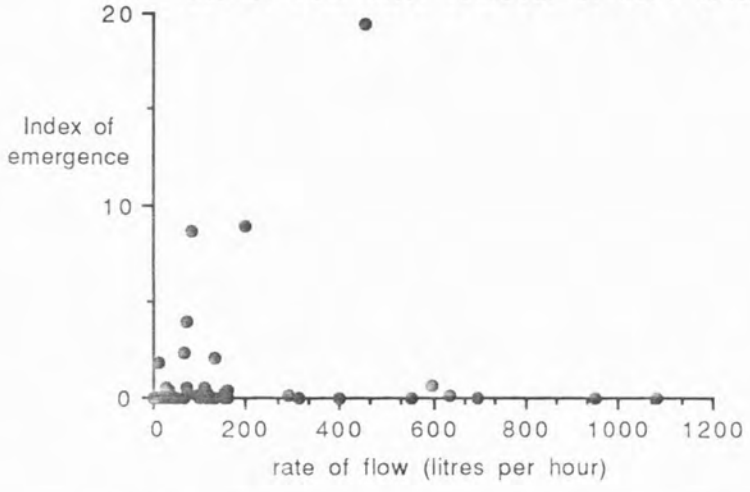


Fig. 9.9) Chydorid emergence index: variation with rate of flow after removal of zero values

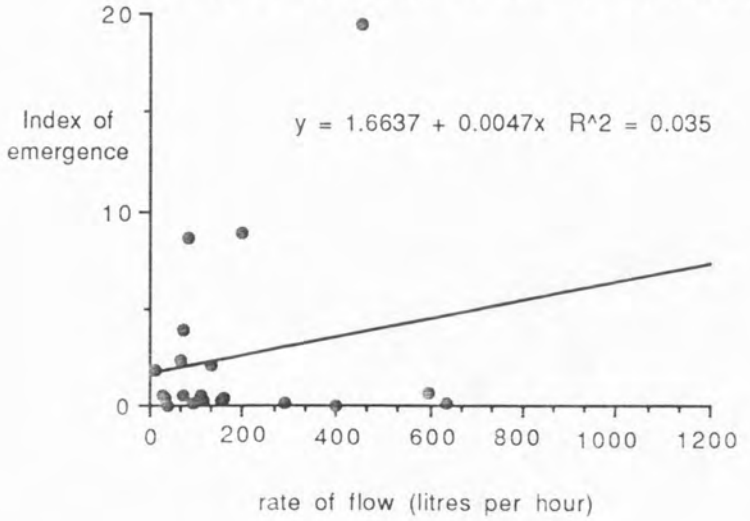


Table 9.3) Monthly temperature of water at time of sampling.

month (1988)	temp. (°C)
Jan.	5.0
Feb.	-
Mar.	7.0
Apr.	8.5
May	12.1
Jun.	14.2
Jul.	15.5
Aug.	16.0
Sep.	14.2
Oct.	11.5

Fig. 9.10) Chironomid emergence per consumer day during 1988

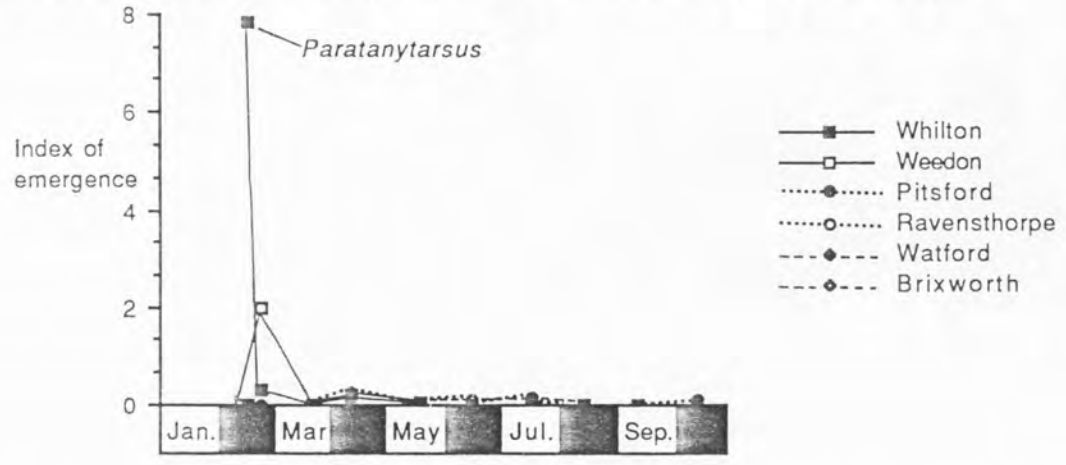


Fig. 9.11) Harpacticoid emergence per consumer day during 1988

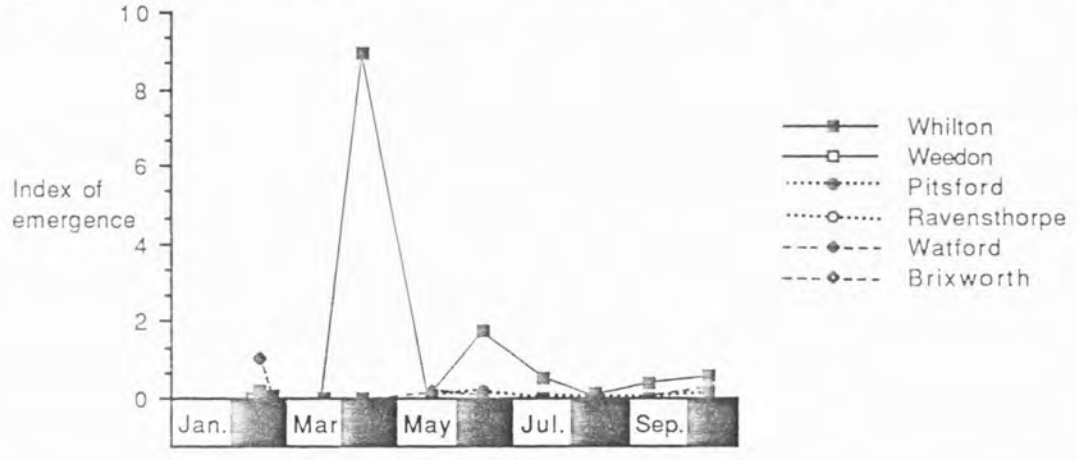
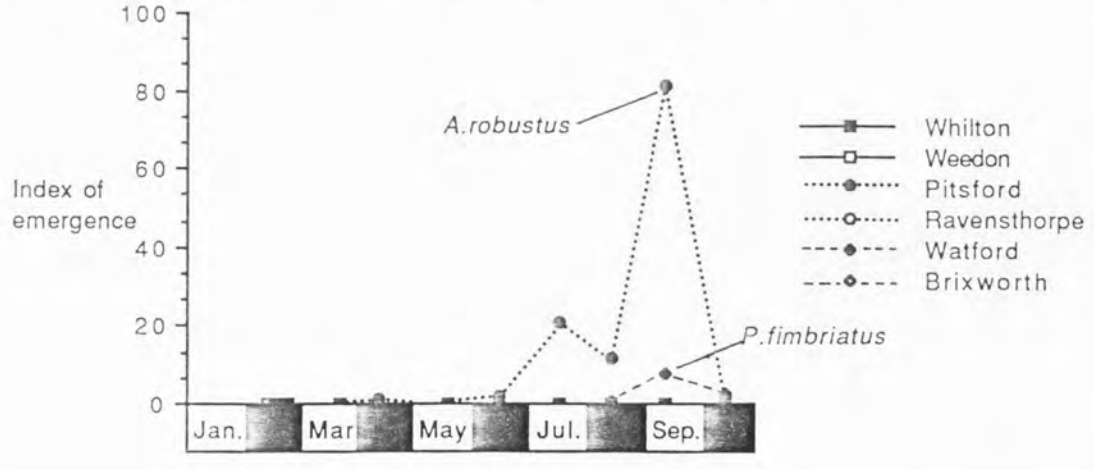


Fig. 9.12) Cyclopoid emergence per consumer day during 1988



concern to the water industry because they cause more complaints from consumers than other taxa. Table 9.2 shows that the density of chironomids that exit at the tap can be high, with a mean of 0.81 chironomids emerging per consumer-day at Whilton. This value reflects the early part of 1988 (Fig. 9.10) when *Paratanytarsus* sp. larvae were exiting at the tap in large numbers (an I_e of approximately 8, ten times the mean, occurred at Whilton during February).

Whilton also shows a greater emergence index for harpacticoids, with levels consistently higher than elsewhere through six months of the 10 month period (Fig. 9.11). It is probable that numbers at Whilton were low in March following the air-scour operations, increased in April and then were depleted by pyrethrin dosing in May. Numbers then increased in June, and declined, perhaps due to the increase in cyclopoid and chydorid density (Figs. 9.12 and 9.13). The reason why Whilton had these particularly high numbers is unclear, since subsequent examination of the pipe fauna in October (see below) did not show any particular difference between sites.

Cyclopoids showed a particularly high I_e level at Pitsford (Fig. 9.12) due to a July-September peak. The animals involved in this peak were *Acanthocyclops robustus* adults, large numbers of copepodites (stage IV and V) which were assumed to be *A.robustus*, and low numbers of adult *Paracyclops fimbriatus*. At Watford, the September cyclopoid peak was due to adults of the species *Paracyclops fimbriatus* (and *P.fimbriatus poppei*). It seems likely that this peak at Watford was due to an increase in numbers of animals in the system which was not related to the final water.

A similar pattern of increase from May was found in the chydorids (Fig. 9.13), with numbers remaining high during October. At Whilton, the change in the dominant exiting taxa was marked. Before March chironomids were obviously present in high numbers, while after May two species of chydorids (*Chydorus sphaericus* and *Graptoleberis testudinaria*) dominated. The initial removal of chironomids from Whilton (fed from Long Buckby Wharf) was believed due to the feed main being air-scoured during February. The chydorid increase from May onwards could have been an effect of temperature or a feature of the pyrethrin dosing during May. Pyrethrin dosing without subsequent flushing increases the detritus (dead animals) available in the pipe which may allow an increase in bacteria, potential food for the rapidly reproducing chydorids that recolonise.

During the study three different groups of mites were found, Halacaridae; Tyroglyphidae; and Hydracarina. The Halacaridae (Fig. 9.14) showed an increase in density following May, which may be a result of temperature, but could be due to an increase in food following pyrethrin

Fig. 9.13) Chydorid emergence per consumer day during 1988

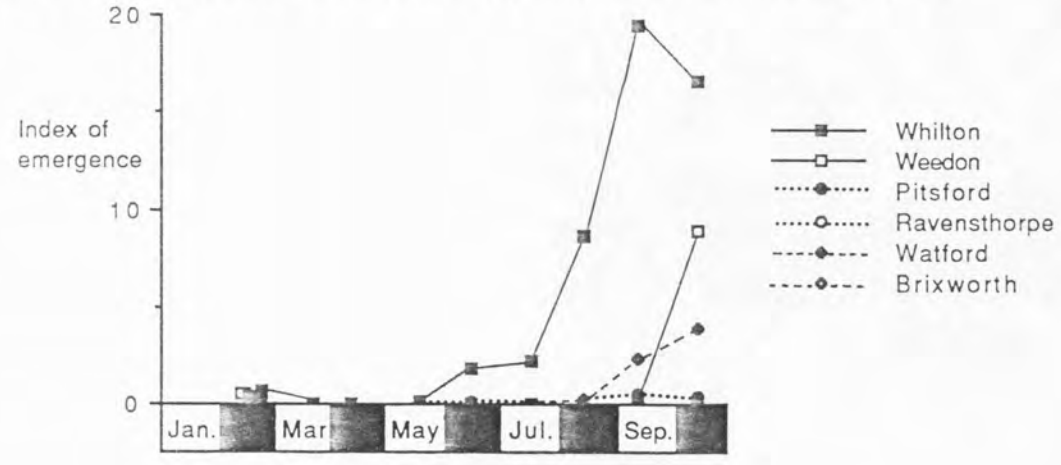


Fig. 9.14) Halacarid emergence per consumer day during 1988

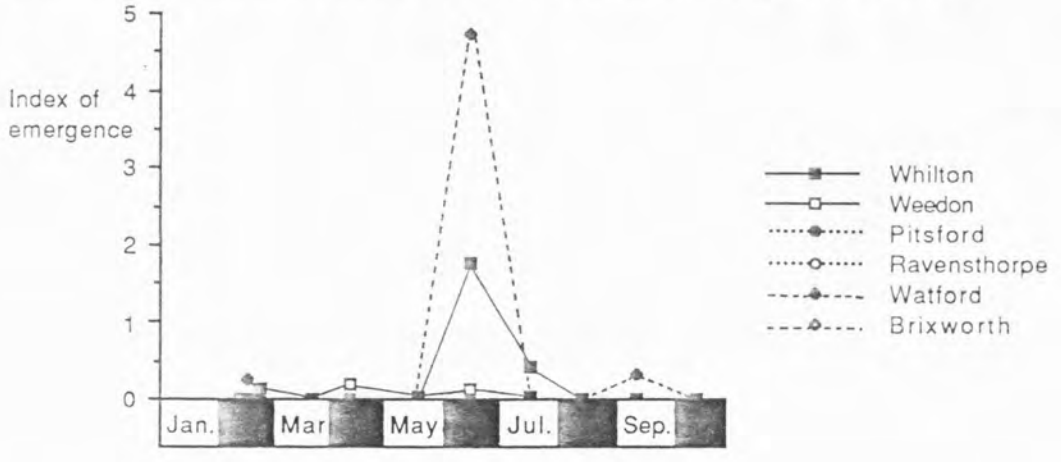
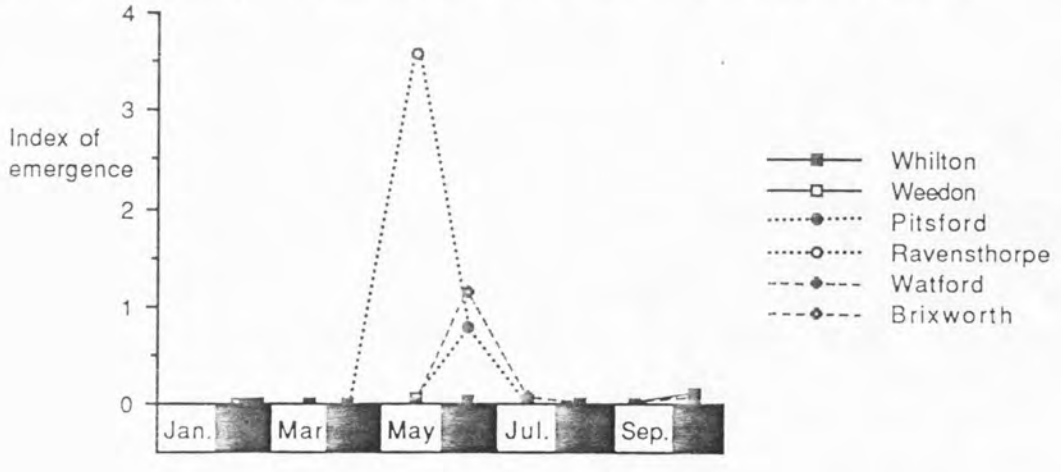


Fig. 9.15) Tyroglyphid emergence per consumer day during 1988



dosing, which enabled the population which survived treatment to increase. (A number of samples taken during the 1986 pyrethrin dosing showed 100% of halacarids present to be killed by the treatment.)

Tyroglyphidae showed peaks at Ravensthorpe and at Brixworth (Fig. 9.15), but why is unclear. The role of these mites in the mains remains uncertain (see Chapter 5). The Hydracarina showed a peak in May also (Fig. 9.16), and this may be due to an increase in copepod prey in the reservoir, which increased the density of these swimming mites in the raw and hence the final water. The large quantities of broken cyclopoid carapcaces and nauplii which were present during the summer may have enabled numbers to increase in the small length of main between treatment and the sample tap.

Figure 9.17 shows the emergence index for *Hydrobia jenkinsi*, the only gastropod mollusc to emerge at the taps during the study. The only animals to occur were small individuals which appeared at Whilton during the winter and at Pitsford in September. The emergence at Pitsford suggests that animals were able to penetrate treatment as small individuals (since *Hydrobia jenkinsi* are ovoviviparous). The sampling site at Pitsford is in the works itself and either comes off a pumping main or a very small length of 3" ring main at the works, and so is unlikely to have a community present. Snails were present in large numbers in the mains at Whilton and Watford and at neither site were animals removed by tap flow.

Table 9.4 shows the I_e values for each species at each site, separated into before and after pyrethrin dosing of the entire system. The samples taken during May are included in the pre-pyrethrin data.

At Whilton and Watford chydorids and halacarids increased after pyrethrin dosing. Chydorids also increased at Weedon and to a lesser degree at Brixworth. At Pitsford, cyclopoids and hydracarina increased and at all the 'system' sites cyclopoids increased while harpacticoids decreased.

The hypotheses that explain these changes, assuming that the I_e are real indicators of changes in the mains (in other words that the chances of being lost at the tap remains constant for an animal despite the rate of flow at the tap) are listed below:

a) Halacarids increased in numbers due to a rise in food available in the main after the death of many organisms following pyrethrin dosing.

b) Chydorids increased due to the increase in temperature and available food, a true seasonal increase.

c) At Pitsford, cyclopoid numbers and hydracarina numbers increased because of higher numbers in the final water, brought

Fig. 9.16) Hydracarina emergence per consumer day during 1988

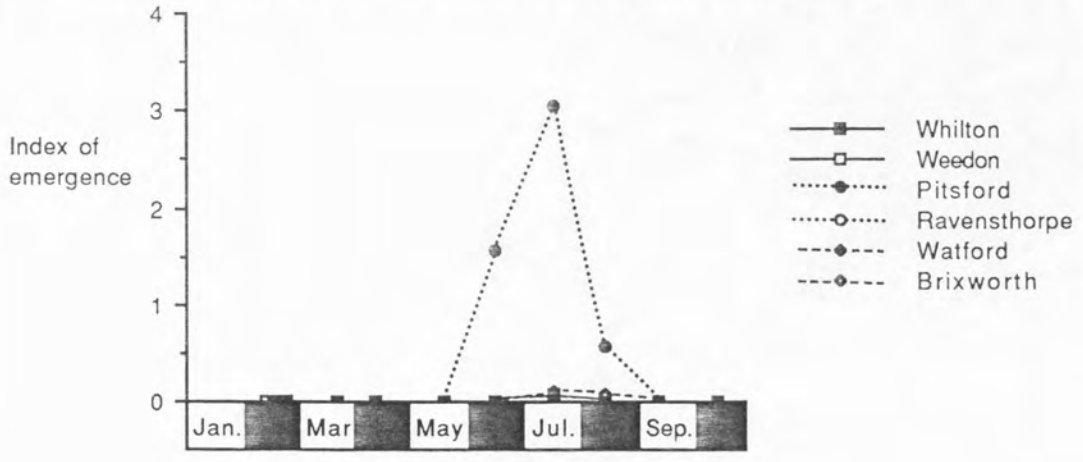


Fig. 9.17) *Hydrobia* emergence per consumer day during 1988

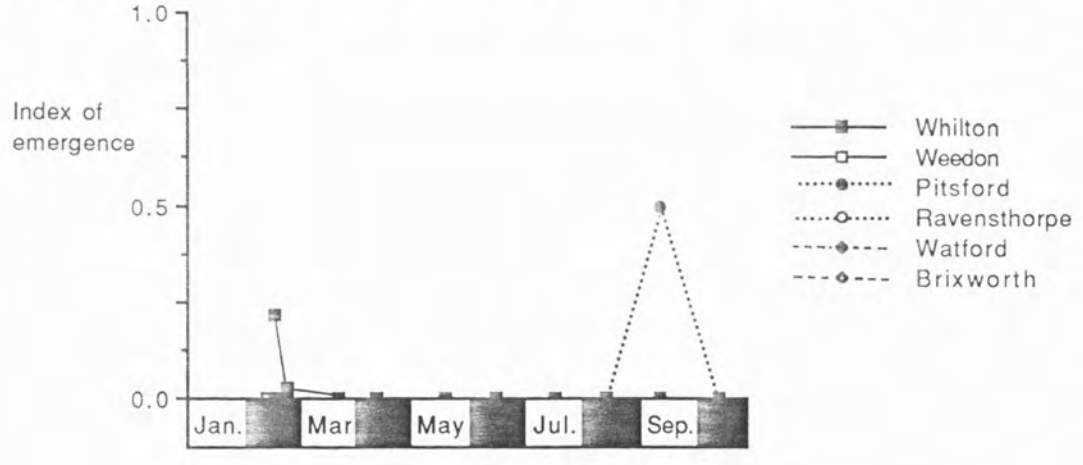


Table 9.4) Index of emergence (I_e) at the tap before and after pyrethrin dosing May 1988.

ROW LABELS:
before pyrethrin: Bp
after pyrethrin: Ap

COLUMN LABELS:
chir lar. - chironomid larvae; chir ex - chironomid exuviae;
harp - hapacticoids; cycl - cyclopoids; chyd - chydorids;
hala - halacarids; tyro - tyroglyphids; hydr - hydracarina;
gast - *Hydrobia jenkinsi*.

site		chir lar.	chir ex	harp	cycl	chyd	hala	tyro	hydr	gast	(n)
Pitsford	Bp	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	(2)
	Ap	0.05	0.16	0.11	23.56	0.18	0.00	0.00	1.03	0.10	(5)
Brixwor.	Bp	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	(1)
	Ap	0.02	0.13	0.00	0.27	0.07	0.00	0.23	0.04	0.00	(5)
Weedon	Bp	0.37	0.34	0.01	0.00	0.12	0.03	0.01	0.00	0.00	(6)
	Ap	0.01	0.00	0.00	0.05	1.80	0.03	0.02	0.00	0.00	(5)
Whilton	Bp	1.64	0.09	1.85	0.00	0.23	0.01	0.00	0.00	0.05	(5)
	Ap	0.00	0.00	0.67	0.20	9.73	0.43	0.02	0.02	0.00	(5)
Ravenst.	Bp	0.00	0.00	0.00	0.00	0.00	0.00	0.89	0.00	0.00	(4)
	Ap	0.02	0.00	0.00	0.02	0.02	0.00	0.16	0.00	0.00	(5)
Watford	Bp	0.05	0.10	0.21	0.00	0.10	0.06	0.00	0.00	0.00	(5)
	Ap	0.00	0.00	0.02	2.16	1.26	1.01	0.17	0.02	0.00	(5)
Total Emergence Index	Bp	0.46	0.13	0.46	0.05	0.10	0.02	0.16	0.00	0.01	(23)
	Ap	0.02	0.05	0.13	4.38	2.18	0.25	0.10	0.19	0.02	(30)

about by changes in the raw water (storage reservoir) due to temperature. Ravensthorpe showed a low increase in cyclopoids due to better filtration. The increase in cyclopoids at the 'system' sites was due to increased density in the final water, seasonal increase in the pipe population, or both.

d) Harpacticoids were killed by pyrethrin in samples taken during the 1986 pyrethrin dosing. Following the 1988 dosing, at all sites where they ocurred before May, a decline in density occurred. This may be because of failure to compete with chydorids or cyclopoids which were increasing in number.

9.5.4.1) Ratio of chydorids in the main and at the tap at Whilton

At Whilton, the ratio of *Graptoleberis* to *Chydorus* exiting at the tap changes between June and October (Table 9.5). The ratio in the mains and the ratio at the tap at this site during October were similar. This suggests that there may be little difference between the ratio of chydorids in the main and the ratio of animals exiting at the tap at any one time. If this is the case, the ratio between animals at the tap would relate directly to ratios in the main (Table 9.5). This would suggest an August peak for *Graptoleberis* and a later peak by *Chydorus*.

9.5.5) Emergence index relative to animal density:

The level of animals exiting at the pipe is likely to be a function of the numbers in the pipe itself if not the rate. Table 9.6 and Figures 9.18a - f show the species which were present in both tap samples and mains samples taken from the four sites at Brixworth; Weedon; Watford; and Whilton. The feed mains were at Brixworth; Watford; Nether Heyford and Long Buckby Wharf respectively. Each graph shows the density of animals per 1000 litres flushed against the density of animals per 1000 litres run through the tap, so are directly comparable. If the numbers exiting are proportional to the numbers in the main, a diagonal through the point (0,0) would be expected.

Figures 9.18a to 9.18d show results which are consistent with the hypothesis that animal density exiting at the tap is related to density in the mains, while Figures 9.18e and 9.18f show results which cannot be explained by the hypothesis.

The data from the Norgren filter system has shown that further work with more sampling points and detailed estimates of the density in the main, rather than per unit volume flushed, is likely to provide significant information about the emergence of animals at the tap relative to their density in the main.

Table 9.5) Index of emergence, density in the mains and ratio at the tap of *Chydorus* and *Graptoleberis* at Whilton

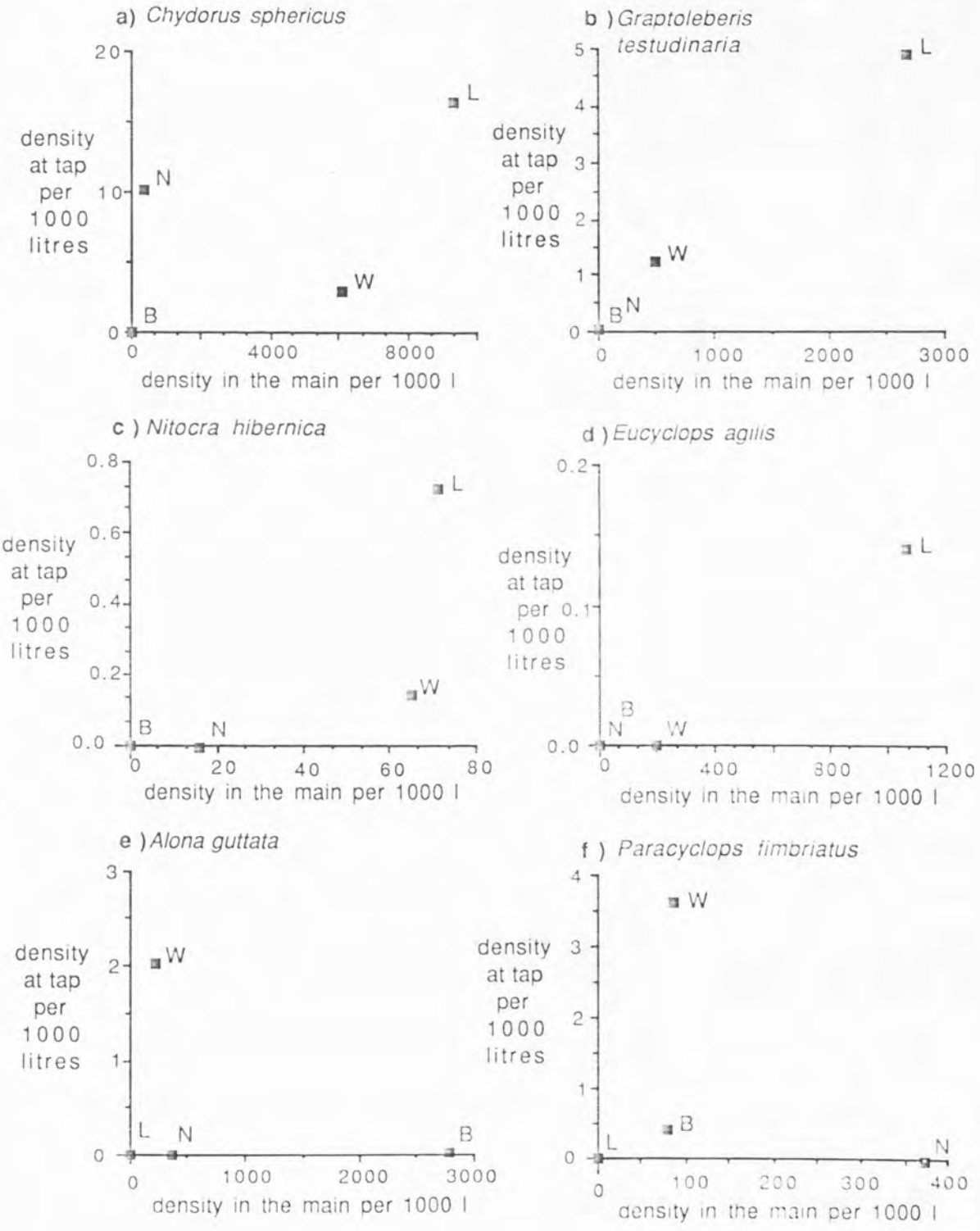
	Chydorus		Graptoleberis		Ratio: (Chydorus/ Graptoleberis)	
	I_e	density in pipe (1000 l^{-1})	I_e	density in pipe (1000 l^{-1})	taps	mains
June	0.9	unknown	0.9	unknown	1.0	unknown
July	0.6	unknown	1.5	unknown	2.3	unknown
Aug.	2.2	unknown	6.5	unknown	0.3	unknown
Sep.	13.9	unknown	5.5	unknown	3.3	unknown
Oct.	12.8	9373	3.8	2678	3.3	3.5

Table 9.6) Species present in mains and taps sampled during October 1988.

Taxonomic Group	Site (Density per 1000 litres in taps: T and Mains: M)			
	Whilton		Weedon	
	T	M	T	M
Hydrobia	0.00	999.00	0.00	0.00
Graptoleberis	4.91	2678.00	1.24	497.00
Chydorus	16.46	9373.00	10.21	404.00
A.qaudrangularis	0.00	804.00	0.00	0.00
A.guttata	0.00	0.00	0.00	373.00
Nitocra	0.72	71.00	0.00	16.00
Bryocamptus	0.00	0.00	0.00	64.00
E.agilis	0.14	1064.00	0.00	0.00
P.fimbriatus	0.00	0.00	0.00	372.00
M.viridis	0.00	0.00	0.00	0.00
A.robustus	0.00	0.00	0.00	0.00
Oligochaetes	0.00	513.00	0.00	11232.00
Halacarids	0.00	1031.00	0.00	94.00
Chironomids	0.00	0.00	0.00	5.00
	Brixworth		Watford	
	T	M	T	M
Hydrobia	0.00	0.00	0.00	243.00
Graptoleberis	0.00	0.00	0.00	0.00
Chydorus	0.19	0.00	3.03	6136.00
A.qaudrangularis	0.00	0.00	0.00	6363.00
A.guttata	0.00	2787.00	2.02	228.00
Nitocra	0.00	0.00	0.14	65.00
Bryocamptus	0.00	6.00	0.00	11.00
E.agilis	0.00	0.00	0.00	202.00
P.fimbriatus	0.38	78.00	3.60	86.00
M.viridis	0.00	10.00	0.00	43.00
A.robustus	0.00	20.00	0.00	0.00
Oligochaetes	0.00	628.00	0.00	4474.00
Halacarids	0.00	6.00	0.00	106.00
Chironomids	0.00	16.00	0.00	36.00

Fig. 9.18) The relationship between animal density per 1000 litres at taps and mains sampled during October 1988

Legend: Tap location/main location
L: Whilton/Long Buckby W: Watford/Watford
N: Weedon/Nether Heyford B: Brixworth/Brixworth



9.5.6) Degree of Infestation at the tap

Figure 9.19 shows the effect of sampling flow rate on the $D.I._t$, and suggests that there is not a relationship between the two, even though samples later in the sampling period when the $D.I._t$ was higher were removed at a greater rate.

On a site by site basis, the general trend of the $D.I._t$ with time is upwards during the summer, (Fig. 9.20) which corresponds to a widely-held belief in the water industry that complaints relating to animals increase during the summer months. The peaks prior to March are largely due to the presence of chironomids at Whilton and Weedon. These were removed at Whilton by air-scour and did not reappear. The degree of infestation at the tap for each supply zone, (Table 9.7) before and after pyrethrin, alters little after pyrethrin treatment. The increase in the Pitsford supply zone can be explained by the cyclopoids at the Pitsford Treatment Works site an effect of temperature change rather than pyrethrin. Of the four sites only Weedon showed a decrease in $D.I._t$ after pyrethrin, due to an apparent loss of chironomid larvae and no rapid increase in chydorid numbers as is the case at Whilton.

9.5.7) Degree of infestation at the tap and in the main

Figure 9.21 shows the values of $D.I._t$ and $D.I._m$, (Table 9.7) and their relationship. The number of sites involved is not sufficient to determine whether any true relationship exists between the $D.I._t$ and $D.I._m$,, but the location of the four sites suggests that a difference does exist between sites of different distance into the system, with fewer animals in the mains and fewer animals exiting at the tap nearer treatment. The important feature that Brixworth does not share with the other sites is its proximity to Pitsford Treatment Works, while the other sites are located some distance into the supply system.

9.6) General Discussion

The system of grouping animals to produce a single number is arbitrary, based upon the knowledge and inferences gained from three years research into the problem by this author and discussion with various workers in the water industry. This is not an ideal ranking and the group ranks should be modified by research into the animals which cause consumer complaints at the tap.

The use of the $D.I._t$ will require the development of a series of levels which can be used by the water industry for levels of service to the consumer. The three 'levels' most suitable for the current method are 2, 4 and 8. A $D.I._t$ of 2 corresponds to approximately 10 chydorids or cyclopoids per consumer day or 1 chironomid per consumer day; 4

Fig. 9.19 Degree of infestation at the tap: variation with rate

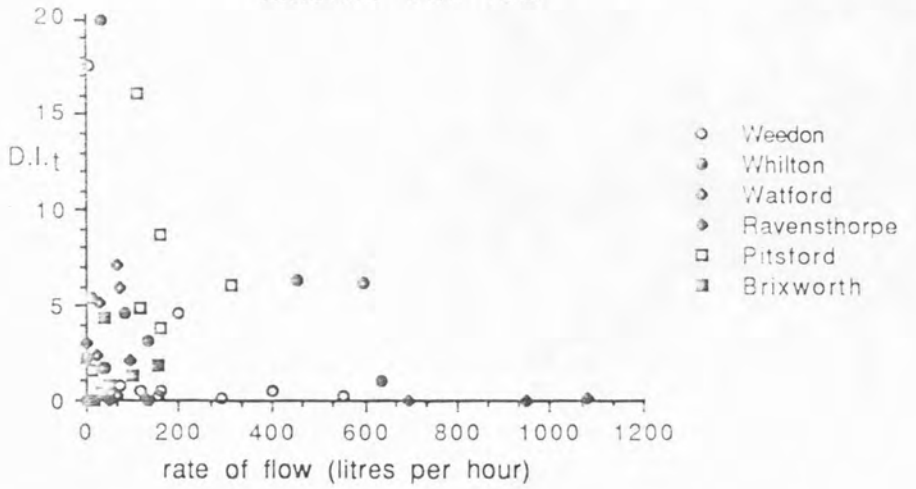


Fig. 9.20) Degree of infestation at the tap: variation during 1988

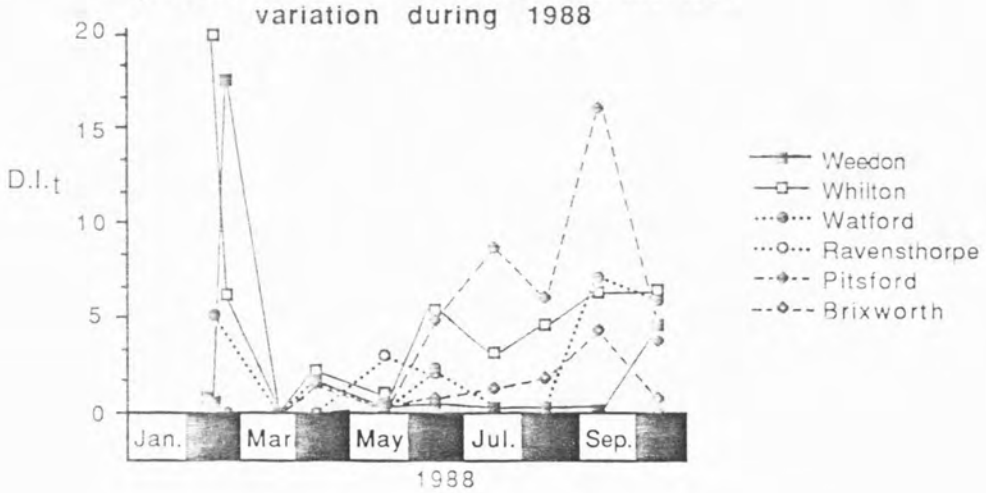


Fig. 9.21) Variation of D.I.t with D.I.m'

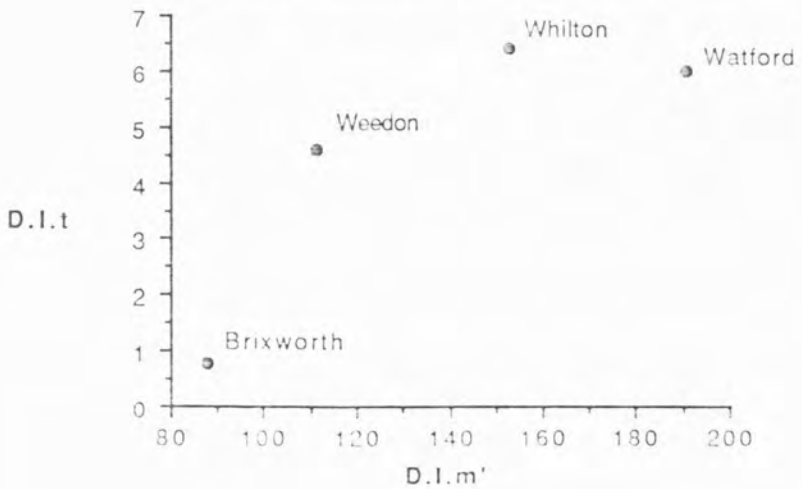


Table 9.7) $D.I._t$ (Degree of infestation at the tap) for each site, before and after pyrethrin levels, over the entire sampling period and $D.I._m$, and $D.I._t$ for October 1988 only.

Site	pre-Pyrethrin (n)	post-Pyrethrin (n)
RAVENSTHORPE SUPPLY ZONE	1.10 (9)	1.82 (10)
Ravensthorpe	0.76 (4)	0.46 (5)
Watford	1.38 (5)	3.17 (5)
PITSFORD SUPPLY ZONE	3.75 (14)	4.03 (20)
Pitsford	0.79 (2)	7.94 (5)
Brixworth	0.39 (1)	1.81 (5)
Weedon	3.51 (6)	1.18 (5)
Whilton	5.90 (5)	5.20 (5)

Site	10 month period (n)	$D.I._m$, (Oct.)	$D.I._t$ (Oct.)
RAVENSTHORPE SUPPLY ZONE	1.48 (19)	-	-
Ravensthorpe	0.60 (9)	-	-
Watford	2.27 (10)	190.8	5.97
PITSFORD SUPPLY ZONE	3.92 (34)	-	-
Pitsford	5.90 (7)	-	-
Brixworth	1.57 (6)	87.8	0.80
Weedon	2.45 (11)	111.3	4.59
Whilton	5.55 (10)	152.8	6.39

corresponds to approximately 99 chydorids or 2 chironomids; and 8 corresponds to 9999 chydorids or 9 chironomids.

Using this system, four levels of service are suggested:

1	$D.I._t \leq 2$	good
2	$2 < D.I._t \leq 4$	poor
3	$4 < D.I._t \leq 8$	bad: requires monitoring
4	$8 < D.I._t$	severe: requires flushing

These show the form such levels would take once the neccessary research is completed. A larger body of data and further work regarding the rank of 'complaint level', (R), would be required to formalise such levels.

It will be possible to obtain direct evidence as to the species of animals which do cause complaints if, on obtaining a complaint from a consumer, a filter system based upon the one used above (a smaller version would be simple to construct) is fitted to the tap from which the offending animal appeared. Once the tap water is filtered for a set period, 'Operations' can undertake cleaning of the mains, by flushing, air-scour or chemical methods (chlorine or permethrin) as required, and where possible, an estimate of the mains fauna can be produced. Thus not only will the ranking be assesed but also information regarding the relationship between $D.I._m$ and $D.I._t$ can be collected.

If this is undertaken throughout each supply zone, it will be possible to establish the percentage of all complaints attributable to each taxonomic group. This percentage can then be compared on a Divisional basis and animals can be ranked accordingly. This will produce a Degree of Infestation that relates directly to the infesting animals present in the area supplied by a Water Authority or Company and their ability to cause complaints. Different Divisions and supply zones can then be compared to establish the best procedures for reducing complaints at the tap, by setting filter units at random throughout the system, enabling the degree of infestation to be monitored.

9.7 Conclusions

It appears from the above work that :

a) Seasonal variation occurs, with animals increasing during June to September despite pyrethrin dosing.

b) Animals exiting at the tap may relate to the animal density in the mains.

c) The relationship between rate of flow through taps and exit rate of animals is unclear.

d) Sites at the extremities of the system have greater infestation levels in the mains and at the tap than sites near to treatment.

PART IIIC: ANIMALS IN SERVICE RESERVOIRS AND TOWERS

CHAPTER 10) SERVICE RESERVOIRS AND TOWERS

10.1) Introduction.....298
10.2) Qualitative analysis of service reservoir and water tower fauna.....299
10.2.1) Methods.....299
10.2.1.1) Sample sites.....300
10.2.2) Results.....300
10.2.3) Discussion.....307
10.3) Methods of sampling to obtain relative measures of density.....308
10.3.1) Test of sampling methods.....310
10.4) Analysis of Service Reservoirs during 1988 using a measure of Relative Density.....310
10.4.1) Introduction of possible scenarios.....310
10.4.2) Survey Sites.....311
10.4.3) Methods.....311
10.4.4) Results and Discussion.....314
10.5) General Conclusions.....320

10.1) Introduction

The role of water towers and service reservoirs in animal infestations is unclear. They frequently harbour large densities of animals which infest the system fed by the reservoir but whether they exist merely as extensions of the main or 'breeding grounds' is not known. Opinion within the water industry suggests that systems fed from water service reservoirs or water towers exist where flushing of mains will not halt infestation, but thorough cleaning of the water tower as well as the mains will successfullly remove all infesting animals. Little work has been recorded regarding this aspect of infestations in distribution systems, apart from high densities of *Nais communis* found in a service reservoir (Wesenburg-Lund 1938).

Barham (1985) investigated the changes in fauna that were found between the final water leaving Wing Treatment Works and the water leaving Beanfield Storage Reservoir. The study used Norgren filter units (see Chapter 9) on taps to sample the water exiting from both locations and found that there was a change in the fauna present in the system between the two. At Wing, the animals present tended to be limnetic whilst at Beanfield, a benthic fauna was found. Barham (1985) was also able to examine the sludge deposits in contact and storage tanks, and found that large numbers of chironomid larvae were in the residues. Not only larvae but also flying adults were present in these tanks, though it was not determined whether these adults were gaining access through hatches, or whether they were larvae which had penetrated the filters and matured in the system.

All service reservoirs and towers are now enclosed, with no hatches open to the air, which restricts access of terrestrial invertebrates to the system. Despite this, large numbers of woodlice, (Malacostraca, order Isopoda), millipedes (Diplopoda), centepedes, (Chilopoda), and extensive ants nests (Insecta, order Hymenoptera) can be found beneath hatches and on the walls of the hatch space. Some hatches have bolts missing at ground level allowing access to invertebrates. The hatch spaces are also characterised by large numbers of breeding spiders of the genus *Tegenaria*, which suggest either ingress of flying insects from outside the reservoir, or swarming of chironomids inside the reservoir. Markall and Barham (1987) refer to a large number of different species of flying insects caught in 'insectocutors' installed within water service reservoirs within Oundle Division. The range of species caught suggests that access by terrestrial invertebrates occurs (Barham pers. comm.)

Service reservoirs consist of large concrete tanks submerged below the ground on high points around the system, enabling the head of water to be maintained. Some are designed to act as storage facilities, filling

at times of low demand and then outflowing in periods of peak demand, though this tends to be the role of water towers rather than service reservoirs. Sediments build up in the bottom of these towers and reservoirs and lie as a 'floc layer' when present in low amounts (pers. obs.), making grab samples impossible (Barham pers. comm.).

This work concentrated on service reservoirs because of the ease of access relative to towers. Towers have variable flow regimes and therefore may have a different role to that of service reservoirs, but were not considered by the quantitative part of this study.

The initial stage of the investigation was a qualitative assessment of service reservoirs and towers throughout the whole Western area of Oundle Division, prior to cleaning procedures that began in 1986. These cleaning operations meant that any further work on the service reservoirs would be carried out on clean rather than 'dirty' reservoirs.

The second investigation considers the animals that enter through treatment in the final water and relates them to the animals in the contact tank at treatment, and their possible passage through the system, by considering the animals present in four 'in-line' reservoirs in the system.

10.2) Qualitative Analysis of Service Reservoir and Water Tower Fauna

This qualitative investigation was intended to show any differences between the fauna of the service reservoirs and water towers in the system and the pipe network itself. It was also hoped that any change from limnetic to benthic community would appear as distance from treatment increased.

10.2.1) Methods

During March - September 1986, Oundle Division - Western Area undertook a cleaning programme of service reservoirs and water towers. This involved draining the reservoirs and towers and removing any deposits found.

At each reservoir or tower, a sample of these deposits (between 0.5 and 2 litres) was sent to Pitsford Laboratory where samples were preserved in alcohol for future analysis.

Each sample was filtered through a nest of Endecott sieves (2 mm, 500 µ, 100 µ) and a 10 ml volume of each fraction was stored. The 10 ml volume of the 500 µ and 100 µ fraction was examined under a binocular microscope and any animals present were recorded. The 2 mm fraction was examined by eye in a sorting tray.

Animals dissected where necessary and mounted and examined under x400 magnification to identify to species or genus.

10.2.1.1) Sample Sites

Samples were examined from the reservoirs and towers listed below. Locations of these reservoirs and towers in the various supply zones are in Chapter 1 (Figs. 1.4 to 1.8). Those sampled during cleaning operations are shown diagrammatically in Figure 10.1a.

Reservoir or Tower	Capacity (m^3)	Cleaning date
Welton Res.	568	4/3/86
Guilsborough Res. (South half)	1136	4/3/86
Guilsborough Res. (North half)		12/3/86
Borough Hill Res. no.2	1591	12/3/86
Upper Weedon Res.	227	19/3/86
Sibbertoft Res.	227	19/3/86
Cold Ashby Res.	454	20/3/86
West Haddon Res.	1136	15/4/86
West Haddon Tower	45	16/4/86
Long Buckby Res.	1136	23/4/86
Boughton Tower	455	19/5/86
Harpole Tower	1136	23/5/86
Brixworth Tower	227	28/5/86
Sutton Basset Res.	227	12/6/86
Lings Res.	24500	23/6/86
Weedon Res.	5454	9/9/86

10.2.2) Results

The results are shown for 'major' taxonomic groups in Table 10.1 and represented in Figures 10.1a) to 10.1i). Figure 10.1a shows the relative positions of the different reservoirs and towers, Figures 10.1b to 10.1i indicate where different taxonomic groups were found. The shaded reservoirs indicating the presence of each species. No obvious communities appear from the table, and the figures also indicate no particular pattern.

