NRA South West 127

Environmental Protection Report

EAST DEVON PUBLIC WATER SUPPLY STRATEGY

EXE FRESHWATER MODEL
WIMBLEBALL PUMP STORAGE SCHEME
SCENARIO MODELLING

JANUARY 1993

RP–NRA–1981AA–1004(01)

Authors: C. Doidge, Technical Assistant
N. Murdoch, Modelling Officer

C.V.M. Davies
Environmental Protection Manager

NRA

National Rivers Authority

South West Region

AUTHORISATION SHEET FOR BINDING WITH REPORT

PROJECT TITLE : EAST DEVON PUBLIC WATER SUPPLY STRATEGY

REPORT TITLE : EXE FRESHWATER MODEL - WIMBLEBALL PUMP STORAGE SCHEME SCENARIO MODELLING

REFERENCE NO : RP - NRA 1981AA - 1004 (01)

AUTHOR(S)	C DOIDGE	SIGNATURE(S)	C Doidge	DATE	24/3/93
	N MURDOCH		Neil Murdoch		24/3/93
CHECKED BY	A W HEATHWOOD	SIGNATURE(S)	A W Heathwood	DATE	26.4.93
	J PROCTOR		J. Proctor		25.3.93
	R GREW		R Grew		6.4.93
FUNCTIONAL APPROVAL BY	B L MILFORD	SIGNATURE(S)	B.L. Milford	DATE	3.8.93
	C D N TUBB		[illegible]		2.8.93
REGIONAL APPROVAL BY	C V M DAVIES	SIGNATURE(S)	[illegible]	DATE	[illegible]

[EP.WR]AW_109293_DSC_AUTHORISATION_SHEET.WP

EXE FRESHWATER MODEL

FOREWORD

The Water Quality function has to assess their response to the determination of abstraction licence applications on the basis that the proposed water resources development does not cause deterioration in water quality (if at all) of more than 10% This effect is defined using key appropriate determinands for the affected inland water or ground water. Large developments affecting almost the whole of a major river system are assessed using a water quality simulation model - QUASAR.

A licence application for a Wimbleball Pumped Storage Scheme was received in January 1993.

The generic QUASAR model requires ...

- o a design, setting out the physical representation of the river
- o calibrating, using a quality controlled data set; and
- o a proposed scenario(s) for modelling.

Three associated reports describe these three processes for the assessment of the Wimbleball Pumped Storage Scheme proposal.

These three reports are...

RP-NRA 1981AA_1001 (01) Quasar model design

RP-NRA 1981AA_1002 (01) Quasar validation/calibration

RP-NRA 1981AA_1004 (01) Wimbleball pumped storage scheme scenario modelling

This foreword is at the front of each of these separate reports to place them in context with one another.

Alan Weston
Water resources planning officer

E X E C U T I V E   S U M M A R Y

* A model of the Haddeo-Exe has been constructed and validated. In it the river is divided into 16 reaches going from Wimbleball reservoir to Trews Weir, Exeter.

* The model has been designed to simulate the operation of the Wimbleball Pump Storage Scheme proposed by South West Water Services Ltd.

* Simulations calculate the change in water quality for scenarios for four years; namely 1976, 1986, 1989 and 1990.

* Statistical analyses of the 1986 and 1990 scenarios show that there are no adverse changes in key water quality determinands greater than 10%, in the percentile range, 80 - 99.

* The 1976 and 1989 scenarios show adverse changes greater than 10% for the Ammonia determinand at a small number of locations. However in these cases the absolute value of the percentile was small, approximately 0.15mg/l.

* The Pump Storage Scheme is shown to have no impact on the current National Water Council (NWC) River Classification of the Haddeo-Exe river system.

C O N T E N T S

1 INTRODUCTION

1.1 Purpose

The purpose of this document is to report on the water quality simulations of the Haddeo-Exe river system in which the operation of the Wimbleball Pump Storage Scheme, proposed by SWWSL, is modelled. The purpose of these simulations is to assess the environmental impact of the Scheme on the Haddeo-Exe river system.

1.2 Audience

The audience is :

NRA South West
East Devon Public Water Supply Coordination Group

1.3 Scope

The scope is limited to simulations for the years 1976, 1986, 1989 and 1990 for the River Exe from the Wimbleball reservoir to above the tidal limit at Trews Weir, Exeter.

1.4 List of Abbreviations

The document contains the following abbreviations:

NRA : National Rivers Authority
SWWSL : South West Water Services Ltd.
BOD : Biochemical Oxygen Demand
DO : Dissolved Oxygen
DMF : Daily Mean Flow

1.5 Glossary of Terms

Scenario : constructed sequence of possible events

2 OVERVIEW

2.1 Review of Model Design

A model of the river system from Wimbleball Reservoir to Trews Weir has been constructed, using the QUASAR (1) software.