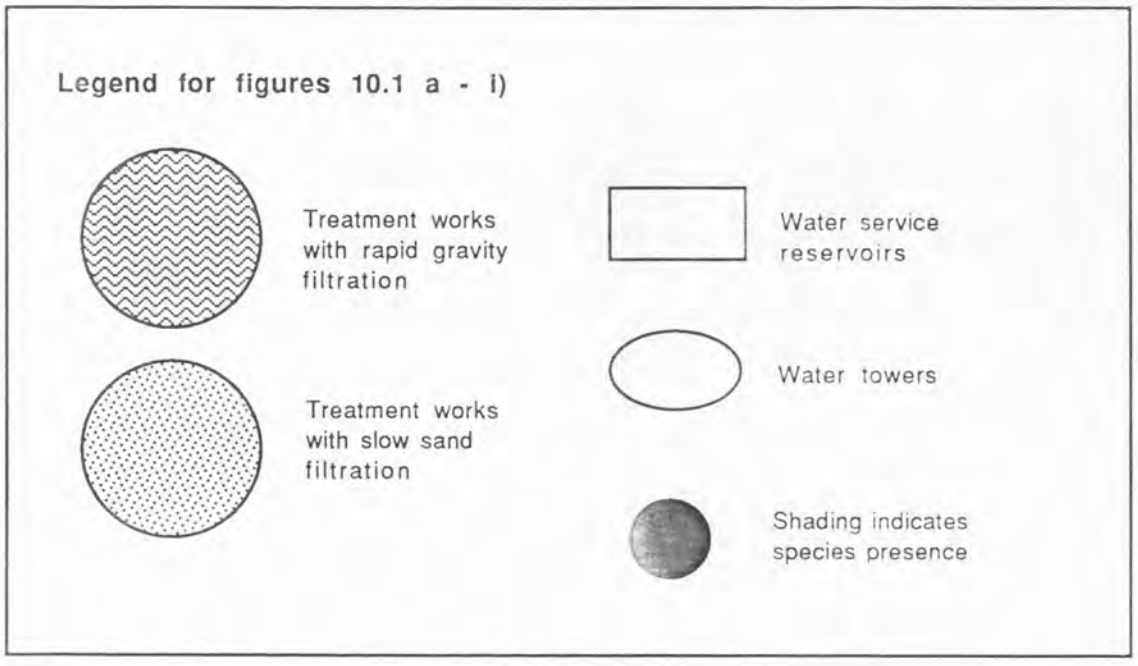
Table 10.1) Presence of each taxonomic group in samples removed from service reservoirs and water towers during cleaning operations in 1986.

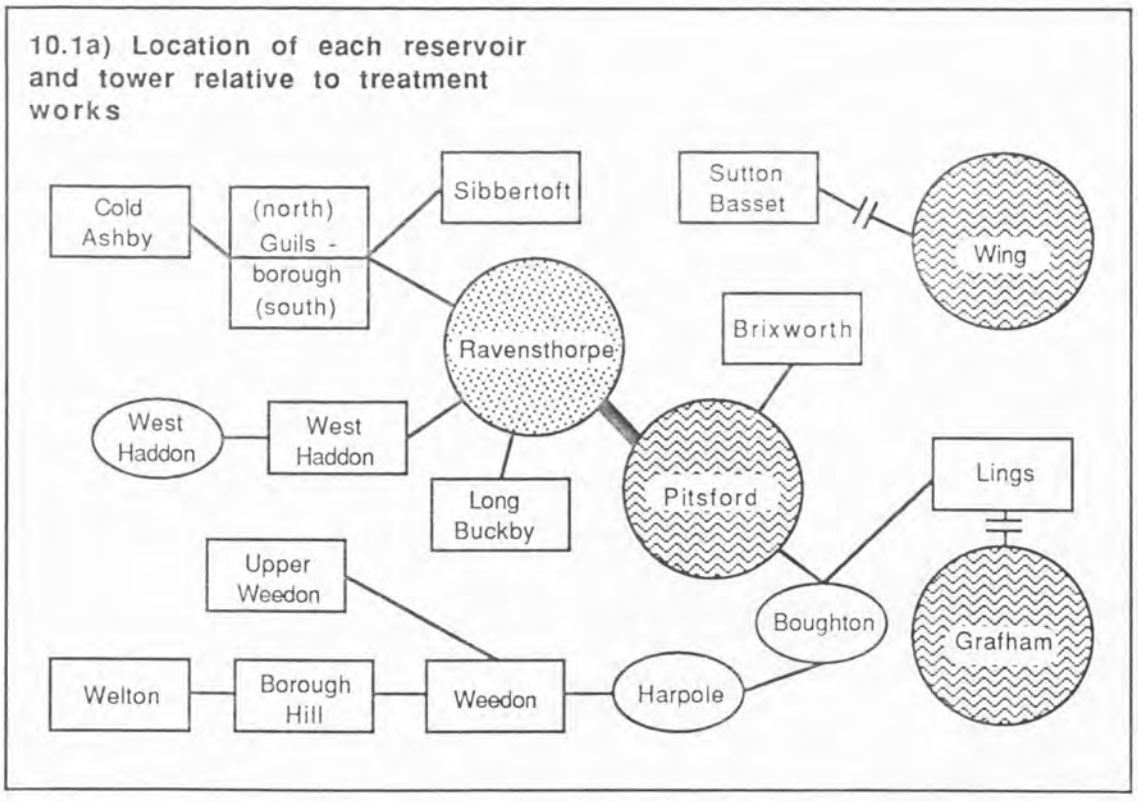
Site	Taxon							
	Ch.	As.	Cy.	Ha.	Chy.	Hal.	Ost.	Ol.
Welton Res.							*	
Guilsborough Res. (South half)	*		*		*			*
Guilsborough Res. (North half)	*				*			*
Borough Hill Res. no.2	*		*	*	*			*
Upper Weedon Res.	*	*	*	*			*	*
Sibbertoft Res.	*		*	*			*	
Cold Ashby Res.			*			*	*	*
West Haddon Res.			*	*	*	*	*	*
West Haddon Tower	*	*	*		*	*		*
Long Buckby Res.	*		*	*	*	*	*	*
Boughton Tower	*			*			*	*
Harpole Tower	*					*		*
Brixworth Tower			*	*				
Sutton Basset Res.			*	*		*		*
Ling Res.					*	*		*
Weedon Res.					*	*		*

Key to taxa:

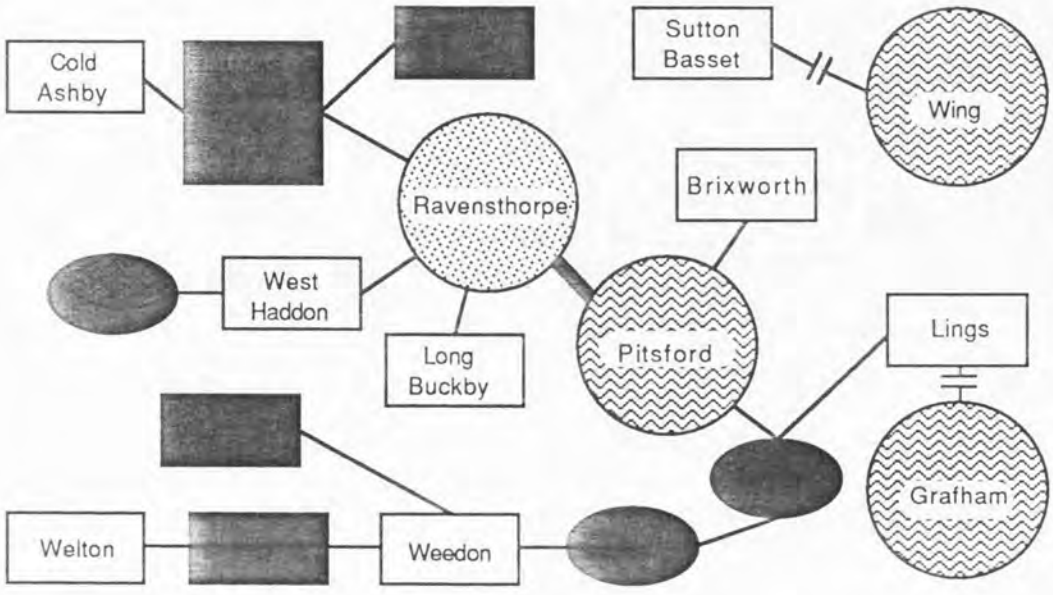
Ch. Chironomid larvae
As. *Asellus*
Cy. Cyclopoids
Ha. Harpacticoids
Chy. Chydorids
Hal. Halacarid mites
Ost. Ostracods
Ol. Oligochaetes

Fig. 10.1) Diagrammatic representation of service reservoirs and water towers sampled during cleaning operations in 1986 and 1987

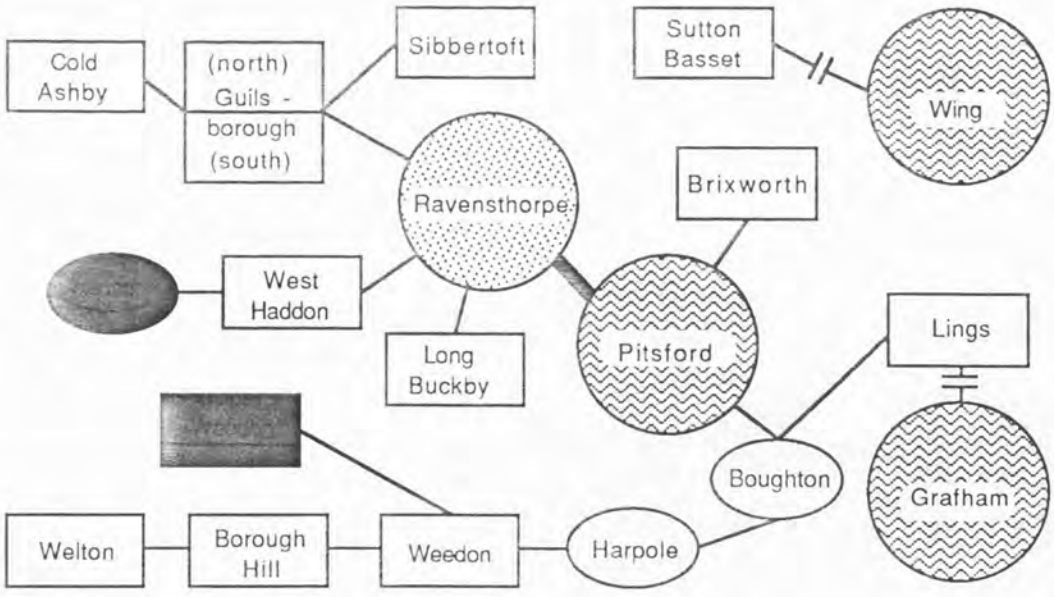


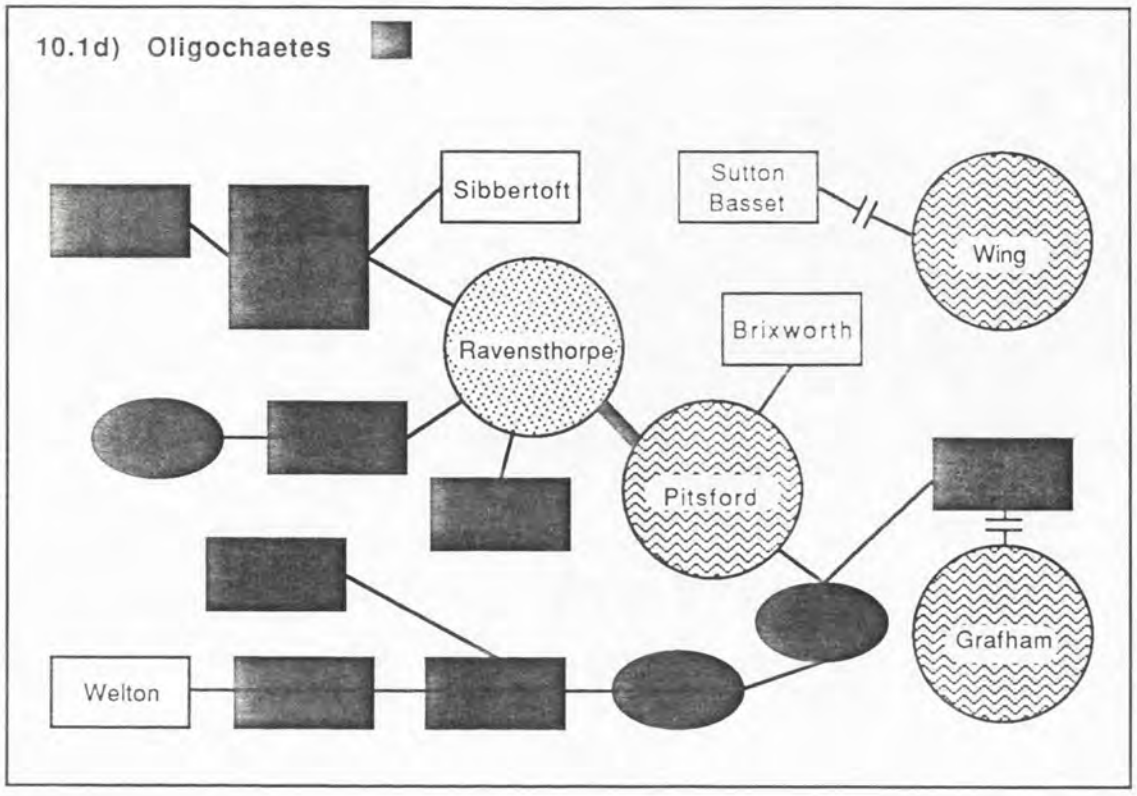


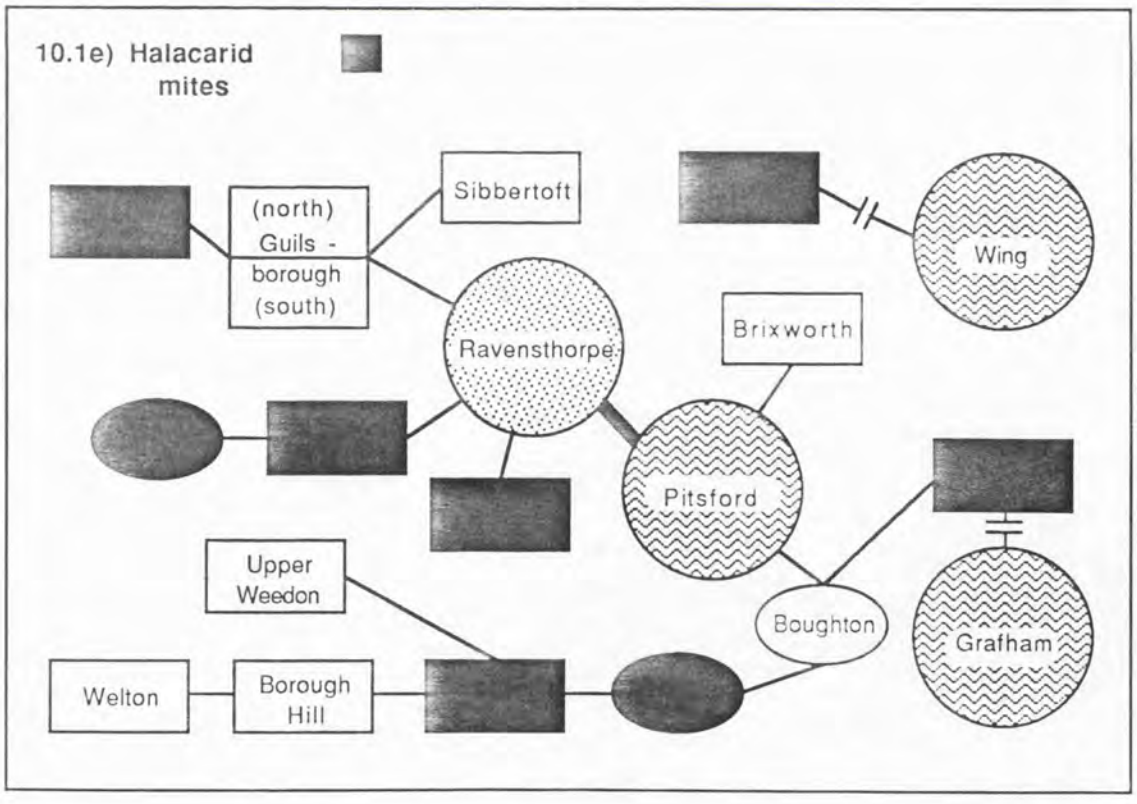
10.1b) Chironomidae



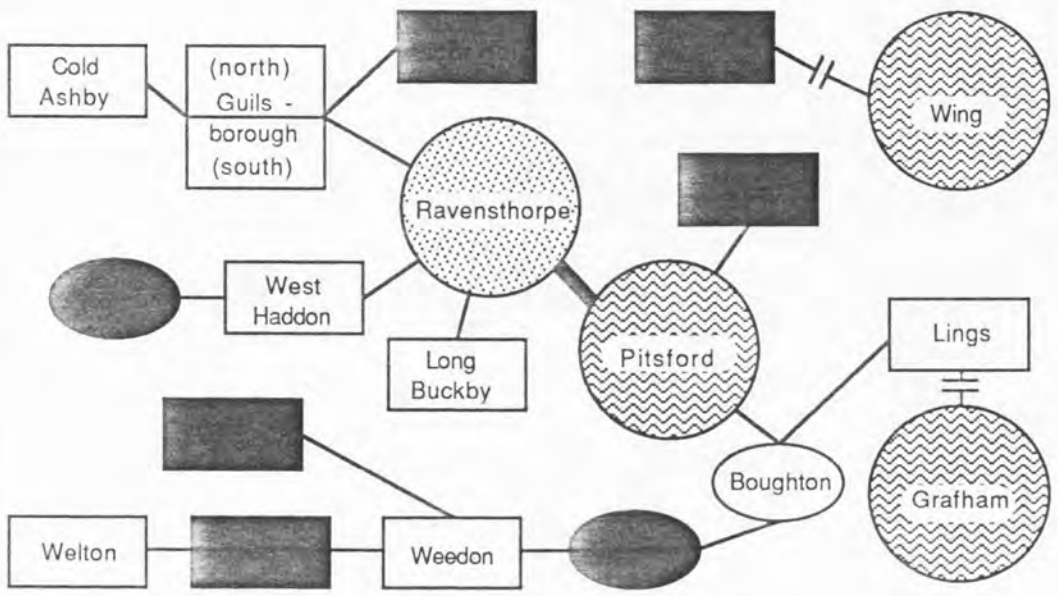
10.1c) *Asellus meridianus*



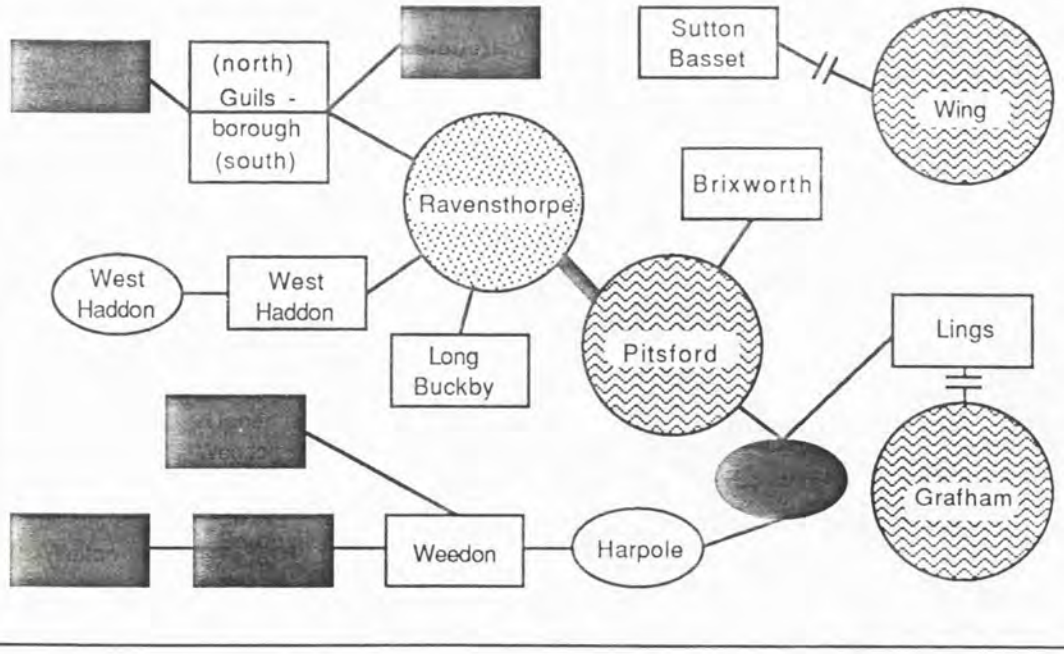

10.1d) Oligochaetes
Sibbertoft
Sutton Basset
Wing
Ravensthorpe
Brixworth
Pitsford
Grafham
Welton

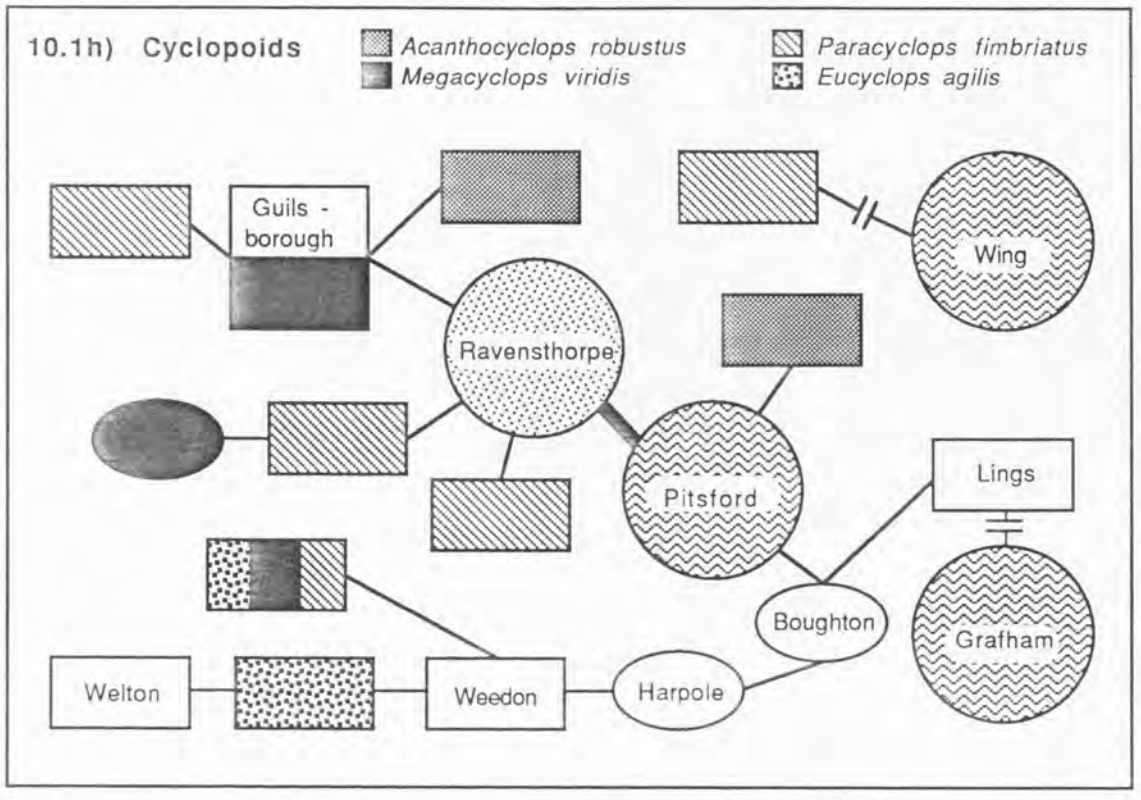

10.1e) Halacarid mites
(north) Guils - borough (south)
Sibbertoft
Wing
Ravensthorpe
Brixworth
Pitsford
Upper Weedon
Boughton
Grafham
Welton
Borough Hill

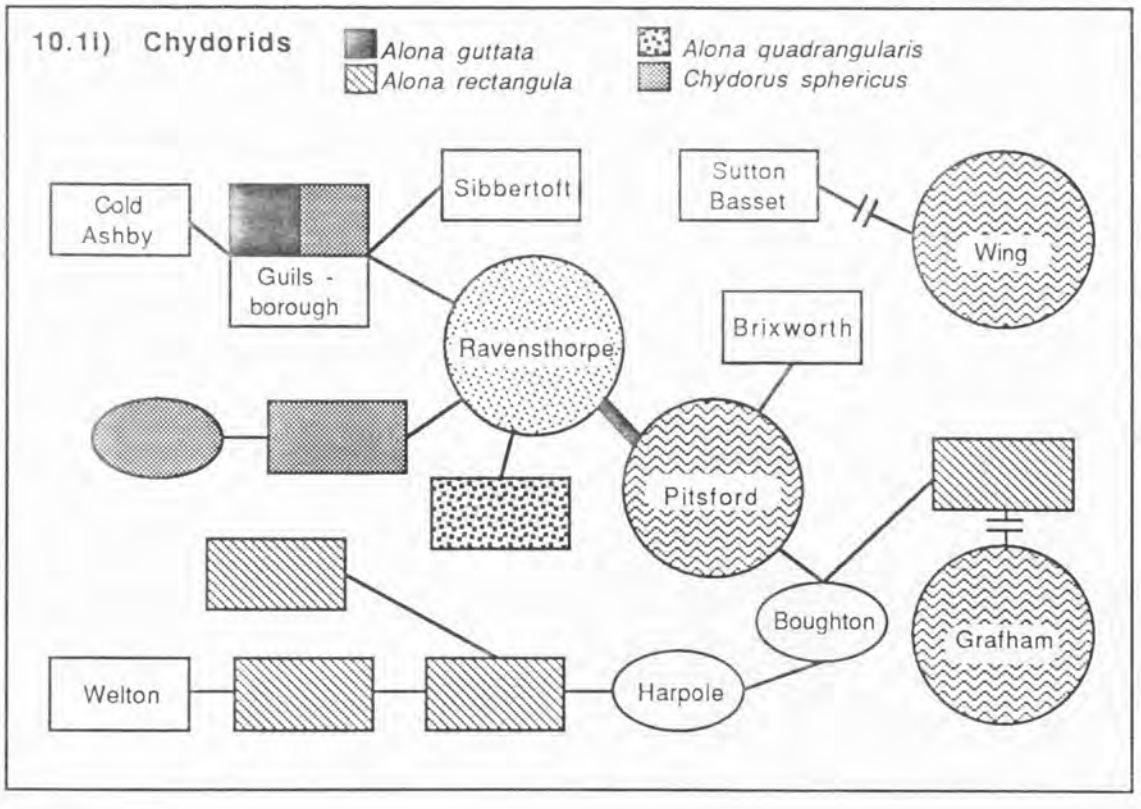
10.1f) Harpacticoids



10.1g) Ostracoda




10.1h) Cyclopoids
Acanthocyclops robustus
Megacyclops viridis
Paracyclops fimbriatus
Eucyclops agilis
Guils - borough
Ravensthorpe
Wing
Pitsford
Lings
Grafham
Boughton
Welton
Weedon
Harpole


10.1i) Chydorids
Alona guttata
Alona rectangula
Alona quadrangularis
Chydorus sphericus
Cold Ashby
Sibbertoft
Guils - borough
Sutton Basset
Wing
Ravensthorpe
Brixworth
Pitsford
Boughton
Grafham
Welton
Harpole

10.2.3) Discussion

Chironomid larvae were present in many of the sampled reservoirs and towers but without any discernible pattern (Fig. 10.1b). If ingress occurs by hatchways and not from treatment this would be the case, but the information is insufficient to draw any conclusion.

The presence of living *Asellus meridianus* in samples from only two sites (Fig. 10.1c) indicates the success of clearance of most of the system following pyrethrin dosing in 1985, prior to which considerable numbers of *Asellus* sp. were present (A.Longhurst pers.comm.). These two sites are both at the extremity of the system and are therefore unlikely to receive high levels of pyrethrin during any dosing of the system. This could be resolved in future by using a pyrethrin dosing trailer (Morgan 1985).

Naid worms appeared in the majority of reservoirs (Fig. 10.1d), but generally only those reservoirs where a large deposit of sediment was present supported any large numbers.

The halacarids (Fig. 10.1e) are known to predate oligochates (see Chapter 5) and the species found in samples from reservoirs were *Soldanonellyx monardi* and *Lobohalacarus weberi*, neither of which has a characterised diet. However, halacarids occurred at only one site where oligochaetes were not present.

Of the remaining taxonomic groups, harpacticoids (Fig. 10.1f) and ostracods showed no particular pattern. These could be expected to be the most ubiquitous of all the species groups since they are frequently found in the drift and being small are more likely to be carried by flow than larger animals.

The three potentially competing cyclopoid species, *Paracyclops fimbriatus*, *Eucyclops agilis* and *Acanthocyclops robustus* did not show any pattern with distance from treatment whereby one species replaces another (the hypothesised change from limnetic to benthic species as distance from treatment increases) (Fig. 10.1h). However the three did not occur together in the same reservoir except where *Megacyclops* sp., a predatory genus, was present, possibly inhibiting the rate of competitive displacement, allowing cohabitation of competing species without exclusion. *Megacyclops* from the distribution system were found to contain only the remains of oligochaetes, but no apparent pattern appears between the distribution of these two taxa.

There does appear to be a difference between the chydorids in the Pitsford and the Ravensthorpe systems (Fig. 10.1i), with *Alona rectangula* present in only the Pitsford system, while other species are found only in the Ravensthorpe system. *Alona guttata* was found in only one reservoir when it is common throughout the distribution system itself.

This qualitative work suggests that some species, such as *Alona guttata*, are not adapted to service reservoirs, but occur in them only when dispersal from the surrounding mains takes place. No obvious transition from limnetic to benthic community appeared in the reservoirs sampled during this study, but this may be a result of the small quantities of sediments examined. There was no apparent relationship between the age of water reaching the reservoir and the number of taxonomic groups present.

If flushing can be carried out on mains above and below service reservoirs and towers, at the same time as the reservoir or tower is sampled, it will be possible to determine whether these sites contain a different community to the main. This would entail a considerable disruption to supply and was not undertaken by this study.

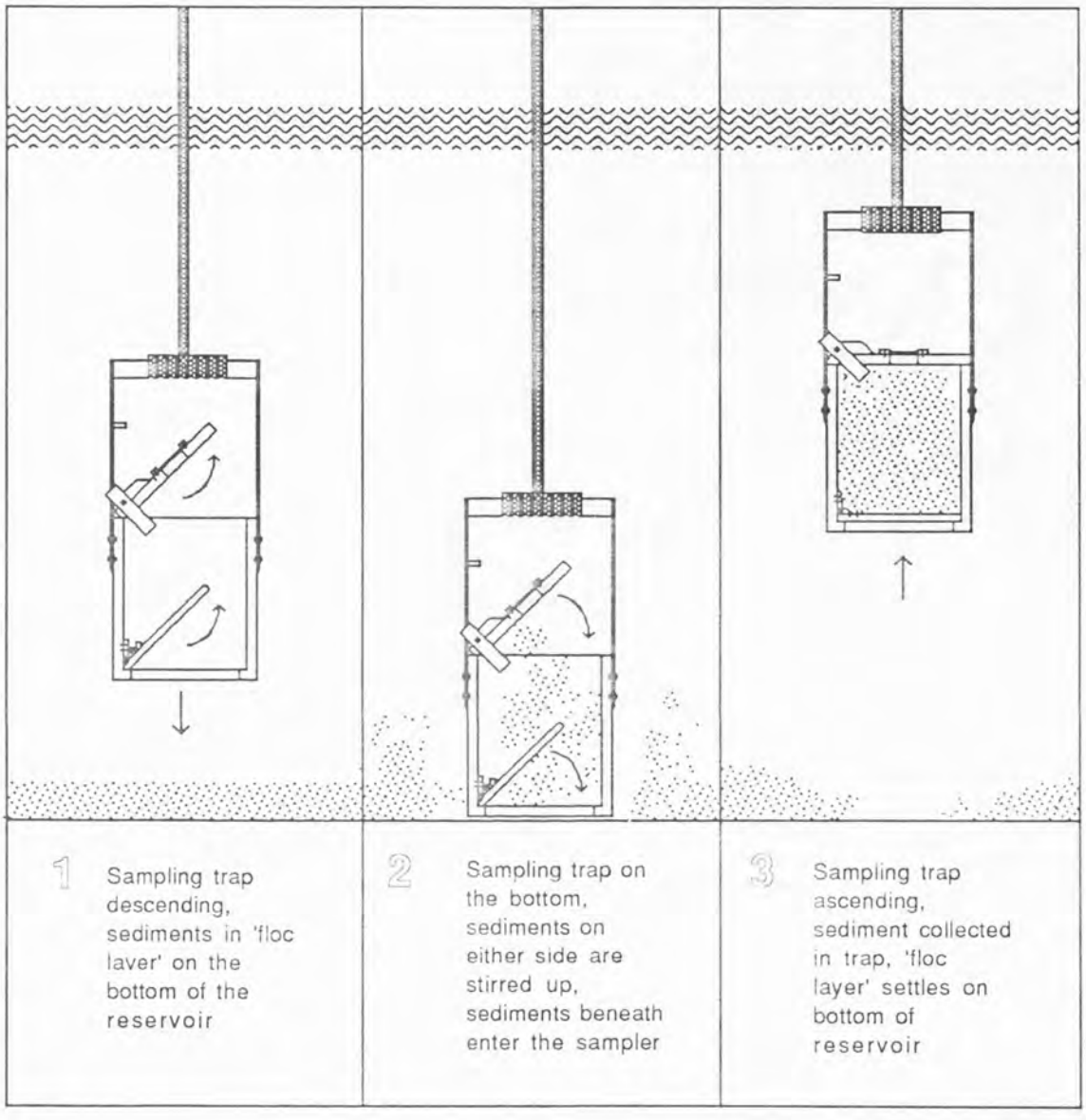
10.3) Methods of sampling to obtain relative measures of density

The major problem in the investigation of service reservoirs and towers is that of sampling, since access is restricted to between one and three hatches (one in most cases).

Various sampling methods were considered, including filter units run from taps (Barham 1985), airlift samplers, pumps (Evins and Greaves 1979) and traps. The possibility of an air lift sampler, such as those described by Drake and Elliott (1982), was considered but rejected on the basis that it would cause too much difficulty when it came to sterilisation of equipment in the field. This was also a problem with the pump sampler used by the WRc (Evins and Greaves 1979). Where possible it was aimed to keep all sampling equipment and procedures simple to enable one individual to be able to carry out the procedure without difficulty. Dredging was also considered, with some form of sledge that would remain on the bottom of the reservoir as it was pulled across, but it was felt this would only be able to provide qualitative samples. Eventuallly it was decided that a modified 'Patalas' sampler (see below), could be used. This was possible because all the reservoirs have a flat bottom, and the sampler would drop until it reached the bottom, disturbing the floccular material upwards as well as sideways and in so doing would provide a sample with sediments inside (Fig. 10.2).

The sampler consisted of a 10 litre cuboidal perspex trap, with upward hinging top and bottom lids which close under their own weight, similar to that used by Schindler (1969) but without an opening in one side of the trap.

Fig. 10.2) Sampling Method For Service Reservoir Sediments



10.3.1) Test of sampling methods

Tests in a controlled tank using river sediments indicated that the sampler disturbs sediments on contact with the substrate and that the disturbed sediments will be collected by the sampler. However, these tests indicated that the sampler frequently failed to close because sediments would lie on the recess on which the bottom lid closes, creating a gap which allowed water and sediments to escape on withdrawal of the sampler from the water column. The possibility that this could be due to the sediments from the river being of a more coarse nature than those commonly occurring in the distribution system was considered. A further test was carried out in a small tank using sediments from the distribution system, and it was found that the sampler bottom lid was rarely blocked by sediments, and that when this did occur the water was able to drain away on removal from the water column.

A number of samples removed from Charwelton, Hellidon, Borough Hill and Guilsborough Reservoirs left clear patches on the floor of the reservoir on removal of the sampler, and samples were found to contain both sediments and animals. The nature of the sediments in the service reservoirs, which form either a layer of floccular material in constant motion above the flat concrete base of the reservoir or a thin layer of sediment, meant that the sampler was able to come into contact with the flat base prior to its closure, and that sediments rarely blocked the lid as described above.

Since there is no means of ensuring that the quantity of sediment collected in the sampler relates to the area onto which the sampler descends, or that sediments are spread evenly across the reservoir floor, these samples will remain of a relative rather than a true quantitative nature.

10.4) Analysis of Service Reservoirs during 1988 using a measure of Relative density

10.4.1) Introduction of possible scenarios

Reservoir sampling investigated which of three scenarios occurred in the Pitsford System during the period of the study. Barham (1985) found that in the supply from Wing Treatnment Works (Rutland Water) there was a change from limnetic to benthic community between the final water and the first service (storage) reservoirs in the system. Of particular interest to this study were the cyclopoid copepods which abound in the final water from Pitsford Treatment Works (Chapter 9). Either these colonise all the reservoirs once penetration has taken place, or simply die in the system, providing the benthic mains community with an increase in organic

material.

Assuming that any animal will penetrate treatment to some degree, three possible scenarios were considered (Fig. 10.3):

A) That the animals complete their life cycle in the reservoirs and thus establish a reservoir population. This does not apply to the contact tank since the retention time is hours rather than days.

B) That the animals are lost from the reservoirs into the system because the retention time is insufficient for completion of the life cycle, which is completed in the distribution system.

C) That the animals die in the contact tank or service reservoirs, during or following passage into the system and hence are an input of dead material (a carbon source) which can be utilised by bacteria or by other larger benthic groups of species.

10.4.2) Survey sites

The following sites were sampled during 1988.

	Capacity:
Pitsford Contact Tank	unknown
Weedon Reservoir	5454 m^3
Borough Hill Reservoir	1591 m^3
Charwelton Reservoir	227 m^3

These four reservoirs can be described as being 'in-line', (Fig. 10.4), with water flowing from Pitsford Contact Tank to Charwelton Reservoir. Though the distance between Weedon and Pitsford appears to be considerable, the large diameter main between Pitsford and Weedon means that the water arrives at Weedon Reservoir approximately 2 hours after leaving Pitsford; at Borough Hill approximately 11 hours from Pitsford; and Charwelton approximately 16 hours from Pitsford. These times were calculated from the WRc Watnet II network analysis, made available by Anglian Water.

10.4.3) Methods

The modified 'Patalas' sampler (described above) was used for sampling the water column, with five 10 litre samples removed from the top and from approximately the middle of the water column if the depth was over 2 m. Only one sample from the bottom could be taken because the sampling sites above have a restricted access. (All are accessed through

Fig.10.3) Possible fate of cyclopoid copepods following penetration of treatment

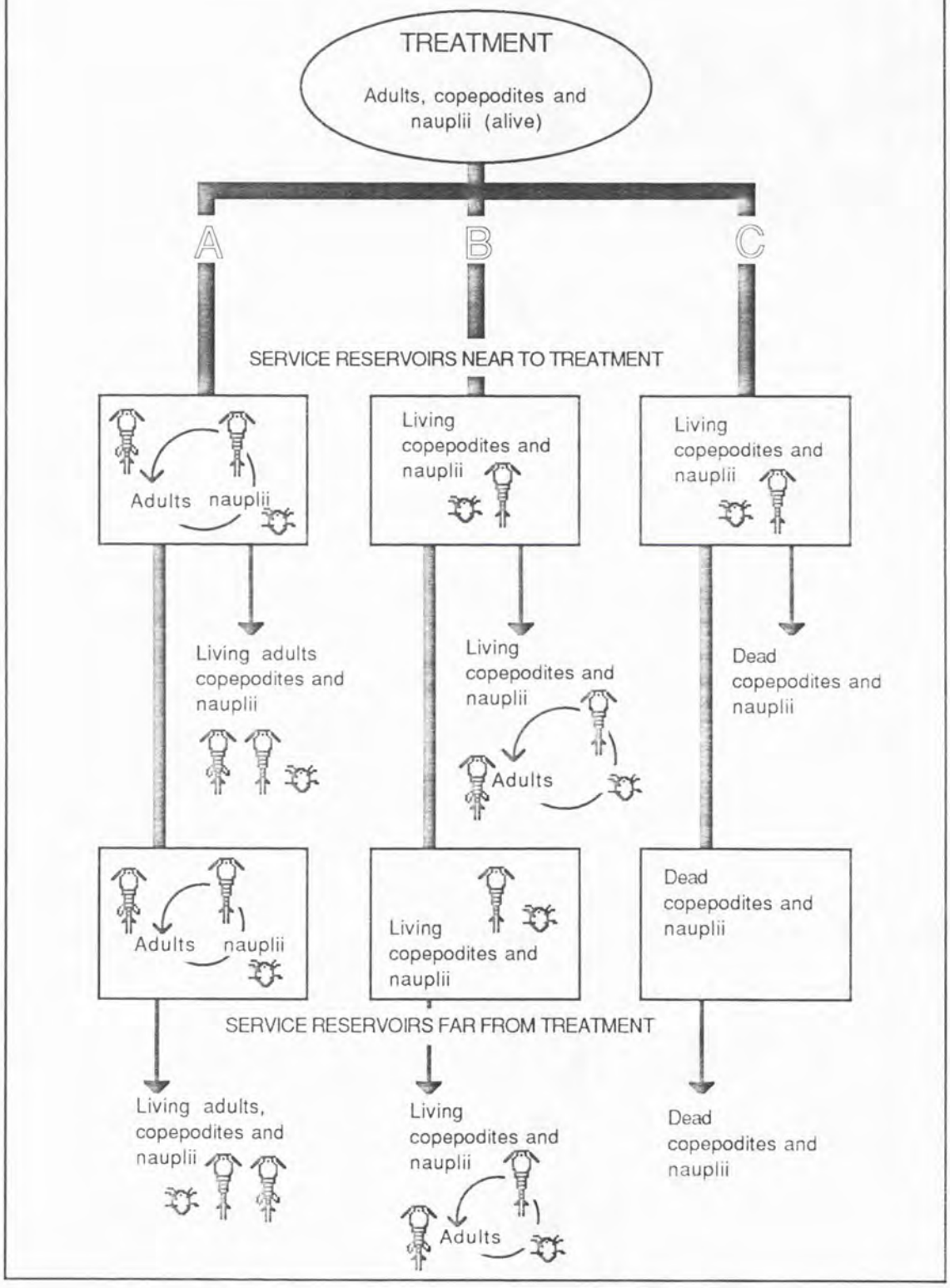
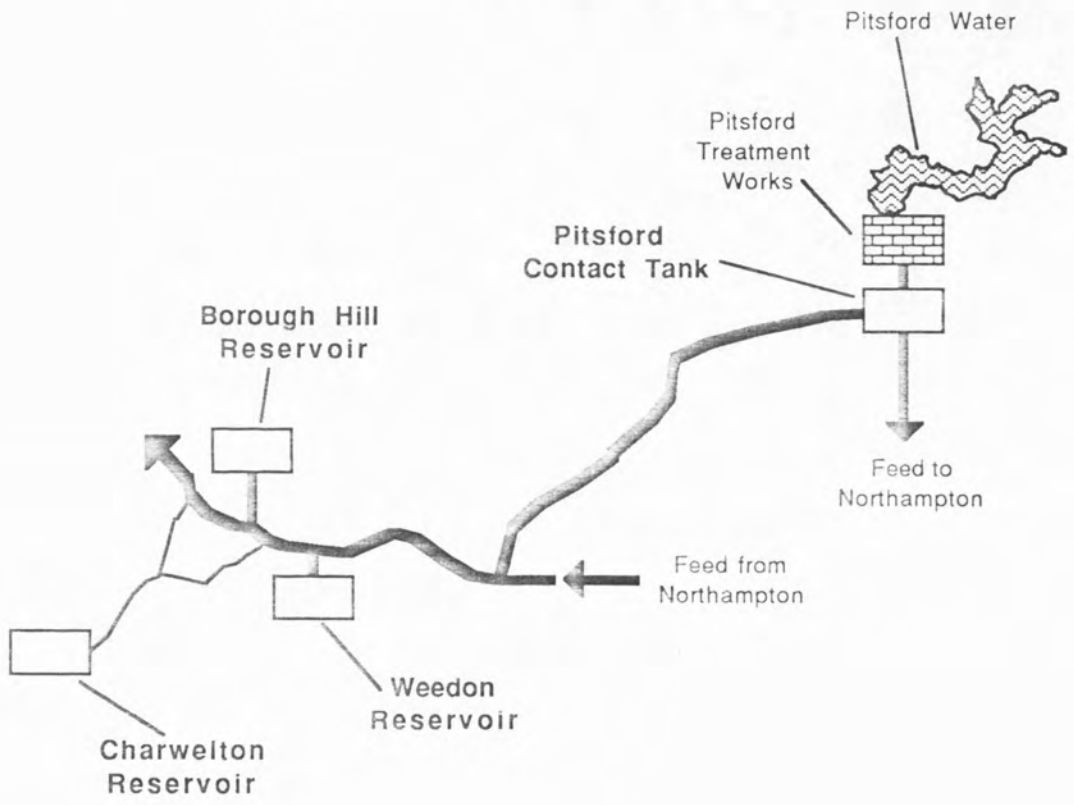


Fig. 10.4) Sketch Map of Service Reservoir sequence sampled in Pitsford Supply Zone during 1988



a single hatch way). Any further sample will contain an unrepresentative quantity of sediment disturbed by the removal of the first sample.

On withdrawal from the reservoir, each sample was emptied into a 15 litre bucket, to minimise the period during which the access hatch was open, and each bucket was then poured through a 142 μ mesh plankton net, which was fixed upright in a perspex frame. The end piece of the net was removed and the animals and sediments present washed into a jar for examination on return to the laboratory. All wash bottles were filled with filtered water to ensure living animals would survive until examination and that no animals were introduced from the wash bottles themselves.

Examination of samples was immediate on return to the laboratory, with microscopic examination, at x15 to x40 magnification, of samples in a Bogarov trough, enabling determination of living and dead animals and counting using a rough taxonomic group classification. Animals were killed and mounted on slides in lactophenol with an appropriate stain (lignin pink or chlorazol black) to identify to species where possible. In some instances, subsampling was necessary for particularly numerous animals notably nauplii and copepodites. If this was the case, samples were mixed between two beakers and subsamples removed as described in Chapter 2 to provide approximately 50 of the taxonomic group in question.

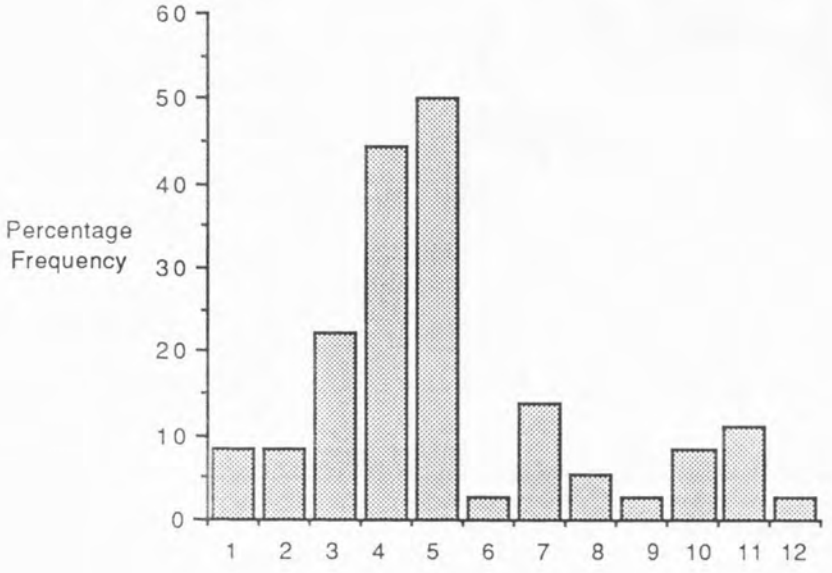
10.4.4) Results and Discussion

Figure 10.5 shows the taxonomic groups present in the samples taken from the reservoirs and their percentage frequency of occurrence. The animals were not particularly numerous, and the difference between benthic and limnetic species does not appear to such a degree as in the study by Barham (1985). Only taxa that occured in over 5% of samples removed during the sample period were considered in the analysis.

The volume sampled varied with reservoir depth, 60 litres in shallow reservoirs and 110 litres in deeper reservoirs. Animals were recorded for comparison as density per litre sampled, with all samples, top, middle and bottom collated to produce a measure of relative density. Due to the nature of the reservoirs and the contact tank, this means that Pitsford and Charwelton have a greater proportion of the mean taken up by the benthic sample, in other words the 'mean density' is weighted so that bottom samples have a greater significance in shallow reservoirs.

These density values are included in Appendix XII and are illustrated by Figures 10.6 to 10.14. Figure 10.5 shows that cyclopoid copepodites and nauplii were the most frequently occurring taxa. At Pitsford, characterised by *Acanthocyclops robustus*, with infrequent *Paracylops*

Fig. 10.5) Percentage Frequency of Taxonomic Groups in samples from Service Reservoirs during 1988



KEY TO TAXA:
1: Harpacticoid copepods
2: Chironomid larvae
3: Halacarid mites
4: Cyclopoid nauplii
5: Cyclopoid copepodites
6: Bosmina sp.
7: Alona sp.
8: Ostracoda
9: Hydracarina
10: Nematodes
11: Oligochaetes
12: Collembola

Fig. 10.6) Copepodite (relative density) in four 'in-line' reservoirs during 1988

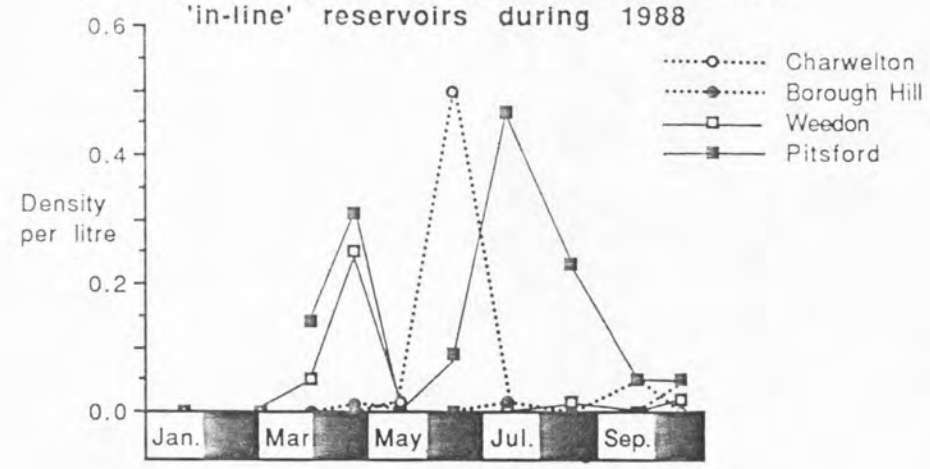


Fig. 10.7) Nauplii (relative density) in four 'in-line' reservoirs during 1988

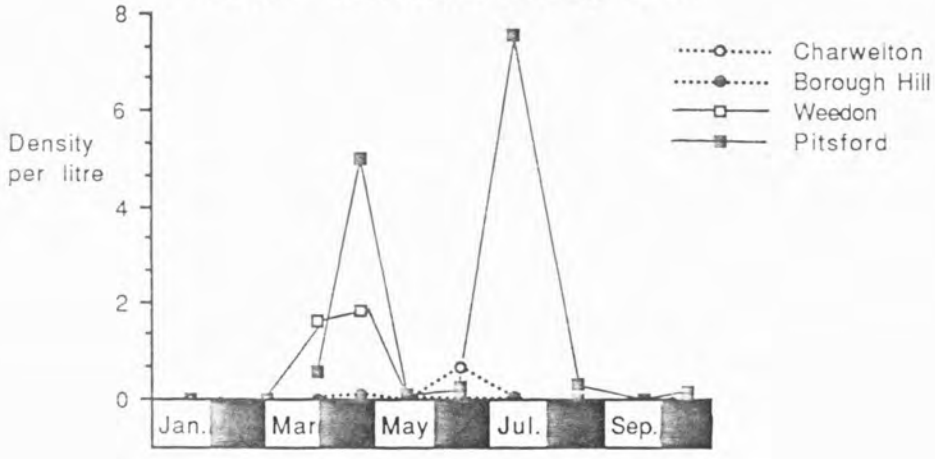


Fig. 10.8) Alona (relative density) in four 'in-line' reservoirs during 1988

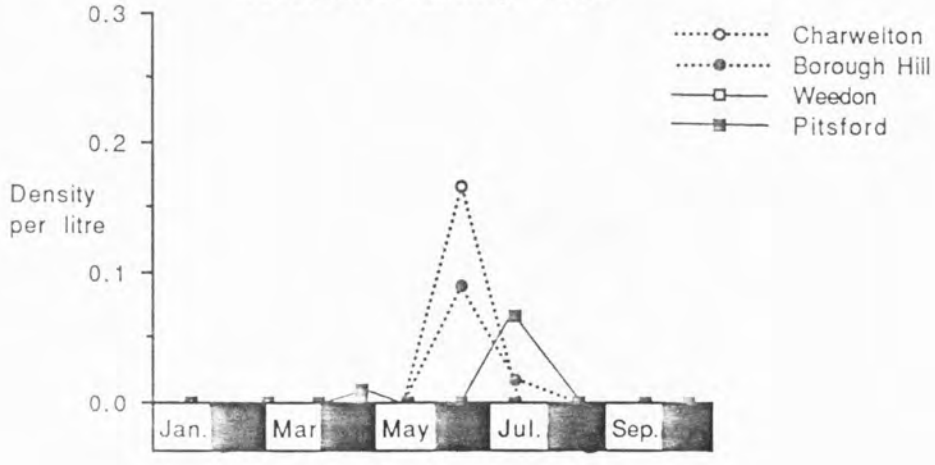


Fig. 10.9) Oligochaete (relative density) in four 'in-line' reservoirs during 1988

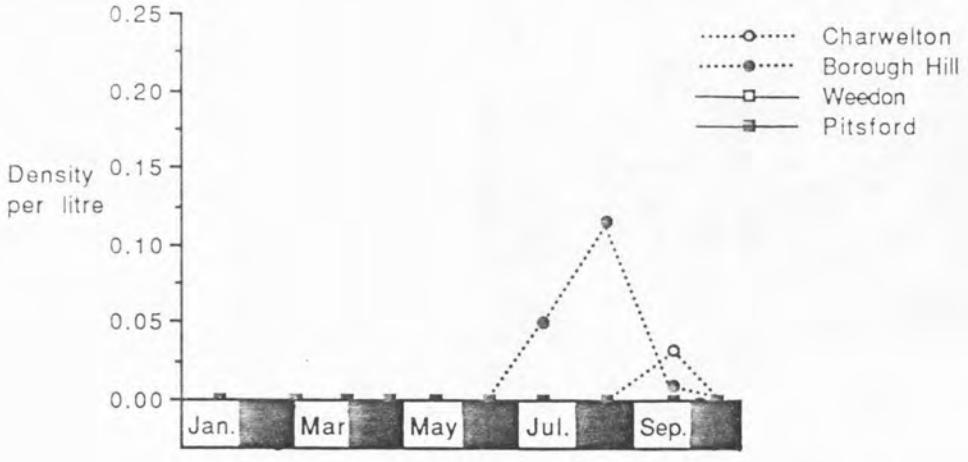


Fig. 10.10) Harpacticoids (relative density) in four 'in-line' reservoirs during 1988

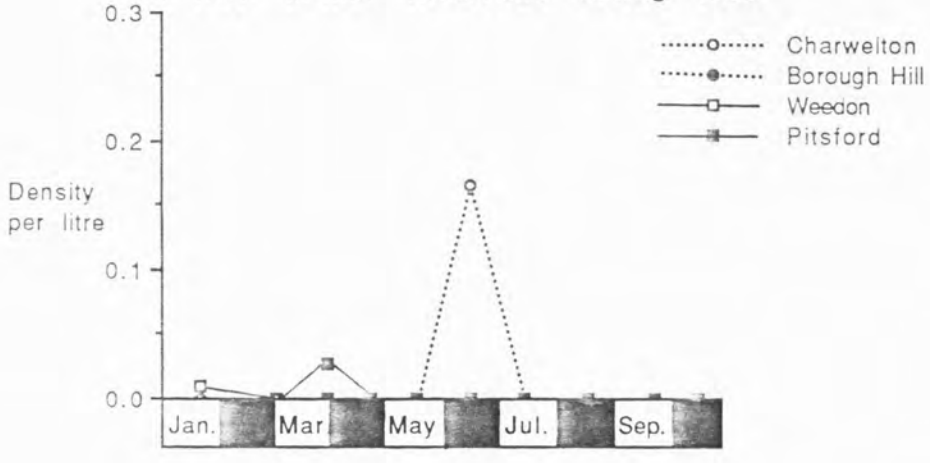


Fig. 10.11) Nematode (relative density) in four 'in-line' reservoirs during 1988

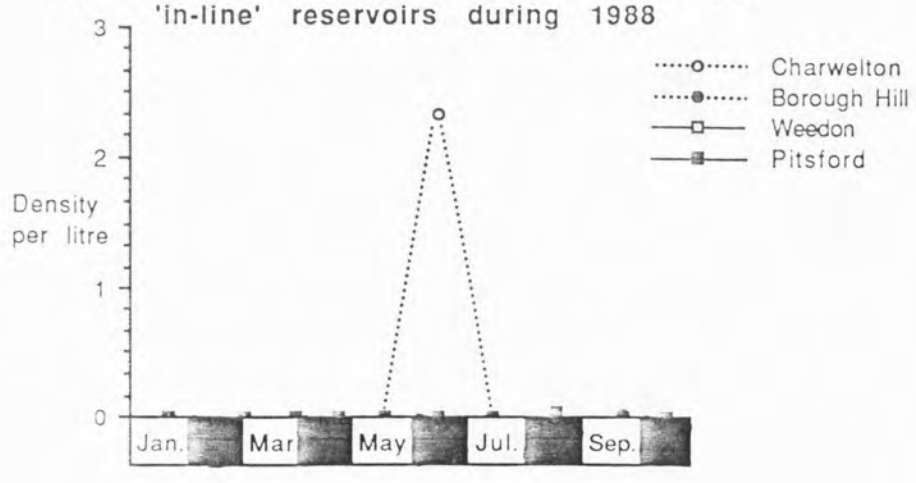


Fig. 10.12) Halacarid (relative density) in four 'in-line' reservoirs during 1988

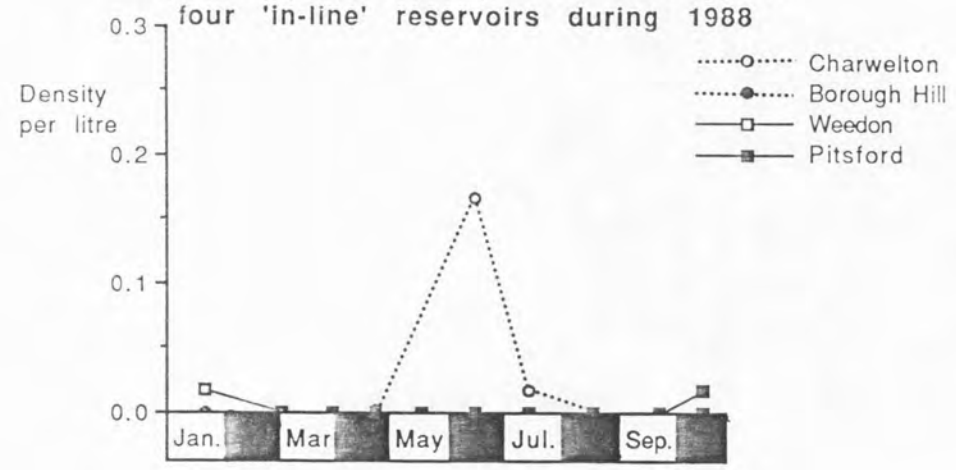


Fig. 10.13) Ostracod (relative density) in four 'in-line' reservoirs during 1988

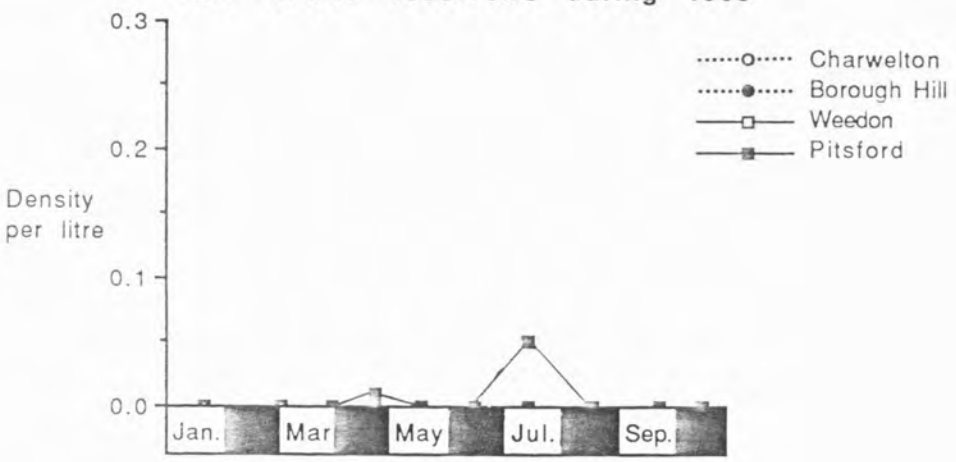
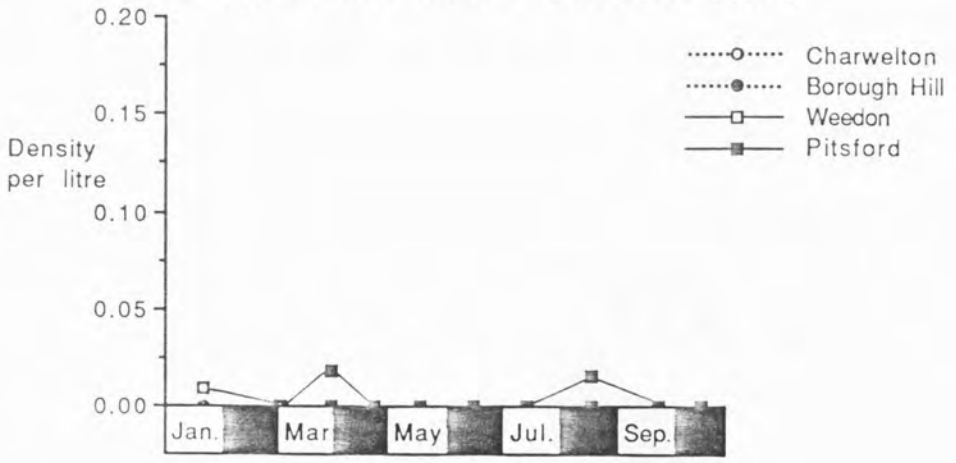


Fig. 10.14) Chironomid larvae (relative density) in four 'in-line' reservoirs during



fimbriatus, copepods were dominated by two peaks of abundance. The two figures (Fig. 10.6 and 10.7) have peaks that coincide, with the pattern that appears in copepodites matched by the nauplii. The July peak at Charwelton was of only *Paracyclops fimbriatus*, and presumably the peak in nauplii that coincides is also due to this species. The first peak at Pitsford (Fig. 10.6) was of similar density with one at Weedon (also of *A.robustus*, but of mainly dead individuals, while those at Pitsford were alive) but the second peak was not. Live animals were present at Weedon during the second peak but at low density. Numbers at Borough Hill Reservoir were only high enough to be measured over zero in July.

Alona (Fig. 10.8) and oligochaetes (Fig. 10.9) are benthic groups that occurred at Borough Hill and Charwelton with peaks in June and July - September respectively and are presumably seasonal. *Alona* also occurred at Pitsford indicating that penetration of treatment by benthic species did take place, a fact supported by the presence of *P.fimbriatus* in some Pitsford samples.

Harpacticoids (Fig. 10.10); nematodes (Fig. 10.11) and halacarid mites (Fig. 10.12) all occurred with highest density in June at Charwelton, and infrequently appeared in samples from Pitsford contact tank showing that they were also able to penetrate treatment. Ostracoda (Fig. 10.13) only occurred at Pitsford, with peaks that corresponded to those shown by copepods, but in such low numbers it was not possible to draw any conclusions.

The final group, chironomid larvae (Fig 10.14) showed infrequent occurrence and low densities throughout the sampling period. When animals did occur they were very small, first or second instar larvae, and as such could not be identified to tribe or genus. If this number of animals penetrating treatment is normal, the maximum level found during this study of 0.016 animals per litre in the contact tank, corresponds to 720000 animals per day, (assuming the works is operating at its average output of 45000 m^3 per day). The mean value of all the samples removed from Pitsford over the ten month period of this study gave a mean of 0.00290 chironomids per litre. This mean value gives a total estimated throughput of animals per day of 130435.

From the various taxa discussed above, particularly the cyclopoid copepodites and nauplii, it seems likely that the three reservoirs are each distinct in the 'sequence' from final water to distribution system. The link between Pitsford Contact Tank and Weedon seems established by the matching pattern of cyclopoids during the May peak in numbers, though the following peak did not appear to any great extent. The copepods which appeared during the first peak at Weedon were mainly dead, suggesting hypothesis C (Fig. 10.3 above). The fact that some did appear to survive

(explaining the presence of *A.robustus* in the mains) suggests that a mixture of B and C is most likely. Little else occurred at Weedon reservoir during the course of this study, one notable absence was any *Alona* or *Chydorus* species, which occurred at both Charwelton and Borough Hill and penetrated treatment at Pitsford on one occasion. The genus *Alona*, is considered to consist of benthic species, and this suggests the change from the influence of the final water to the distribution system is taking place at Borough Hill. The presence of oligochaetes in samples during July and August represent an increase in a benthic group that is not found in either Weedon Reservoir or Pitsford contact tank. Similarly the increase in *Paracyclops fimbriatus* (rather than *A.robustus*) during July suggests that Charwelton reservoir is linked with the distribution system rather than the final water.

10.5) General Conclusions

The two peaks of copepods (see Figure 9.3a, Chapter 9) in the final water during March - April and June - July coincided with the two peaks in Pitsford contact tank, though the high numbers in the final water during September did not coincide. The rapid turnover time in Pitsford Contact Tank which is the final treatment stage means that any animal present therein has penetrated treatment or is from a community within the treatment works. The link between the animals in the raw and final water has been shown for copepods at Wing (Barham 1985) and is supported by data from Pitsford raw and final water during 1988 (for some species) made available to this study by Anglian Water.

A number of significant points have appeared from these two studies:

a) Benthic animals do penetrate treatment at low measured densities, but at daily rates such that high actual numbers are entering the system.

b) Penetrating copepods and nauplii survive treatment and some survive passage though the system. *A.robustus* appears able to adapt to a benthic mode of life (see chapter 5).

c) The community in the reservoirs differs with distance from treatment, with reservoirs close in time to treatment being influenced by the final water, and those distant from treatment being under the influences that affect the distribution system.

d) Samples removed during the qualitative work tended to have higher species richness than those removed during the quantitative part of the study after cleaning had been carried out. The build up in sediment appears to have an effect on the species richness of the community and the abundance of species.

PART IV) CONCLUSIONS

CHAPTER 11) GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK TO AID MANAGEMENT OF INVERTEBRATE INFESTATIONS OF THE DISTRIBUTION SYSTEM.

11.1) Introduction.....322
11.2) Quantitative sampling methods for distribution systems including mains, service reservoirs and towers.....322
11.2.1) Sampling methods for the distribution system.....322
11.2.2) Sampling methods for animals emerging at the tap.....322
11.2.3) Sampling methods for Service Reservoirs.....323
11.3) The relationships between the operational and physical characteristics of water mains - construction, material,condition, age, etc. - and animal infestation.....323
11.4) The effect of treatment works final waters on animal infestations of mains, in particular to identify the principal food sources of the mains fauna.....325
11.5) Survey strategies using these methods for the monitoring of levels of infestation, to guide the derivation of quality objectives.....326
11.5.1) Survey strategies for the distribution system.....326
11.5.2) Survey strategies for animals emerging at the tap.....327
11.5.3) Survey strategies for Service Reservoirs.....327
11.6) Priorities for future work.....327

CHAPTER 11) GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK TO AID MANAGEMENT OF INVERTEBRATE INFESTATIONS OF THE DISTRIBUTION SYSTEM.

11.1) Introduction

Each of the four original aims of the project (Chapter 1) is considered with reference to the distribution system, the service reservoirs, and the density of animals emerging at the tap. Each of the aims is considered using the work undertaken during this project and further development of the work is suggested from the results obtained. Finally, further work is discussed which could lead to methods of controlling infestations and improving the level of service to the consumer.

11.2) Quantitative sampling methods for distribution systems including mains, service reservoirs and towers.

11.2.1) Sampling methods for the distribution system

The development of a sampling strategy to use throughout distribution networks was the priority of this project. The method developed in Chapter 2 and tested in Chapter 3 is a simple and efficient means of obtaining quantitative data but is restricted to rates of flow at sampling sites of at least 7.0 l s^{-1}. At lower flow rates in the system a quantitative measure cannot be guaranteed. It may be that a modification of air scour procedures which results in the volume of water introduced to the pipe being known will enable pipes to be sampled quantitatively despite low pressure. However, this would lead to a loss of efficiency of sampling because of the complexity of air-scour operations relative to a simple flush sample. Comparison between sites is achieved using a measure of density per unit pipe length. In order to obtain density per unit pipe volume, fibroscopic examination of the pipe being sampled could be carried out and a correction factor to account for volume introduced into the model.

11.2.2) Sampling methods for animals emerging at the tap

Two measures, the degree of infestation and the index of emergence, are introduced in Chapter 9. These enabled direct comparison between samples at tap sites. The quantification of the fauna emerging at the tap by a single number, the degree of infestation ($D.I._t$), has produced a measure of problems at the tap, which showed differences between season and site. This single number can be used to define levels of water quality required by the Water Industry to ensure fewer consumer

complaints. The nature of the sampling equipment and method restricted the available sites for this study, but the development of a more compact Norgren Filter Unit that can be easily installed at consumer taps will enable sampling of any pipe in the system from a tap. This will enable the relationship between the $D.I._t$ and $D.I._m$ to be established. Thus the use of tap or main samples to determine when infestation levels increase to complaint proportions can be decided.

Further work is required on the nature of consumer complaints and the relative ranking of animals which cause complaints. When consumer complaints occur, these Norgren Filter Units could be installed to establish what animals are emerging at the tap and their index of emergence. This will aid the ranking of the species in the community on their ability to cause complaints. Subsequent flushing of the mains will enable the link between the $D.I._m$ and $D.I._t$ to be established.

11.2.3) Sampling methods for Service Reservoirs

Quantitative data for animal density in the water column can be obtained simply using the perspex trap described in Chapter 10. However, the majority of the fauna is found in or above the sediment. This sediment can be sampled to give a measure of relative density using the same sampling method as long as sediments are fine and lie in a 'floc layer' at the bottom of the reservoir. As the quantity of sediment builds up, it is likely that some other method, such as a weighted net on a sledge, will provide better information regarding density in the sediments.

11.3) The relationships between the operational and physical characteristics of water mains - construction, material, condition, age, etc. - and animal infestation.

The study of community structure (Chapter 6) established five distinct types of community in undisturbed mains:

1) Sites with very few animals present of few species
2) Sites dominated by naids with few chironomids
3) Sites dominated by *Chydorus*
4) Sites dominated by *Paracyclops*
5) Sites dominated by Chironomidae

The study was unable to fit Huston's General Hypothesis of Species Diversity (Huston 1979) to the data from Chapters 6 and 7 implying that a successional sequence was absent in the distribution system. A second alternative, that of a 'competitive lottery', was supported by the data. This means that if a habitat becomes available for recolonisation

following a population reduction, all species in the infesting community will be equally likely to recolonise, and maintain a population until a further disaster occurs. Thus recolonisation will be due to random penetration, drift and sufficient animals to establish a population surviving until they reach an available habitat.

Seasonal variation exists for some taxa within the distribution system (Chapter 7). Recolonisation of Chironomini and Orthocladiinae occurs at high density during the period of June - September. *Acanthocyclops robustus*, Hydracarina and Chydoridae also increase in density during this period, while not to such an extent during the winter periods, despite reproductive animals being found during the latter. The increase in density of the first two taxa was linked to the density in the raw water prior to treatment. The increase in Chydoridae is probably due to higher temperatures increasing reproductive rates. The quantity of sediment and organic matter removed from two-monthly sites (Chapter 7) is higher during summer months and is probably seasonal, influencing the extent to which animals can recolonise the main. All species appear to be able to recolonise to greater densities than were initially present in the main suggesting that in undisturbed mains some degree of population reduction through competition or predation is occurring.

Animals exiting at the tap also showed a seasonal increase in the period June - October, despite pyrethrin dosing during the previous May. Measures of the degree of infestation increased to levels above those recorded prior to dosing.

The characteristics of the main itself which have some effect on animal density are the quantity and organic quantity of the sediments, the number of properties fed by the pipe (consumption rate) and the 'travel time' (age of water) from treatment. The first and last will be linked since as flows drop, so sediments will be deposited in the pipe. These characteristics identify potential infestation sites as dead-ends at the extremities of the system. Recolonisation at sites such as these was more rapid than at sites near to large diameter mains (i.e. nearer to treatment in time) presumably because of animals appearing in the drift from an 'upstream' community.

The features of the main that determine which animals appear in the community and to what extent population density is limited by these characteristics require further research. Field work should be designed to limit the number of variables where possible, with sites chosen such that only one or two variables have a wide range. Alternativly, studies based on a model system, using pipe lengths that can be seeded and subjected to controlled conditions, would be possible. This would enable variables to be tested separately and the effect of each on a known

community monitored, without the restrictions of working in a system designed to supply the consumer.

11.4) The effect of treatment works final waters on animal infestations of mains, in particular to identify the principal food sources of the mains fauna.

Work undertaken on the distribution system, mains and taps indicates that slow sand filtration reduces the levels of infestation relative to rapid gravity filtration, by both reducing the quantity of organic material passing through treatment that would have been available for food and reducing the number of animals that penetrated treatment and were able to recolonise.

The results from the reinfestation work in Chapter 7 showed that following the change to S.S.F., Chironominae, Tanypodinae and Orthocladiinae density recolonising the mains declined immediately at all sites obtaining water from S.S.F. despite differences in period between flushing. At the two-monthly flushed sites, only Chydoridae and Cyclopoda of the other taxa present showed any major differences between R.G.F. and S.S.F. sites, with numbers greater at R.G.F. sites. These other taxa showed increases in density at both S.S.F. and R.G.F. sites when the period between flushes was greater than two months. This indicates that chironomids are penetrating Pitsford R.G.F. and infesting the main, but are not at Ravensthorpe S.S.F.

The failure of chironomids to recolonise at any S.S.F. sites following the switch, though other taxa did, implies that the Ravensthorpe system does not have any chironomids present that are able to reproduce in the mains, the explanation for the greater density of taxa at sites with different flushing regimes. At the two-monthly sampled sites fed from Ravensthorpe, the greatest densities of taxa which occurred after the switch to S.S.F. were in the six month period at the end of the study, which implies that a longer time period was required for a measurable population to establish because fewer colonisers were able to penetrate treatment. The difference between chydorids and cyclopoids and the other taxa at Pitsford two-monthly sites may be due to a better ability to penetrate treatment, a greater rate of reproduction once established in the main, or both.

Those sites fed by S.S.F. were not reinfested by *Acanthocyclops robustus*, which occurred at high densities at R.G.F. sites. *Acanthocyclops bisetosus* occurred only at S.S.F. sites, and never in high densities. It is suggested that this reflects a difference in the cyclopoid fauna of the two storage reservoirs and the different efficiency of treatment at the two works.

Results from tap sampling with Norgren Filter Units (Chapter 9) supported the above suggestion. *A.robustus* appeared at the Pitsford site in high densities during the summer months, while the Ravensthorpe site continued to remain relatively clear of animals. The quantity of debris collected in the filter at Pitsford was also greater than that at Ravensthorpe.

The penetration of R.G.F. by *A.robustus* was also confirmed by the work on the service reservoirs (chapter 10) where nauplii and copepodites of this species were 'followed' down the system. It appears that these cyclopoids die off as they pass through the system, but many complete their life cycle and colonise mains. Thus an influx of both animals and a potential food source occurred during the summer period.

The possibility that iron bacteria are of importance to infesting species is of little consequence if influxes of organic material (which can be broken down by bacteria once settled with sediment) through treatment occurrs regularly. Problems in filtration (such as those that occurred at Ravensthorpe, allowing penetration of algal filaments) and the failure to remove dead animals following pyrethrin dosing support the suggestion by Collingwood (1970) that sufficient material exists and enters the distribution system through treatment to support the community.

11.5) Survey strategies using these methods for the monitoring of levels of infestation, to guide the derivation of quality objectives.

11.5.1) Survey strategies for the distribution system

The methods of sampling used in Chapters 6 and 7 can easily be adapted to provide information on the extent of infestation in the distribution system. A number of small diameter mains, fed by large diameter mains (see Chapter 7) can be used as sampling points to determine the degree of infestation (see Chapter 9) at sites within the system. Regular flushing of sites in the system will enable any changes in the density of animals or new infesting species to be determined.

Ideally, the supply zone could be separated into networks (such as those flushed in Chapter 6), each network having a leg which was regularly sampled. In networks which suffer from low pressure, the first hydrant along a leg could be used, since this will enable clean water to be pulled through into the main and minimise disturbance of sediments. Sampling on a regular basis would provide information as to the extent of infestations in different networks and enable cleaning operations to be directed to those areas most in need.

11.5.2) Survey stategies for animals emerging at the tap

Once the requirements of section 11.2.2 have been carried out, redesigned Norgren Filter Units could be installed at points in the system associated with particular pipe networks and allowed to run on a consumer tap for a period of three or four days. Regular sampling would provide considerable information as to the areas most likely to face problems from infestations. Norgren units at the tap will also provide the first indication should particular problem species such as *Asellus* or *Paratanytarsus* appear in the system. The appearance of either of these animals in a tap sample could be followed by an immediate flush or air-scour of the network in question before animals can build up to infestation levels that will cause serios consumer complaints.

11.5.3) Survey Strategies for Service Reservoirs

The diference in fauna between reservoirs sampled before and after cleaning indicates that the build up of sediment in the reservoirs is important for the infesting community to become established. The change in community from limnetic to benthic as distance of in-line reservoirs from treatment increases, supports this evidence. As reservoir sediment load increases, density of benthic species will probably increase in all reservoirs since they penetrate treatment in low numbers. Continued monitoring of service reservoirs throughout the system using the method described in Chapter 10 will enable the extent to which sediments determines animal density to be established.

Since service reservoirs are frequently the initial site at which any animal which penetrates treatment is likely to find a suitable habitat, monitoring of the animals in the sediment will enable the arrival of any problem species in the system from treatment to be determined. The isolation and cleaning of the reservoir will then restrict the possibility of the infestation spreading through the system from the reservoir.

11.6) Priorities for future work

Various aspects of this study (particularly the links between environmental parameters and the infesting species) proved inconclusive because of the nature of the system in which the research was carried out. The difficulty of sampling at sites which will provide useful information when required negates the benefit of working in a field situation. Since the system is not natural, the way forward must lie with studies of the community in similar controlled systems where a range of conditions can be tested to determine the effect on the community of the different features in the distribution system.

The link between the level of animals that give rise to consumer complaints and animals at the taps and in the mains must be established. Once a relationship between the $D.I._t$ and $D.I._m$ is quantified, monitoring taps throughout the system (rather than mains) will enable any I_e that precludes an infestation level in the main to be detected and cleaning operations to remove infestations before they reach levels which can cause consumer complaints.

Alternatively, once links are established between animal density, environmental parameters and flushing frequency, it will be possible for the water industry to determine the ideal rate of flushing in different regions of supply zones (determined by environmental parameters) to maintain levels of infestation below those that give rise to consumer complaints.

PART V: APPENDICES

Appendix I: Data for hydrants E, F and G, site 2: Obelisk Rise, Northampton, Northants.....330

Appendix II: Computer programs to produce quantitative results using the sampling model and examples of input and output.....333

Appendix III: Environmental parameters recorded and estimated for undisturbed sites sampled during May/June and October 1987.....362

Appendix IV: Environmental measurements taken on sampling occasions and estimated for disturbed sites sampled during April 1986 to May 1988.....369

Appendix V: Detailed sketch maps of undisturbed sites sampled for Chapter 6.....374

Appendix VI: Animal density per 10 metres of pipe at undisturbed sites sampled during May/June and October 1987.....397

Appendix VII: Agglomeration schedules for dendrograms constructed using Ward's method (Ward 1963) and used in Chapter 6.....406

Appendix VIII: Detailed sketch maps of disturbed sites sampled for Chapter 7.....414

Appendix IX: Animal density per 10 metres of pipe from disturbed sites sampled between April 1986 and May 1988.....423

Appendix X: Data used to consider Huston's General Hypothesis of Species Diversity.....433

Appendix XI: Norgren Filter animal densities and index of emergence for each taxa on each sampling occasion during 1988.....437

Appendix XII: Relative density of animals per litre in samples removed from service reservoirs during 1988.....449

APPENDIX I: DATA FOR HYDRANTS E, F AND G, SITE 2: OBELISK RISE, NORTHAMPTON, NORTHANTS.

Table I.i) Hydrant E, Obelisk Rise, Northampton, Northants, Agreement of sequential samples with drift

Taxonomic group	Animal density per 1000 litres in drift sample	Animal density per 1000 litres in each flush sample: Flush Number					Comparison of flush samples within sequence: Flush Number					Comparison of flush samples with drift: Flush Number				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Chironomid larvae (< 2 mm)	0	6	2	0	0	0	d	d	d	d	d	D	D	D	D	D
Harpacticoids	0	10	0	0	2	0	d	d	d	d	d	1	D	D	D	D
Cyclopoids	9	511	9	4	0	2	1	d	d	d	d	1	2	D	D	D
Chydorids	9	116	0	2	2	5	1	d	d	d	d	1	D	D	D	D
Halacarids	0	358	4	4	2	0	1	d	d	d	d	1	D	D	D	D
Oligochaetes	0	4	0	0	0	0	d	d	d	d	d	D	D	D	D	D
Ostracods	0	3	0	0	0	2	d	d	d	d	d	D	D	D	D	D

Column 2 - Drift density: Density/1000 litres flushed from the large diameter feed or a nearby clean pipe.
Column 3 - Animal density: Density/1000 litres flushed in each of 5 sequential flushes at the hydrant.
Column 4 - Comparison within sequence: 5 subsamples from each of the flushes compared using ANOVA and QTEST to determine significant differences. Numbers refer to ranked values where they differ from remaining values, d refer to point at which samples are not significantly different (the assumed 'drift').
Column 5 - Comparison with drift sample: 5 subsamples from each flush compared to 5 subsamples from drift density using ANOVA and QTEST. Numbers refer to ranked higest values - D refers to no significant difference with drift density. This D is actual drift and can be compared with assumed drift to assess sampling success.

Table I.ii) Hydrant F, Obelisk Rise, Northampton, Northants, Agreement of sequential samples with drift

Taxonomic group	Animal density per 1000 litres in drift sample	Animal density per 1000 litres in each flush sample: Flush Number 1	2	3	4	5	Comparison of flush samples within sequence: Flush Number 1	2	3	4	5	Comparison of flush samples with drift sample Flush Number 1	2	3	4	5
Chironomid larvae (< 2 mm)	0	33	0	0	0	0	1	d	d	d	d	1	D	D	D	D
Harpacticoids	0	29	0	0	0	0	1	d	d	d	d	1	D	D	D	D
Cyclopoids	9	60	0	0	0	0	1	d	d	d	d	1	D	D	D	D
Chydorids	9	541	0	0	0	0	1	d	d	d	d	1	D	D	D	D
Halacarids	0	193	2	0	2	2	1	d	d	d	d	1	D	D	D	D
Oligochaetes	0	7	0	0	0	0	d	d	d	d	d	D	D	D	D	D
Ostracods	0	3	0	0	0	0	d	d	d	d	d	D	D	D	D	D

Column 2 - Drift density: Density/1000 litres flushed from the large diameter feed or a nearby clean pipe.
Column 3 - Animal density: Density/1000 litres flushed in each of 5 sequential flushes at the hydrant.
Column 4 - Comparison within sequence: 5 subsamples from each of the flushes compared using ANOVA and QTEST to determine significant differences. Numbers refer to ranked values where they differ from remaining values, d refer to point at which samples are not significantly different (the assumed 'drift').
Column 5 - Comparison with drift sample: 5 subsamples from each flush compared to 5 subsamples from drift density using ANOVA and QTEST. Numbers refer to ranked higest values – D refers to no significant difference with drift density. This D is actual drift and can be compared with assumed drift to assess sampling success.

Table I.iii) Hydrant G, Obelisk Rise, Northampton, Northants, Agreement of sequential samples with drift

Taxonomic group	Animal density per 1000 litres in drift sample	Animal density per 1000 litres in each flush sample: Flush Number 1	2	3	4	5	Comparison of flush samples within sequence: Flush Number 1	2	3	4	5	Comparison of flush samples with drift: Flush Number 1	2	3	4	5
Chironomid larvae (< 2 mm)	0	22	2	0	-	-	d	d	d	-	-	1	D	D	-	-
Harpacticoids	0	33	0	0	-	-	1	d	d	-	-	1	D	D	-	-
Cyclopoids	9	285	2	0	-	-	1	d	d	-	-	1	D	D	-	-
Chydorids	9	302	0	0	-	-	1	d	d	-	-	1	D	D	-	-
Halacarids	0	275	4	9	-	-	1	d	d	-	-	1	D	D	-	-
Oligochaetes	0	2	0	2	-	-	d	d	d	-	-	D	D	D	-	-

Column 2 - Drift density: Density/1000 litres flushed from the large diameter feed or a nearby clean pipe.
Column 3 - Animal density: Density/1000 litres flushed in each of 5 sequential flushes at the hydrant.
Column 4 - Comparison within sequence: 5 subsamples from each of the flushes compared using ANOVA and QTEST to determine significant differences. Numbers refer to ranked values where they differ from remaining values, d refer to point at which samples are not significantly different (the assumed 'drift').
Column 5 - Comparison with drift sample: 5 subsamples from each flush compared to 5 subsamples from drift density using ANOVA and QTEST. Numbers refer to ranked higest values - D refers to no significant difference with drift density. This D is actual drift and can be compared with assumed drift to assess sampling success.