2.1.1 Structure

The reach structure of the model is shown in Figure 1 overleaf. As the figure shows there are 16 reaches. The top reach is at Hartford on the River Haddeo and the last reach is at Trews Weir on the River Exe. Shown on the left hand side of the figure are the modelled tributaries which flow into the main stem of the Haddeo-Exe river system. The River Pulham is the first tributary and the River Creedy is the last. Shown on the right hand side are the various abstractions and discharges on the main stem. It is proposed to pump water from the river at Exebridge to Wimbleball reservoir. Exebridge is already used as a site for the Exe-Taw transfer. Other important public water supply abstractions are at Bolham, above Tiverton, and at Northbridge, above Exeter. Sewage Treatment Works at Tiverton, Thorveton and Brampford Speke are also shown in the Figure.

The details and rationale of the model design are given in (2).

2.1.2 Calibration and Validation

The water quality processes occurring in the river are modelled by QUASAR using conventional process equations as described in (1). Water quality decay parameters to be used by these equations were found by calibration with a 1989 data set. The model was then validated using a 1990 data set. This procedure is fully described in (3).

2.2 Data Sets

The model aims to calculate the water quality in the main stem of the Haddeo-Exe river system.

To do this it requires data on the flow and water quality of all the tributaries, discharges and abstractions (flow only). These data, which power the model, are constructed as annual time series. Background data define these river inputs and outputs over a year when the proposed Pump Storage Scheme is not in operation. Scenario data sets define what these river inputs and outputs are calculated to have been had the Pump Storage Scheme been in operation for the chosen year.

Background and Scenario data sets for the years 1976, 1986, 1989 and 1990 are assembled. The data sets are described below.

2.3 Water Quality Determinands

Supplied with these data sets and calibration parameters the model then calculates the daily mean values of flow and water quality determinands. The determinands modelled are :

- BOD
- Dissolved Oxygen
- Ammonia
- Nitrate
- Temperature
- pH

2.4 Summary

In summary the preparatory work for scenario modelling consists of :

- determining the reach structure with tributaries, abstractions and discharges, as shown in Figure 1
- calibrating and validating the model
- assembling the background and scenario data sets

```
Reach     Tributary                   Abstraction/Discharge
                      WIMBLEBALL
                          |
          PULHAM--->-----
                          |----->---HARTFORD FISH FARM ABS.
                          |
1                     HARTFORD
                          |-----<---HARTFORD FISH FARM DIS.
          UPPER EXE-->---
                          |
2                       PIXTON
                          |
          BARLE---->-----
                          |----->----WIMBLEBALL PUMP STORAGE ABS.
                          |          /EXE-TAW TRANSFER
3                     EXEBRIDGE
                          |
          BROCKEY--->----
                          |----->----HIGHLEIGH FISH FARM ABS.
                          |-----<----HIGHLEIGH FISH FARM DIS.
4                      OAKFORD
                          |----->----OAKFORDBRIDGE FISH FARM ABS.
                          |-----<----OAKFORDBRIDGE FISH FARM DIS.
          IRONMILL--->---
                          |
5                     HALFPENNY
                          |
          BATHERM--->----
                          |
6                     LYTHCOURT
                          |
                          |----->----BOLHAM ABS.
                          |
7                    BOLHAM LEAT
                          |
          CALVERLEIGH->--
                          |----->----HEATHCOATS ABS.
                          |
8                     TIVERTON
                          |
          LOWMAN--->-----
                          |-----<----HEATHCOATS DIS.
                          |
9                    COLLIPRIEST
                          |
                          |-----<----TIVERTON STW
                          |
10                      ASHLEY
                          |
          DART----->-----
                          |
11                    BICKLEIGH
                          |
          BURN----->-----
                          |-----<----THORVERTON STW
                          |
12                   THORVERTON
                          |
                          |----->----NORTHBRIDGE ABS.
                          |
13                   NORTH BRIDGE
                          |
          CULM----->-----
                          |
14                    STAFFORD
                          |
                          |-----<----BRAMPFORD SPEKE STW
          CREEDY--->-----
                          |
15                     EXWICK
                          |
16                   TREWS WEIR
```

Figure 1 . Schematic diagram of River Exe Model

3 METHODOLOGY

3.1 Aims

The aims of this study are to determine the following.

3.1.1 The Relative Impact of the Scheme

The aim here is to calculate the change in water quality in the Haddeo–Exe river system due to the operation of the Pump Storage Scheme.

To quantify this change as a percentage change of the background quality, expressed in statistical form.

3.1.2 The River Classification Impact

The aim here is to investigate whether or not the operation of the Pump Storage Scheme will alter the current NWC Classification of the Haddeo–Exe river system.

3.2 Approach

The relative impact of the scheme is calculated through the following steps

1. Perform annual simulations using the background data sets to drive the model. Obtain time series of daily mean flows and water quality determinands.