APPENDIX II) COMPUTER PROGRAMS TO PRODUCE QUANTITATIVE INFORMATION USING THE SAMPLING MODEL AND EXAMPLES OF INPUT AND OUTPUT

SECTION A: i) Program pipe (for subsamples)
(USES NAG LIBRARY, ONE WAY ANALYSIS OF VARIANCE, ROUTINE G04AEF)
ii) Input data file
iii) Example of output

SECTION B: i) Program pipe (for removed animals)
ii) Input data file
iii) Example of output

SECTION A:

i) Subsample analysis programme (Fortran 77)

```
      program pipe
c
c*****variables to be read in are as follows:
c        c(3)         - pipe length (m)
c        c(4)         - pipe diameter (mm)
c     for 1st flush
c        c(5)-c(9)    - yield of organisms
c        c(10)        - dilution factor
c        c(11)        - rate of flush (l/s)
c        c(12)        - length of flush (s)
c     for 2nd flush
c        c(13)-c(17) - yield of organisms
c        c(18)        - dilution factor
c        c(19)        - rate of flush (l/s)
c        c(20)        - length of flush (s)
c     for 3rd flush
c        c(21)-c(25) - yield of organisms
c        c(26)        - dilution factor
c        c(27)        - rate of flush (l/s)
c        c(28)        - length of flush (s)
c
c*****other arrays used:
c        a,b,d - new variables computed for 1st,2nd,3rd flush
c        y     - observations for ANOVA
c        nobs  - number of observations in each group
c        gbar  - group means
c        ss    - ss of ANOVA
c        idf   - df for ss of ANOVA
c
c*****dimension arrays to be used
c
      implicit double precision (a-h, o-z)
      double precision c(28),a(22),b(22),d(22)
      double precision y(15),gbar(3),ss(3)
      integer nobs(3),idf(3)
```

```
c
c*****read raw data into array c
c
      CHARACTER DATE*10,LABEL*10
      INTEGER NCHAN,IER
C
C     OPEN THE FILE
C
      NCHAN=7
      OPEN(NCHAN,FILE='ACS1',STATUS='OLD',RECL=140)

C*****reads first line to nothing
      READ (NCHAN,*)

C
C     READ FROM IT
C
    5 CALL INLINE(DATE,LABEL,C,NCHAN,IER)
c
c*****define default output channel
c
      nout=6
C
C     TEST FOR THE END OF FILE
C
      IF(IER.EQ.-1)GOTO 99

ccccccwrite(nout,*) (c(i),i=3,28)
c
c*****1.multiply each sample by dilution factor,
c     2.calculate density per 1000 litres flushed,
c     3.take sqrt of standardized data calculated in step 2.
c

      do 10 i=1,5

      a(i)=c(i+ 4)*c(10)
      b(i)=c(i+12)*c(18)
```

```
      d(i)=c(i+20)*c(26)

      a(i+5)=(a(i)*1000.)/(c(11)*c(12))
      b(i+5)=(b(i)*1000.)/(c(19)*c(20))
      d(i+5)=(d(i)*1000.)/(c(27)*c(28))

      a(i+10)=sqrt(a(i+5)+0.5)
      b(i+10)=sqrt(b(i+5)+0.5)
      d(i+10)=sqrt(d(i+5)+0.5)

c
c*****put elements 11-15 of the 3 arrays a,b,d in array y ready
c     for ANOVA
c

      y(i)   =a(i+10)
      y(i+5) =b(i+10)
      y(i+10)=d(i+10)

   10 continue
ccccccwrite(nout,*) (y(i),i=1,15)
c
c*****carry out one-way ANOVA using NAG routine G04AEF
c
c*****initialize various parameters passed to G04AEF
c
      n=15
      k=3
      ifail=0
      do 20 i=1,3
      nobs(i)=5
   20 continue
ccccccwrite(nout,*) n,k,(nobs(i),i=1,3)

c
c*****call G04AEF and compute the residual mean square (rms)
c
      nout=6
```

```
      call G04AEF(y,n,k,nobs,gbar,gm,ss,idf,f,fp,ifail)
      if(ifail.eq.0) goto 30
      write (nout,1020) ifail
      stop
   30 continue
ccccccwrite(nout,*) (y(i),i=1,15)
ccccccwrite(nout,*) n,k,(nobs(i),i=1,3)
ccccccwrite(nout,*) (gbar(i),i=1,3),gm
ccccccwrite(nout,*) (ss(i),i=1,3)
ccccccwrite(nout,*) (idf(i),i=1,3)
ccccccwrite(nout,*)  f,fp,ifail
      rms=ss(2)/float(idf(2))
ccccccwrite(nout,*) rms

c
c*****put group means in a(16),b(16),d(16)
c
      a(16)=gbar(1)
      b(16)=gbar(2)
      d(16)=gbar(3)
c
c*****calculate 95% confidence intervals for the group means
c     using pooled variance from 15 subsamples
c
      t12=2.179
      cl=t12*sqrt(rms/5.)
      a(17)=a(16)-cl
      a(18)=a(16)+cl
      b(17)=b(16)-cl
      b(18)=b(16)+cl
      d(17)=d(16)-cl
      d(18)=d(16)+cl
c
c*****detransform the means and confidence limits but first check
c     that values to be detransformed are not less than sqrt(0.5)
c     as such values would generate negative densities (impossible)
c     or spurious positive values when a negative value is squared;
c     in both cases the confidence limit should be set to 0.0 .
```

```
c
      do 40 i=16,18
      if (a(i).le.sqrt(0.5)) then
      a(i+3)=0.0
      else
      a(i+3)=a(i)*a(i)-0.5
      end if
   40 continue
      do 42 i=16,18
      if (b(i).le.sqrt(0.5)) then
      b(i+3)=0.0
      else
      b(i+3)=b(i)*b(i)-0.5
      end if
   42 continue
      do 44 i=16,18
      if (d(i).le.sqrt(0.5)) then
      d(i+3)=0.0
      else
      d(i+3)=d(i)*d(i)-0.5
     end if
   44 continue
c
c*****calculate the means of animals in samples
c
      a(22)=(a(1)+a(2)+a(3)+a(4)+a(5))/5.
      b(22)=(b(1)+b(2)+b(3)+b(4)+b(5))/5.
      d(22)=(d(1)+d(2)+d(3)+d(4)+d(5))/5.
c
c*****calculate pipe volume (v litres) and internal area (w m*m)
c
      pi=3.14159265
      v=1000.0*c(3)*pi*(c(4)/2000.0)**2
      w=c(3)*pi*c(4)/1000.0
c
c*****calculate ratio (r) of volume flushed per pipe volume (1st
sample)
c
```

```
      r=c(11)*c(12)/v
c
c*****check samples 1 and 2 against 3
c
      g=a(22)-((c(11)*c(12)-v)/(c(27)*c(28)))*d(22)
      h=b(22)-((c(19)*c(20))  /(c(27)*c(28)))*d(22)
c
c*****calculate - calculate number of amimals in pipe (q)
c               - density per 100 litres volume (q1)
c               - density per unit area (q2)
c               - Removal coefficient s1 (p1)
c               - Removal coefficient s1 + s2 (p2)
c               - Removal coefficient s3 (p3)
c               - animals remaining in pipe after flush (t)
c         - animals remaining in pipe as density per 100 litres
volume (z)
c               - animals in pipe/unit length (10m)(q3)
c               - animals remaining in pipe/ unit length (10m)(q4)
c*****check whether ANOVA is significant - if not, set q=0
c                 and go straight to report stage.
c
      if (fp.gt.0.05) then
           q=0.
           goto 80
      else
           q=g+h
           q1=q/v*100.
           q2=q/w
        q3=10*q/c(3)
        IF (Q.LT.0) THEN
          p1=999
          p2=999
            p3=999
          ELSE
            p1= a(22)/(a(22)+b(22)+d(22))
            p2= (a(22) + b(22))/(a(22)+b(22)+d(22))
            p3= d(22)/(a(22)+b(22)+d(22))
        ENDIF
```

```
            t=(d(22)*v)/(c(27)*c(28))
          z= (t/v)*100
            q4=10*t/c(3)
        end if
c
c*****print out results in tabular format
c
   80 continue
        write(nout,1100) date
        write(nout,1110) label
        write(nout,1120) c(11),c(19),c(27)
        write(nout,1130) v,c(3)
        write(nout,1140) w,c(4)
        write(nout,1150) (a(i),i=19,21)
        write(nout,1160) (b(i),i=19,21)
        write(nout,1170) (d(i),i=19,21)
        write(nout,1180) f,fp
        write(nout,1190) rms
        write(nout,1200) q
c
c*****if q=0 finish here
c
        if (q.eq.0.0) goto 90
        write(nout,1210) t
        write(nout,1220) q3
        write(nout,1221) q4
        write(nout,1222) q1
        write(nout,1230) z
        write(nout,1240) q2
        write(nout,1250) p1
        write(nout,1251) p2
        write(nout,1260) p3
        write(nout,1261) r
        write(nout,1270) g
        write(nout,1280) h
        write(nout,1281)
c
c*****if g or h < 0 , print warning message
```

```
c
      if (g.ge.0. .and. h.ge.0.) goto 90
      write(nout,1290)
      write(nout,1291)
      write(nout,1292) a(16)
      write(nout,1293) b(16)
      write(nout,1294) d(16)
      write(nout,1295)
c
c*****go back to top of program to see if there is more data
c
   90 goto 5
   99 write (nout,1030)
      stop
 1020 format( ' Failed in G04AEF , ifail=',i2)
 1030 format(/'1end of data file ')
 1100 format(/'1Date            ',A10)
 1110 format( ' Site Code       ',A10)
 1120 format( ' Rates of flush  ',3f14.4)
 1130  format( ' Pipe volume       ',f14.4,'          Pipe length
',f14.4)
 1140  format( ' Pipe area         ',f14.4,'         Pipe diameter
',f14.4)
 1150 format(/' Density/1000 litres flushed (detransformed)'
     +         /'                              mean           minimum
maximum'
     +       /' Sample1    ',3(F14.4))
 1160 format( ' Sample2    ',3(F14.4))
 1170 format( ' Sample3    ',3(F14.4),
     +       /'   (df=12, t value at 95% is 2.179)')
 1180 format( ' ANOVA results - F value ',f14.4,
     +        '   Significance of F',F8.4)
 1190 format( '                Residual mean square',f14.4)
 1200 format(//' Animals in pipe                          : ',f14.4)
 1210 format(  ' animals remaining in pipe after flush : ',f14.4)
 1220 format(/ ' Animals/10m of pipe    : ',f14.4)
 1221 format(  ' Animal remaining/10m  : ',f14.4)
 1222 format(/ ' Animals/100 litres                       : ',f14.4)
```

```
 1230 format(  ' animals remaining in pipe / 100 lites : ',f14.4)
 1240 format(  ' Animals/m**2                          : ',f14.4)
 1250 format(/ ' Removal coefficient s1     : ',f14.4)
 1251 format(  ' Removal coefficient s1 + s2: ',f14.4)
 1260 format(  ' Removal coefficient s3     : ',f14.4)
 1261 format(/ ' ratio of volume flushed/pipe volume   : ',f14.4)
 1270 format(/ ' Sample1 check (+ve)   : ',f14.4)
 1280 format(  ' Sample2 check (+ve)   : ',f14.4)
 1281                                                  format(
'-------------------------------------------------')
 1290 format(/ ' CHECK DATA :- Q TEST REQUIRED')
 1291 format(  ' Transformed mean density/10001')
 1292 format(  ' S1: ',f14.4)
 1293 format(  ' S2: ',f14.4)
 1294 format(  ' D : ',f14.4)
 1295                                                  format(
'=================================================')
       end

      SUBROUTINE INLINE(DATE,LABEL,C,NCHAN,IER)
C
C     ROUTINE TO READ FREE FORMAT DATA FORM THE ACS DATA FILE
C
C     DATE  - FIRST ELEMENT OF THE LINE
C     LABEL - SECOND ELEMENT OF THE LINE
C     C     - ARRAY CONTAINING THE REAL NUMBERS FROM THE LINE
C             ELEMENTS (1 AND 2 ARE LEFT BLANK)
C             C(3) CONTAINS THE THIRD ELEMENT ON THE LINE AND SO ON
C
C     NCHAN - FORTRAN CHANNEL NUMBER FOR THE DATA FILE
C     IER   - USUALLY 0 ON EXIT BUT -1 IF END OF FILE FOUND
C
C     ROUTINE PRINTS A WARNING IF THE NUMBER OF COMMA SEPARATORS IS
C     NOT CORRECT
C
      CHARACTER DATE*10,LABEL*10,LINE*140
      double precision C(28)
C
```

```
C     READ IN THE RAW LINE OF DATA
C
      READ(NCHAN,'(A140)',END=98) LINE
      BACKSPACE (NCHAN)
      READ(NCHAN,'(A8,X,A8,F5.0,F6.1,5F5.0,F5.0,F6.2,F5.0,
     *5F4.0,F5.0,F6.2,F5.0,5F4.0,F5.0,F6.2,F5.0)',ERR=41)
     *DATE,LABEL,(C(J),J=3,28,1)
      GOTO 42
C
C       TRAP BAD DATA
C
   41   PRINT*,'BAD NUMERIC DATA IN THIS LINE'
        PRINT*,LINE
        PRINT*,' '
   42   CONTINUE
C
C     RETRUN THE COLLECTED LINES TO THE PROGRAM
C
      IER=0
      GOTO 99
C
C     END OF FILE DETECTED
C     FLAG THE ERROR AND CLEAR THE VARIABLES
C
   98 IER=-1
      DATE=' '
      LABEL=' '
      DO 88 I=1,28
        C(I)=0.0
   88 CONTINUE
C
C     RETURN NORMALLY
C
   99 CONTINUE
      RETURN
      END
```

SECTION A
ii) EXAMPLE OF INPUT FOR CPQUANT.FOR

Line 1: data file label
Line 2 onwards:

1-8 date	10-11 site code	13-17 taxa
19-22 pipe length (m)	24-28 pipe diameter (mm)	30-33 first flush subsample a
35-38 first flush subsample b	40-43 first flush subsample c	45-48 first flush subsample d
50-53 first flush subsample e	55-58 first flush dilution	60-64 rate of first flush
66-69 time (sec) of first flush	71-73 2nd flush subsample a	75-77 2nd flush subsample b
79-81 2nd flush subsample c	83-85 2nd flush subsample d	87-89 2nd flush subsample e
91-94 2nd flush dilution	96-100 rate of 2nd flush	102-105 time (sec) of 2nd flush
107-109 3rd flush subsample a	111-113 3rd flush subsample b	115-117 3rd flush subsample c
119-121 3rd flush subsample d	123-125 3rd flush subsample e	127-130 3rd flush dilution
132-136 rate of 3rd flush	138-140 time (sec) of 3rd flush	

■ indicates continuing line


```
chapel brampton and obelisk rise
27.06.86 bl chirs 0150 076.2 0002 0001 0001 0000 0000 0060 08.33 0180 000 000 000 000 000 0040 ■
08.33 0180 000 000 000 000 000 0040 08.33 180
27.06.86 bl harpa 0150 076.2 0025 0038 0035 0020 0026 0060 08.33 0180 001 000 000 000 000 0040 ■
08.33 0180 000 000 000 001 000 0040 08.33 180
27.06.86 bl cyclo 0150 076.2 0000 0000 0000 0000 0000 0060 08.33 0180 001 000 000 000 000 0040 ■
08.33 0180 000 000 000 001 000 0040 08.33 180
27.06.86 bl chydo 0150 076.2 1218 1153 1174 1043 1178 0060 08.33 0180 031 028 028 020 029 0040 ■
08.33 0180 002 002 002 005 000 0040 08.33 180
27.06.86 bl limno 0150 076.2 0011 0010 0009 0007 0009 0060 08.33 0180 006 006 010 008 011 0040 ■
08.33 0180 001 003 005 001 003 0040 08.33 180
27.06.86 bl oligo 0150 076.2 0001 0004 0002 0004 0000 0060 08.33 0180 003 002 002 004 005 0040 ■
08.33 0180 000 000 004 001 001 0040 08.33 180
27.06.86 bl nemat 0150 076.2 0003 0002 0001 0000 0000 0060 08.33 0180 002 001 002 001 001 0040 ■
08.33 0180 000 000 000 000 000 0040 08.33 180
27.06.86 bl tardi 0150 076.2 0003 0002 0002 0007 0001 0060 08.33 0180 002 001 001 000 000 0040 ■
08.33 0180 000 000 000 000 001 0040 08.33 180
```

SECTION A
iii) Examples of output from CPQUANT.FOR
commands:

```
$set def [acs.quant]
$for CPquant
$link CPquant,nag/lib
$run CPquant
```

output:

```
Date              27.06.86
Site Code         bl chirs
Rates of flush          8.3300        8.3300        8.3300
Pipe volume           684.0551        Pipe length          150.0000
Pipe area              35.9084        Pipe diameter         76.2000

Density/1000 litres flushed (detransformed)
                    mean          minimum       maximum
Sample1           20.8788          5.8747       44.6937
Sample2            0.0000          0.0000        7.3737
Sample3            0.0000          0.0000        7.3737
  (df=12, t value at 95% is 2.179)
ANOVA results - F value          5.5110   Significance of F  0.0201
               Residual mean square        4.6392

Animals in pipe                        :        48.0000
animals remaining in pipe after flush  :         0.0000
Animals/10m of pipe   :          3.2000
Animal remaining/10m  :          0.0000

Animals/100 litres                     :         7.0170
animals remaining in pipe / 100 lites  :         0.0000
Animals/m**2                           :         1.3367

Removal coefficient s1     :         1.0000
Removal coefficient s1 + s2:         1.0000
Removal coefficient s3     :         0.0000
ratio of volume flushed/pipe volume   :         2.1919

Sample1 check (+ve)   :         48.0000
Sample2 check (+ve)   :          0.0000
-------------------------------------------------
```

Date 27.06.86
Site Code bl harpa
Rates of flush 8.3300 8.3300 8.3300
Pipe volume 684.0551 Pipe length 150.0000
Pipe area 35.9084 Pipe diameter 76.2000

Density/1000 litres flushed (detransformed)

	mean	minimum	maximum
Sample1	1136.9583	946.6520	1344.6743
Sample2	2.0867	0.0000	20.2819
Sample3	2.0867	0.0000	20.2819

(df=12, t value at 95% is 2.179)
ANOVA results - F value 187.5548 Significance of F 0.0000
Residual mean square 9.1667

Animals in pipe : 1723.6498
animals remaining in pipe after flush : 3.6498

Animals/10m of pipe : 114.9100
Animal remaining/10m : 0.2433

Animals/100 litres : 251.9753
animals remaining in pipe / 100 lites : 0.5335
Animals/m**2 : 48.0013

Removal coefficient s1 : 0.9908
Removal coefficient s1 + s2: 0.9954
Removal coefficient s3 : 0.0046

ratio of volume flushed/pipe volume : 2.1919

Sample1 check (+ve) : 1723.6498
Sample2 check (+ve) : 0.0000

Date	27.06.86		
Site Code	bl cyclo		
Rates of flush	8.3300	8.3300	8.3300
Pipe volume	684.0551	Pipe length	150.0000
Pipe area	35.9084	Pipe diameter	76.2000

Density/1000 litres flushed (detransformed)

	mean	minimum	maximum
Sample1	0.0000	0.0000	4.8384
Sample2	2.0867	0.0000	9.8151
Sample3	2.0867	0.0000	9.8151

(df=12, t value at 95% is 2.179)

ANOVA results - F value 0.5000 Significance of F 0.6186

Residual mean square 2.7073

Animals in pipe : 0.0000

The above case shows that despite animals being present in the samples removed from the hydrant, the analysis of variance produces an F value that is not significant at $p < 0.05$ and hence there is no difference between the three flushes. Since the final (third) flush is assumed to contain only drift animals, the densityof animals in the pipe is taken to be zero.

Date 27.06.86
Site Code bl chydo
Rates of flush 8.3300 8.3300 8.3300
Pipe volume 684.0551 Pipe length 150.0000
Pipe area 35.9084 Pipe diameter 76.2000

Density/1000 litres flushed (detransformed)

	mean	minimum	maximum
Sample1	46115.4357	44282.1350	47985.9200
Sample2	721.8060	508.6312	972.1644
Sample3	46.5425	5.9869	124.2817

(df=12, t value at 95% is 2.179)
ANOVA results - F value 3358.8626 Significance of F 0.0000
Residual mean square 19.5783

Animals in pipe : 70144.1473
animals remaining in pipe after flush : 40.1473

Animals/10m of pipe : 4676.2765
Animal remaining/10m : 2.6765

Animals/100 litres : 10254.1663
animals remaining in pipe / 100 lites : 5.8690
Animals/m**2 : 1953.4187

Removal coefficient s1 : 0.9833
Removal coefficient s1 + s2: 0.9987
Removal coefficient s3 : 0.0013

ratio of volume flushed/pipe volume : 2.1919

Sample1 check (+ve) : 69144.1473
Sample2 check (+ve) : 1000.0000

SECTION B:

i) Program to analyse removed animals (Fortran 77)

```
      program pipe
c*****for chironomid and other non-subsampled data
c
c*****variables to be read in are as follows:
c        c(3)        - pipe length (m)
c        c(4)        - pipe diameter (mm)
c     for 1st flush
c        c(5)        - yield of organisms
c        c(6)       - rate of flush (l/s)
c        c(7)       - length of flush (s)
c     for 2nd flush
c        c(8)       - yield of organisms
c        c(9)       - rate of flush (l/s)
c        c(10)       - length of flush (s)
c     for 3rd flush
c        c(11)       - yield of organisms
c        c(12)       - rate of flush (l/s)
c        c(13)       - length of flush (s)
c
c*****other arrays used:
c        a,b,d - new variables computed for 1st,2nd,3rd flush
c
c*****dimension arrays to be used
c
      implicit double precision (a-h, o-z)
      double precision c(13),a(22),b(22),d(22)
      integer nobs(3),idf(3)
c
c*****read raw data into array c
c
      CHARACTER DATE*10,LABEL*10
      INTEGER NCHAN,IER
C
C     OPEN THE FILE
C
```

```
      NCHAN=7
      OPEN(NCHAN,FILE='ACS2',STATUS='OLD',RECL=132)
C
C     READ FROM IT
C
    5 CALL INLINE(DATE,LABEL,C,NCHAN,IER)
c
c*****define default output channel
c
      nout=6
C
C     TEST FOR THE END OF FILE
C
      IF(IER.EQ.-1)GOTO 99

ccccccwrite(nout,*) (c(i),i=3,13)
c
c*****1.calculate density per 1000 litres flushed,
c
c
      a(1)=c(5)
      b(1)=c(8)
      d(1)=c(11)

      a(2)=(a(1)*1000.)/(c(6)*c(7))
      b(2)=(b(1)*1000.)/(c(9)*c(10))
      d(2)=(d(1)*1000.)/(c(12)*c(13))
c
c*****X2 test on densities to ensure significant difference
c
c     X2 = S ((o-e)(o-e)/e)
c
c    a(10) - a(14) used to calculate X2 values
c
     a(10)=(a(2)+b(2)+d(2))/3
     a(11)=((a(2)-a(10))*(a(2)-a(10)))/a(10)
     a(12)=((b(2)-a(10))*(b(2)-a(10)))/a(10)
     a(13)=((d(2)-a(10))*(d(2)-a(10)))/a(10)
```

```
      a(14)=a(11)+a(12)+a(13)
c
c


c
c
c*****produce numbers of animals in samples
c
      a(22)=(a(1))
      b(22)=(b(1))
      d(22)=(d(1))
c
c*****calculate pipe volume (v litres) and internal area (w m*m)
c
      pi=3.14159265
      v=1000.0*c(3)*pi*(c(4)/2000.0)**2
      w=c(3)*pi*c(4)/1000.0
c
c*****calculate ratio (r) of volume flushed per pipe volume (1st
sample)
c
      r=c(6)*c(7)/v
c
c*****check samples 1 and 2 against 3
c
      g=a(22)-((c(6)*c(7)-v)/(c(12)*c(13)))*d(22)
      h=b(22)-((c(9)*c(10))  /(c(12)*c(13)))*d(22)
c
c*****calculate - calculate number of amimals in pipe (q)
c               - density per 100 litres volume (q1)
c               - density per unit area (q2)
c               - animals/10mpipe (q3)
c               - animals remaining/10m pipe (q4)
c               - animals remaining in pipe after flush (t)
c                 - animals remaining in pipe as density/100 litres
(z)
c               - Removal coefficient s1 (p1)
c               - Removal coefficient s1 + s2 (p2)
```

```
c                - Removal coefficient s3 (p3)
c                -
c
c
c
c******** use x2test to put q=0 if no sig.diff. between densities
c      X2 is 5.99146 at 95% with 2 deg. freed.
c
      if (a(14).le.5.99146) then
       q=o
      else
       q=g+h
      endif
c
c
            q1=q/v*100.
            q2=q/w
          q3=10*q/c(3)
          IF (Q.LE.0) THEN
            p1=999
            p2=999
               p3=999
             ELSE
               p1 = a(22)/(a(22)+b(22)+d(22))
               p2 = (a(22)+b(22))/(a(22)+b(22)+d(22))
               p3 = d(22)/(a(22)+b(22)+d(22))
          ENDIF
             t=(d(22)*v)/(c(12)*c(13))
          z = (t/v)*100
             q4 = t*10/c(3)
c
c
ccc
c*****print out results in tabular format
c
   80 continue
      write(nout,1100) date
      write(nout,1110) label
```

```
      write(nout,1120) c(6),c(9),c(12)
      write(nout,1130) v,c(3)
      write(nout,1140) w,c(4)
      write(nout,1150) a(2)
      write(nout,1160) b(2)
      write(nout,1170) d(2)
      write(nout,1180) a(14)
      write(nout,1200) q
c
c*****if q=0 finish here
c
      if (q.eq.0.0) goto 90
      write(nout,1210) t
      write(nout,1220) q3
      write(nout,1221) q4
      write(nout,1222) q1
      write(nout,1230) z
      write(nout,1240) q2
      write(nout,1250) p1
      write(nout,1251) p2
      write(nout,1260) p3
      write(nout,1261) r
      write(nout,1270) g
      write(nout,1280) h
      write(nout,1281)
c
c*****if g or h < 0 , print warning message
c
      if (g.ge.0. .and. h.ge.0.) goto 90
      write(nout,1290)
      write(nout,1295)
c
c*****go back to top of program to see if there is more data
c
   90 goto 5
   99 write (nout,1030)
      stop
 1020 format( ' Failed in G04AEF , ifail=',i2)
```

```
 1030 format(/'1end of data file ')
 1100 format(/'1Date            ',A10)
 1110 format( ' Site Code       ',A10)
 1120 format( ' Rates of flush  ',3f14.4)
 1130  format( ' Pipe volume       ',f14.4,'           Pipe length
',f14.4)
 1140  format( ' Pipe area         ',f14.4,'         Pipe diameter
',f14.4)
 1150 format(/' Density/1000 litres flushed '
     +       /'                   '
     +       /' Sample1    ',(F14.4))
 1160 format( ' Sample2    ',(F14.4))
 1170 format( ' Sample3    ',(F14.4),
     +       /'   Values are absolute (not estimated)')
 1180 format(/'  X2 value : ',(F14.4),
     +        '  X2 at p=0.05 with 2 deg. free. is 5.99 ')
 1200 format(//' Animals in pipe                        : ',f14.4)
 1210 format(  ' animals remaining in pipe after flush : ',f14.4)
 1220 format(/ ' animals per 10m pipe              :',f14.4)
 1221 format(  ' animals remaining in 10m of pipe :',f14.4)
 1222 format(/ ' Animals/100 litres                     : ',f14.4)
 1230 format(  ' animals remaining in pipe / 100 litres: ',f14.4)
 1240 format(  ' Animals/m**2                           : ',f14.4)
 1250 format(/ ' Removal coefficient s1      :',f14.4)
 1251 format(  ' removal coefficient s1 + s2 :',f14.4)
 1260 format(  ' removal coefficient s3      :',f14.4)
 1261 format(/ ' ratio of volume flushed/pipe volume   : ',f14.4)
 1270 format(/ ' Sample1 check (+ve)   : ',f14.4)
 1280 format(  ' Sample2 check (+ve)   : ',f14.4)
 1281                                                    format(
'-------------------------------------------------- ')
 1290 format(/ ' CHECK DATA :- DRIFT LARGER THAN SAMPLE'
     +        ' X2 at P=0.05 with 1 d.f. is 3.841 ')
 1295                                                    format(
'================================================== ')
      end

      SUBROUTINE INLINE(DATE,LABEL,C,NCHAN,IER)
```

```
C
C     ROUTINE TO READ FREE FORMAT DATA FORM THE ACS DATA FILE
C
C     DATE  - FIRST ELEMENT OF THE LINE
C     LABEL - SECOND ELEMENT OF THE LINE
C     C     - ARRAY CONTAINING THE REAL NUMBERS FROM THE LINE
C             ELEMENTS (1 AND 2 ARE LEFT BLANK)
C             C(3) CONTAINS THE THIRD ELEMENT ON THE LINE AND SO ON
C
C     NCHAN - FORTRAN CHANNEL NUMBER FOR THE DATA FILE
C     IER   - USUALLY 0 ON EXIT BUT -1 IF END OF FILE FOUND
C
C     ROUTINE PRINTS A WARNING IF THE NUMBER OF COMMA SEPARATORS IS
C     NOT CORRECT
C
      CHARACTER DATE*10,LABEL*10,LINE*132
      double precision c(13)
C
C     READ IN THE RAW LINE OF DATA
C
      READ(NCHAN,'(A132)',END=98) LINE
      BACKSPACE (NCHAN)
      READ(NCHAN,'(A8,X,A7,F4.0,F6.1,F5.0,F6.2,
     *2F4.0,F6.2,F4.0,F3.0,F6.2,F4.0)',ERR=41)
     *DATE,LABEL,(C(J),J=3,13,1)
      GOTO 42
C
C       TRAP BAD DATA
C
   41   PRINT*,'BAD NUMERIC DATA IN THIS LINE'
        PRINT*,LINE
        PRINT*,' '
   42   CONTINUE
C
C     RETRUN THE COLLECTED LINES TO THE PROGRAM
C
      IER=0
      GOTO 99
```

```
C
C     END OF FILE DETECTED
C     FLAG THE ERROR AND CLEAR THE VARIABLES
C
   98 IER=-1
      DATE=' '
      LABEL=' '
      DO 88 I=1,28
        C(I)=0.0
   88 CONTINUE
C
C     RETURN NORMALLY
C
   99 CONTINUE
      RETURN
      END
```

SECTION B
ii) INPUT FILE FOR QUANTCHIR.FOR

Line 1 onwards:

1-8 date	11-16 site code	18-20 pipe length (m)
22-26 pipe diameter (mm)	28-31 1st flush sample	33-37 rate of 1st flush
39-41 time of 1st flush	43-45 2nd flush sample	47-51 rate of 2hd flush
53-55 time of 2nd flush	57-58 3rd flush sample	60-64 rate of 3rd flush
65-68 time of 3rd flush		

```
26.05.87  SC(WH) 095 101.6 0040 13.00 120 021 13.00 600 00 11.00 238
27.05.87  A5(WA) 850 101.6 0000 10.00 642 000 10.00 581 27 10.00 591
12.06.87  TR(UW) 117 076.2 0012 15.00 253 003 15.00 230 00 15.00 154
05.06.87  PC(B)  116 101.6 0001 16.00 120 000 16.00 120 00 16.00 120
15.06.87  H2(BL) 594 076.2 0007 04.40 709 000 04.40 507 00 04.40 512
15.06.87  H6(BL) 330 076.2 0000 05.00 382 001 05.00 370 00 05.00 360
15.06.87  H8(BL) 079 076.2 0000 11.00 232 000 11.00 217 01 11.00 200
10.06.87  H!(CA) 873 101.6 0058 08.00 600 000 08.00 615 00 08.00 557
08.06.87  CAR(G) 195 100.0 0001 05.80 518 000 05.80 539 00 05.80 492
08.06.87  PC(G)  117 076.2 0015 05.20 308 000 05.20 294 00 05.20 320
03.06.87  H1(W)  830 101.6 0038 07.25 999 038 05.20 775 00 04.80 780
03.06.87  H2(W)  362 101.6 0023 04.00 900 024 04.00 710 00 04.00 620
03.06.87  H3(W)  323 101.6 0021 03.60 854 000 03.60 769 00 03.60 933
03.06.87  H4(W)  729 101.6 0001 03.50 999 015 03.50 780 02 03.50 706
14.10.87  H3(AR) 140 076.2 0001 15.00 273 000 15.00 305 00 15.00 240
07.10.87  H5(CH) 128 076.2 0000 04.00 394 001 04.00 540 00 04.00 410
07.10.87  H6(CH) 186 076.2 0001 11.00 565 000 11.00 468 00 11.00 437
```

SECTION B
iii) Examples of output from QUANTCHIR.FOR
commands:

```
$set def [acs.quant]
$for quantchir
$link quantchir
$run quantchir
```

output:

```
Date            26.05.87
Site Code        SC(WH)
Rates of flush         13.0000       13.0000       11.0000
Pipe volume           770.1954        Pipe length           95.0000
Pipe area              30.3227        Pipe diameter        101.6000

Density/1000 litres flushed

Sample1           25.6410
Sample2            2.6923
Sample3            0.0000
  Values are absolute (not estimated)

 X2 value :        42.0478  X2 at p=0.05 with 2 deg. free. is 5.99

Animals in pipe                          :        61.0000
animals remaining in pipe after flush :           0.0000
animals per 10m pipe                :        6.4211
animals remaining in 10m of pipe :        0.0000

Animals/100 litres                       :         7.9201
animals remaining in pipe / 100 litres:           0.0000
Animals/m**2                             :         2.0117

Removal coefficient s1      :        0.6557
removal coefficient s1 + s2 :        1.0000
removal coefficient s3      :        0.0000
ratio of volume flushed/pipe volume   :           2.0255

Sample1 check (+ve)   :        40.0000
Sample2 check (+ve)   :        21.0000
-------------------------------------------------
```

```
Date            27.05.87
Site Code        A5(WA)
Rates of flush         10.0000       10.0000       10.0000
Pipe volume          6891.2217        Pipe length          850.0000
Pipe area             271.3079        Pipe diameter        101.6000

Density/1000 litres flushed

Sample1            0.0000
Sample2            0.0000
Sample3            4.5685
  Values are absolute (not estimated)

 X2 value :         9.1371  X2 at p=0.05 with 2 deg. free. is 5.99

Animals in pipe                          :       -24.3904
animals remaining in pipe after flush :         31.4827
animals per 10m pipe                :       -0.2869
animals remaining in 10m of pipe :         0.3704

Animals/100 litres                       :        -0.3539
animals remaining in pipe / 100 litres:          0.4569
Animals/m**2                             :        -0.0899

Removal coefficient s1      :      999.0000
removal coefficient s1 + s2 :      999.0000
removal coefficient s3      :      999.0000
ratio of volume flushed/pipe volume   :          0.9316

Sample1 check (+ve)   :         2.1528
Sample2 check (+ve)   :       -26.5431
-------------------------------------------------
CHECK DATA :- DRIFT LARGER THAN SAMPLE X2 at P=0.05 with 1 d.f. is 3.841
=================================================
```

The above case shows an occasion when there are more animals in the third sample than in the first or second sample. This is an anomaly, in that each sample is assumed to contain drift animals and therefore the third sample should not contain greater densities than the first or second. Samples producing this type of data are rare and are recorded as -99.0 in the data values and treated as missing values.

Date 12.06.87
Site Code TR(UW)
Rates of flush 15.0000 15.0000 15.0000
Pipe volume 533.5630 Pipe length 117.0000
Pipe area 28.0086 Pipe diameter 76.2000

Density/1000 litres flushed

Sample1 3.1621
Sample2 0.8696
Sample3 0.0000
Values are absolute (not estimated)

X2 value : 3.9712 X2 at p=0.05 with 2 deg. free. is 5.99

Animals in pipe : 0.0000

Date 15.06.87
Site Code H2(BL)
Rates of flush 4.4000 4.4000 4.4000
Pipe volume 2708.8582 Pipe length 594.0000
Pipe area 142.1973 Pipe diameter 76.2000

Density/1000 litres flushed

Sample1 2.2439
Sample2 0.0000
Sample3 0.0000
Values are absolute (not estimated)

X2 value : 4.4878 X2 at p=0.05 with 2 deg. free. is 5.99

Animals in pipe : 0.0000

In the above two cases, the Chi^2 test shows no significant difference between the three samples, using the mean of the three as an expected value. Cases such as this are assumed to contain no animals in the pipe since there is no difference between the first two samples and the drift sample.

```
Date              10.06.87
Site Code          H!(CA)
Rates of flush          8.0000        8.0000        8.0000
Pipe volume          7077.6901        Pipe length          873.0000
Pipe area             278.6492        Pipe diameter        101.6000

Density/1000 litres flushed

Sample1             12.0833
Sample2              0.0000
Sample3              0.0000
  Values are absolute (not estimated)

 X2 value :         24.1667  X2 at p=0.05 with 2 deg. free. is 5.99


Animals in pipe                          :         58.0000
animals remaining in pipe after flush :          0.0000

animals per 10m pipe              :         0.6644
animals remaining in 10m of pipe :          0.0000

Animals/100 litres                       :          0.8195
animals remaining in pipe / 100 litres:          0.0000
Animals/m**2                             :          0.2081

Removal coefficient s1       :         1.0000
removal coefficient s1 + s2 :          1.0000
removal coefficient s3       :         0.0000

ratio of volume flushed/pipe volume   :          0.6782

Sample1 check (+ve)   :          58.0000
Sample2 check (+ve)   :           0.0000
-------------------------------------------------
```

APPENDIX III) ENVIRONMENTAL PARAMETERS RECORDED AND ESTIMATED FOR UNDISTURBED SAMPLE SITES SAMPLED DURING MAY/JUNE AND OCTOBER 1987

MISSING VALUES: -1

COLUMNS:
- CL - Total chlorine in water (p.p.m.)
- O2 - Percentage dissolved oxygen in water
- PH - pH of water
- TEMP - Water temperature
- IRON - Iron concentration in water from parish
- TURB - Turbidity of water from parish
- RES - Treatment source
- AGE - Time taken for water to travel from treatment
- D.O.C. - Dissolved organic carbon in water
- P.O.C. - Realtive measure of particulate organic carbon in water
- CONS. - Consumption rate based on number of properties fed from pipe
- DIAM - Pipe diameter
- PIPE - Pipe material
- SERRES - Number of service reservoirs and towers between site and treatment
- BAR - Pressure in main
- DRYWT - Dry weight of sediment
- DWVOL - Dry weight of sediment per 1000 litres flushed
- OMWT - Weight of organic material in sediment
- OMVOL - Weight of organic material in sediment per 1000 litres flushed

DATE	CODE	CL	O2	PH	TEMP	IRON	TURB	RES	AGE
26.05.87	WH-SC	0.2	60	7.6	14.5	2	2	P	7
27.05.87	WS-A5	0.1	78	7.2	12.0	3	2	P	80
28.05.87	WI-H3	0.0	58	7.6	11.0	2	2	P	25
28.05.87	WI-H4	0.0	86	7.4	11.0	2	2	P	25
28.05.87	WI-H5	1.0	100	7.8	11.0	2	2	P	25
28.05.87	WI-H6	0.0	77	7.6	11.0	2	2	P	25

DATE	CODE	CL	02	PH	TEMP	IRON	TURB	RES	AGE
28.05.87	WI-H7	0.0	40	7.2	11.0	2	2	P	25
02.06.87	HO-OC	0.0	59	7.6	13.0	2	2	P	9
03.06.87	WA-H1	0.0	48	7.6	13.0	3	2	P	13
03.06.87	WA-H2	0.0	41	7.6	13.0	3	2	P	13
03.06.87	WA-H3	0.0	45	7.4	13.0	3	2	P	13
03.06.87	WA-H4	0.0	26	7.4	13.0	3	2	P	13
05.06.87	BR-OC	0.0	92	7.5	15.0	1	1	P	-1
05.06.87	BR-PC	0.0	72	7.6	15.0	2	2	P	-1
08.06.87	GU-NO	0.0	58	7.6	14.0	2	2	P	2
08.06.87	GU-H1	0.0	76	7.3	13.0	2	2	P	2
08.06.87	GU-H2	0.0	52	7.4	13.0	2	2	P	2
08.06.87	GU-PC	0.1	84	7.6	13.0	2	2	P	2
10.06.87	CA-HX	0.1	60	-1	13.0	2	2	P	20
12.06.87	UW-TR	0.1	70	7.6	16.0	2	2	P	3
15.06.87	BL-H2	0.0	68	7.3	13.0	2	2	P	-1
15.06.87	BL-H3	0.0	86	7.6	13.0	2	2	P	-1
15.06.87	BL-H4	0.0	82	7.6	13.0	2	2	P	-1
15.06.87	BL-H6	0.0	88	7.7	13.0	2	2	P	-1
15.06.87	BL-H7	0.0	64	7.6	13.0	2	2	P	-1
15.06.87	BL-H8	0.0	76	7.6	13.0	2	2	P	-1
17.06.87	BH-HM	0.0	84	7.6	12.0	2	2	P	13
17.06.87	BH-HR	0.0	90	7.6	12.0	2	2	P	13
19.06.87	HA-H1	0.0	90	7.6	12.0	2	2	P	13
19.06.87	HA-H2	0.0	90	7.4	14.0	2	2	P	11
19.06.87	HA-H3	0.0	90	7.4	14.0	2	1	P	11
07.10.87	CH-H3	0.0	86	7.3	13.0	2	2	P	16
07.10.87	CH-H4	0.5	88	7.3	13.5	2	2	P	16
07.10.87	CH-H5	0.5	84	7.4	14.0	2	2	P	16
07.10.87	CH-H6	0.2	96	7.4	13.5	2	2	P	16
09.10.87	BA-H1	0.3	82	7.4	14.0	2	2	P	10
09.10.87	BA-H2	0.0	80	7.4	14.0	2	2	P	10
09.10.87	BA-H3	1.0	82	7.3	14.0	2	2	P	10
12.10.87	WH-H1	0.0	86	7.3	13.0	2	2	P	22
12.10.87	WH-H2	0.0	84	7.7	13.0	2	2	P	22
12.10.87	WH-H4	0.0	83	7.4	12.5	2	2	P	22
12.10.87	WH-H5	0.0	86	7.3	12.5	2	2	P	22

DATE	CODE	CL	02	PH	TEMP	IRON	TURB	RES	AGE
12.10.87	WH-H6	0.0	76	7.4	12.0	2	2	P	22
14.10.87	AR-H1	0.0	81	7.6	12.5	1	1	W	-1
14.10.87	AR-H2	0.5	86	7.8	12.5	1	1	W	-1
14.10.87	AR-H3	0.0	80	7.7	12.5	1	1	W	-1
14.10.87	AR-H4	0.0	68	7.6	12.5	1	1	W	-1
14.10.87	AR-H5	0.0	86	7.7	12.5	1	1	W	-1
14.10.87	AR-H6	1.0	86	7.6	12.5	1	1	W	-1
16.10.87	CR-TL	0.0	54	7.5	11.0	2	2	R	3
19.10.87	WF-H2	0.0	78	7.2	12.0	2	2	P	36
19.10.87	WF-H3	0.0	82	7.3	12.5	2	2	P	36
19.10.87	WF-H4	1.0	80	7.4	12.5	2	2	P	36
19.10.87	WF-H5	0.0	78	7.7	13.0	2	2	P	36
21.10.87	NE-CR	0.0	70	-1	12.0	3	2	P	12
21.10.87	NE-MA	0.0	50	-1	11.5	3	2	P	12
21.10.87	NE-MO	0.0	82	-1	12.0	3	2	P	12
22.10.87	GL-H1	-1	-1	-1	-1	2	2	P	-1
22.10.87	GL-H2	0.0	68	-1	12.5	2	2	P	-1
23.10.87	CV-H1	0.0	32	-1	11.0	2	2	P	3
23.10.87	CV-H2	0.0	23	-1	12.0	2	2	P	3
23.10.87	CV-H3	0.0	82	-1	12.0	2	2	P	3
23.10.87	CV-H4	0.0	82	-1	12.0	2	2	P	3
23.10.87	WB-RD	0.5	82	-1	12.0	2	2	P	3

DATE	CODE	D.O.C.	P.O.C.	CONS.	DIAM	PIPE	SERRES	BAR
26.05.87	WH-SC	4	9	2	4	I	2	0.0
27.05.87	WS-A5	4	1	1	4	P	2	3.7
28.05.87	WI-H3	3	1	1	3	I	2	1.0
28.05.87	WI-H4	3	3	2	3	I	2	1.0
28.05.87	WI-H5	2	5	1	3	I	2	3.0
28.05.87	WI-H6	3	6	1	3	I	2	2.0
28.05.87	WI-H7	2	1	1	3	I	2	4.0
02.06.87	HO-OC	-1	3	1	4	I	0	6.5
03.06.87	WA-H1	4	8	2	4	I	1	0.0
03.06.87	WA-H2	16	-1	2	4	I	1	0.0

DATE	CODE	D.O.C.	P.O.C.	CONS.	DIAM	PIPE	SERRES	BAR
03.06.87	WA-H3	4	2	2	4	I	1	0.0
03.06.87	WA-H4	5	1	1	4	I	1	0.0
05.06.87	BR-OC	4	3	2	4	-	-	4.0
05.06.87	BR-PC	3	1	1	4	-	-	4.0
08.06.87	GU-NO	3	8	2	3	-	0	3.5
08.06.87	GU-H1	12	5	1	3	-	0	0.2
08.06.87	GU-H2	3	2	1	3	-	0	0.0
08.06.87	GU-PC	3	-1	2	3	-	0	1.0
10.06.87	CA-HX	26	1	3	4	C	2	0.0
12.06.87	UW-TR	12	1	1	3	I	1	3.0
15.06.87	BL-H2	9	2	1	3	C	0	1.7
15.06.87	BL-H3	3	1	2	3	C	0	2.0
15.06.87	BL-H4	4	1	1	3	C	0	2.5
15.06.87	BL-H6	3	3	1	3	C	0	2.0
15.06.87	BL-H7	3	0	1	3	C	0	4.0
15.06.87	BL-H8	3	3	1	3	C	0	4.0
17.06.87	BH-HM	3	1	1	4	I	1	2.2
17.06.87	BH-HR	2	1	2	4	I	1	1.5
19.06.87	HA-H1	3	2	1	4	P	1	2.0
19.06.87	HA-H2	5	3	1	4	I	1	2.5
19.06.87	HA-H3	4	1	1	4	I	1	2.5
07.10.87	CH-H3	4	0	3	3	I	2	1.5
07.10.87	CH-H4	7	1	2	3	I	2	1.7
07.10.87	CH-H5	5	5	2	3	I	2	2.0
07.10.87	CH-H6	4	0	2	3	I	2	2.0
09.10.87	BA-H1	4	0	1	3	I	1	5.2
09.10.87	BA-H2	4	3	1	3	I	1	4.5
09.10.87	BA-H3	25	7	1	3	I	1	5.0
12.10.87	WH-H1	4	0	1	3	C	2	2.0
12.10.87	WH-H2	4	1	3	3	C	2	2.0
12.10.87	WH-H4	4	1	3	4	C	2	2.0
12.10.87	WH-H5	3	1	2	4	C	2	2.5
12.10.87	WH-H6	5	3	1	4	P	2	1.7
14.10.87	AR-H1	4	1	3	4	-	-	-1
14.10.87	AR-H2	4	2	1	3	-	-	5.5
14.10.87	AR-H3	4	0	3	3	-	-	5.0

DATE	CODE	D.O.C.	P.O.C.	CONS.	DIAM	PIPE	SERRES	BAR
14.10.87	AR-H4	4	6	3	3	-	-	-1
14.10.87	AR-H5	2	0	2	3	-	-	5.2
14.10.87	AR-H6	7	10	1	3	-	-	4.5
16.10.87	CR-TL	2	1	1	3	-	0	4.5
19.10.87	WF-H2	3	1	4	4	C	2	3.0
19.10.87	WF-H3	13	0	3	3	C	2	2.7
19.10.87	WF-H4	-1	14	2	3	C	2	3.7
19.10.87	WF-H5	5	1	2	3	C	2	2.7
21.10.87	NE-CR	4	2	2	4	C	1	6.0
21.10.87	NE-MA	3	1	2	3	C	1	6.5
21.10.87	NE-MO	3	0	2	3	C	1	5.5
22.10.87	GL-H1	-1	-1	2	3	I	0	3.5
22.10.87	GL-H2	3	1	1	3	I	0	3.0
23.10.87	CV-H1	2	0	1	4	I	1	1.0
23.10.87	CV-H2	3	1	1	4	I	1	1.2
23.10.87	CV-H3	3	1	1	3	I	1	1.5
23.10.87	CV-H4	-1	4	1	3	I	1	1.7
23.10.87	WB-RD	-1	1	2	3	I	1	4.2

DATE	CODE	DRYWT	DWVOL	OMWT	OMVOL
26.05.87	WH-SC	214.36	17.90	33.31	2.78
27.05.87	WS-A5	47.73	2.63	8.16	0.45
28.05.87	WI-H3	51.79	-1	3.03	-1
28.05.87	WI-H4	129.61	-1	15.01	-1
28.05.87	WI-H5	12.28	-1	1.81	-1
28.05.87	WI-H6	36.39	-1	1.77	-1
28.05.87	WI-H7	14.09	-1	1.76	-1
02.06.87	HO-OC	84.10	9.53	11.03	1.25
03.06.87	WA-H1	44.52	-1	9.19	-1
03.06.87	WA-H2	80.25	-1	20.07	-1
03.06.87	WA-H3	17.46	-1	5.32	-1
03.06.87	WA-H4	59.19	-1	7.47	-1
05.06.87	BR-OC	36.03	5.49	3.89	0.59
05.06.87	BR-PC	18.99	3.28	3.69	0.64

DATE	CODE	DRYWT	DWVOL	OMWT	OMVOL
08.06.87	GU-NO	53.75	-1	9.67	-1
08.06.87	GU-H1	22.29	1.76	4.05	0.32
08.06.87	GU-H2	23.72	-1	1.90	-1
08.06.87	GU-PC	59.46	-1	7.03	-1
10.06.87	CA-HX	4.43	0.31	0.55	0.04
12.06.87	UW-TR	330.03	34.54	20.56	2.15
15.06.87	BL-H2	5.07	-1	0.35	-1
15.06.87	BL-H3	23.81	-1	1.42	-1
15.06.87	BL-H4	35.03	-1	2.22	-1
15.06.87	BL-H6	324.85	-1	17.60	-1
15.06.87	BL-H7	37.33	5.86	2.23	0.35
15.06.87	BL-H8	66.81	9.36	5.19	0.73
17.06.87	BH-HM	29.27	3.94	2.76	0.37
17.06.87	BH-HR	97.43	12.30	15.43	1.95
19.06.87	HA-H1	15.31	-1	5.09	-1
19.06.87	HA-H2	3.52	-1	1.35	-1

DATE	CODE	DRYWT	DWVOL	OMWT	OMVOL
19.06.87	HA-H3	2.47	-1	0.71	-1
07.10.87	CH-H3	7.21	-1	1.89	-1
07.10.87	CH-H4	13.60	-1	3.87	-1
07.10.87	CH-H5	10.69	-1	3.32	-1
07.10.87	CH-H6	5.37	0.33	4.80	0.30
09.10.87	BA-H1	41.62	4.95	10.03	1.19
09.10.87	BA-H2	55.97	6.36	10.09	1.15
09.10.87	BA-H3	36.20	4.39	7.84	0.95
12.10.87	WH-H1	6.11	-1	1.27	-1
12.10.87	WH-H2	17.41	-1	3.32	-1
12.10.87	WH-H4	26.35	3.70	2.34	0.33
12.10.87	WH-H5	12.91	1.88	1.52	0.22
12.10.87	WH-H6	10.72	1.30	0.20	0.02
14.10.87	AR-H1	43.87	3.52	6.15	0.49
14.10.87	AR-H2	32.00	2.59	4.47	0.36
14.10.87	AR-H3	17.76	1.45	2.07	0.17

DATE	CODE	DRYWT	DWVOL	OMWT	OMVOL
14.10.87	AR-H4	12.84	1.09	1.80	0.15
14.10.87	AR-H5	19.97	1.87	2.45	0.23
14.10.87	AR-H6	10.29	1.20	1.18	0.14
16.10.87	CR-TL	13.34	2.15	2.25	0.36
19.10.87	WF-H2	20.18	3.34	2.10	0.35
19.10.87	WF-H3	27.87	3.36	3.31	0.40
19.10.87	WF-H4	22.39	3.32	2.34	0.35
19.10.87	WF-H5	266.89	29.24	32.20	3.53
21.10.87	NE-CR	21.82	2.70	6.43	0.80
21.10.87	NE-MA	38.37	7.05	7.31	1.34
21.10.87	NE-MO	13.22	2.61	-1	-1
22.10.87	GL-H1	65.18	9.50	17.49	2.55
22.10.87	GL-H2	18.24	2.85	2.99	0.47
23.10.87	CV-H1	4.71	-1	2.21	-1
23.10.87	CV-H2	24.45	3.26	4.91	0.65
23.10.87	CV-H3	2.53	0.39	0.72	0.11
23.10.87	CV-H4	2.92	0.69	0.36	0.08
23.10.87	WB-RD	61.92	5.62	12.82	1.16

APPENDIX IV) ENVIRONMENTAL MEASUREMENTS TAKEN ON SAMPLING OCCASIONS AND ESTIMATED FOR DISTURBED SITES SAMPLED DURING APRIL 1986 TO MAY 1988

MISSING VALUES -1

COLUMNS:

- FLUSH - number of times sampling has taken place at site
- FRATE - rate of flow at hydrant during flushing
- BAR - pressure in main
- TEMP - water temperature
- O2 - percentage dissolved oxygen in water
- PH - pH of water
- CL - total chlorine in water (p.p.m.)
- DRYWT - dry weight of sediment
- OMWT - organic content of sediment (weight)
- FLUSH - flush number
- S.S.F. - presence of water from Ravensthorpe slow sand filter
- CONS. - Consumption rate based on number of properties fed from pipe
- P.O.C. - realtive measure of particulate organic carbon in water
- D.O.C. - dissolved organic carbon in water
- SER.RES. - Number of service reservoirs and towers between site and treatment
- AGE - Time taken for water to travel from treatment
- OM/VOL - Organic matter in sediment per 1000 litres flushed
- DW/VOL - Dry weight of sediment per 1000 litres flushed

DATE	SITE	FLUSH	FRATE	BAR	TEMP	O2	PH	CL	DRYWT	OMWT	DW/VOL	OM/VOL
16.04.86	PC(NH)	1	11.36	-1	-1	-1	-1	-1	17.36	5.28	2.12	0.64
28.05.86	PC(NH)	2	11.36	-1	-1	-1	-1	-1	-1	-1	-1	-1
21.04.87	PC(NH)	3	16.00	5.5	11.0	22	7.1	0.1	13.89	3.63	2.06	0.57
10.05.88	PC(NH)	4	16.00	3.7	13.0	-1	7.4	0.1	15.53	3.28	1.62	0.34
16.04.86	WW(NH)	1	15.15	-1	-1	-1	-1	-1	30.57	10.37	2.80	0.95
28.05.86	WW(NH)	2	15.15	-1	-1	-1	-1	-1	-1	-1	-1	-1
14.07.87	WW(NH)	3	15.00	5.0	20.0	88	7.3	0.2	147.42	23.53	13.35	2.13
10.05.88	WW(NH)	4	16.00	4.0	13.0	89	7.4	0.1	40.86	7.48	3.78	0.69
12.05.86	WW(W)	1	15.15	-1	-1	-1	-1	-1	42.75	10.57	7.83	1.94
15.09.86	WW(W)	2	15.15	5.1	11.9	90	7.7	0.1	37.33	4.87	6.35	0.83
28.01.87	WW(W)	3	15.15	5.1	2.0	92	7.6	0.1	18.20	2.47	2.96	0.40
15.05.87	WW(W)	4	16.00	4.0	12.5	100	7.7	0.1	35.53	3.33	7.28	0.68
21.09.87	WW(W)	5	16.00	4.0	17.5	80	7.0	0.1	15.31	2.61	1.91	0.33

DATE	SITE	FLUSH	FRATE	BAR	TEMP	O2	PH	CL	DRYWT	OMWT	DW/VOL	OM/VOL
11.05.88	WW(W)	6	15.00	3.0	12.5	90	7.4	0.1	9.66	3.04	1.16	0.37
12.05.86	B(W)	1	15.15	-1	-1	-1	-1	-1	76.42	15.27	21.01	4.20
18.11.86	B(W)	2	15.15	5.4	8.5	98	7.8	0.4	21.93	5.62	2.68	0.69
15.05.87	B(W)	3	15.00	4.0	14.0	100	7.6	0.1	30.67	5.24	3.38	0.58
18.11.87	B(W)	4	15.00	4.0	10.0	86	7.2	0.4	14.57	4.03	1.49	0.41
11.05.88	B(W)	5	14.00	4.2	13.0	95	7.4	0.1	12.23	2.65	1.39	0.30
27.06.86	BL(CB)	1	8.33	3.7	14.6	82	7.8	0.1	12.16	2.24	2.70	0.50
12.09.86	BL(CB)	2	8.33	4.2	13.7	80	8.0	0.1	1.57	0.35	0.33	0.07
19.11.86	BL(CB)	3	8.33	3.4	9.0	86	7.9	0.1	3.23	0.68	0.72	0.15
28.01.87	BL(CB)	4	8.33	3.4	3.0	94	7.7	0.2	25.73	3.00	5.46	0.64
20.03.87	BL(CB)	5	6.60	3.5	10.0	98	7.9	0.1	3.31	0.60	0.60	0.11
20.05.87	BL(CB)	6	6.00	2.5	12.0	90	7.1	0.1	3.14	0.68	0.57	0.12
15.07.87	BL(CB)	7	6.60	3.0	18.0	92	7.2	0.2	1.34	0.16	0.21	0.03
18.09.87	BL(CB)	8	6.40	3.0	17.0	62	7.0	0.1	1.04	0.20	0.16	0.03
18.11.87	BL(CB)	9	6.50	3.0	10.0	68	7.4	0.1	1.76	0.38	0.27	0.06
10.05.88	BL(CB)	10	6.60	2.7	12.5	58	7.4	0.1	2.14	0.47	0.46	0.10
14.07.86	BC(R)	1	15.15	5.7	18.6	82	7.8	0.1	51.82	20.09	6.33	2.45
16.09.86	BC(R)	2	15.15	5.4	11.3	92	7.6	0.2	4.74	1.60	0.58	0.19
18.11.86	BC(R)	3	15.15	4.7	9.5	88	7.8	0.2	8.96	2.95	1.09	0.36
28.01.87	BC(R)	4	15.15	5.4	3.0	91	7.6	0.1	7.89	2.08	0.96	0.25
20.03.87	BC(R)	5	16.00	5.5	6.0	43	7.7	0.1	13.66	7.10	1.51	0.79
19.05.87	BC(R)	6	16.00	4.5	13.0	76	7.2	0.1	13.37	6.56	1.16	0.57
15.07.87	BC(R)	7	16.00	4.5	19.5	84	7.0	0.1	8.19	3.04	0.87	0.32
18.09.87	BC(R)	8	16.00	4.5	17.5	77	7.0	0.1	8.23	3.17	0.91	0.35
18.11.87	BC(R)	9	16.00	4.7	10.0	82	7.2	0.1	7.53	4.35	0.68	0.39
10.05.87	BC(R)	10	16.00	4.5	12.5	76	7.3	0.1	11.19	2.80	1.07	0.27
15.05.86	SC(CA)	1	9.09	-1	-1	-1	-1	-1	5.95	1.40	2.73	0.64
17.09.86	SC(CA)	2	7.58	2.2	12.9	83	7.9	0.8	1.28	0.40	0.31	0.10
29.01.87	SC(CA)	3	8.33	0.7	2.0	94	7.1	0.3	5.43	1.45	1.10	0.29
14.05.87	SC(CA)	4	6.20	1.5	11.5	76	7.5	0.1	11.84	1.54	2.80	0.36
21.09.87	SC(CA)	5	6.00	0.0	16.5	44	7.0	0.1	2.60	0.31	0.44	0.05
11.05.88	SC(CA)	6	6.40	0.5	10.5	72	7.4	0.1	9.24	0.61	1.86	0.12
15.05.86	WHR(CA)	1	11.36	-1	-1	-1	-1	-1	8.71	2.09	6.39	1.52
19.11.86	WHR(CA)	2	10.61	2.4	9.0	84	7.9	0.1	4.02	0.53	0.70	0.09
14.05.87	WHR(CA)	3	11.50	0.5	13.0	82	7.6	0.1	11.44	1.84	1.79	0.29
23.11.87	WHR(CA)	4	7.00	1.0	9.0	84	7.4	0.2	4.71	1.11	0.57	0.13
11.05.88	WHR(CA)	5	9.00	1.5	13.0	-1	7.4	0.1	5.07	0.45	0.70	0.06
13.05.86	CM(G)	1	15.15	-1	-1	-1	-1	-1	68.99	10.37	12.64	1.90

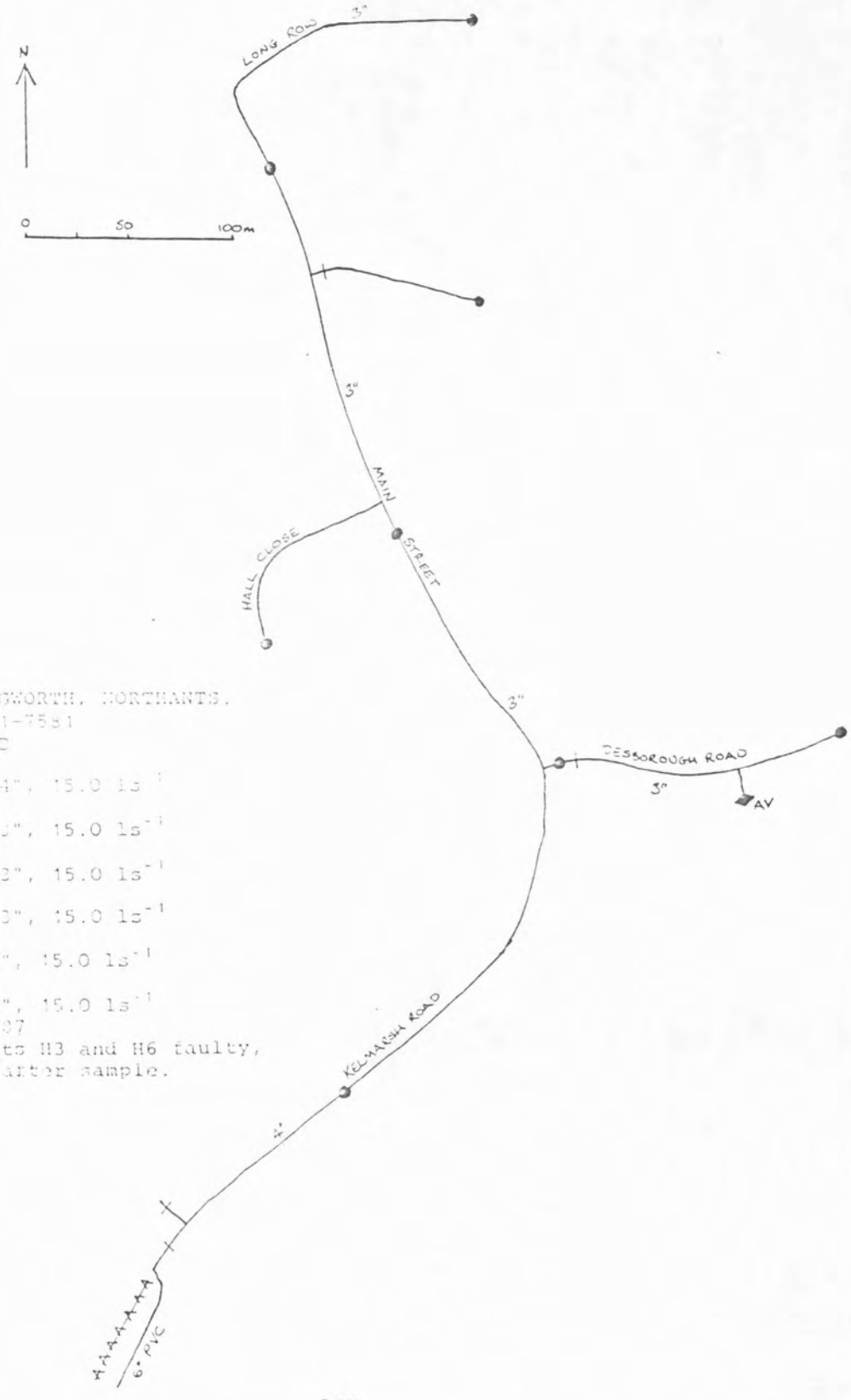
DATE	SITE	FLUSH	FRATE	BAR	TEMP	O2	PH	CL	DRYWT	OMWT	DW/VOL	OM/VOL
15.07.86	CM(G)	2	15.15	-1	8.9	80	7.8	0.1	11.17	-1	1.36	-1
19.09.86	CM(G)	3	15.15	2.5	14.5	97	7.9	0.1	0.81	0.08	0.09	0.01
17.11.86	CM(G)	4	15.15	2.7	8.0	97	7.5	0.1	1.00	0.25	0.12	0.03
29.01.87	CM(G)	5	15.15	2.7	2.0	90	7.2	0.1	1.90	0.25	0.22	0.03
19.03.87	CM(G)	6	15.15	2.5	6.0	78	7.8	0.4	0.63	0.16	0.07	0.02
18.05.87	CM(G)	7	15.00	1.3	12.0	94	7.6	0.2	23.69	1.28	2.46	0.13
13.07.87	CM(G)	8	15.00	1.5	19.5	74	7.0	0.1	4.36	0.65	0.38	0.05
17.09.87	CM(G)	9	15.00	1.5	17.0	47	7.0	0.1	1.50	0.32	0.13	0.03
18.11.87	CM(G)	10	15.00	1.3	9.0	90	7.2	0.1	2.79	0.36	0.23	0.03
09.05.88	CM(G)	11	15.00	1.5	13.0	-1	7.4	0.1	4.02	0.65	0.34	0.06
08.05.86	SC(R)	1	15.15	-1	-1	-1	-1	-1	172.05	15.25	23.65	2.10
15.07.86	SC(R)	2	15.15	4.8	20.2	80	7.9	0.1	50.46	6.21	9.25	1.14
18.09.86	SC(R)	3	15.15	5.1	14.0	90	7.7	0.2	7.02	0.97	1.29	0.18
17.11.86	SC(R)	4	15.15	5.4	9.0	80	7.8	0.3	2.41	0.32	0.29	0.04
29.01.87	SC(R)	5	15.15	5.1	4.0	60	7.6	0.1	2.60	0.38	0.46	0.06
19.03.87	SC(R)	6	15.15	5.4	4.0	88	-1	0.2	14.67	1.85	2.30	0.29
18.05.87	SC(R)	7	16.00	3.5	12.5	92	7.3	0.1	6.48	1.01	0.73	0.11
13.07.86	SC(R)	8	16.00	4.5	20.5	82	7.4	0.2	9.98	2.24	1.06	0.24
17.09.87	SC(R)	9	16.00	3.7	17.0	54	7.4	0.1	2.21	0.51	0.24	0.06
18.11.87	SC(R)	10	16.00	4.0	9.5	94	7.4	0.1	3.12	0.53	0.37	0.06
09.05.88	SC(R)	11	16.00	3.5	12.0	72	7.4	0.1	16.74	3.45	1.74	0.36
11.07.86	PL(W)	1	9.09	4.9	15.6	74	7.5	0.1	33.52	5.36	10.24	1.64
14.07.87	PL(W)	2	6.90	3.0	16.5	60	7.0	0.2	14.55	0.54	3.02	0.11
09.05.88	PL(W)	3	8.00	3.5	11.0	-1	7.6	0.1	16.69	2.88	2.71	0.47

DATE	SITE	FLUSH	S.S.F.	CONS.	P.O.C.	D.O.C.	SER.RES.	AGE
16.04.86	PC(NH)	1	0	1	-1	-1	0	0.5
28.05.86	PC(NH)	2	0	1	-1	-1	0	0.5
21.04.87	PC(NH)	3	0	1	1.2	9.3	0	0.5
10.05.88	PC(NH)	4	0	1	0.2	3.2	0	0.5
16.04.86	WW(NH)	1	0	2	-1	-1	0	0.5
28.05.86	WW(NH)	2	0	2	-1	-1	0	0.5
14.07.87	WW(NH)	3	0	2	0.3	3.7	0	0.5
10.05.88	WW(NH)	4	0	2	0.0	4.2	0	0.5
12.05.86	WW(W)	1	0	1	-1	-1	1	2.5

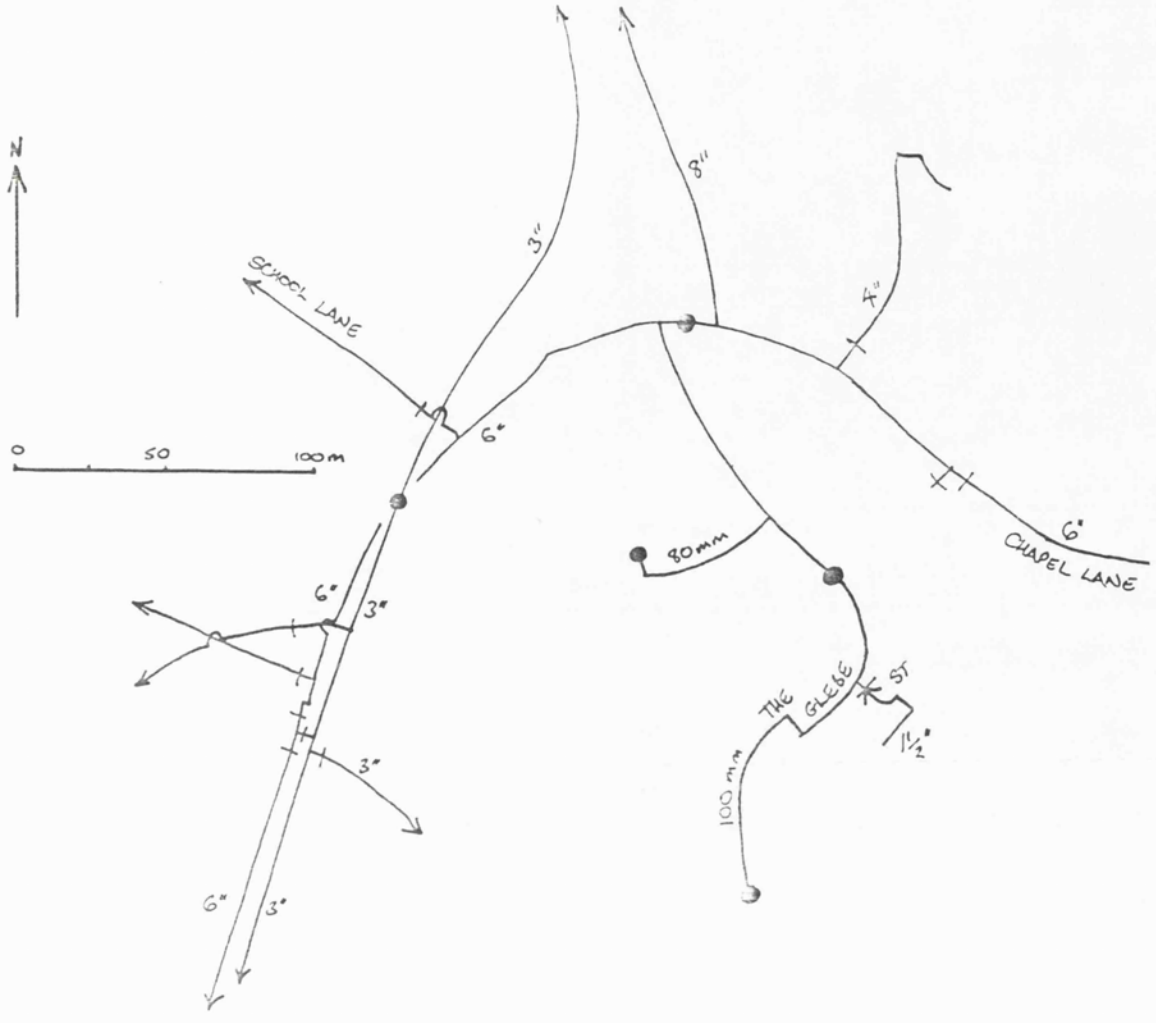
DATE	SITE	FLUSH	S.S.F.	CONS.	P.O.C.	D.O.C.	SER.RES.	AGE
15.09.86	WW(W)	2	0	1	19.0	6.5	1	2.5
28.01.87	WW(W)	3	0	1	4.9	6.5	1	2.5
15.05.87	WW(W)	4	0	1	9.2	57.7	1	2.5
21.09.87	WW(W)	5	0	1	0.9	2.9	1	2.5
11.05.88	WW(W)	6	0	1	2.7	4.0	1	2.5
12.05.86	B(W)	1	0	1	-1	-1	1	2.5
18.11.86	B(W)	2	0	1	1.1	4.1	1	2.5
15.05.87	B(W)	3	0	1	0.0	7.8	1	2.5
18.11.87	B(W)	4	0	1	2.8	4.2	1	2.5
11.05.88	B(W)	5	0	1	1.6	6.5	1	2.5
27.06.86	BL(CB)	1	0	2	26.1	4.8	0	-1
12.09.86	BL(CB)	2	0	2	2.4	8.8	0	-1
19.11.86	BL(CB)	3	0	2	1.1	3.9	0	-1
28.01.87	BL(CB)	4	0	2	0.7	3.9	0	-1
20.03.87	BL(CB)	5	0	2	0.7	2.5	0	-1
20.05.87	BL(CB)	6	0	2	1.1	3.5	0	-1
15.07.87	BL(CB)	7	0	2	1.5	4.3	0	-1
18.09.87	BL(CB)	8	0	2	1.9	19.0	0	-1
18.11.87	BL(CB)	9	0	2	1.1	3.1	0	-1
10.05.88	BL(CB)	10	0	2	5.9	8.8	0	-1
14.07.86	BC(R)	1	0	2	2.5	3.1	0	-1
16.09.86	BC(R)	2	0	2	0.4	4.2	0	-1
18.11.86	BC(R)	3	0	2	0.9	4.2	0	-1
28.01.87	BC(R)	4	0	2	0.5	3.3	0	-1
20.03.87	BC(R)	5	0	2	0.7	4.6	0	-1
19.05.87	BC(R)	6	0	2	1.1	13.3	0	-1
15.07.87	BC(R)	7	0	2	1.2	3.2	0	-1
18.09.87	BC(R)	8	0	2	0.6	3.4	0	-1
18.11.87	BC(R)	9	0	2	0.0	3.8	0	-1
10.05.87	BC(R)	10	0	2	1.5	4.2	0	-1
15.05.86	SC(CA)	1	0	1	-1	-1	1	4.5
17.09.86	SC(CA)	2	0	1	2.4	3.9	1	4.5
29.01.87	SC(CA)	3	0	1	2.4	2.8	1	4.5
14.05.87	SC(CA)	4	0	1	0.2	41.7	1	4.5
21.09.87	SC(CA)	5	1	1	2.2	23.7	1	4.5
11.05.88	SC(CA)	6	1	1	0.0	2.1	1	4.5

DATE	SITE	FLUSH	S.S.F.	CONS.	P.O.C.	D.O.C.	SER.RES.	AGE
15.05.86	WHR(CA)	1	0	2	-1	-1	1	4.5
19.11.86	WHR(CA)	2	0	2	0.8	3.5	1	4.5
14.05.87	WHR(CA)	3	0	2	1.7	7.0	1	4.5
23.11.87	WHR(CA)	4	1	2	0.0	2.3	1	4.5
11.05.88	WHR(CA)	5	1	2	0.0	1.5	1	4.5
13.05.86	CM(G)	1	0	2	-1	-1	0	1.5
15.07.86	CM(G)	2	0	2	0.2	2.8	0	1.5
19.09.86	CM(G)	3	0	2	0.7	4.7	0	1.5
17.11.86	CM(G)	4	0	2	0.4	4.0	0	1.5
29.01.87	CM(G)	5	0	2	0.0	4.6	0	1.5
19.03.87	CM(G)	6	0	2	0.0	4.2	0	1.5
18.05.87	CM(G)	7	0	2	0.0	15.0	0	1.5
13.07.87	CM(G)	8	1	2	1.0	1.8	0	1.5
17.09.87	CM(G)	9	1	2	1.6	27.0	0	1.5
18.11.87	CM(G)	10	1	2	0.5	2.4	0	1.5
09.05.88	CM(G)	11	1	2	0.6	2.6	0	1.5
08.05.86	SC(R)	1	0	2	-1	-1	0	1.0
15.07.86	SC(R)	2	0	2	1.7	9.2	0	1.0
18.09.86	SC(R)	3	0	2	1.5	4.4	0	1.0
17.11.86	SC(R)	4	0	2	0.0	4.4	0	1.0
29.01.87	SC(R)	5	0	2	0.4	12.0	0	1.0
19.03.87	SC(R)	6	0	2	0.0	4.7	0	1.0
18.05.87	SC(R)	7	0	2	0.3	10.4	0	1.0
13.07.86	SC(R)	8	1	2	1.2	2.3	0	1.0
17.09.87	SC(R)	9	1	2	1.4	4.9	0	1.0
18.11.87	SC(R)	10	1	2	0.7	2.2	0	1.0
09.05.88	SC(R)	11	1	2	0.3	3.3	0	1.0
11.07.86	PL(W)	1	0	1	2.2	3.4	1	2.5
14.07.87	PL(W)	2	1	1	1.7	4.3	1	2.5
09.05.88	PL(W)	3	1	1	1.0	3.6	1	2.5

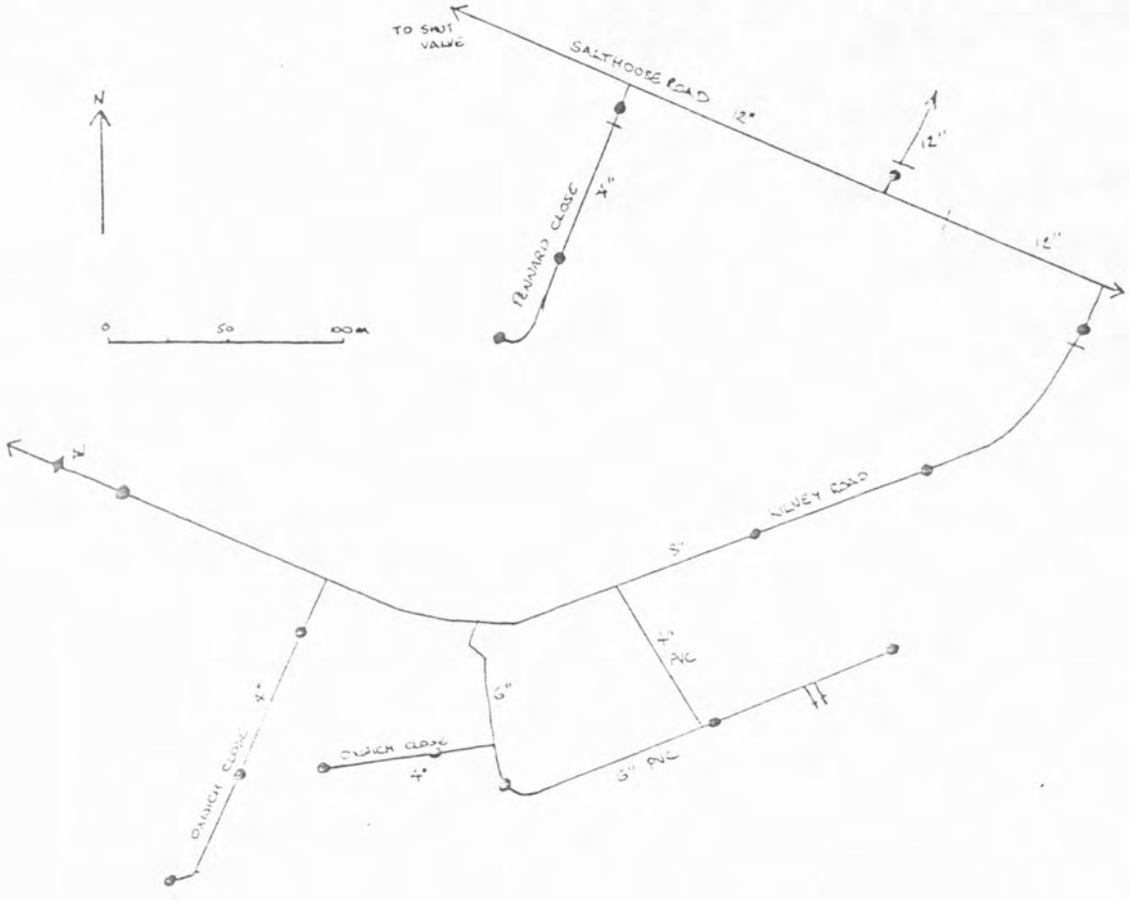
APPENDIX V: DETAILED SKETCH MAPS OF UNDISTURBED SITES SAMPLED FOR CHAPTER 6



ARTHINGWORTH, NORTHANTS.
SP 7481-7581
[illegible] FEED
H1;
[illegible]m, 4", 15.0 ls^{-1}
H2;
135m, 3", 15.0 ls^{-1}
H3;
140m, 3", 15.0 ls^{-1}
H4;
200m, 3", 15.0 ls^{-1}
H5;
93m, 4", 15.0 ls^{-1}
H6;
[illegible]m, 3", 15.0 ls^{-1}
14.10.87
Hydrants H3 and H6 faulty,
noted after sample.

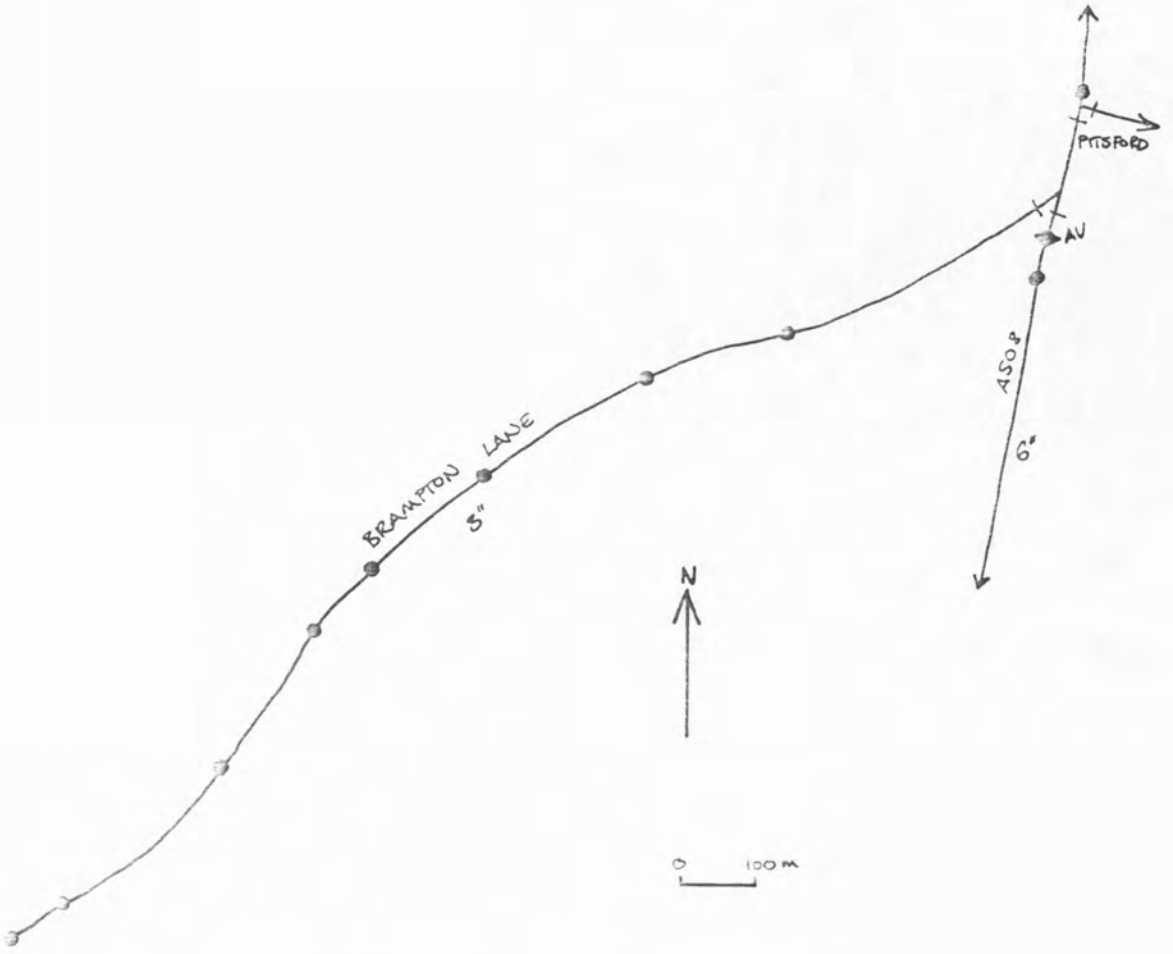


DADBY, NORTHANTS.
SP 5559
SP 5558
SP 5658
SP 5659
THE GLEBE
6" FEED
H1;
97m, 100mm, 15 ls^{-1}
H2;
144m, 100mm, 15 ls^{-1}
H3;
53m, 80mm, 15 ls^{-1}
09.10.87

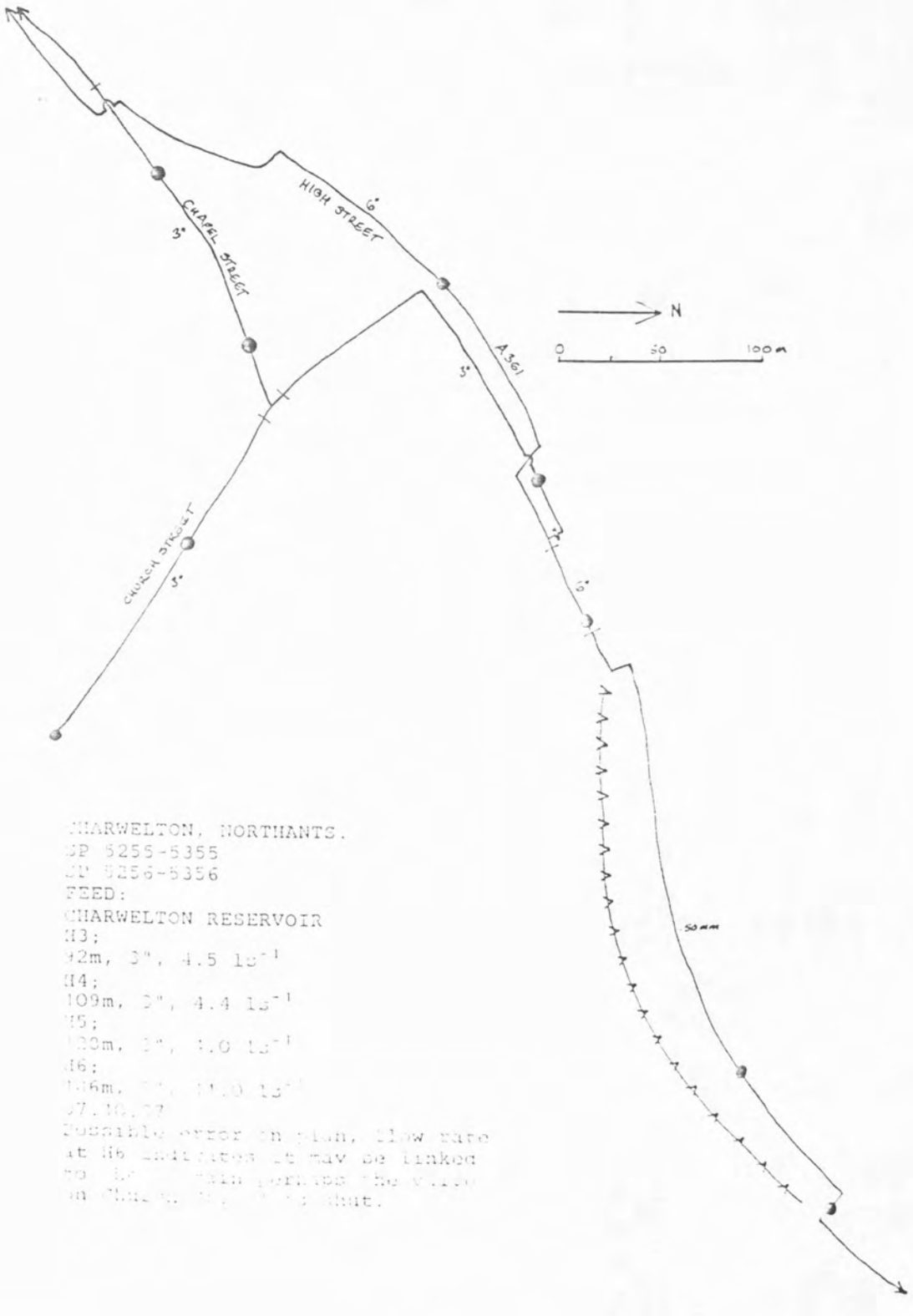


BRACKMILLS IND. EST. , NORTHANTS.
SP 7658-7758
OXWICH CLOSE;
139m, 4" off 8", 16.0 Ls
PENNARD CLOSE;
116m, 4" off 12", 16.0 Ls
05.06.07

CANONS ASHBY, NORTHANTS.
SP 5654-5754
SP 5653-5753
SP 5652-5752
SP 5651-5751
SP 5650-5750
8" FEED
(Obtained by closing valve to [illegible])
N1:
[illegible]m, 4", 8.0 ls^{-1}
[illegible].06.07
Remainder of hydrants did not have sufficient flow to register on flow gauge.



CHAPEL BRAMPTON, NORTHANTS.
SP 7266-7366
SP 7467-7567
SP 7267-7367
BRAMPTON LANE
6" FEED
H2;
594m, 3", 4.4 ls^{-1}
H3;
242m, 3", 4.4 ls^{-1}
H4;
199m, 3", 4.4 ls^{-1}
H6;
330m, 3", 5.0 ls^{-1}
H7;
300m, 3", 10.0 ls^{-1}
H8;
[illegible]m, 3", 11.0 ls^{-1}
[illegible]6.87
Drainage problems at H1 and H5 led to these hydrants being ignored.

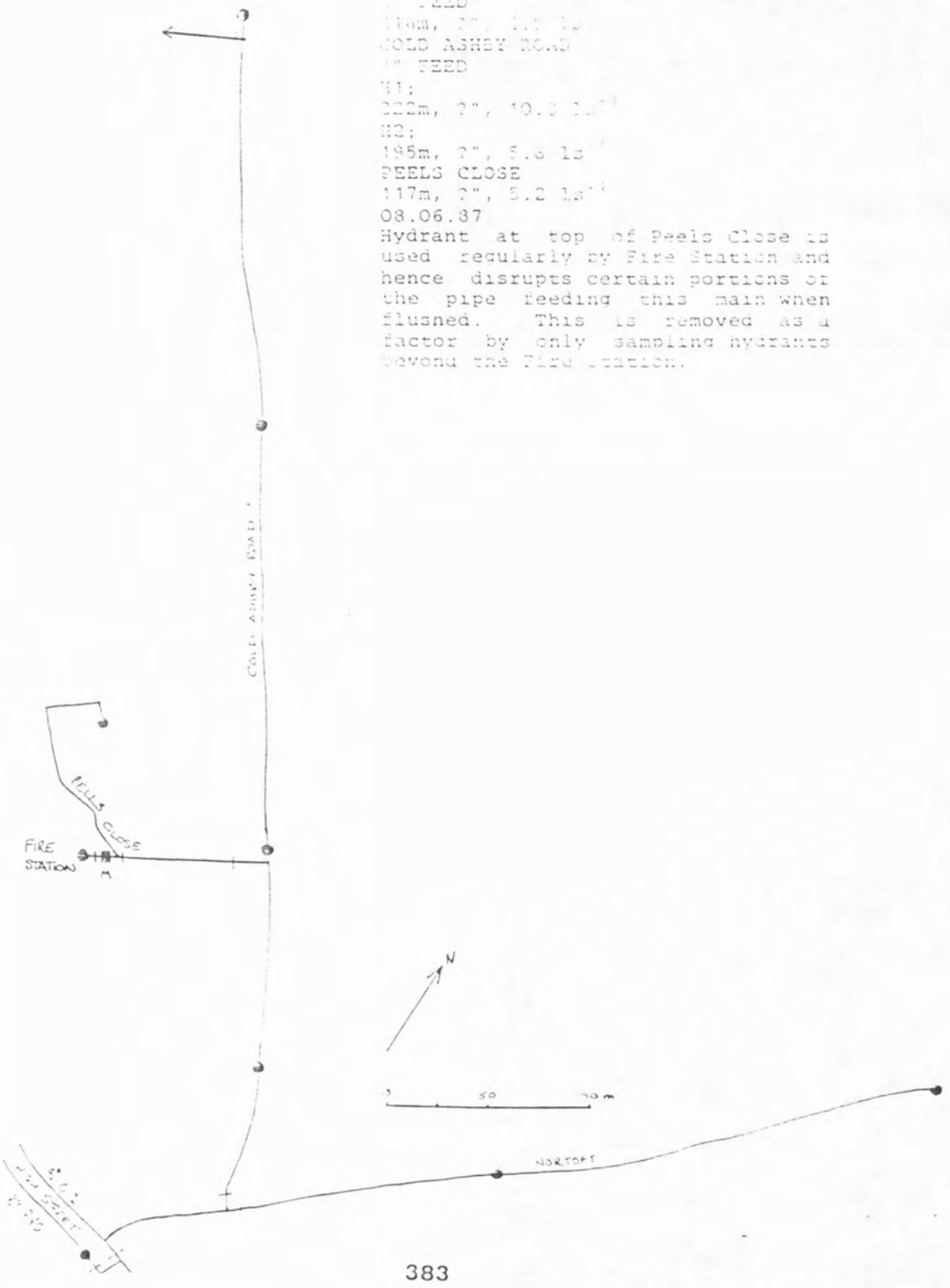


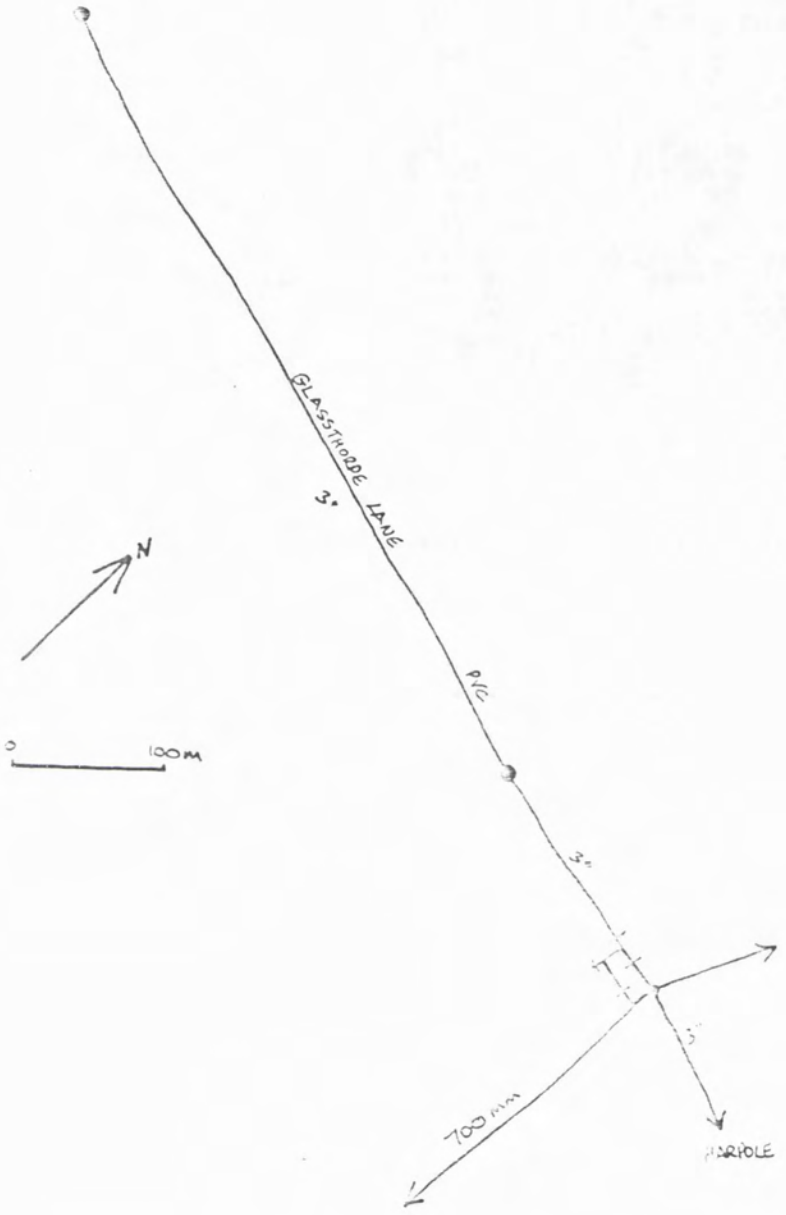
CHARWELTON, NORTHANTS.
SP 5255-5355
SP 5256-5356
FEED:
CHARWELTON RESERVOIR
H3;
92m, 3", 4.5 ls^{-1}
H4;
109m, 3", 4.4 ls^{-1}
H5;
[illegible]m, 3", [illegible].0 ls^{-1}
H6;
[illegible]6m, [illegible], [illegible].0 ls^{-1}
[illegible]
Possible error in plan, flow rate at H6 indicates it may be linked to [illegible] main perhaps the valve on Church [illegible] shut.

[illegible]REATON, NORTHANTS.
SP [illegible]
TEETON ROAD;
154m, [illegible] off [illegible], [illegible]
16.10.87

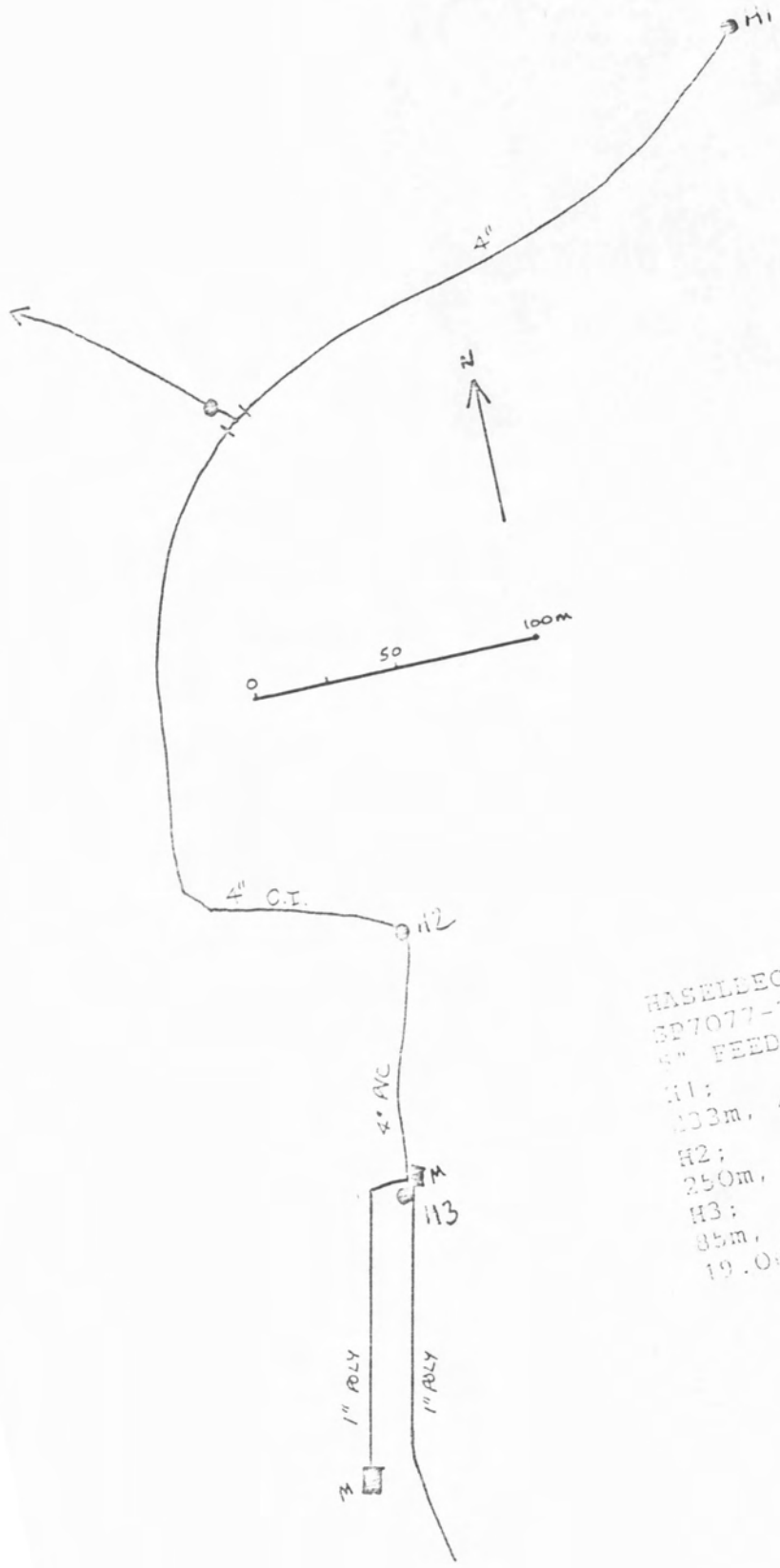
DAVENTRY, NORTHANTS.
SP 5861-5961
HIGH MARCH CLOSE;
104m, 4" off 6", 15 ls^{-1}
HACKWOOD ROAD;
105m, 4" off 6", 15 ls^{-1}
17.06.87

[illegible]
[illegible]
NORTOFT
" FEED
[illegible]
COLD ASHBY ROAD
" FEED
H1;
222m, 2", 10.3 l/s
H2;
195m, 2", 5.6 l/s
PEELS CLOSE
117m, 2", 5.2 l/s
08.06.87
Hydrant at top of Peels Close is used regularly by Fire Station and hence disrupts certain portions of the pipe feeding this main when flushed. This is removed as a factor by only sampling hydrants beyond the Fire Station.





HARPOLE, NORTHANTS.
SP 6660-6760
SP 6850-6960
GLASSTHORPE LANE
700mm FEED
H1;
158m, 3", 9.0 LS
H2;
[illegible]
12.10.87

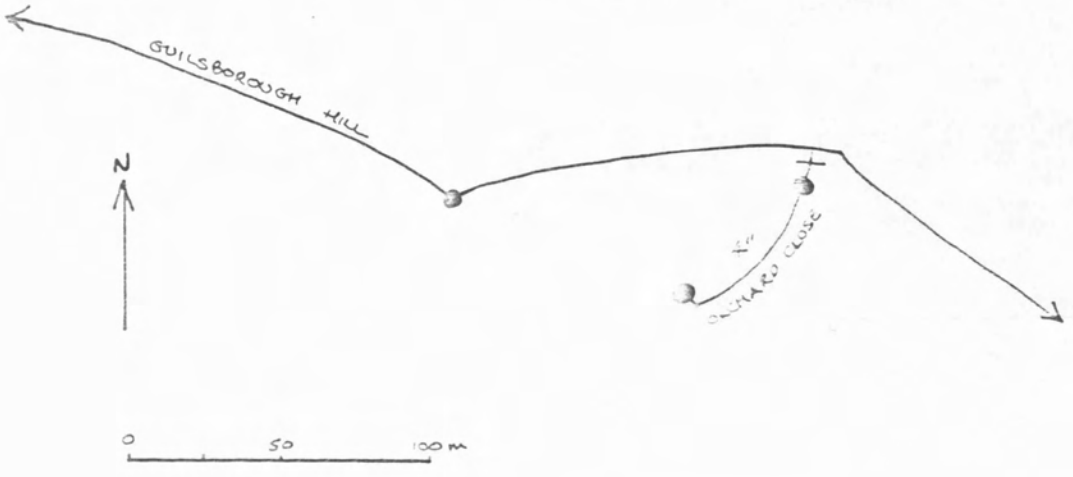


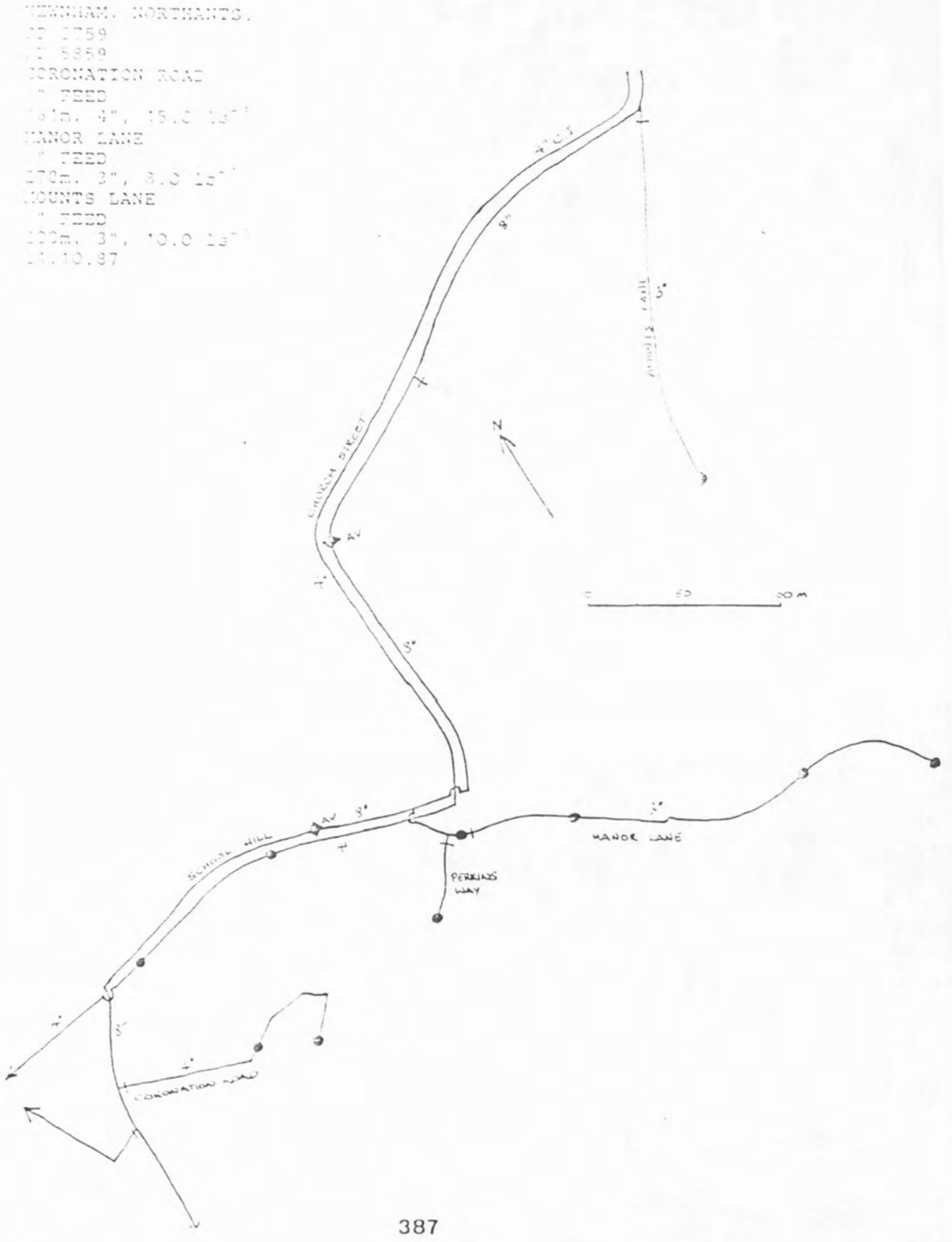
HASELLECH, NORTHANTS.
SP7077-7177
6" FEED

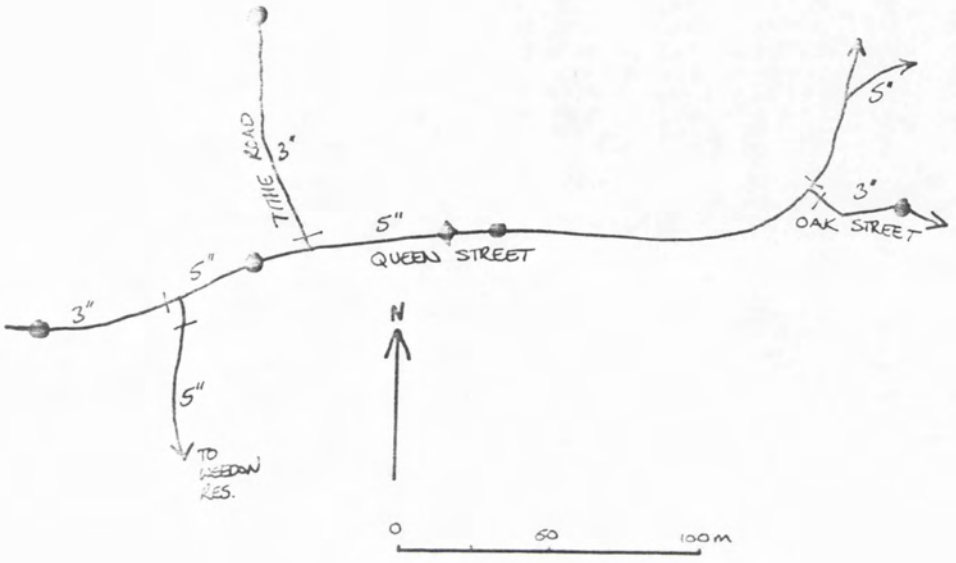
H1:
133m, 4", 3.2 [illegible]

H2;
250m, 4", 3.2 [illegible]

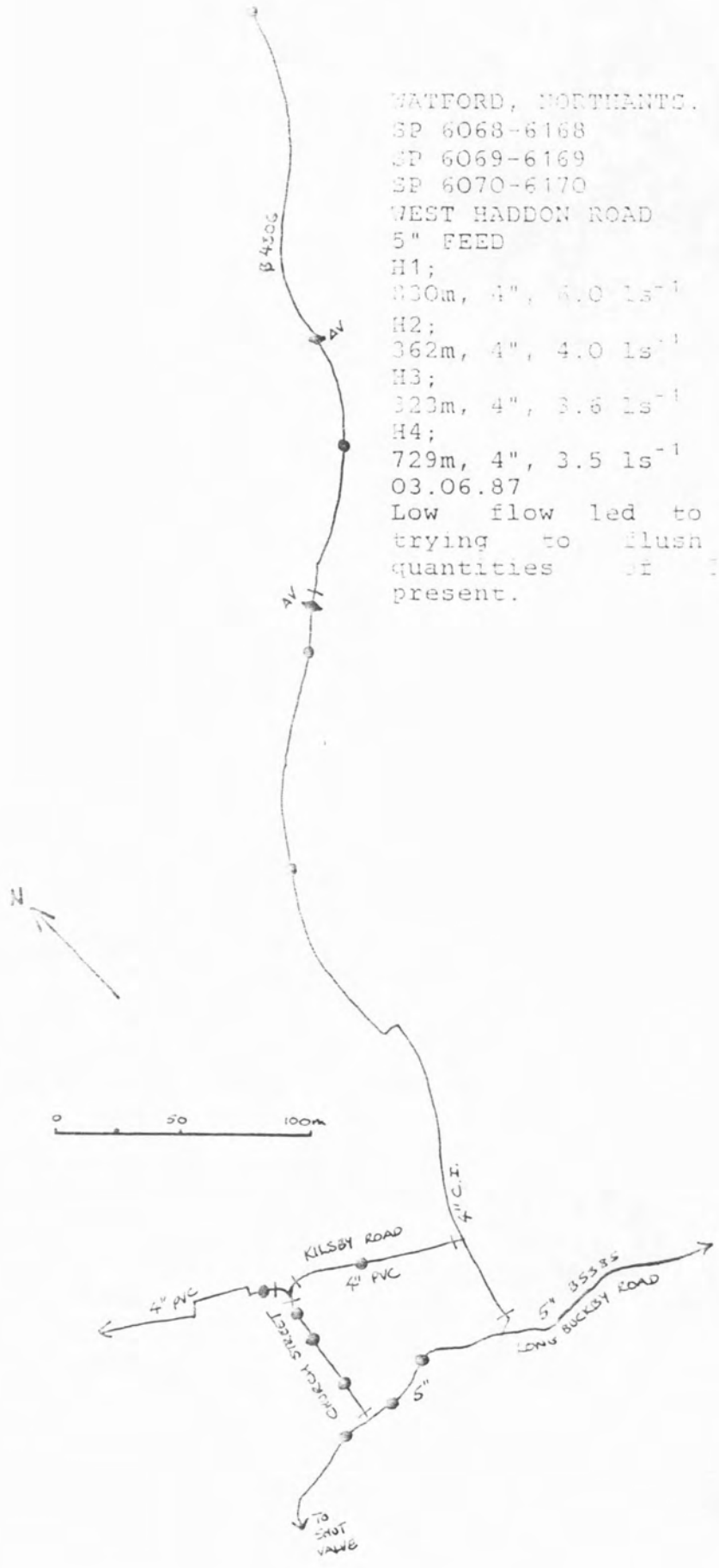
H3:
85m, 4", 3.2 [illegible]
19.05.87


GUILSBOROUGH HILL
N
ORCHARD CLOSE
0
50
100 m

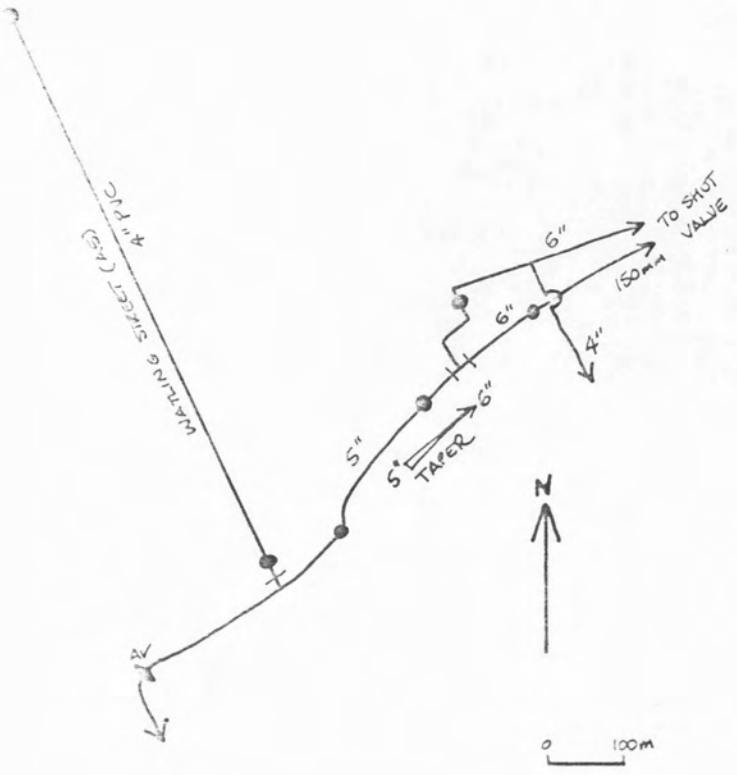

NEWNHAM, NORTHANTS.
CORONATION ROAD
" FEED
MANOR LANE
" FEED
MOUNTS LANE
" FEED
CHURCH STREET
SCHOOL HILL
PERKINS WAY
MANOR LANE
CORONATION ROAD
N
AV
8"
4"
3"
0
50
100 m



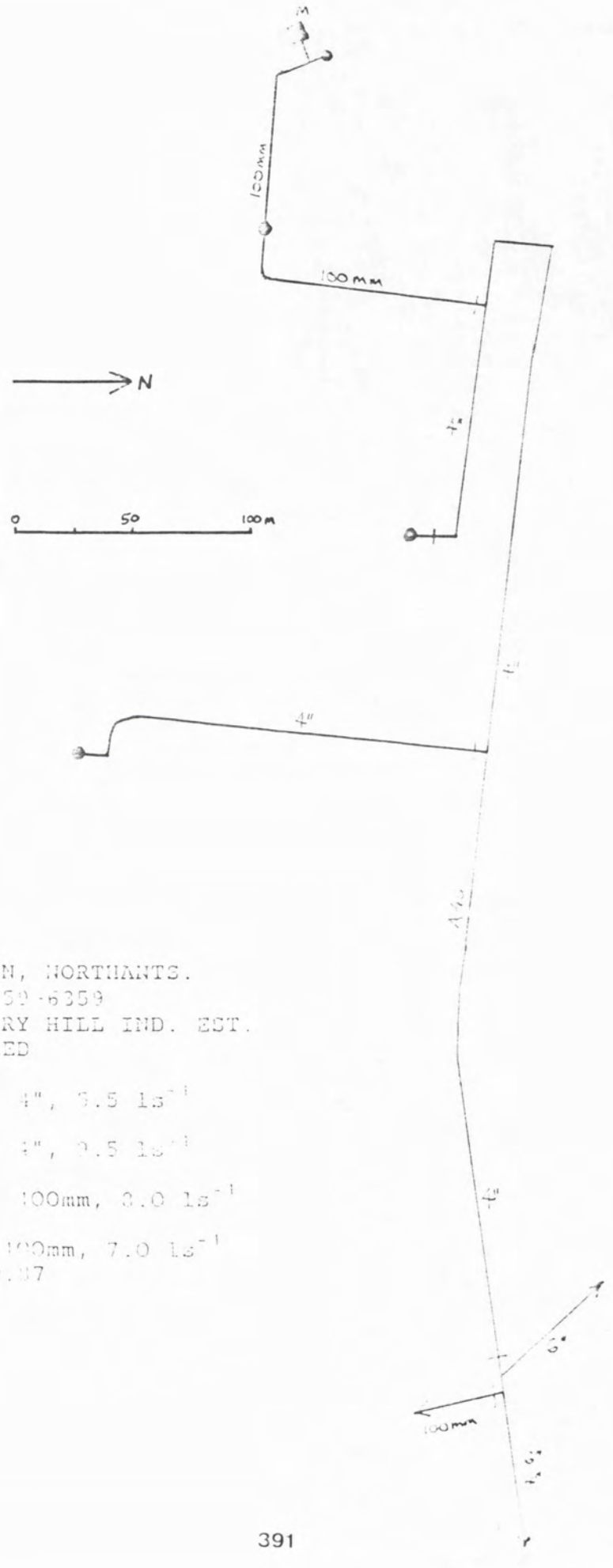
UPPER WEEDON, NORTHANTS.
UP 6258-6358
TITHE ROAD;
117m, 3" off 5", 15 Ls"
12.06.87



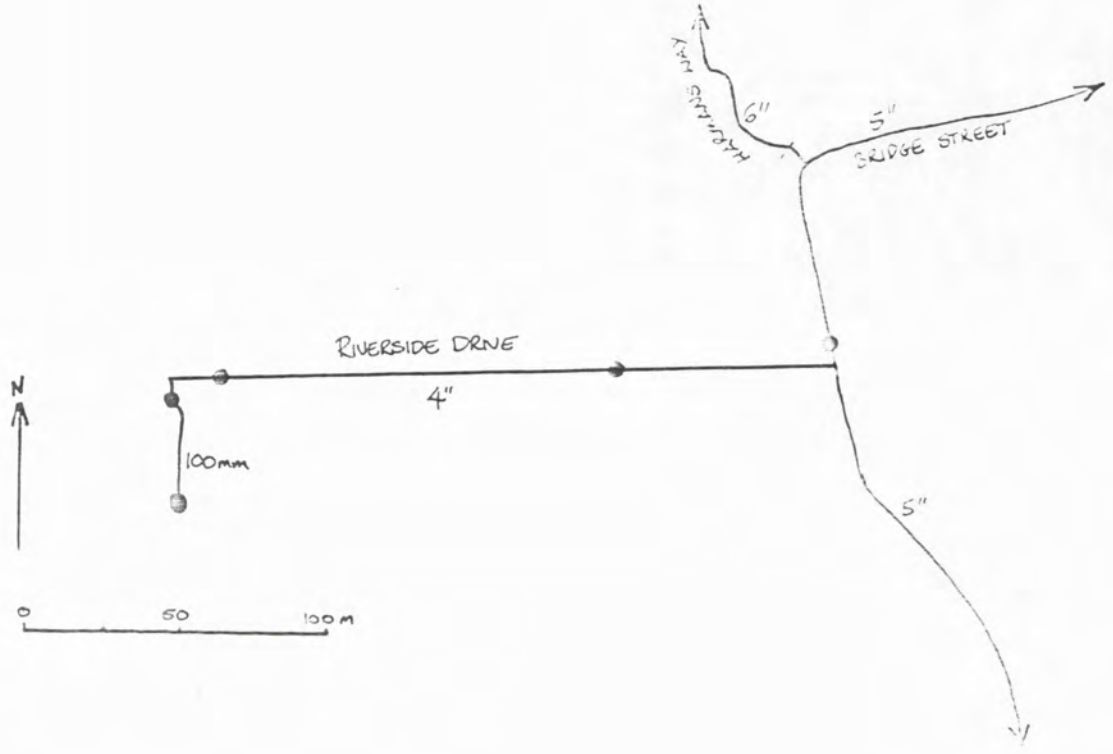
WATFORD, NORTHANTS.
SP 6068-6168
SP 6069-6169
SP 6070-6170
WEST HADDON ROAD
5" FEED
H1;
830m, 4", 6.0 ls^{-1}
H2;
362m, 4", 4.0 ls^{-1}
H3;
323m, 4", 3.6 ls^{-1}
H4;
729m, 4", 3.5 ls^{-1}
03.06.87
Low flow led to problems when trying to flush clean, large quantities of fine sediments present.



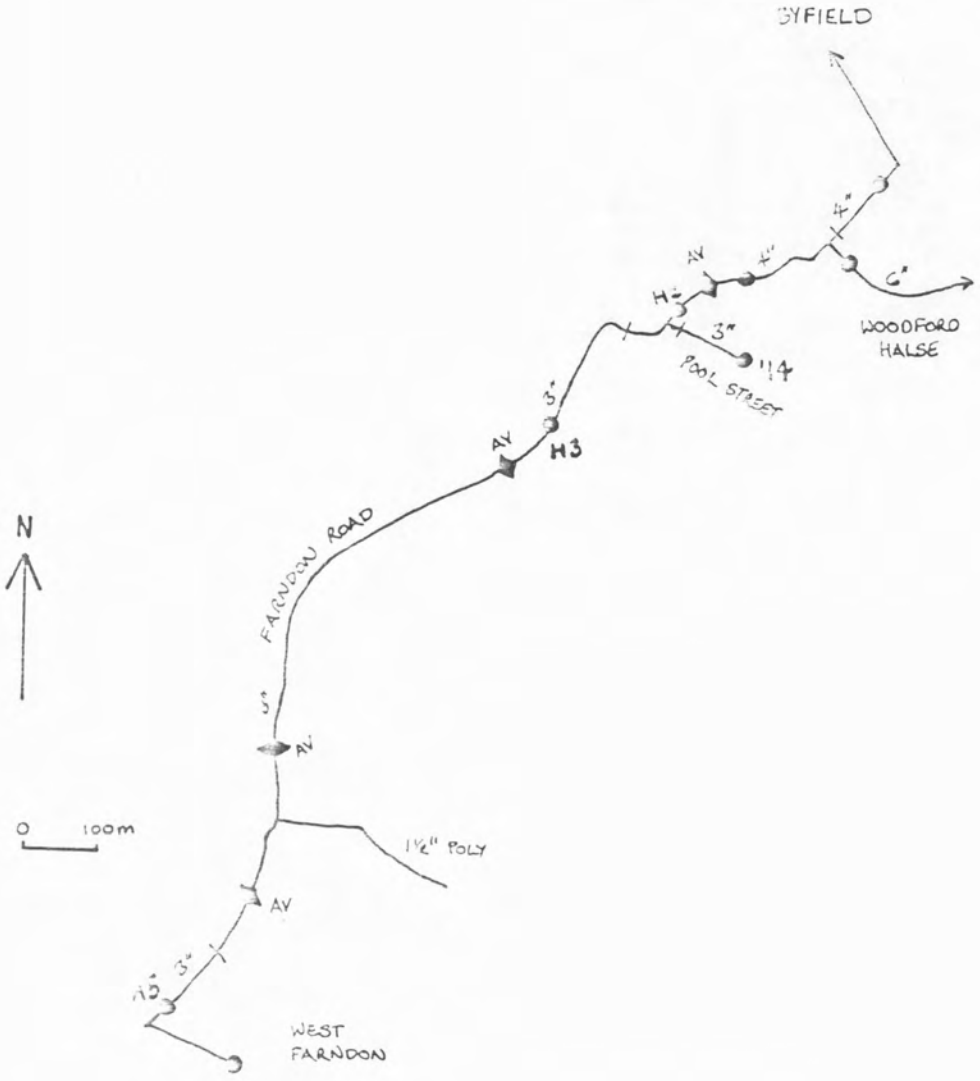
WATLING STREET, NORTHANTS.
SP 5867-5967
SP 5868-5968
WATLING STREET;
350m, 4" [illegible] 5", 10 Is
27.05.87



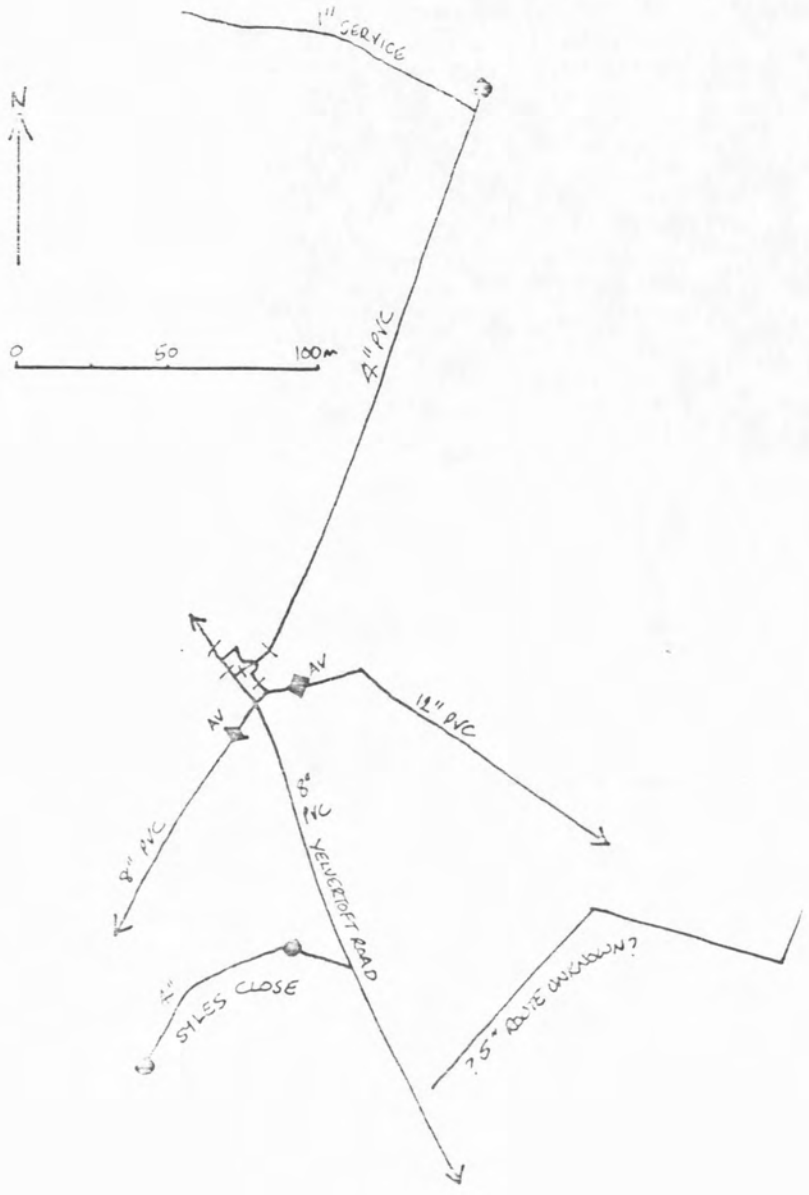
WEEDON, NORTHANTS.
TP 6259-6359
CAVALRY HILL IND. EST.
6" FEED
H1;
461m, 4", 6.5 ls^{-1}
H2;
170m, 4", 6.5 ls^{-1}
H3;
117m, 100mm, 8.0 ls^{-1}
H4;
30m, 100mm, 7.0 ls^{-1}
10.10.87



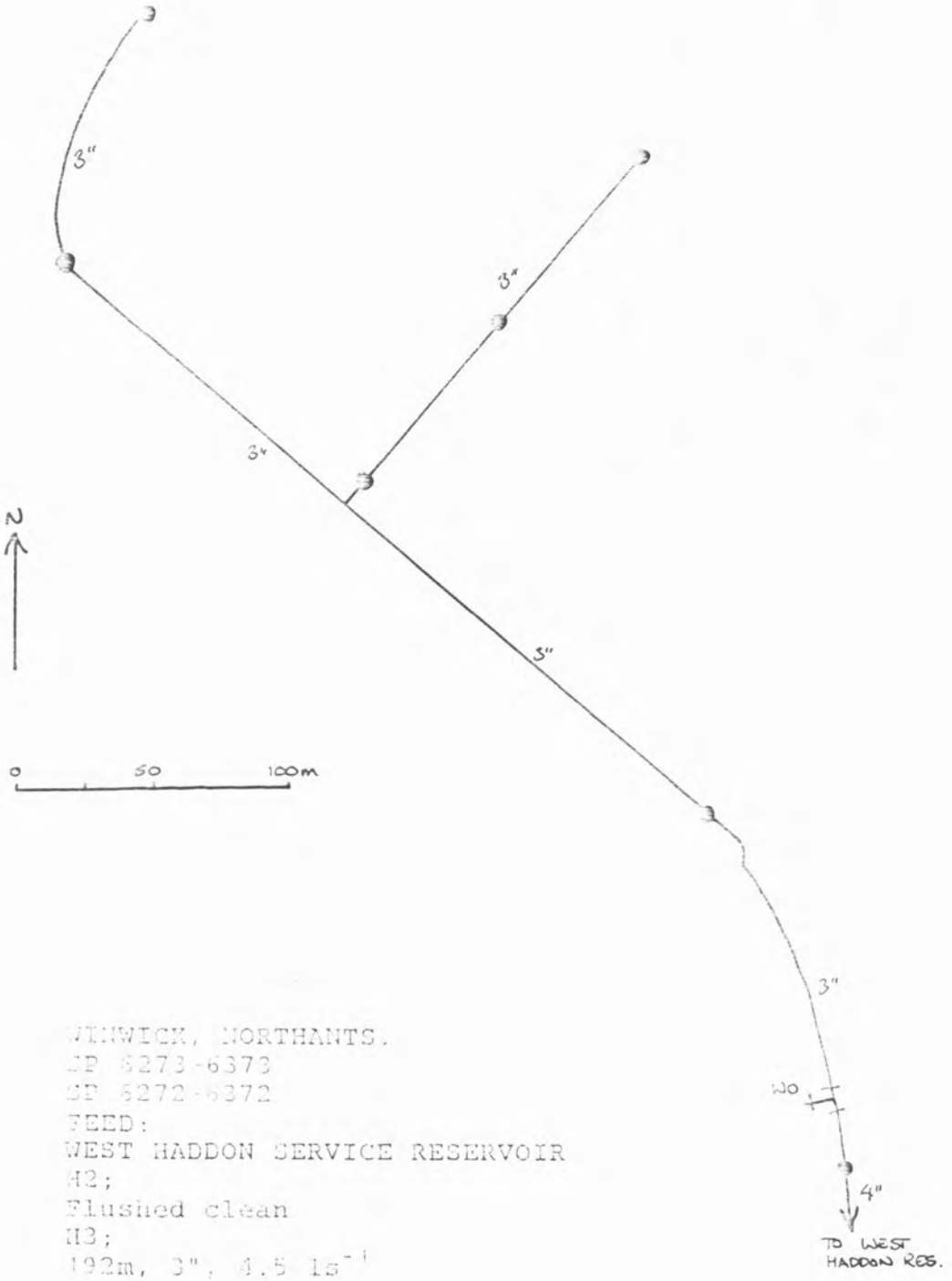
[illegible] DEC, NORTHANTS.
SP 4259-6159
RIVERSIDE DRIVE;
378m, (4" and 100mm), [illegible]
23.10.87.
N.B. Sample taken from two pipes
with different diameters and
adjusted as neccessary.



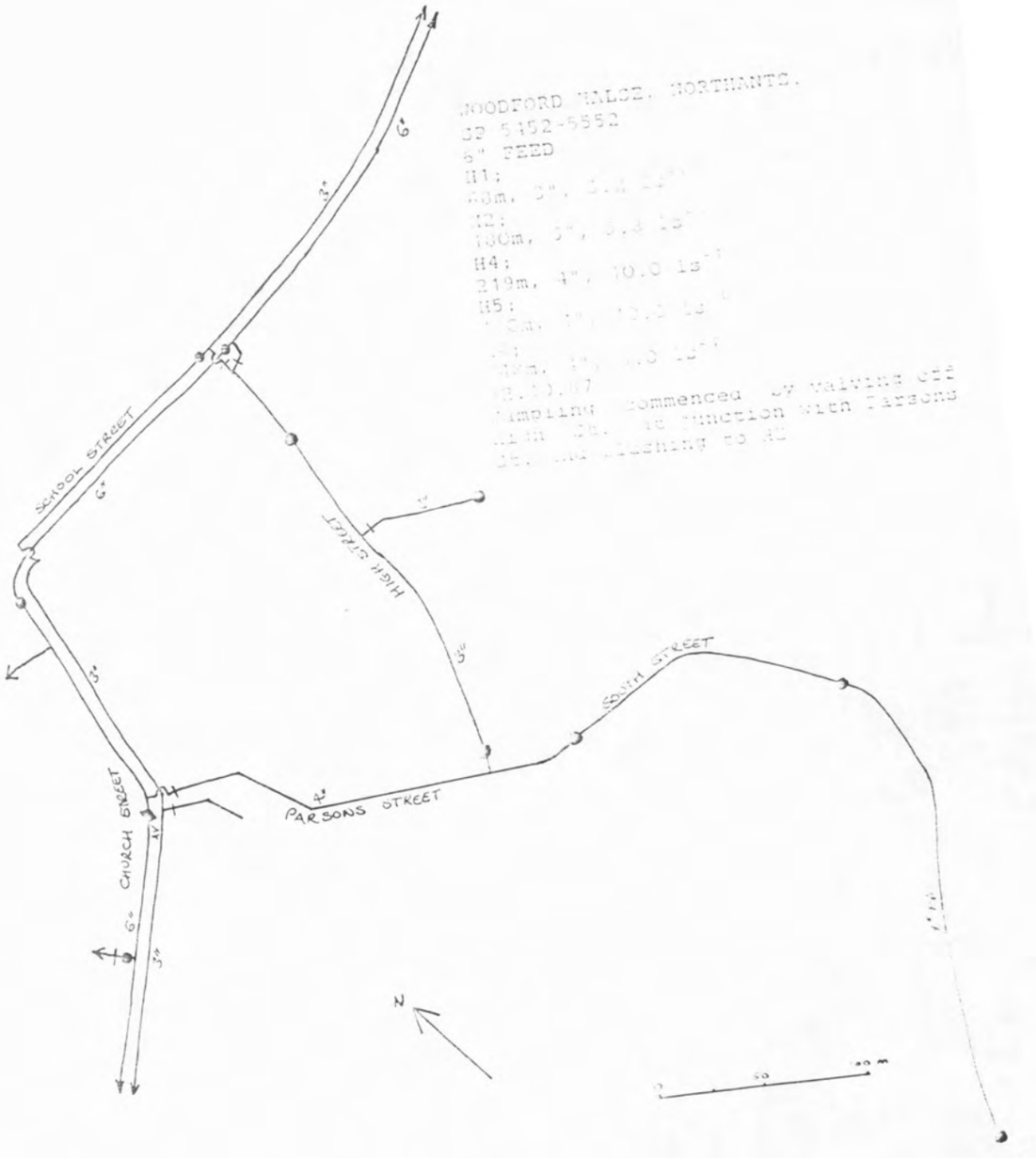
WEST FARNDON, NORTHANTS.
SP 5251-5351
SP 5252-5352
6" FEED
H2;
131m, 4", 11.0 lb
H3;
[illegible]0m, 4", [illegible] lb
[illegible]
[illegible]m, [illegible]
[illegible]
[illegible]m, [illegible]
[illegible]
[illegible] low [illegible] was below minimum
[illegible] low [illegible]



WEST HADDON, NORTHANTS.
SP 6272-6372
SYLES CLOSE;
95m, 4" off 8", 13 ls
26.05.87
Probable contamination of sample
from 4" PVC to Winwick due to back
drainage.



WINWICK, NORTHANTS.
SP 6273-6373
SP 6272-6372
FEED:
WEST HADDON SERVICE RESERVOIR
H2;
Flushed clean
H3;
192m, 3", 4.5 ls^{-1}
H4;
82m, 3", 4.0 ls^{-1}
H5;
88m, 3", 3.5 ls^{-1}
H6;
115m, 3", 3.5 ls^{-1}
H7;
124m, 3", 3.4 ls^{-1}
28.05.87


SCHOOL STREET
HIGH STREET
SOUTH STREET
PARSONS STREET
CHURCH STREET
6"
4"
3"
N

APPENDIX VI: ANIMAL DENSITY PER 10 METRES OF PIPE AT UNDISTURBED SITES SAMPLED DURING MAY/JUNE AND OCTOBER 1987

MISSING VALUES: -99.0 - failure of sampling equation (third flush contains more animal per litre than first and second flushes)
-2.0 - Sample not taken

Columns: t1 Chironominae larvae (excl. Tanytarsini) t2 Tanytarsini larvae
t3 Tanypodinae larvae t4 Orthocladiini larvae
t5 Corynoneura sp. larvae t6 Nitocra hibernica
t7 Byocamptus pygmaeus t8 Paracyclops fimbriatus
t9 Paracyclops fimbriatus poppei t10 Acanthocyclops bisetosus
t11 Megacyclops viridis t12 Eucyclops agilis
t13 Acanthocyclops robustus t14 Acanthocyclops vicinis
t15 Acanthocyclops copepodites t16 Chydorus sphaericus
t17 Alona rectangular t18 Alona guttata
t19 Alona quandrangularis t20 Alona affinis
t21 Graptoleberis testudinaria t22 Macrothrix laticornis
t23 Soldanellonyx monardi t24 Lobohalacarus weberi
t25 Porohalacarus alpinus t26 Tyroglyphidae
t27 Hydrozetes sp. t28 Hydracarina
t29 Naid worms t30 Tubificid worms
t31 Aeolsomatid worms t32 Enchytraid worms
t33 Nematoda t34 Ostracoda
t35 Tardigrada t36 Microturbularia
t37 Planorbis crista t38 Hydrobia jenkinsi

DATE	CODE	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
26.05.87	WH-SC	0.0	0.9	3.3	2.1	0.0	0.0	0.0	0.0	15.7	0.0
27.05.87	WS-A5	0.0	9.4	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
28.05.87	WI-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.87	WI-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.87	WI-H5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.87	WI-H6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.87	WI-H7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
02.06.87	HO-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.4	36.4	0.0
03.06.87	WA-H1	0.0	0.3	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0

DATE	CODE	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
03.06.87	WA-H2	0.0	0.2	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
03.06.87	WA-H3	0.0	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
03.06.87	WA-H4	0.0	0.1	0.2	0.0	0.0	1.0	0.0	0.0	0.0	14.0
05.06.87	BR-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-99.0
05.06.87	BR-PC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.06.87	GU-NO	0.0	-99.0	0.0	-99.0	-99.0	0.0	0.0	0.0	0.0	0.0
08.06.87	GU-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
08.06.87	GU-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.06.87	GU-PC	0.0	1.0	3.5	1.8	0.0	0.0	0.0	16.5	16.5	0.0
10.06.87	CA-HX	0.0	0.4	0.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0
12.06.87	UW-TR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H2	0.0	1.6	0.7	0.4	0.4	0.0	1.0	0.0	-99.0	0.0
15.06.87	BL-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.06.87	BH-HM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.06.87	BH-HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.06.87	HA-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.06.87	HA-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.06.87	HA-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H5	0.0	9.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.10.87	BA-H1	6.0	3.0	0.0	3.0	0.0	0.0	0.0	25.0	17.8	0.0
09.10.87	BA-H2	0.0	1.5	1.5	3.0	0.0	0.0	0.0	110.7	4.2	0.0
09.10.87	BA-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0
12.10.87	WH-H1	0.0	-99.0	0.0	-99.0	0.0	22.0	0.0	-99.0	0.0	0.0
12.10.87	WH-H2	0.0	836.0	0.0	0.0	0.0	127.0	0.0	0.0	0.0	0.0
12.10.87	WH-H4	0.0	112.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.10.87	WH-H5	0.0	122.0	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0
12.10.87	WH-H6	0.0	27.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	1.7	0.0
14.10.87	AR-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	165.0	0.0	0.0

DATE	CODE	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
14.10.87	AR-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H4	0.0	3.0	0.0	0.0	0.0	0.0	0.0	1.5	1.5	0.0
14.10.87	AR-H5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	153.5	22.5	0.0
14.10.87	AR-H6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.8	15.2	0.0
16.10.87	CR-TL	0.0	0.0	0.0	0.0	0.0	1.0	0.0	18.0	65.0	0.0
19.10.87	WF-H2	0.0	379.5	0.0	11.5	0.0	64.0	0.0	0.0	0.8	0.0
19.10.87	WF-H3	0.0	489.0	0.0	0.0	0.0	171.0	0.0	0.0	0.0	0.0
19.10.87	WF-H4	0.0	104.0	0.0	0.0	0.0	71.0	0.0	0.0	0.0	0.0
19.10.87	WF-H5	0.0	0.0	0.0	0.0	0.0	389.0	0.0	0.0	0.0	0.0
21.10.87	NE-CR	0.0	0.0	0.0	0.0	0.0	6.0	0.0	23.7	284.3	0.0
21.10.87	NE-MA	0.5	0.5	0.0	1.0	0.0	0.9	8.1	0.0	0.0	0.0
21.10.87	NE-MO	1.3	0.8	0.0	0.0	0.8	0.0	0.0	0.0	3.2	0.0
22.10.87	GL-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.10.87	GL-H2	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
23.10.87	CV-H1	0.0	-99.0	0.0	0.0	-99.0	0.0	0.0	0.0	0.0	0.0
23.10.87	CV-H2	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0
23.10.87	CV-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	CV-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	WB-RD	0.0	3.8	1.3	0.0	0.0	0.0	0.0	11.4	51.7	0.0

DATE	CODE	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
26.05.87	WH-SC	73.6	5.3	5.3	0.0	21.0	0.0	0.0	0.0	0.0	0.0
27.05.87	WS-A5	128.6	364.5	0.0	0.0	42.9	523.8	0.0	0.0	0.0	857.2
28.05.87	WI-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.87	WI-H4	0.0	-99.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.87	WI-H5	0.0	19.2	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0
28.05.87	WI-H6	0.0	15.0	0.0	0.0	15.0	0.0	0.0	0.0	0.0	0.0
28.05.87	WI-H7	0.0	22.0	0.0	0.0	22.0	1.0	0.0	0.0	0.0	0.0
02.06.87	HO-OC	0.0	0.0	0.0	0.0	5.2	17.0	0.0	0.0	0.0	0.0
03.06.87	WA-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
03.06.87	WA-H2	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
03.06.87	WA-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
03.06.87	WA-H4	0.0	0.0	0.0	0.0	0.0	2.2	2.8	0.0	0.0	0.0
05.06.87	BR-OC	0.0	0.0	0.0	0.0	0.0	1073.3	122.7	0.0	0.0	0.0
05.06.87	BR-PC	0.0	-99.0	-99.0	0.0	0.0	4323.1	336.9	0.0	0.0	0.0

DATE	CODE	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
08.06.87	GU-NO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.06.87	GU-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.06.87	GU-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.06.87	GU-PC	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0
10.06.87	CA-HX	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0
12.06.87	UW-TR	0.0	2.0	0.0	0.0	0.0	241.9	0.0	0.0	0.0	0.0
15.06.87	BL-H2	0.0	0.0	0.0	0.0	0.0	0.2	0.7	1.1	0.0	0.0
15.06.87	BL-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H6	0.0	0.0	0.0	0.0	0.0	6.3	0.7	0.0	0.0	0.0
15.06.87	BL-H7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H8	0.0	0.0	0.0	0.0	0.0	26.5	1.5	0.0	0.0	0.0
17.06.87	BH-HM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.06.87	BH-HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.06.87	HA-H1	0.0	0.0	0.0	0.0	0.0	1184.2	0.0	1466.8	0.0	0.0
19.06.87	HA-H2	0.0	0.0	0.0	0.0	0.0	4096.0	0.0	0.0	0.0	0.0
19.06.87	HA-H3	0.0	0.0	0.0	0.0	0.0	2946.0	0.0	0.0	0.0	0.0
07.10.87	CH-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H5	0.0	0.0	-99.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.10.87	BA-H1	0.0	0.0	7.2	0.0	0.0	1.7	0.0	6.8	1.7	0.0
09.10.87	BA-H2	0.0	0.0	0.0	0.0	0.0	0.0	7.5	0.0	37.5	0.0
09.10.87	BA-H3	0.0	0.0	1.0	0.0	0.0	6.8	0.0	3.4	1.7	0.0
12.10.87	WH-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-99.0	0.0
12.10.87	WH-H2	0.0	435.2	0.0	0.0	200.8	46.9	0.0	0.0	15.6	0.0
12.10.87	WH-H4	0.0	59.0	0.0	0.0	0.0	31.4	0.0	0.0	0.0	0.0
12.10.87	WH-H5	0.0	126.0	0.0	0.0	0.0	23.5	0.0	0.0	0.0	0.0
12.10.87	WH-H6	0.0	28.0	0.0	0.0	0.0	8.8	0.0	0.0	0.0	0.0
14.10.87	AR-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0
14.10.87	AR-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H5	0.0	0.0	0.0	0.0	0.0	0.0	10.0	3.0	0.0	0.0
14.10.87	AR-H6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.10.87	CR-TL	0.0	0.0	0.0	0.0	0.0	22.5	0.0	1.7	0.0	0.0

DATE	CODE	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
19.10.87	WF-H2	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.10.87	WF-H3	0.0	28.0	0.0	0.0	0.0	2.7	0.0	0.0	13.3	0.0
19.10.87	WF-H4	0.0	89.0	0.0	0.0	0.0	74.7	0.0	0.0	0.0	0.0
19.10.87	WF-H5	0.0	80.0	0.0	0.0	0.0	225.0	0.0	0.0	0.0	0.0
21.10.87	NE-CR	0.0	0.0	0.0	0.0	0.0	0.0	187.5	35.2	111.3	0.0
21.10.87	NE-MA	0.0	0.0	0.0	0.0	0.0	471.9	0.0	0.0	13.1	0.0
21.10.87	NE-MO	0.0	0.0	0.8	0.0	0.0	5.6	144.7	27.6	0.0	0.0
22.10.87	GL-H1	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.10.87	GL-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	CV-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	CV-H2	0.0	0.0	0.0	0.0	0.0	44.6	0.0	0.0	0.0	0.0
23.10.87	CV-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	CV-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	WB-RD	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0

DATE	CODE	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30
26.05.87	WH-SC	0.0	0.0	2000.9	250.1	0.0	0.0	0.0	0.0	2295.0	0.0
27.05.87	WS-A5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.87	WI-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.87	WI-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	586.7	0.0
28.05.87	WI-H5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	373.0	0.0
28.05.87	WI-H6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	504.0	0.0
28.05.87	WI-H7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	786.0	0.0
02.06.87	HO-OC	0.0	0.0	39.6	4.4	0.0	0.0	0.0	0.0	0.0	0.0
03.06.87	WA-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-99.0	0.0
03.06.87	WA-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4284.0	0.0
03.06.87	WA-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1378.0	0.0
03.06.87	WA-H4	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	-99.0	0.0
05.06.87	BR-OC	0.0	0.0	-99.0	0.0	0.0	0.0	0.0	-99.0	0.0	0.0
05.06.87	BR-PC	0.0	0.0	-99.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.06.87	GU-NO	0.0	0.0	0.0	0.0	0.0	-99.0	0.0	0.0	17.2	0.0
08.06.87	GU-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.06.87	GU-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0
08.06.87	GU-PC	0.0	0.0	20.6	5.9	0.0	1.5	0.0	0.0	148.0	0.0

DATE	CODE	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30
10.06.87	CA-HX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.06.87	UW-TR	0.0	0.0	51.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H2	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	2.0	0.0
15.06.87	BL-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-99.0	0.0
15.06.87	BL-H8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.06.87	BH-HM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.06.87	BH-HR	0.0	0.0	0.0	-99.0	0.0	0.0	0.0	0.0	0.0	0.0
19.06.87	HA-H1	0.0	0.0	0.0	506.0	0.0	0.0	0.0	0.0	0.0	0.0
19.06.87	HA-H2	0.0	0.0	0.0	247.0	0.0	0.0	0.0	0.0	0.0	0.0
19.06.87	HA-H3	0.0	0.0	0.0	324.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H4	0.0	0.0	66.9	0.0	33.5	44.6	0.0	0.0	0.0	0.0
07.10.87	CH-H5	-99.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	213.0	0.0
07.10.87	CH-H6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-99.0	0.0
09.10.87	BA-H1	1.7	0.0	6.9	0.0	0.0	103.6	3.4	0.0	0.0	0.0
09.10.87	BA-H2	0.0	0.0	111.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.10.87	BA-H3	0.0	0.0	42.4	0.0	0.0	26.5	0.0	0.0	0.0	0.0
12.10.87	WH-H1	0.0	0.0	30.6	0.0	18.4	0.0	0.0	0.0	961.0	0.0
12.10.87	WH-H2	187.5	0.0	111.9	0.0	43.1	0.0	0.0	0.0	534.0	0.0
12.10.87	WH-H4	912.5	0.0	464.4	0.0	16.6	0.0	0.0	0.0	14.0	0.0
12.10.87	WH-H5	728.5	0.0	386.0	0.0	0.0	0.0	0.0	0.0	48.1	0.0
12.10.87	WH-H6	228.2	0.0	21.7	0.0	10.0	8.3	0.0	0.0	0.0	0.0
14.10.87	AR-H1	0.0	0.0	2.7	1.8	0.0	6.4	0.0	0.0	0.0	0.0
14.10.87	AR-H2	0.0	0.0	55.6	0.0	0.0	2.4	0.0	0.0	0.0	0.0
14.10.87	AR-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H5	0.0	0.0	11.2	2.1	0.0	0.7	0.0	0.0	0.0	0.0
14.10.87	AR-H6	0.0	0.0	4.0	0.7	0.0	1.3	0.0	0.0	0.0	0.0
16.10.87	CR-TL	1.7	0.0	12.1	3.6	0.0	12.1	0.0	0.0	4.0	0.0
19.10.87	WF-H2	0.0	0.0	104.9	0.0	96.1	0.0	0.0	0.0	580.6	89.3
19.10.87	WF-H3	0.0	0.0	27.1	0.0	10.8	0.0	0.0	0.0	793.2	37.8
19.10.87	WF-H4	181.3	0.0	234.4	0.0	20.3	0.0	10.2	0.0	-99.0	0.0
19.10.87	WF-H5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	507.0	0.0

DATE	CODE	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30
21.10.87	NE-CR	0.0	0.0	14.3	0.0	0.0	4.8	0.0	0.0	14.0	0.0
21.10.87	NE-MA	0.0	0.0	25.5	0.0	0.0	1.5	0.0	0.0	43.0	0.0
21.10.87	NE-MO	0.0	0.0	0.8	0.0	0.0	17.2	0.0	0.0	0.0	0.0
22.10.87	GL-H1	0.0	0.0	0.0	0.0	0.0	11.0	0.0	0.0	0.0	0.0
22.10.87	GL-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	CV-H1	0.0	0.0	0.0	0.0	0.0	2.9	1.1	0.0	1.0	0.0
23.10.87	CV-H2	3.4	0.0	13.0	0.0	0.0	0.0	0.0	0.0	265.0	0.0
23.10.87	CV-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	CV-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	WB-RD	0.0	0.0	12.5	0.0	0.0	2.5	0.0	0.0	0.0	0.0

DATE	CODE	T31	T32	T33	T34	T35	T36	T37	T38
26.05.87	WH-SC	0.0	0.0	972.0	0.0	0.0	0.0	0.0	0.0
27.05.87	WS-A5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	687.0
28.05.87	WI-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.87	WI-H4	0.0	29.3	0.0	36.0	0.0	0.0	0.0	0.0
28.05.87	WI-H5	0.0	0.0	4.0	53.0	0.0	0.0	0.0	0.0
28.05.87	WI-H6	0.0	0.0	0.0	43.0	0.0	0.0	0.0	0.0
28.05.87	WI-H7	0.0	0.0	3.0	33.0	0.0	80.0	0.0	0.0
02.06.87	HO-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
03.06.87	WA-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	166.0
03.06.87	WA-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0
03.06.87	WA-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0
03.06.87	WA-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.0
05.06.87	BR-OC	0.0	0.0	0.0	0.0	0.0	0.0	-99.0	0.0
05.06.87	BR-PC	0.0	0.0	0.0	0.0	0.0	0.0	-99.0	0.0
08.06.87	GU-NO	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.06.87	GU-H1	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
08.06.87	GU-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.06.87	GU-PC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.06.87	CA-HX	0.0	0.0	0.0	0.0	0.0	0.0	0.6	2.0
12.06.87	UW-TR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DATE	CODE	T31	T32	T33	T34	T35	T36	T37	T38
15.06.87	BL-H6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.06.87	BL-H8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.06.87	BH-HM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.06.87	BH-HR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.06.87	HA-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.06.87	HA-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.06.87	HA-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07.10.87	CH-H6	-99.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.10.87	BA-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.10.87	BA-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.10.87	BA-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.10.87	WH-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.10.87	WH-H2	0.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0
12.10.87	WH-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.10.87	WH-H5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.10.87	WH-H6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.87	AR-H6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.10.87	CR-TL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.10.87	WF-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.10.87	WF-H3	0.0	0.0	0.0	0.0	0.0	31.0	0.0	0.0
19.10.87	WF-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.10.87	WF-H5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.10.87	NE-CR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.10.87	NE-MA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.10.87	NE-MO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.10.87	GL-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.10.87	GL-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DATE	CODE	T31	T32	T33	T34	T35	T36	T37	T38
23.10.87	CV-H1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	CV-H2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	CV-H3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	CV-H4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.10.87	WB-RD	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0

APPENDIX VII) AGGLOMERATION SCHEDULES FOR DENDROGRAMS CONSTRUCTED USING WARD'S METHOD (WARD 1963) AND USED IN CHAPTER 6.

Table 6.6) Agglomeration Schedule using Ward's Method for clusters using density of animals at all sites sampled at over 7.0 ls^{-1} (Fig.6.2)

Stage	Clusters Cluster 1	Combined Cluster 2	Coefficient	Stage Cluster 1st Appears Cluster 1	Cluster 2	Next Stage
1	30	31	.000000	0	0	2
2	8	30	.000000	0	1	3
3	8	17	.000000	2	0	4
4	8	28	.800000	3	0	5
5	4	8	2.500000	0	4	6
6	4	18	13.714286	5	0	7
7	4	5	25.521250	6	0	9
8	15	20	167.226257	0	0	12
9	4	27	364.180573	7	0	11
10	21	32	801.945618	0	0	13
11	4	7	1422.959106	9	0	12
12	4	15	2146.366943	11	8	15
13	3	21	3061.342041	0	10	17
14	16	19	4432.421875	0	0	16
15	4	11	6655.904785	12	0	17
16	10	16	13132.118164	0	14	24
17	3	4	20436.625000	13	15	18
18	3	9	30393.455078	17	0	19
19	3	26	51019.597656	18	0	23
20	12	13	74097.765625	0	0	30
21	6	25	101920.281250	0	0	27
22	22	23	144695.937500	0	0	29
23	3	14	195888.859375	19	0	24
24	3	10	252920.484375	23	16	25
25	3	29	322463.812500	24	0	26
26	3	24	438714.156250	25	0	27
27	3	6	670198.187500	26	21	28
28	2	3	1487349.375000	0	27	29
29	2	22	2734398.500000	28	22	30
30	2	12	4307659.000000	29	20	31
31	1	21	3849185.00000	0	30	0

Table 6.7) Agglomeration Schedule using Ward's Method For Clusters Using density of animals (log classified) at all sites (Fig. 6.3)

Stage	Clusters Combined Cluster 1	Cluster 2	Coefficient	Stage Cluster 1st Appears Cluster 1	Cluster 2	Next Stage
1	62	63	.000000	0	0	2
2	3	62	.000000	0	1	5
3	32	46	.000000	0	0	5
4	25	35	.000000	0	0	10
5	3	32	.000000	2	3	8
6	30	31	.000000	0	0	45
7	23	27	.000000	0	0	8
8	3	23	.000000	5	7	9
9	3	22	.000000	8	0	11
10	17	25	.166667	0	4	19
11	3	28	.388889	9	0	15
12	13	14	.638889	0	0	46
13	44	49	1.138889	0	0	22
14	24	26	1.638889	0	0	34
15	3	59	2.541667	11	0	19
16	10	11	3.541667	0	0	42
17	6	7	4.541667	0	0	18
18	5	6	5.541667	0	17	30
19	3	17	6.596154	15	10	26
20	15	60	7.846154	0	0	25
21	16	47	9.346154	0	0	26
22	44	48	12.179487	13	0	31
23	41	42	15.179487	0	0	35
24	9	12	18.179487	0	0	39
25	15	34	21.262821	20	0	42
26	3	16	24.350000	19	21	60
27	19	21	27.975000	0	0	39
28	38	58	31.975000	0	0	33
29	37	45	35.975002	0	0	47
30	4	5	40.162502	0	18	51
31	44	64	44.579170	22	0	40
32	8	50	49.079170	0	0	40
33	33	38	53.745838	0	28	49
34	20	24	59.245838	0	14	46

table 6.7) continued:

Stage	Clusters Combined Cluster 1	Cluster 2	Coefficient	Stage Cluster 1st Appears Cluster 1	Cluster 2	Next Stage
35	41	43	64.912506	23	0	38
36	56	61	70.912506	0	0	48
37	51	52	77.412506	0	0	41
38	41	53	84.183342	35	0	53
39	9	19	91.245842	24	27	50
40	8	44	98.662506	32	31	43
41	39	51	108.162506	0	37	57
42	10	15	118.229172	16	25	51
43	8	18	128.562500	40	0	47
44	36	57	139.062500	0	0	49
45	29	30	149.729172	0	6	58
46	13	20	161.479172	12	34	54
47	8	37	173.256958	43	29	52
48	54	56	185.256958	0	36	54
49	33	36	198.090286	33	44	55
50	2	9	216.102783	0	39	56
51	4	10	236.959732	30	42	60
52	8	55	258.381958	47	0	55
53	40	41	280.144470	0	38	59
54	13	54	305.706970	46	48	56
55	8	33	333.973633	52	49	62
56	2	13	362.672668	50	54	58
57	1	39	395.672668	0	41	59
58	2	29	436.122589	56	45	61
59	1	40	482.811493	57	53	63
60	3	4	538.329529	26	51	61
61	2	3	615.574341	58	60	62
62	2	8	722.607117	61	55	63
63	1	2	887.656372	59	62	0

Table 6.8) Cluster analysis for community based on log transformed data flushed at over 7.0 ls-1 (Fig. 6.4)

Agglomeration Schedule using Ward's Method

Stage	Clusters Cluster 1	Combined Cluster 2	Coefficient	Stage Cluster 1st Appears Cluster 1	Cluster 2	Next Stage
1	30	31	.000000	0	0	2
2	8	30	.000000	0	1	3
3	8	17	.000000	2	0	4
4	8	28	.072495	3	0	5
5	4	8	.226548	0	4	7
6	15	20	.708529	0	0	9
7	4	18	1.262937	5	0	8
8	4	5	1.830811	7	0	13
9	15	32	3.232084	6	0	16
10	12	13	4.664681	0	0	20
11	3	21	6.263262	0	0	19
12	10	16	7.883993	0	0	23
13	4	7	9.703632	8	0	15
14	25	29	11.626555	0	0	22
15	4	27	13.718774	13	0	27
16	15	19	15.844203	9	0	19
17	22	23	18.416002	0	0	28
18	6	11	21.210369	0	0	22
19	3	15	25.087757	11	16	21
20	12	14	29.185659	10	0	29
21	3	9	34.279160	19	0	23
22	6	25	40.551224	18	14	26
23	3	10	47.376469	21	12	25
24	24	26	54.240925	0	0	25
25	3	24	67.417435	23	24	30
26	2	6	85.223129	0	22	27
27	2	4	107.387245	26	15	30
28	1	22	132.097427	0	17	29
29	1	12	160.308090	28	20	31
30	2	3	191.202225	27	25	31
31	1	2	261.583099	29	30	0

Table 6.9) Agglomeration Schedule using Ward's Method for clusters based on environmental and operational parameters at all sites (Fig 6.11)

Stage	Clusters Combined Cluster 1	Cluster 2	Coefficient	Stage Cluster 1st Appears Cluster 1	Cluster 2	Next Stage
1	19	20	3.756050	0	0	10
2	18	22	23.252300	0	0	5
3	21	28	44.419502	0	0	11
4	29	31	68.109505	0	0	9
5	18	23	106.140060	2	0	11
6	16	30	166.511459	0	0	18
7	13	33	236.489914	0	0	24
8	8	38	307.793365	0	0	19
9	29	32	384.096375	4	0	16
10	19	24	477.218719	1	0	17
11	18	21	567.485535	5	3	16
12	34	35	661.330627	0	0	23
13	7	9	768.865906	0	0	24
14	25	26	878.618958	0	0	30
15	12	37	1014.426636	0	0	25
16	18	29	1152.630859	11	9	21
17	19	41	1305.376953	10	0	26
18	6	16	1492.033447	0	6	23
19	8	11	1734.361450	8	0	22
20	39	40	1982.360229	0	0	27
21	5	18	2242.378174	0	16	26
22	3	8	2538.256348	0	19	29
23	6	34	2937.320068	18	12	32
24	7	13	3341.678955	13	7	27
25	12	27	3747.328125	15	0	30
26	5	19	4195.763672	21	17	34
27	7	39	4842.129883	24	20	31
28	4	17	5503.119141	0	0	39
29	3	10	6247.731934	22	0	35
30	12	25	7012.189453	25	14	32
31	7	14	8043.551758	27	0	35
32	6	12	9172.326172	23	30	34
33	1	36	11221.307617	0	0	37

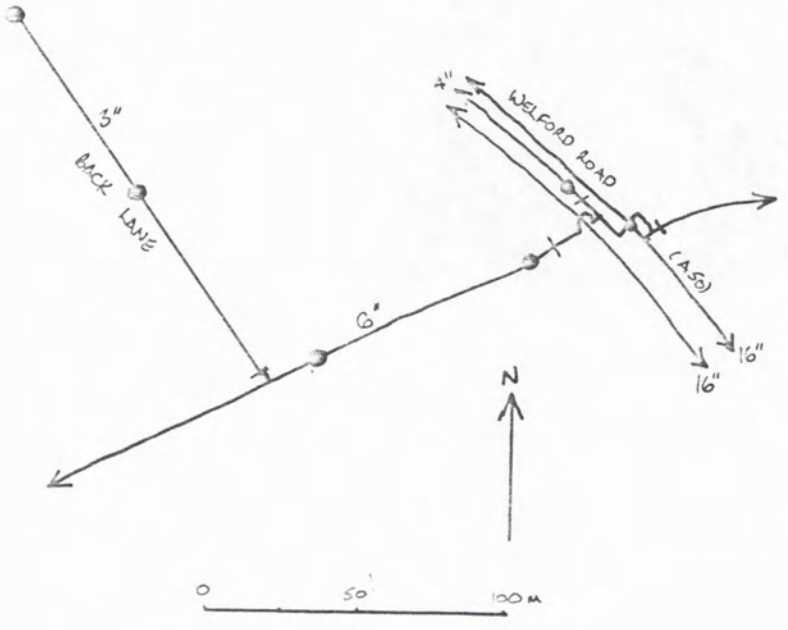
table 6.9) continued:

Stage	Clusters Combined Cluster 1	Cluster 2	Coefficient	Stage Cluster 1st Appears Cluster 1	Cluster 2	Next Stage
34	5	6	14788.476563	26	32	36
35	3	7	18532.373047	29	31	38
36	2	5	23187.013672	0	34	38
37	1	15	28927.144531	33	0	40
38	2	3	41913.144531	36	35	39
39	2	4	58184.765625	38	28	40
40	1	2	223316.296875	37	39	0

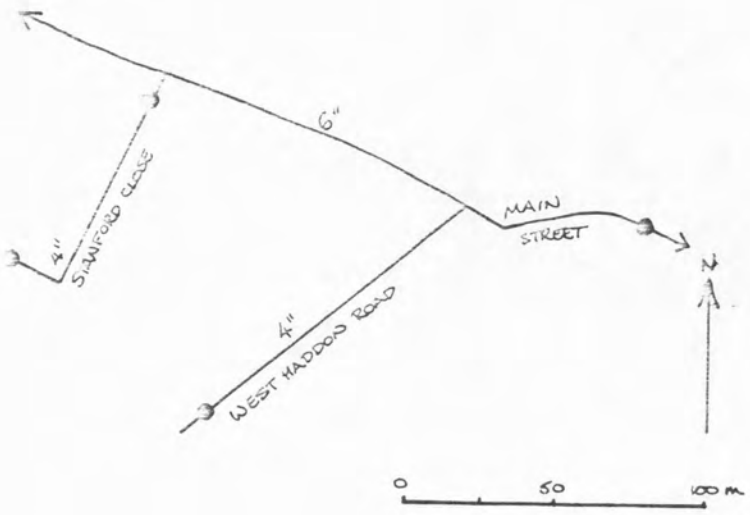
Table 6.10) Agglomeration Schedule using Ward's Method for clusters based on environmental and operational parameters at all sites sampled at over 7.0ls^{-1} (Fig 6.12)

Stage	Clusters Combined Cluster 1	Cluster 2	Coefficient	Stage Cluster 1st Appears Cluster 1	Cluster 2	Next Stage
1	13	14	60.089249	0	0	7
2	6	12	120.460648	0	0	8
3	16	17	214.305756	0	0	13
4	9	10	324.058807	0	0	10
5	3	18	459.866455	0	0	8
6	8	21	660.867493	0	0	7
7	8	13	949.468262	6	1	12
8	3	6	1238.096924	5	2	12
9	15	19	1615.649170	0	0	11
10	9	11	2040.020752	4	0	15
11	15	20	2629.674805	9	0	17
12	3	8	3368.552002	8	7	13
13	3	16	4268.824707	12	3	14
14	3	4	5252.362305	13	0	15
15	3	9	7485.456543	14	10	17
16	2	7	11080.853516	0	0	18
17	3	15	14948.920898	15	11	18
18	2	3	21464.824219	16	17	20
19	1	5	28364.884766	0	0	20
20	1	2	137335.765625	19	18	0

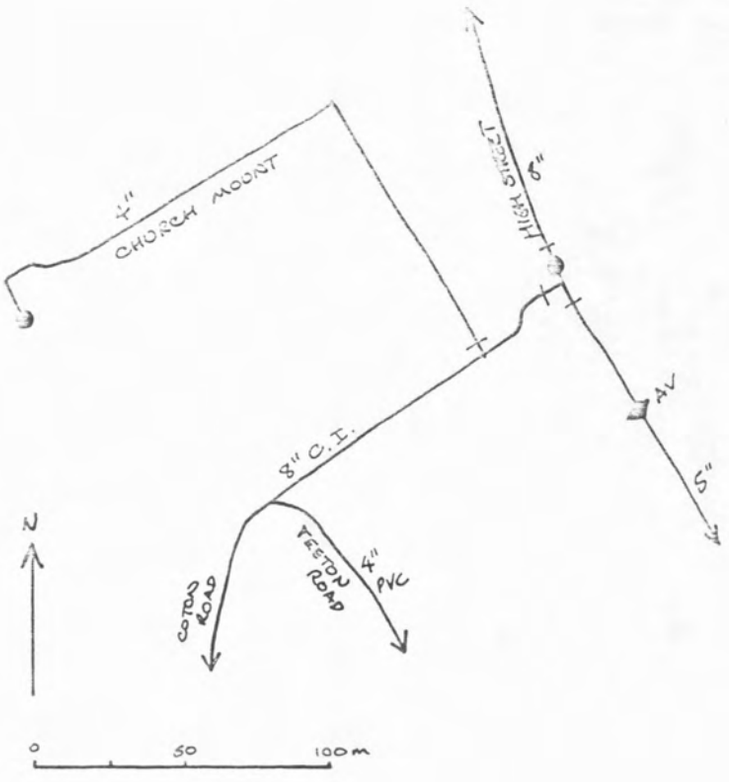
APPENDIX VIII: DETAILED SKETCH MAPS OF DISTURBED SITES SAMPLED FOR CHAPTER 7



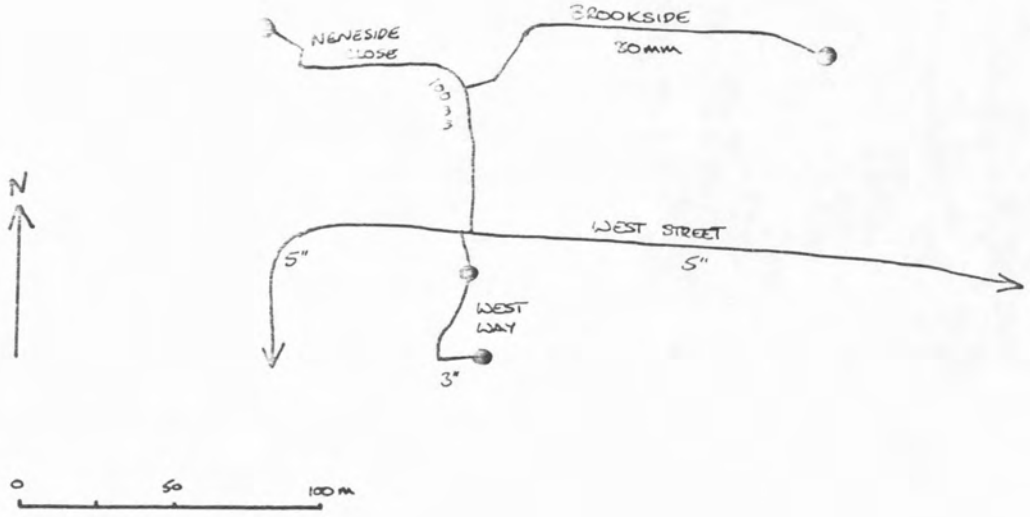
HAPEL BRAMPTON, NORTHANTS.
[illegible]
ACK LANE;
[illegible]
7.06.86 at 8.3 ls^{-1}
2.09.86 at 8.3 ls^{-1}
9.11.86 at 8.3 ls^{-1}
0.01.87 at 8.3 ls^{-1}
0.03.87 at 6.6 ls^{-1}
0.05.87 at 6.0 ls^{-1}
5.07.87 at 6.6 ls^{-1}
9.09.87 at 6.4 ls^{-1}
9.11.87 at 8.5 ls^{-1}
[illegible] low rates of flush [illegible] continue to show [illegible] differences between [illegible] third flush is [illegible].



COLD ASHBY, NORTHANTS.
SP 6476
STANFORD CLOSE;
110m, 4" off 6"
15.05.86 at 9.1 ls^{-1}
17.09.86 at 7.6 ls^{-1}
29.01.87 at 8.4 ls^{-1}
14.05.87 at 6.2 ls^{-1}
21.09.87 at 6.0 ls^{-1}
WEST HADDON ROAD;
77m, 4" off 6"
15.05.87 at 11.4 ls^{-1}
19.11.87 at 10.8 ls^{-1}
14.05.87 at 11.5 ls^{-1}
18.11.87 at 7.0 ls^{-1}
Diameters to be confirmed by valving. Fluctuations in rate of flow frequnt during flush sequences.

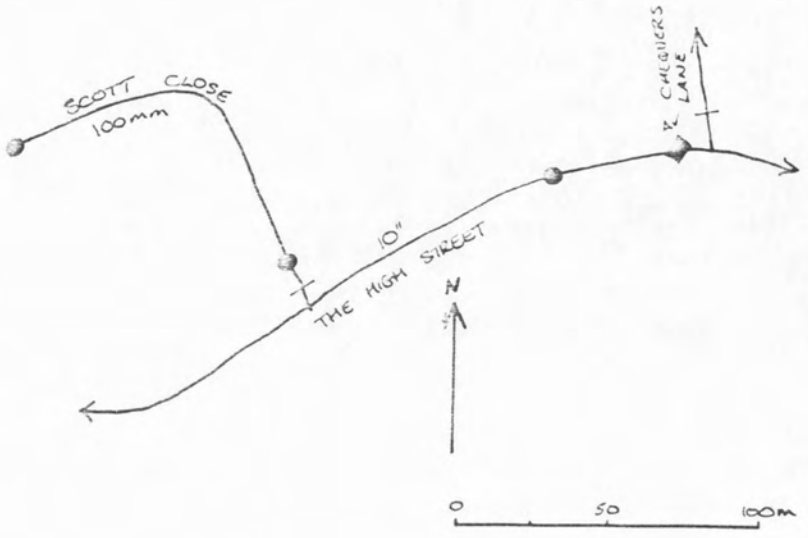


GUILSBOROUGH, NORTHANTS.
SP6672
CHURCH MOUNT;
241m, 4" off 8"
13.05.86 at 15.1 ls^{-1}
15.07.86 at 15.1 ls^{-1}
19.09.86 at 15.1 ls^{-1}
17.11.86 at 15.1 ls^{-1}
09.01.87 at 15.1 ls^{-1}
19.03.87 at 15.1 ls^{-1}
18.05.87 at 15.0 ls^{-1}
13.07.87 at 15.0 ls^{-1}
17.09.87 at 15.0 ls^{-1}
18.11.87 at 15.0 ls^{-1}

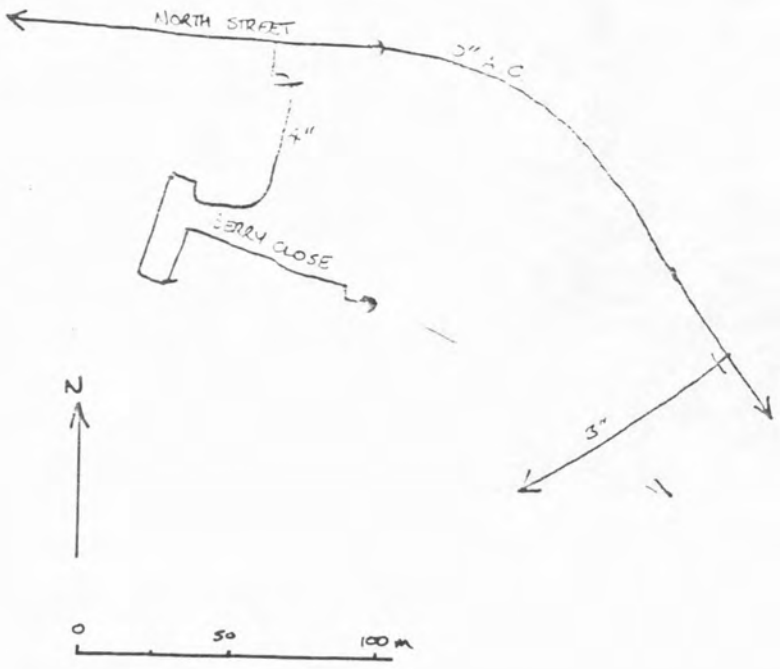


LOWER WEEDON, NORTHANTS.
SP 6259-6359
BROOKSIDE;
100m, 30mm off 100mm off 4"
12.05.86 at 15.1 ls
18.11.86 at 15.1 ls
15.05.87 at 15.0 ls
18.11.87 at 15.0 ls
WEST WAY;
55m , 3" off 5"
12.05.86 at [illegible]
[illegible]
[illegible]
15.05.87 at 16.0 ls
21.09.87 at 16.0 ls
When sampling Brookside, Neneside Close is flushed clean prior to sampling Brookside.

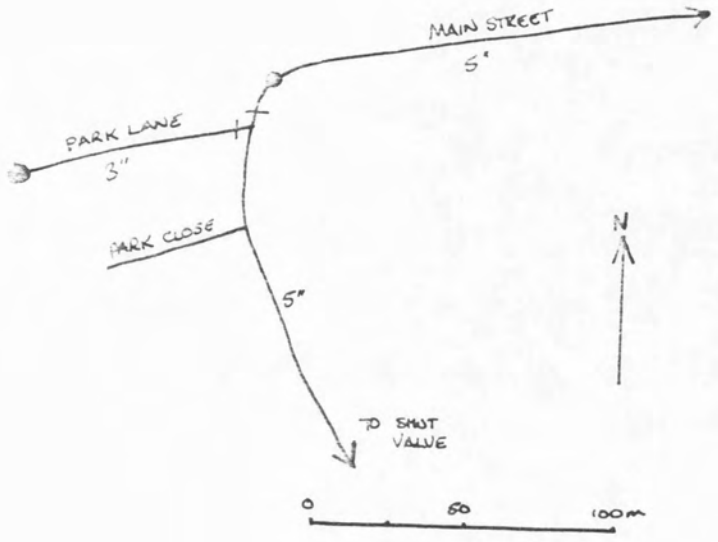
WETHER HEYFORD, NORTHANTS.
SP6658
PARSONS CLOSE;
83 m, 3" off 12"
16.04.86 at 11.4 ls^{-1}
28.05.86 at 11.4 ls^{-1}
21.04.87 at 16.0 ls^{-1}
WAKEFIELD WAY;
114 m, 4" off 6"
16.04.86 at 15.1 ls^{-1}
28.05.86 at 15.1 ls^{-1}
14.07.87 at 15.0 ls^{-1}
First two sampling occasions used
as basis for effectiveness of all
rooms with pyrethrin



RAVENSTHORPE, NORTHANTS.
SP6670
SCOTT CLOSE;
188m,100mm off 10"
08.05.86 at 15.1 LS
15.07.86 at 15.1 LS
16.09.86 at 15.1 LS
17.11.86 at 15.1 LS
20.01.87 at 15.1 LS
19.03.87 at 15.1 LS
18.05.87 at 16.0 LS
13.07.87 at 16.0 LS
17.09.87 at 16.0 LS
18.11.87 at 16.0 LS
Flushed clean 28.01.87 when new hydrant fitted by Operations.



ROTHERSTHORPE, NORTHANTS.
SP 7156
PERRY CLOSE;
228m, 4" OFF 10"
14.07.86 at 15.1 lb^{-1}
16.09.86 at 15.1 lb^{-1}
18.11.86 at 15.1 lb^{-1}
28.01.87 at 15.1 lb^{-1}
20.03.87 at 16.0 lb^{-1}
19.05.87 at 16.0 lb^{-1}
15.07.87 at 16.0 lb^{-1}
18.09.87 at 16.0 lb^{-1}
18.11.87 at 16.0 lb^{-1}
Water supply varies from Fletford and Grafham.



WATFORD, NORTHANTS.
296068
PARK LANE;
07m, 3" off 5"
11.07.86 at 9.0 ls^{-1}
14.07.87 at 6.9 ls^{-1}
Failure to obtain clean water on third flush 14.07.87.

APPENDIX IX) ANIMAL DENSITY PER 10 METRES OF PIPE FROM DISTURBED SITES SAMPLED BETWEEN APRIL 1986 AND MAY 1988

MISSING VALUES: - 2.0 - samples not taken
- 99.0 - failure of sampling equation (third flush contains more animals than first and second)

Columns:
t1 Chironominae larvae (excl. Tanytarsini)
t2 Tanytarsini larvae
t3 Tanypodinae larvae
t4 Orthocladiini larvae
t5 Corynoneura sp. larvae
t6 Nitocra hibernica
t7 Byocamptus pygmaeus
t8 Atheyella crassa
t9 Paracyclops fimbriatus
t10 Paracyclops fimbriatus poppei
t11 Acanthocyclops bisetosus
t12 Megacyclops viridis
t13 Eucyclops agilis
t14 Acanthocyclops robustus
t15 Acanthocyclops vicinis
t16 Acanthocyclops copepodites
t17 Chydorus sphaericus
t18 Alona rectangular
t19 Alona guttata
t20 Alona quandrangularis
t21 Alona affinis
t22 Graptoleberis testudinaria
t23 Soldanellonyx monardi
t24 Lobohalacarus weberi
t25 Porohalacarus alpinus
t26 Tyroglyphidae
t27 Hydrozetes sp.
t28 Hydracarina
t29 Naid worms
t30 Tubificid worms
t31 Aeolsomatid worms
t32 Enchytraid worms
t33 Nematoda
t34 Ostracoda
t35 Tardigrada
t36 Microturbularia
t37 Planorbis crista
t38 Hydrobia jenkinsi

DATE	SITE	FLUSH	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
16.04.86	PC(NH)	1	1.9	0.0	0.0	0.6	0.0	0.0	469.2	0.0	5.9	5.9
28.05.86	PC(NH)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.04.87	PC(NH)	3	0.0	1.3	2.5	0.0	0.0	0.0	5.8	0.0	0.0	0.0
10.05.88	PC(NH)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.04.86	WW(NH)	1	11.4	0.0	2.9	0.0	0.0	0.0	1556.4	0.0	0.0	13.2
28.05.86	WW(NH)	2	0.0	0.0	0.0	0.0	0.0	12.3	24.5	0.0	0.0	0.0
14.07.87	WW(NH)	3	4.0	0.0	0.8	4.0	0.0	0.0	6.4	0.0	2.3	0.0
10.05.88	WW(NH)	4	1.9	4.3	2.4	1.4	0.0	0.0	0.8	0.0	0.0	0.0
12.05.86	WW(W)	1	7.2	50.6	0.0	0.0	0.0	0.0	-99.0	0.0	39.4	0.0

DATE	SITE	FLUSH	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
15.09.86	WW(W)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.01.87	WW(W)	3	0.8	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.05.87	WW(W)	4	0.0	44.2	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.09.87	WW(W)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
11.05.88	WW(W)	6	0.0	4.6	0.0	0.0	6.9	0.0	0.0	0.0	3.1	0.0
12.05.86	B(W)	1	4.5	20.2	2.2	0.0	0.0	0.0	60.9	4.4	0.0	0.0
18.11.86	B(W)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2
15.05.87	B(W)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.87	B(W)	4	0.0	3.1	0.0	0.7	2.8	0.0	0.0	0.0	0.0	0.0
11.05.88	B(W)	5	1.4	1.4	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.06.86	BL(CB)	1	0.0	0.3	0.0	0.0	0.0	0.0	113.4	0.0	0.0	0.0
12.09.86	BL(CB)	2	14.0	5.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
19.11.86	BL(CB)	3	9.7	0.7	0.5	4.1	0.0	2.5	13.8	0.0	0.0	0.0
28.01.87	BL(CB)	4	0.9	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
20.03.87	BL(CB)	5	5.7	0.0	0.0	2.8	0.0	0.0	3.6	0.0	0.0	0.0
20.05.87	BL(CB)	6	2.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
15.07.87	BL(CB)	7	0.0	0.0	0.0	7.8	0.0	0.0	0.0	0.0	0.0	0.0
18.09.87	BL(CB)	8	2.2	1.7	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0
18.11.87	BL(CB)	9	3.8	1.9	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0
10.05.88	BL(CB)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.07.86	BC(R)	1	0.0	0.0	0.0	0.0	0.0	0.0	11.2	0.0	2.3	0.5
16.09.86	BC(R)	2	4.7	0.0	0.0	1.4	0.0	0.0	3.0	0.0	2.7	0.0
18.11.86	BC(R)	3	1.1	0.1	0.0	0.1	0.0	0.0	2.9	0.0	0.0	0.0
28.01.87	BC(R)	4	0.0	0.0	0.0	0.0	0.0	0.0	33.2	0.0	0.0	0.0
20.03.87	BC(R)	5	0.0	0.0	0.0	0.0	0.0	0.0	19.6	0.0	0.0	0.0
19.05.87	BC(R)	6	0.5	1.6	1.6	2.1	0.0	0.0	0.9	0.0	0.3	0.0
15.07.87	BC(R)	7	1.3	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.5	0.0
18.09.87	BC(R)	8	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.87	BC(R)	9	0.0	3.2	0.0	1.6	0.0	0.0	0.0	0.0	31.3	25.0
10.05.87	BC(R)	10	0.0	6.1	1.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0
15.05.86	SC(CA)	1	3.3	6.6	0.0	0.0	0.0	9.0	13.5	0.0	0.0	0.0
17.09.86	SC(CA)	2	1.1	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	6.7
29.01.87	SC(CA)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.5
14.05.87	SC(CA)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.09.87	SC(CA)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.05.88	SC(CA)	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DATE	SITE	FLUSH	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
15.05.86	WHR(CA)	1	3.3	0.0	0.0	0.0	0.0	15.7	62.9	0.0	0.0	0.0
19.11.86	WHR(CA)	2	0.7	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
14.05.87	WHR(CA)	3	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7
23.11.87	WHR(CA)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.05.88	WHR(CA)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.05.86	CM(G)	1	2.3	0.0	0.0	0.0	0.0	0.0	114.0	0.0	50.8	0.0
15.07.86	CM(G)	2	0.0	0.0	0.0	0.0	0.0	0.0	9.9	0.0	11.0	5.9
19.09.86	CM(G)	3	12.1	0.5	0.5	1.0	0.0	0.0	4.2	0.0	62.4	114.4
17.11.86	CM(G)	4	4.4	4.4	2.2	0.0	0.0	0.0	17.0	0.0	1.9	9.9
29.01.87	CM(G)	5	0.0	1.0	0.0	1.0	1.5	0.0	1.2	0.0	0.0	0.0
19.03.87	CM(G)	6	0.0	0.9	0.0	1.9	0.0	0.0	5.5	0.0	0.3	0.0
18.05.87	CM(G)	7	0.7	0.7	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
13.07.87	CM(G)	8	0.6	0.3	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
17.09.87	CM(G)	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
18.11.87	CM(G)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.05.88	CM(G)	11	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
08.05.86	SC(R)	1	5.6	0.5	2.0	0.0	0.0	0.0	229.5	0.0	280.5	1168.9
15.07.86	SC(R)	2	0.9	0.0	0.0	2.5	0.0	0.0	11.7	0.0	3.7	8.5
18.09.86	SC(R)	3	10.2	1.4	0.9	0.9	0.0	0.0	0.0	0.0	53.6	122.0
17.11.86	SC(R)	4	0.0	0.0	0.0	1.9	1.9	0.0	3.9	0.0	2.9	2.9
29.01.87	SC(R)	5	0.0	0.0	0.0	0.4	1.8	0.0	2.4	0.0	0.0	0.0
19.03.87	SC(R)	6	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0
18.05.87	SC(R)	7	0.5	0.5	0.2	0.2	0.0	0.0	0.0	0.0	0.5	0.0
13.07.86	SC(R)	8	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0
17.09.87	SC(R)	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.87	SC(R)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.05.88	SC(R)	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.07.86	PL(W)	1	0.0	0.0	0.0	0.0	0.0	53.6	0.0	0.0	0.0	0.0
14.07.87	PL(W)	2	0.0	0.0	0.0	0.0	0.0	184.6	0.0	0.0	0.0	0.0
09.05.88	PL(W)	3	0.0	0.0	0.0	0.0	0.0	111.1	0.0	0.0	0.0	0.0

DATE	SITE	FLUSH	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
16.04.86	PC(NH)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	25.4	0.0
28.05.86	PC(NH)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.04.87	PC(NH)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.9	0.0

DATE	SITE	FLUSH	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
10.05.88	PC(NH)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.04.86	WW(NH)	1	0.0	0.0	0.0	0.0	0.0	0.0	10.5	0.0	20.9	0.0
28.05.86	WW(NH)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.07.87	WW(NH)	3	0.0	0.0	0.0	6.9	0.0	2.3	10.6	0.0	31.7	0.0
10.05.88	WW(NH)	4	0.0	0.0	0.0	0.0	0.0	0.0	8.8	0.0	0.0	0.0
12.05.86	WW(W)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.09.86	WW(W)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.01.87	WW(W)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.05.87	WW(W)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.09.87	WW(W)	5	0.0	0.0	0.0	4.7	0.0	0.0	0.0	0.0	0.0	0.0
11.05.88	WW(W)	6	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0
12.05.86	B(W)	1	0.0	0.0	131.1	0.0	0.0	0.0	32.7	37.0	16.4	44.9
18.11.86	B(W)	2	0.0	0.0	0.0	2.6	0.0	0.0	227.4	0.0	0.0	0.0
15.05.87	B(W)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0
18.11.87	B(W)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	207.0	0.0	0.0
11.05.88	B(W)	5	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.5	0.0
27.06.86	BL(CB)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	201.9	5957.0	379.0
12.09.86	BL(CB)	2	0.0	0.0	0.0	0.0	0.0	-99.0	0.0	7.3	138.3	0.0
19.11.86	BL(CB)	3	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	19.0	0.6
28.01.87	BL(CB)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.03.87	BL(CB)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.05.87	BL(CB)	6	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.07.87	BL(CB)	7	0.0	0.0	0.0	10.5	0.0	0.0	0.0	0.0	0.0	0.0
18.09.87	BL(CB)	8	0.0	0.0	0.0	15.7	0.0	0.0	0.0	0.0	0.0	0.9
18.11.87	BL(CB)	9	0.0	0.0	0.0	0.9	0.0	0.0	0.3	0.6	0.0	0.0
10.05.88	BL(CB)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.07.86	BC(R)	1	0.0	0.0	0.0	0.0	0.0	0.0	42.6	1.4	0.0	1.4
16.09.86	BC(R)	2	0.0	0.0	0.0	0.9	0.0	0.0	240.7	0.0	0.0	0.0
18.11.86	BC(R)	3	0.0	0.0	0.0	0.0	0.0	0.0	67.1	0.0	0.0	0.0
28.01.87	BC(R)	4	0.0	0.0	0.0	0.0	0.0	0.0	3.1	28.2	8.7	0.0
20.03.87	BC(R)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.05.87	BC(R)	6	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.07.87	BC(R)	7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
18.09.87	BC(R)	8	0.0	1.2	0.0	7.1	0.0	0.0	5.2	0.0	3.1	0.0
18.11.87	BC(R)	9	0.0	0.0	0.0	0.0	0.0	3.1	12.2	34.8	9.9	0.0
10.05.87	BC(R)	10	0.0	13.3	0.0	0.0	0.0	66.7	1.0	0.0	0.0	0.0

DATE	SITE	FLUSH	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
15.05.86	SC(CA)	1	0.0	0.0	0.0	0.0	0.0	0.0	249.5	63.4	79.2	0.0
17.09.86	SC(CA)	2	0.0	6.7	0.0	0.0	0.0	0.0	2221.8	571.3	95.2	0.0
29.01.87	SC(CA)	3	0.0	3.5	0.0	0.0	0.0	0.0	3211.8	298.8	746.9	0.0
14.05.87	SC(CA)	4	0.0	0.0	0.0	0.0	0.0	0.0	64.3	52.9	0.0	0.0
21.09.87	SC(CA)	5	0.0	0.0	0.0	0.0	0.0	0.0	158.0	4.4	4.4	0.0
11.05.88	SC(CA)	6	0.0	0.0	0.0	0.0	0.0	0.0	850.6	0.0	0.0	0.0
15.05.86	WHR(CA)	1	0.0	47.5	0.0	0.0	0.0	47.5	15100.7	314.6	314.6	0.0
19.11.86	WHR(CA)	2	0.0	0.0	0.0	0.0	0.0	0.0	38.0	1.4	0.7	0.0
14.05.87	WHR(CA)	3	0.0	0.9	0.0	0.0	0.0	0.0	2044.0	0.0	0.0	0.0
23.11.87	WHR(CA)	4	0.0	0.0	0.0	0.0	0.0	0.0	926.1	0.0	0.0	0.0
11.05.88	WHR(CA)	5	0.0	0.0	0.0	0.0	0.0	0.0	390.5	0.0	0.0	0.0
13.05.86	CM(G)	1	0.0	0.0	0.0	0.0	0.0	0.0	36.9	0.0	0.0	0.0
15.07.86	CM(G)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.09.86	CM(G)	3	0.0	0.0	0.0	0.0	0.0	0.0	2.7	52.1	34.8	0.0
17.11.86	CM(G)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	77.7	0.0
29.01.87	CM(G)	5	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0
19.03.87	CM(G)	6	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
18.05.87	CM(G)	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
13.07.87	CM(G)	8	17.2	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0
17.09.87	CM(G)	9	0.2	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.0
18.11.87	CM(G)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.05.88	CM(G)	11	21.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0
08.05.86	SC(R)	1	0.0	0.0	0.0	0.0	0.0	0.0	262.2	0.0	7.9	0.0
15.07.86	SC(R)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.09.86	SC(R)	3	0.0	0.0	0.0	0.0	0.0	0.0	88.6	0.0	132.9	0.0
17.11.86	SC(R)	4	0.0	0.0	0.0	0.0	0.0	0.0	17.7	0.0	20.2	0.0
29.01.87	SC(R)	5	0.0	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0
19.03.87	SC(R)	6	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0
18.05.87	SC(R)	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.07.86	SC(R)	8	13.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.09.87	SC(R)	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.87	SC(R)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.05.88	SC(R)	11	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.07.86	PL(W)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.07.87	PL(W)	2	0.0	0.0	166.8	0.0	0.0	0.0	-99.0	0.0	0.0	0.0
09.05.88	PL(W)	3	0.0	0.0	-99.0	0.0	0.0	0.0	2951.5	0.0	0.0	0.0

DATE	SITE	FLUSH	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30
16.04.86	PC(NH)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.86	PC(NH)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.04.87	PC(NH)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.05.88	PC(NH)	4	0.0	0.0	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.04.86	WW(NH)	1	0.0	0.0	3.0	13.9	0.0	3.0	0.0	0.0	0.0	0.0
28.05.86	WW(NH)	2	0.0	0.0	35.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0
14.07.87	WW(NH)	3	0.0	0.0	2.5	0.0	0.0	8.4	0.8	11.8	0.0	0.0
10.05.88	WW(NH)	4	0.0	0.0	19.7	9.8	0.0	4.9	0.0	0.0	0.0	0.0
12.05.86	WW(W)	1	0.0	0.0	11.5	0.0	0.0	11.5	11.5	0.0	0.0	0.0
15.09.86	WW(W)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.01.87	WW(W)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.05.87	WW(W)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.09.87	WW(W)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.05.88	WW(W)	6	0.0	0.0	2.9	0.0	0.0	5.8	0.0	0.0	0.0	0.0
12.05.86	B(W)	1	0.0	89.9	73.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.86	B(W)	2	0.0	472.4	198.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.05.87	B(W)	3	0.0	0.0	3.6	0.0	0.0	7.2	0.0	0.0	0.0	0.0
18.11.87	B(W)	4	0.0	116.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.05.88	B(W)	5	0.0	3.6	0.9	0.5	0.0	4.7	0.0	0.0	0.0	0.0
27.06.86	BL(CB)	1	0.0	0.0	7.9	39.5	0.0	0.0	0.0	0.0	11.9	0.0
12.09.86	BL(CB)	2	0.0	0.0	1.3	11.3	0.0	0.0	0.0	0.0	0.0	0.0
19.11.86	BL(CB)	3	0.0	0.0	5.4	8.9	0.0	0.0	0.0	0.0	2.9	0.0
28.01.87	BL(CB)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.03.87	BL(CB)	5	0.0	0.0	0.9	19.9	0.0	0.9	0.0	0.0	0.0	0.0
20.05.87	BL(CB)	6	0.0	0.0	1.3	6.8	0.0	0.7	0.0	0.0	0.0	0.0
15.07.87	BL(CB)	7	0.0	0.0	0.9	4.4	0.0	0.9	0.0	8.0	0.0	0.0
18.09.87	BL(CB)	8	0.0	0.0	0.3	0.3	0.0	0.9	0.0	0.0	0.0	0.0
18.11.87	BL(CB)	9	0.0	0.0	0.7	0.0	0.0	0.5	0.2	0.5	0.0	0.0
10.05.88	BL(CB)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.07.86	BC(R)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.09.86	BC(R)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.86	BC(R)	3	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.01.87	BC(R)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.03.87	BC(R)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.05.87	BC(R)	6	0.0	0.0	1.7	0.0	0.0	0.7	0.0	0.0	0.0	0.0
15.07.87	BC(R)	7	0.0	0.0	2.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0

DATE	SITE	FLUSH	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30
18.09.87	BC(R)	8	0.0	0.0	0.7	0.3	0.0	3.3	0.3	0.5	0.0	0.0
18.11.87	BC(R)	9	0.0	0.0	2.4	0.0	0.0	13.2	0.0	0.0	0.0	0.0
10.05.87	BC(R)	10	0.0	0.0	0.0	0.0	0.0	10.5	0.0	0.0	0.0	0.0
15.05.86	SC(CA)	1	0.0	0.0	31.8	0.0	0.0	0.0	0.0	0.0	65.4	0.0
17.09.86	SC(CA)	2	0.0	0.0	16.3	4.1	0.0	0.0	0.0	0.0	24.6	0.0
29.01.87	SC(CA)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	136.6	0.0
14.05.87	SC(CA)	4	0.0	0.0	7.1	2.4	0.0	0.0	0.0	0.0	0.0	0.0
21.09.87	SC(CA)	5	0.0	0.0	51.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.05.88	SC(CA)	6	0.0	0.0	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.05.86	WHR(CA)	1	0.0	0.0	24.5	32.7	0.0	0.0	0.0	0.0	477.4	0.0
19.11.86	WHR(CA)	2	0.0	0.0	31.7	4.8	0.0	0.0	0.0	0.0	25.1	0.0
14.05.87	WHR(CA)	3	0.0	0.0	11.0	18.4	0.0	0.0	0.0	0.0	0.0	0.0
23.11.87	WHR(CA)	4	0.0	0.0	30.3	25.3	0.0	0.0	0.0	0.0	5.0	0.0
11.05.88	WHR(CA)	5	0.0	0.0	2.7	20.0	0.0	0.0	0.0	0.0	0.0	0.0
13.05.86	CM(G)	1	0.0	0.0	27.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.07.86	CM(G)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.09.86	CM(G)	3	0.0	0.0	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0
17.11.86	CM(G)	4	0.0	0.0	6.6	1.9	0.0	0.0	0.0	0.0	0.0	0.0
29.01.87	CM(G)	5	0.0	0.0	2.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0
19.03.87	CM(G)	6	0.0	0.0	1.9	0.0	0.0	1.9	0.0	0.0	0.0	0.0
18.05.87	CM(G)	7	0.0	0.0	3.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0
13.07.87	CM(G)	8	0.0	0.0	0.7	0.2	0.0	0.2	0.0	0.0	0.0	0.0
17.09.87	CM(G)	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.87	CM(G)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.05.88	CM(G)	11	0.7	0.0	0.7	1.1	0.0	0.0	0.0	0.0	0.0	0.0
08.05.86	SC(R)	1	0.0	0.0	73.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.07.86	SC(R)	2	0.0	0.0	3.6	0.8	0.0	0.4	0.0	0.0	0.0	0.0
18.09.86	SC(R)	3	0.0	0.0	3.4	2.3	0.0	0.0	0.0	0.0	0.0	0.0
17.11.86	SC(R)	4	0.0	0.0	2.5	0.0	0.0	1.6	0.0	0.0	0.0	0.0
29.01.87	SC(R)	5	0.0	0.0	0.2	0.9	0.0	0.0	0.0	0.0	0.0	0.0
19.03.87	SC(R)	6	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0
18.05.87	SC(R)	7	0.0	0.0	1.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
13.07.86	SC(R)	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.09.87	SC(R)	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.87	SC(R)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.05.88	SC(R)	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DATE	SITE	FLUSH	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30
11.07.86	PL(W)	1	0.0	0.0	186.2	3.5	0.0	0.0	0.0	0.0	0.0	0.0
14.07.87	PL(W)	2	0.0	0.0	125.4	25.1	0.0	0.0	0.0	0.0	-99.0	0.0
09.05.88	PL(W)	3	508.8	0.0	206.6	13.8	0.0	0.0	0.0	0.0	672.4	0.0

DATE	SITE	FLUSH	T31	T32	T33	T34	T35	T36	T37	T38
16.04.86	PC(NH)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.86	PC(NH)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.04.87	PC(NH)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.05.88	PC(NH)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.04.86	WW(NH)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.86	WW(NH)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.07.87	WW(NH)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.05.88	WW(NH)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.05.86	WW(W)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.09.86	WW(W)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.01.87	WW(W)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.05.87	WW(W)	4	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0
21.09.87	WW(W)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.05.88	WW(W)	6	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0
12.05.86	B(W)	1	0.0	0.0	13.2	0.0	0.0	0.0	0.0	0.0
18.11.86	B(W)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.05.87	B(W)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.87	B(W)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.05.88	B(W)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.06.86	BL(CB)	1	0.0	0.0	8.4	0.0	13.1	0.0	0.0	0.0
12.09.86	BL(CB)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.11.86	BL(CB)	3	0.0	1.5	1.8	0.0	7.4	0.0	0.0	0.0
28.01.87	BL(CB)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.03.87	BL(CB)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.05.87	BL(CB)	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.07.87	BL(CB)	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.09.87	BL(CB)	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.87	BL(CB)	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.05.88	BL(CB)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.07.86	BC(R)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DATE	SITE	FLUSH	T31	T32	T33	T34	T35	T36	T37	T38
16.09.86	BC(R)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.86	BC(R)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.01.87	BC(R)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.03.87	BC(R)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.05.87	BC(R)	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.07.87	BC(R)	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.09.87	BC(R)	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.87	BC(R)	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.05.87	BC(R)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.05.86	SC(CA)	1	0.0	0.0	24.1	0.0	46.3	10.2	0.0	0.0
17.09.86	SC(CA)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29.01.87	SC(CA)	3	10.5	0.0	0.0	0.0	4.4	0.0	0.0	0.0
14.05.87	SC(CA)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.09.87	SC(CA)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.05.88	SC(CA)	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.05.86	WHR(CA)	1	62.3	0.0	63.9	8.2	121.6	13.2	0.0	0.0
19.11.86	WHR(CA)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.05.87	WHR(CA)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.11.87	WHR(CA)	4	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.05.88	WHR(CA)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.05.86	CM(G)	1	0.0	0.0	0.0	123.0	0.0	0.0	0.0	0.0
15.07.86	CM(G)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.09.86	CM(G)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.11.86	CM(G)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29.01.87	CM(G)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.03.87	CM(G)	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.05.87	CM(G)	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.07.87	CM(G)	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.09.87	CM(G)	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.87	CM(G)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.05.88	CM(G)	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.05.86	SC(R)	1	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0
15.07.86	SC(R)	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.09.86	SC(R)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.11.86	SC(R)	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29.01.87	SC(R)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DATE	SITE	FLUSH	T31	T32	T33	T34	T35	T36	T37	T38
19.03.87	SC(R)	6	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0
18.05.87	SC(R)	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.07.86	SC(R)	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.09.87	SC(R)	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.11.87	SC(R)	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.05.88	SC(R)	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.07.86	PL(W)	1	0.0	0.0	0.0	0.0	0.0	4.8	0.0	7.8
14.07.87	PL(W)	2	-99.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.05.88	PL(W)	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.9

APPENDIX X) DATA USED TO CONSIDER HUSTON'S GENERAL HYPOTHESIS OF SPECIES DIVERSITY

X.A) VARIABLES USED TO TEST HUSTON'S DIVERSITY HYPOTHESIS

Data from undisturbed sites (Chapter 6)

NOSP: - NUMBER OF SPECIES IN PIPE
H: - SHANNON - WEINER INDEX
AGE: - AGE OF WATER SINCE TREATMENT (HRS)
ASHWT: - WEIGHT OF ORGANIC MATERIAL IN SEDIMENT

DATE	CODE	NOSP	H	AGE	ASHWT
26.05.87	WH-SC	11	0.55	7	33.31
27.05.87	WS-A5	7	0.65	80	8.16
28.05.87	WI-H4	4	-	25	15.01
28.05.87	WI-H5	4	0.25	25	1.81
28.05.87	WI-H6	3	0.17	25	1.77
28.05.87	WI-H7	6	0.25	25	1.76
02.06.87	HO-OC	5	0.60	9	11.03
03.06.87	WA-H1	5	-	13	9.19
03.06.87	WA-H2	5	0.02	13	20.07
03.06.87	WA-H3	4	0.01	13	5.32
03.06.87	WA-H4	9	-	13	7.47
05.06.87	BR-OC	6	-	-	3.89
05.06.87	BR-PC	6	-	-	3.69
08.06.87	GU-NO	6	-	2	9.67
08.06.87	GU-H1	2	0.30	2	4.05
08.06.87	GU-PC	10	0.52	2	7.03
10.06.87	CA-HX	7	0.71	20	0.55
12.06.87	UW-TR	3	0.22	3	20.56
15.06.87	BL-H2	11	-	-	0.35
15.06.87	BL-H6	2	0.14	-	17.60
15.06.87	BL-H8	2	0.09	-	5.19
19.06.87	HA-H1	3	0.44	13	5.09
19.06.87	HA-H2	2	0.09	11	1.35
19.06.87	HA-H3	2	0.14	11	0.71
07.10.87	CH-H4	3	0.46	16	3.87
07.10.87	CH-H5	5	-	16	3.32
07.10.87	CH-H6	2	-	16	4.80
09.10.87	BA-H1	13	0.70	10	10.03

DATE	CODE	NOSP	H	AGE	ASHWT
09.10.87	BA-H2	8	0.55	10	10.09
09.10.87	BA-H3	7	0.56	10	7.84
12.10.87	WH-H1	8	-	22	1.27
12.10.87	WH-H2	10	0.87	22	3.32
12.10.87	WH-H4	7	0.50	22	2.34
12.10.87	WH-H5	7	0.58	22	1.52
12.10.87	WH-H6	7	0.50	22	0.20
14.10.87	AR-H1	5	0.55	-	6.15
14.10.87	AR-H2	4	0.30	-	4.47
14.10.87	AR-H4	3	0.45	-	1.80
14.10.87	AR-H5	7	0.39	-	2.45
14.10.87	AR-H6	5	0.48	-	1.18
16.10.87	CR-TL	10	0.72	3	2.25
19.10.87	WF-H2	9	0.74	36	2.10
19.10.87	WF-H3	10	0.82	36	3.31
19.10.87	WF-H4	9	-	36	2.34
19.10.87	WF-H5	4	1.37	36	32.20
21.10.87	NE-CR	9	0.67	12	6.43
21.10.87	NE-MA	10	0.30	12	7.31
21.10.87	NE-MO	10	0.44	12	-
22.10.87	GL-H1	2	0.30	-	17.49
23.10.87	CH-H1	5	-	3	2.21
23.10.87	CH-H2	5	0.31	3	4.91
23.10.87	WB-RD	7	0.54	3	12.82

X.B) NUMBER OF SPECIES PRESENT (INCLUDING DRIFT) AND NUMBER OF SPECIES FROM PIPE ALONE IN EACH SAMPLE TAKEN FROM DISTURBED SITES DURING THE PERIOD APRIL 1986 TO MAY 1988.

-1: - SAMPLE NOT EXAMINED
NOSP: - IDENTIFIED TAXA IN PIPE
H: - SHANNON - WEINER INDEX
SPPRES: - IDENTIFIED TAXA IN SAMPLE (INCLUDING DRIFT)
FTIME: - TIME SINCE LAST FLUSH

SITES FED FROM RAVENSTHORPE:

SITE	DATE	NOSP	H	SPPRES	FTIME
SC(CA)	17.09.86	10	0.33	12	125
SC(CA)	29.01.87	8	0.38	15	134
SC(CA)	14.05.87	4	0.41	7	105
WHR(CA)	19.11.86	8	0.60	12	188
WHR(CA)	14.05.87	6	0.05	8	176
CM(G)	15.07.86	3	0.46	10	63
CM(G)	19.09.86	12	0.69	17	66
CM(G)	17.11.86	10	0.63	13	59
CM(G)	29.01.87	7	0.82	11	73
CM(G)	19.03.87	6	0.63	11	49
CM(G)	18.05.87	6	0.64	8	60
SC(R)	15.07.86	8	0.71	11	68
SC(R)	18.09.86	10	0.66	14	65
SC(R)	17.11.86	9	0.73	10	60
SC(R)	29.01.87	6	0.63	9	73
SC(R)	18.05.87	7	0.97	7	60

SITES FED FROM PITSFORD:

SITE	DATE	NOSP	H	SPPRES	FTIME
PC(NH)	21.04.87	4	0.52	10	328
WW(NH)	28.05.86	4	0.70	8	42
WW(NH)	14.07.87	12	0.88	15	412
WW(NH)	10.05.88	9	0.78	11	331
WW(W)	28.01.87	3	0.42	5	135
WW(W)	15.05.87	3	0.25	8	107
WW(W)	21.09.87	2	0.22	7	129
WW(W)	11.05.88	7	0.99	7	233
B(W)	18.11.86	5	0.46	9	190
B(W)	15.05.87	3	0.42	7	178
B(W)	18.11.87	5	0.33	11	187
B(W)	11.05.88	9	0.85	15	175
BL(CB)	12.09.86	7	0.38	17	77
BL(CB)	19.11.86	14	0.97	20	68
BL(CB)	28.01.87	2	1.14	7	70
BL(CB)	20.03.87	6	0.53	7	51
BL(CB)	20.05.87	6	0.59	11	61
BL(CB)	15.07.87	6	0.63	10	56
BL(CB)	18.09.87	8	0.58	14	65
BL(CB)	18.11.87	10	0.84	13	61
BC(R)	16.09.86	6	0.12	9	64
BC(R)	18.11.86	6	0.20	10	63
BC(R)	28.01.87	4	0.48	10	71
BC(R)	19.05.87	9	0.87	14	60
BC(R)	15.07.87	6	0.65	9	57
BC(R)	18.09.87	10	0.83	14	65
BC(R)	18.11.87	9	0.81	13	61
BC(R)	10.05.87	6	0.61	9	174

APPENDIX XI) NORGREN FILTER ANIMAL DENSITIES AND INDEX OF EMERGENCE ON EACH SAMPLING OCCASION DURING 1988 FOR EACH TAXA

XI.A) VOLUME AND TIME OF FILTER RUN AND ANIMAL NUMBERS IN FILTER SAMPLES REMOVED FROM TAP FILTER SITES DURING JANUARY - OCTOBER 1988.

Column labels:

CHAD - adult chironomids
CHPU - chironomid pupae
CHLA - chironomid larvae
CHEX - chironomid larval exuviae
HARP - harpacticoid copepods
CYCL - cyclopoid copepods
CHYD - chydorids
OLIG - oligochaete worms
DAPH - daphnids
HALA - halacarid mites
HYDR - Hydracarina
TYRO - Tyroglyphidae
OSTR - ostracods
TARD - tardigrades
GAST - gastropods

(Presence only indicated by *)
CYFR - cyclopoid fragments
CHCA - chydorid carapaces
PART - particulate matter
CPDT - copepodites
NAUP - nauplii

WATFORD

DATE	CHAD	CHPU	CHLA	CHEX	HARP	CYCL	CHYD
15.02.88	0	0	0	2	4	0	2
22.02.88	0	0	0	0	0	0	0
21.03.88	0	0	0	0	0	0	0
11.04.88	0	0	1	0	0	0	0
16.05.88	0	0	0	0	0	0	0
13.06.88	0	0	0	0	0	0	0
14.07.88	0	0	0	0	0	0	0
18.08.88	0	0	0	0	0	1	0
16.09.88	0	0	0	0	0	46	14
18.10.88	0	0	0	0	1	25	35

DATE	OLIG	DAPH	HALA	HYDR	TYRO	OSTR	TARD	GAST
15.02.88	0	0	1	0	0	0	0	0
22.02.88	0	0	0	0	0	0	0	0
21.03.88	0	0	0	0	0	0	0	0
11.04.88	0	0	0	0	0	0	0	0
16.05.88	0	0	0	0	0	0	0	0
13.06.88	0	0	12	0	2	0	0	0
14.07.88	0	0	0	1	1	0	0	0
18.08.88	0	0	0	0	0	0	0	0
16.09.88	0	0	2	0	0	0	0	0
18.10.88	0	0	0	0	0	0	0	0

DATE	VOLUME	TIME	CYFR	CHCA	PART	CPDT	NAUP
15.02.88	2957.9	119.42	0	0	*	0	0
22.02.88	47.2	93.70	0	0	*	0	0
21.03.88	793.5	96.42	0	0	*	0	0
11.04.88	3212.4	94.75	0	*	*	0	0
16.05.88	5580.3	112.30	0	0	*	0	0
13.06.88	1981.7	92.25	0	0	*	0	0
14.07.88	8917.0	70.58	0	0	*	0	0
18.08.88	4687.0	71.33	*	*	*	0	0
16.09.88	4598.8	69.92	*	*	0	0	0
18.10.88	6922.6	97.08	*	*	*	0	0

WEEDON

DATE	CHAD	CHPU	CHLA	CHEX	HARP	CYCL	CHYD
11.02.88	0	0	0	0	0	0	1
15.02.88	0	0	0	0	0	0	5
22.02.88	0	0	1	1	0	0	0
21.03.88	0	0	0	0	0	0	0
11.04.88	0	0	1	0	0	0	0
16.05.88	0	0	0	1	1	0	0
13.06.88	0	0	1	0	0	4	1
14.07.88	0	0	1	0	0	2	0
18.08.88	0	0	0	0	0	2	0
16.09.88	0	0	0	0	0	0	2
18.10.88	0	0	0	0	0	0	222

DATE	OLIG	DAPH	HALA	HYDR	TYRO	OSTR	TARD	GAST
11.02.88	0	0	0	0	0	0	0	0
15.02.88	0	0	0	0	0	0	0	0
22.02.88	0	0	0	0	0	0	0	0
21.03.88	0	0	0	0	0	0	0	0
11.04.88	0	0	1	0	0	0	0	0
16.05.88	0	1	0	0	1	0	0	0
13.06.88	0	0	6	0	1	0	0	0
14.07.88	0	0	2	1	0	0	0	0
18.08.88	0	0	0	0	0	0	0	0
16.09.88	0	0	0	0	0	0	0	0
18.10.88	0	0	0	0	2	0	0	0

DATE	VOLUME	TIME	CYFR	CHCA	PART	CPDT	NAUP
11.02.88	1672.7	24.25	0	0	*	0	0
15.02.88	13699.6	119.50	0	0	*	0	0
22.02.88	388.4	95.20	0	*	*	0	0
21.03.88	12758.5	96.33	0	0	*	0	0
11.04.88	3699.3	97.92	0	*	*	0	0
16.05.88	18052.9	112.75	0	*	*	0	0
13.06.88	37313.7	92.75	0	*	*	0	0
14.07.88	39236.8	70.58	*	0	*	0	0
18.08.88	10786.4	71.33	0	*	*	0	0
16.09.88	20319.0	69.92	*	*	*	0	0
18.10.88	19391.3	97.83	0	*	0	0	0

WHILTON

DATE	CHAD	CHPU	CHLA	CHEX	HARP	CYCL	CHYD
15.02.88	0	0	36	0	1	0	2
22.02.88	0	0	24	28	5	3	47
21.03.88	0	0	0	0	0	0	0
11.04.88	0	0	0	0	1	0	0
16.05.88	0	0	4	6	3	0	9
13.06.88	0	0	0	0	2	1	2
14.07.88	0	0	0	0	6	0	26
18.08.88	0	0	0	0	1	0	67
16.09.88	0	0	0	0	15	0	790
18.10.88	0	0	0	0	5	1	148

DATE	OLIG	DAPH	HALA	HYDR	TYRO	OSTR	TARD	GAST
15.02.88	0	0	0	0	0	0	0	1
22.02.88	0	0	1	0	0	0	0	2
21.03.88	0	0	0	0	0	0	0	0
11.04.88	0	0	0	0	0	0	0	0
16.05.88	0	0	3	0	0	0	0	0
13.06.88	0	0	2	0	0	0	0	0
14.07.88	0	0	5	1	0	0	1	0
18.08.88	0	0	0	0	0	0	0	0
16.09.88	0	0	0	0	0	0	0	0
18.10.88	0	0	0	0	1	0	1	0

DATE	VOLUME	TIME	CYFR	CHCA	PART	CPDT	NAUP
15.02.88	3592.3	119.20	0	0	*	0	0
22.02.88	57211.9	95.70	0	*	*	0	0
21.03.88	39.0	96.42	0	0	*	0	0
11.04.88	87.1	99.25	0	*	*	0	0
16.05.88	71817.7	112.66	0	0	*	0	0
13.06.88	878.2	92.42	0	*	*	0	0
14.07.88	9393.3	70.58	*	0	*	0	0
18.08.88	6036.0	71.25	*	*	*	0	0
16.09.88	31627.0	69.92	*	*	*	0	0
18.10.88	6967.1	.	0	0	0	0	0

RAVENSTHORPE

DATE	CHAD	CHPU	CHLA	CHEX	HARP	CYCL	CHYD
22.02.88	0	0	0	0	0	0	0
21.03.88	0	0	0	0	0	0	0
11.04.88	0	0	0	0	0	0	0
16.05.88	0	0	0	0	0	0	0
13.06.88	1	0	1	0	0	0	1
14.07.88	0	0	0	0	0	10	0
18.08.88	0	0	0	0	0	1	0
16.09.88	0	0	0	0	0	0	0
18.10.88	0	0	0	0	0	0	0

DATE	OLIG	DAPH	HALA	HYDR	TYR0	OSTR	TARD	GAST
22.02.88	0	0	0	0	0	0	0	0
21.03.88	0	0	0	0	0	0	0	0
11.04.88	0	0	0	0	0	0	0	0
16.05.88	0	1	0	0	1	0	0	0
13.06.88	0	0	0	0	9	0	0	0
14.07.88	0	0	0	0	0	0	0	0
18.08.88	0	0	0	0	0	0	0	0
16.09.88	0	0	0	0	0	0	0	0
18.10.88	0	0	0	0	0	0	0	0

DATE	VOLUME	TIME	CYFR	CHCA	PART	CPDT	NAUP
22.02.88	4.5	92.80	0	0	*	0	0
21.03.88	44.5	97.17	0	0	*	0	0
11.04.88	417.0	96.42	0	0	*	0	0
16.05.88	218.4	113.58	0	0	*	0	0
13.06.88	8980.2	93.75	0	0	*	0	0
14.07.88	77062.5	71.42	*	0	*	0	0
18.08.88	48915.0	70.33	*	0	*	0	0
16.09.88	66146.6	69.83	0	0	*	0	0
18.10.88	5677.1	.	0	0	0	0	0

PITSFORD

DATE	CHAD	CHPU	CHLA	CHEX	HARP	CYCL	CHYD
11.04.88	0	0	0	0	0	2	0
16.05.88	0	0	0	0	0	0	0
13.06.88	0	0	0	3	3	29	0
14.07.88	0	0	2	0	0	302	0
18.08.88	0	0	0	2	2	320	0
16.09.88	0	0	0	5	0	815	5
18.10.88	0	0	2	0	5	40	8

DATE	OLIG	DAPH	HALA	HYDR	TYRO	OSTR	TARD	GAST
11.04.88	0	0	0	0	0	0	0	0
16.05.88	0	0	0	0	0	0	0	0
13.06.88	0	0	0	22	0	0	0	0
14.07.88	0	0	0	44	0	1	0	0
18.08.88	0	0	0	16	0	0	0	0
16.09.88	0	0	0	0	0	0	5	5
18.10.88	0	0	0	0	0	0	0	0

DATE	VOLUME	TIME	CYFR	CHCA	PART	CPDT	NAUP
11.04.88	1292.2	97.92	0	0	*	0	0
16.05.88	1585.6	114.25	0	0	*	0	0
13.06.88	10943.1	93.33	*	0	*	0	0
14.07.88	11237.5	70.50	0	0	0	*	*
18.08.88	21736.0	69.58	*	0	*	0	*
16.09.88	7820.3	69.75	*	0	0	*	*
18.10.88	15626.0	97.00	*	0	0	*	*

BRIXWORTH

DATE	CHAD	CHPU	CHLA	CHEX	HARP	CYCL	CHYD
16.05.88	0	0	0	0	1	0	0
13.06.88	0	0	0	0	0	0	0
14.07.88	0	0	1	0	0	2	0
18.08.88	0	0	0	1	0	7	3
16.09.88	0	0	0	2	0	1	0
18.10.88	0	0	0	0	0	2	1

DATE	OLIG	DAPH	HALA	HYDR	TYRO	OSTR	TARD	GAST
16.05.88	0	1	0	0	0	0	0	0
13.06.88	0	0	0	0	7	0	0	0
14.07.88	0	0	0	1	0	0	0	0
18.08.88	0	0	0	1	0	0	0	0
16.09.88	0	0	0	0	0	0	0	0
18.10.88	0	0	0	0	0	0	0	0

DATE	VOLUME	TIME	CYFR	CHCA	PART	CPDT	NAUP
16.05.88	3593.6	113.08	0	0	*	0	0
13.06.88	4798.5	94.00	0	0	*	0	0
14.07.88	7115.9	71.42	*	0	*	0	0
18.08.88	10665.0	69.17	0	0	*	0	0
16.09.88	2595.4	69.08	*	*	*	0	0
18.10.88	5178.6	.	0	0	*	0	0

APPENDIX XI: B) NUMBER OF 'CONSUMER DAYS' DURING FILTER RUN AND ANIMAL NUMBERS PER 'CONSUMER DAY' (INDEX OF EMERGENCE, I_e) DURING TAP FILTER SAMPLES REMOVED DURING JANUARY - OCTOBER 1988.

RATE - rate of sampling
CHAD - adult chironomids
CHLA - chironomid larvae
HARP - harpacticoid copepods
OLIG - oligochaetes
DAPH - daphnids
HYDR - Hydracarina
OSTR - ostracods
GAST - gastropods

CONSDAY - 'NUMBER OF CONSUMER DAYS IN FILTER RUN'
CHPU - chironomid pupae and pupal exuviae
CHEX - chironomid larval exuviae
CYCL - cyclopoid copepods
CHYD - chydorids
HALA - halacarid mites
TYRO - Tyroglyphidae
TARD - tardigrades

CODES USED TO DETERMINE SITES:

a - WATFORD PUMPING STATION
e - WEEDON SEWAGE TREATMENT WORKS
h - DAVENTRY DISTRICT OFFICE, WHILTON
r - RAVENSTHORPE WATER TREATMENT WORKS
p - PITSFORD WATER TREATMENT WORKS
b - BRIXWORTH SEWAGE TREATMENT WORKS

DATE	SITE	CONSDAY	RATE	CHAD	CHPU	CHLA	CHEX	HARP	CYCL
15.02.88	a	3.792	24.769	0.000	0.000	0.000	0.527	1.055	0.000
22.02.88	a	0.060	0.504	0.000	0.000	0.000	0.000	0.000	0.000
21.03.88	a	1.017	8.230	0.000	0.000	0.000	0.000	0.000	0.000
11.04.88	a	4.118	33.904	0.000	0.000	0.243	0.000	0.000	0.000
16.05.88	a	7.154	49.691	0.000	0.000	0.000	0.000	0.000	0.000
13.06.88	a	2.541	21.482	0.000	0.000	0.000	0.000	0.000	0.000
14.07.88	a	11.432	126.339	0.000	0.000	0.000	0.000	0.000	0.000
18.08.88	a	6.009	65.709	0.000	0.000	0.000	0.000	0.000	0.166
16.09.88	a	5.896	65.772	0.000	0.000	0.000	0.000	0.000	7.802
18.10.88	a	8.875	71.308	0.000	0.000	0.000	0.000	0.113	2.817

DATE	SITE	OLIG	CHYD	DAPH	HALA	HYDR	TYRO	OSTR	TARD	GAST
15.02.88	a	0.000	0.527	0.000	0.264	0.000	0.000	0.000	0.000	0.000
22.02.88	a	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21.03.88	a	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11.04.88	a	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16.05.88	a	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13.06.88	a	0.000	0.000	0.000	4.723	0.000	0.787	0.000	0.000	0.000
14.07.88	a	0.000	0.000	0.000	0.000	0.087	0.087	0.000	0.000	0.000
18.08.88	a	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16.09.88	a	0.000	2.374	0.000	0.339	0.000	0.000	0.000	0.000	0.000
18.10.88	a	0.000	3.944	0.000	0.000	0.000	0.000	0.000	0.000	0.000

DATE	SITE	CONSDAY	RATE	CHAD	CHPU	CHLA	CHEX	HARP	CYCL
11.02.88	e	2.144	68.977	0.000	0.000	0.000	0.000	0.000	0.000
15.02.88	e	17.564	114.641	0.000	0.000	0.000	0.000	0.000	0.000
22.02.88	e	0.498	4.080	0.000	0.000	2.008	2.008	0.000	0.000
21.03.88	e	16.357	132.446	0.000	0.000	0.000	0.000	0.000	0.000
11.04.88	e	4.743	37.779	0.000	0.000	0.211	0.000	0.000	0.000
16.05.88	e	23.145	160.114	0.000	0.000	0.000	0.043	0.043	0.000
13.06.88	e	47.838	402.304	0.000	0.000	0.021	0.000	0.000	0.084
14.07.88	e	50.304	555.920	0.000	0.000	0.020	0.000	0.000	0.040
18.08.88	e	13.829	151.218	0.000	0.000	0.000	0.000	0.000	0.145
16.09.88	e	26.050	290.604	0.000	0.000	0.000	0.000	0.000	0.000
18.10.88	e	24.861	198.214	0.000	0.000	0.000	0.000	0.000	0.000

DATE	SITE	OLIG	CHYD	DAPH	HALA	HYDR	TYRO	OSTR	TARD	GAST
11.02.88	e	0.000	0.466	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15.02.88	e	0.000	0.285	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22.02.88	e	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21.03.88	e	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11.04.88	e	0.000	0.000	0.000	0.211	0.000	0.000	0.000	0.000	0.000
16.05.88	e	0.000	0.000	0.043	0.000	0.000	0.043	0.000	0.000	0.000
13.06.88	e	0.000	0.021	0.000	0.125	0.000	0.021	0.000	0.000	0.000
14.07.88	e	0.000	0.000	0.000	0.040	0.020	0.000	0.000	0.000	0.000
18.08.88	e	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16.09.88	e	0.000	0.077	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18.10.88	e	0.000	8.930	0.000	0.000	0.000	0.080	0.000	0.000	0.000

DATE	SITE	CONSDAY	RATE	CHAD	CHPU	CHLA	CHEX	HARP	CYCL
15.02.88	h	4.605	30.137	0.000	0.000	7.817	0.000	0.217	0.000
22.02.88	h	73.347	597.825	0.000	0.000	0.327	0.382	0.068	0.041
21.03.88	h	0.050	0.404	0.000	0.000	0.000	0.000	0.000	0.000
11.04.88	h	0.112	0.878	0.000	0.000	0.000	0.000	8.955	0.000
16.05.88	h	92.074	637.473	0.000	0.000	0.043	0.065	0.033	0.000
13.06.88	h	1.126	9.502	0.000	0.000	0.000	0.000	1.776	0.888
14.07.88	h	12.043	133.087	0.000	0.000	0.000	0.000	0.498	0.000
18.08.88	h	7.738	84.716	0.000	0.000	0.000	0.000	0.129	0.000
16.09.88	h	40.547	452.331	0.000	0.000	0.000	0.000	0.370	0.000
18.10.88	h	8.932	.	0.000	0.000	0.000	0.000	0.560	0.112

DATE	SITE	OLIG	CHYD	DAPH	HALA	HYDR	TYRO	OSTR	TARD	GAST
15.02.88	h	0.000	0.434	0.000	0.000	0.000	0.000	0.000	0.000	0.217
22.02.88	h	0.000	0.641	0.000	0.014	0.000	0.000	0.000	0.000	0.028
21.03.88	h	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11.04.88	h	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16.05.88	h	0.000	0.098	0.000	0.033	0.000	0.000	0.000	0.000	0.000
13.06.88	h	0.000	1.777	0.000	1.776	0.000	0.000	0.000	0.000	0.000
14.07.88	h	0.000	2.159	0.000	0.415	0.083	0.000	0.000	0.083	0.000
18.08.88	h	0.000	8.658	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16.09.88	h	0.000	19.483	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18.10.88	h	0.000	16.569	0.000	0.000	0.000	0.112	0.000	0.112	0.000

DATE	SITE	CONSDAY	RATE	CHAD	CHPU	CHLA	CHEX	HARP	CYCL
22.02.88	r	0.006	0.05	0.000	0.000	0.000	0.000	0.000	0.000
21.03.88	r	0.057	0.46	0.000	0.000	0.000	0.000	0.000	0.000
11.04.88	r	0.535	4.32	0.000	0.000	0.000	0.000	0.000	0.000
16.05.88	r	0.280	1.92	0.000	0.000	0.000	0.000	0.000	0.000
13.06.88	r	11.513	95.79	0.087	0.000	0.087	0.000	0.000	0.000
14.07.88	r	98.798	1079.00	0.000	0.000	0.000	0.000	0.000	0.101
18.08.88	r	62.711	695.51	0.000	0.000	0.000	0.000	0.000	0.016
16.09.88	r	84.803	947.25	0.000	0.000	0.000	0.000	0.000	0.000
18.10.88	r	7.278	.	0.000	0.000	0.000	0.000	0.000	0.000

DATE	SITE	OLIG	CHYD	DAPH	HALA	HYDR	TYRO	OSTR	TARD	GAST
22.02.88	r	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21.03.88	r	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11.04.88	r	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16.05.88	r	0.000	0.000	3.571	0.000	0.000	3.571	0.000	0.000	0.000
13.06.88	r	0.000	0.087	0.000	0.000	0.000	0.782	0.000	0.000	0.000
14.07.88	r	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18.08.88	r	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16.09.88	r	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18.10.88	r	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

DATE	SITE	CONSDAY	RATE	CHAD	CHPU	CHLA	CHEX	HARP	CYCL
11.04.88	p	1.657	13.196	0.000	0.000	0.000	0.000	0.000	1.207
16.05.88	p	2.033	13.878	0.000	0.000	0.000	0.000	0.000	0.000
13.06.88	p	14.300	117.252	0.000	0.000	0.000	0.214	0.214	2.067
14.07.88	p	14.407	159.397	0.000	0.000	0.139	0.000	0.000	20.962
18.08.88	p	27.867	312.389	0.000	0.000	0.000	0.072	0.072	11.483
16.09.88	p	10.026	112.119	0.000	0.000	0.000	0.499	0.000	81.288
18.10.88	p	20.033	161.093	0.000	0.000	0.100	0.000	0.250	1.997

DATE	SITE	OLIG	CHYD	DAPH	HALA	HYDR	TYRO	OSTR	TARD	GAST
11.04.88	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16.05.88	p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13.06.88	p	0.000	0.000	0.000	0.000	1.568	0.000	0.000	0.000	0.000
14.07.88	p	0.000	0.000	0.000	0.000	3.054	0.000	0.069	0.000	0.000
18.08.88	p	0.000	0.000	0.000	0.000	0.574	0.000	0.000	0.000	0.000
16.09.88	p	0.000	0.499	0.000	0.000	0.000	0.000	0.000	0.499	0.499
18.10.88	p	0.000	0.399	0.000	0.000	0.000	0.000	0.000	0.000	0.000

DATE	SITE	CONSDAY	RATE	CHAD	CHPU	CHLA	CHEX	HARP	CYCL
16.05.88	b	4.607	31.779	0.000	0.000	0.000	0.000	0.217	0.000
13.06.88	b	6.152	51.048	0.000	0.000	0.000	0.000	0.000	0.000
14.07.88	b	9.123	99.635	0.000	0.000	0.110	0.000	0.000	0.219
18.08.88	b	13.673	154.185	0.000	0.000	0.000	0.073	0.000	0.512
16.09.88	b	3.328	37.571	0.000	0.000	0.000	0.601	0.000	0.300
18.10.88	b	6.639	.	0.000	0.000	0.000	0.000	0.000	0.301

DATE	SITE	OLIG	CHYD	DAPH	HALA	HYDR	TYRO	OSTR	TARD	GAST
16.05.88	b	0.000	0.000	0.217	0.000	0.000	0.000	0.000	0.000	0.000
13.06.88	b	0.000	0.000	0.000	0.000	0.000	1.138	0.000	0.000	0.000
14.07.88	b	0.000	0.000	0.000	0.000	0.110	0.000	0.000	0.000	0.000
18.08.88	b	0.000	0.219	0.000	0.000	0.073	0.000	0.000	0.000	0.000
16.09.88	b	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18.10.88	b	0.000	0.151	0.000	0.000	0.000	0.000	0.000	0.000	0.000

APPENDIX XII: RELATIVE DENSITY OF ANIMALS PER LITRE IN SAMPLES REMOVED FROM SERVICE RESERVOIRS DURING 1988.

Site codes: P - PITSFORD CONTACT TANK
B - BOROUGH HILL SERVICE RESERVOIR NO.2
W - WEEDON SERVICE RESERVOIR

C - CHARWELTON SERVICE RESERVOIR

Column codes:
CHIR - chironomid larvae
HARP - harpacticoid copepods
CPDT - cyclopoid copepodites
NAUP - cyclopoid nauplii
ALON - Alona sp.
HALA - Halacarid mites
BOSM - Bosmina sp.
OSTR - ostracods
HYDR - hydracarina
NEMA - nematodes
OLIG - oligochaete worms
COLL - collembola

DATE	SITE	CHIR	HARP	CPDT	NAUP	ALON	HALA
29.03.88	P	0.018	0.027	0.140	0.554	0.000	0.000
22.04.88	P	0.000	0.000	0.310	5.030	0.010	0.000
16.05.88	P	0.000	0.000	0.000	0.100	0.000	0.000
14.06.88	P	0.000	0.000	0.091	0.273	0.000	0.000
13.07.88	P	0.000	0.000	0.467	7.567	0.067	0.000
16.08.88	P	0.016	0.000	0.233	0.316	0.000	0.000
20.09.88	P	0.000	0.000	0.050	0.000	0.000	0.000
13.10.88	P	0.000	0.000	0.050	0.183	0.000	0.017

DATE	SITE	BOSM	OSTR	HYDR	NEMA	OLIG	COLL
29.03.88	P	0.000	0.000	0.000	0.000	0.000	0.000
22.04.88	P	0.010	0.010	0.000	0.000	0.000	0.000
16.05.88	P	0.000	0.000	0.000	0.000	0.000	0.000
14.06.88	P	0.000	0.000	0.091	0.000	0.000	0.000
13.07.88	P	0.000	0.050	0.000	0.000	0.000	0.033
16.08.88	P	0.000	0.000	0.000	0.033	0.000	0.000
20.09.88	P	0.000	0.000	0.000	0.000	0.000	0.000
13.10.88	P	0.000	0.000	0.000	0.000	0.000	0.017

DATE	SITE	CHIR	HARP	CPDT	NAUP	ALON	HALA
29.03.88	B	0.000	0.000	0.000	0.000	0.000	0.000
22.04.88	B	0.000	0.000	0.010	0.100	0.000	0.000
16.05.88	B	0.000	0.000	0.000	0.000	0.000	0.000
14.06.88	B	0.000	0.000	0.000	0.000	0.091	0.000
13.07.88	B	0.000	0.000	0.017	0.033	0.017	0.000
16.08.88	B	0.000	0.000	0.000	0.000	0.000	0.000
20.09.88	B	0.000	0.000	0.000	0.000	0.000	0.000
13.10.88	B	0.000	0.000	0.050	0.000	0.000	0.000

DATE	SITE	BOSM	OSTR	HYDR	NEMA	OLIG	COLL
29.03.88	B	0.000	0.000	0.000	0.000	0.000	0.000
22.04.88	B	0.000	0.000	0.000	0.000	0.000	0.000
16.05.88	B	0.000	0.000	0.000	0.000	0.000	0.000
14.06.88	B	0.000	0.000	0.000	0.000	0.000	0.000
13.07.88	B	0.000	0.000	0.000	0.000	0.050	0.000
16.08.88	B	0.000	0.000	0.000	0.000	0.116	0.000
20.09.88	B	0.000	0.000	0.000	0.000	0.009	0.000
13.10.88	B	0.000	0.000	0.000	0.000	0.000	0.000

DATE	SITE	CHIR	HARP	CPDT	NAUP	ALON	HALA
20.01.88	W	0.009	0.009	0.000	0.000	0.000	0.018
01.03.88	W	0.000	0.000	0.000	0.000	0.000	0.000
29.03.88	W	0.000	0.000	0.050	1.636	0.000	0.000
22.04.88	W	0.000	0.000	0.250	1.818	0.000	0.000
16.05.88	W	0.000	0.000	0.000	0.033	0.000	0.000
14.06.88	W	0.000	0.000	0.000	0.000	0.000	0.000
13.07.88	W	0.000	0.000	0.000	0.000	0.000	0.000
16.08.88	W	0.000	0.000	0.017	0.000	0.000	0.000
20.09.88	W	0.000	0.000	0.000	0.000	0.000	0.000
13.10.88	W	0.000	0.000	0.018	0.000	0.000	0.000

DATE	SITE	BOSM	OSTR	HYDR	NEMA	OLIG	COLL
20.01.88	W	0.000	0.000	0.000	0.000	0.000	0.000
01.03.88	W	0.000	0.000	0.000	0.000	0.000	0.000
29.03.88	W	0.000	0.000	0.000	0.000	0.000	0.000
22.04.88	W	0.000	0.000	0.000	0.000	0.000	0.000
16.05.88	W	0.000	0.000	0.000	0.000	0.000	0.000
14.06.88	W	0.000	0.000	0.000	0.000	0.000	0.000
13.07.88	W	0.000	0.000	0.000	0.000	0.000	0.000
16.08.88	W	0.000	0.000	0.000	0.000	0.000	0.000
20.09.88	W	0.000	0.000	0.000	0.000	0.000	0.000
13.10.88	W	0.000	0.000	0.000	0.000	0.000	0.000

DATE	SITE	CHIR	HARP	CPDT	NAUP	ALON	HALA
20.01.88	C	0.000	0.000	0.000	0.000	0.000	0.000
01.03.88	C	0.000	0.000	0.000	0.000	0.000	0.000
29.03.88	C	0.000	0.000	0.000	0.000	0.000	0.000
22.04.88	C	0.000	0.000	0.000	0.070	0.000	0.002
16.05.88	C	0.000	0.000	0.016	0.016	0.000	0.000
14.06.88	C	0.000	0.167	0.500	0.667	0.167	0.167
13.07.88	C	0.000	0.000	0.017	0.000	0.000	0.017
16.08.88	C	0.000	0.000	0.000	0.000	0.000	0.000
20.09.88	C	0.000	0.000	0.050	0.017	0.000	0.000
13.10.88	C	0.000	0.000	0.000	0.000	0.000	0.000

DATE	SITE	BOSM	OSTR	HYDR	NEMA	OLIG	COLL
20.01.88	C	0.000	0.000	0.000	0.000	0.000	0.000
01.03.88	C	0.000	0.000	0.000	0.000	0.000	0.000
29.03.88	C	0.000	0.000	0.000	0.000	0.000	0.000
22.04.88	C	0.000	0.000	0.000	0.000	0.000	0.000
16.05.88	C	0.000	0.000	0.000	0.000	0.000	0.000
14.06.88	C	0.000	0.000	0.000	2.333	0.000	0.000
13.07.88	C	0.000	0.000	0.000	0.000	0.000	0.000
16.08.88	C	0.000	0.000	0.000	0.000	0.000	0.000
20.09.88	C	0.000	0.000	0.000	0.017	0.033	0.000
13.10.88	C	0.000	0.000	0.000	0.000	0.000	0.000

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