2. Perform annual simulations using the scenario data sets to drive the model and similarly obtain time series output.

3. Organise the output data from each simulation into percentiles using the Weibel method (4).

4. For each percentile, for a given year's simulation, quantify the change for BOD, Dissolved Oxygen, Ammonia, Nitrates, Temperature, pH and flow thus:

Change = [%ile(WQ,Yr,Scen) - %ile(WQ,Yr,Back)]/%ile(WQ,Yr,Back) *100

where	%ile	=	percentile
	WQ	=	water quality determinand
	Yr	=	year
	Scen	=	Scenario data
	Back	=	Background data

This expresses the change for each percentile as a percentage of the background quality.

5. Generate plots of the determinand deterioration at selected locations and identify excursions above 10%.

The effect on the current NWC Classification impact is ascertained by performing scenario simulations and identifying whether or not the determinand statistical values would change the NWC class.

3.3 Background Data

The background data model the river system with no pump storage system in operation.

3.3.1 Years

Models for the following years were constructed:

1990
1989
1986
1976

1989 and 1990 were chosen because of the availability of water quality spot sample data. 1989 experienced low flows. 1990 had higher flows.

1976 was chosen as it represents an extreme low flow year.

1986 was identified as a high flow year by the Exe Hydrology sub-Group.

3.3.2 Flow Data

The Flow Data sets were supplied by Watson Hawksley, consultants to SWWSL. The methodology used to generate the data sets was approved by the Exe Hydrology sub-Group.

3.3.3 Water Quality Data

The models for the years 1989 and 1990 are based on empirical data as described in (3).

Water Quality data were largely not available for 1976 and 1986. Consequently data for these years had to be synthesised.

The flow correlation method (5) was used to construct the 1976 data set from the 1989 data. The 1989 data set was used as it was the lower flow set of the two years 1989 and 1990.

Similarly, the correlation method was used to construct the 1986 data set from the 1990 data set.

The audited data sets were supplied by Watson Hawksley.

3.4 Scenario Data

The scenario data model the river system when the Wimbleball Pump Storage Scheme is presumed to be in operation.

3.4.1 Flow Data

The Flow Data sets were supplied by Watson Hawksley, consultants to SWWSL. The methodology used to generate the data sets was approved by the Exe Hydrology sub-Group.

The scenario Flow Data modelled the direct effects (ie pump storage abstraction) and indirect effects (ie reservoir releases, alterations of other Exe river abstractions) of the Scheme.

3.4.2 Water Quality Data

The background water quality data set was used.

This data set is obviously valid in for the tributary inputs.

The reservoir water quality under the operation of the pump storage scheme is assumed to be similar to the background reservoir data.

The justification for this assumption is give in (5) where it is shown that there is no evidence of a correlation of reservoir quality with reservoir volume. Also, as shown in (5), mixing of the pumped water with the reservoir water is calculated not to have a significant impact on reservoir water quality.

4 RESULTS

4.1 Relative Impact

Profiles of the above determinands (see section 2.3) for the above scenarios were generated at following ten points down the river system:

Hartford
Pixton
Halfpenny Bridge
Tiverton
Collipriest
Ashley
Thorverton
Northbridge
Stafford Bridge
Exwick
Trews Weir

Profiles of the percentile changes across the whole percentile range were generated. These profiles are comparative and show percentage changes between the background and scenario simulations. The profiles are generated using the equation in 3.2 above.

Positive values in the profiles indicate increases in the scenario concentration of the determinand over the background. Thus, for BOD, Ammonia and Nitrates positive values imply a deterioration in water quality. For Flow and Dissolved Oxygen, positive values imply an improvement in the water environment.

The significant percentile range for BOD, Ammonia and Nitrate concentrations is the 80 - 99 range as this is where the higher concentrations are. A significant deterioration in water quality is judged to have occurred when the change is greater than 10% in this range for these determinands.

The significant range for Dissolved Oxygen is the 1 - 20 percentile range as this is where the low concentrations occur.

The significant range for flow is the 1 - 20 percentile range as this is where low flows occur. Note that the 5th percentile flow is the one perhaps more familiar as the Q95 flow. It is the daily mean flow which is exceeded 95% of the time.

The results for the scenarios are now presented.

4.1.1 Empirically Based Scenarios

4.1.1.1 1989

The relevant figures are in appendix A.

Flow

At Hartford there are large increases in flow from the 20th to 80th percentile, as more water is released from the reservoir.
From Pixton to Thorverton, there are increases in the percentile range from 1 to approximately 40, as reservoir releases progress through the system. From Stafford Bridge to Trews Weir there are slight decreases at the lower percentiles. These sites lie below the Northbridge Abstraction.

BOD

There are no excursions above 10% in the 80 - 99 percentile range.
In general there are improvements in this range. These improvements are correlated with the flow profiles and hence are related to the increased dilution at low flows.

Ammonia

There are no excursions above 10% in the 80 - 99 percentile range.
In general there are slight improvements in this range above the Northbridge Abstraction. These improvements are correlated with the flow profiles and hence are related to the increased dilution at low flows. Below Northbridge there are slight increases which is correlated with the flow reduction after the abstraction.

Nitrates

There are no excursions above 10% in the 80 - 99 percentile range.
In general the changes are small.

Dissolved Oxygen

There are no excursions above 10% in 1 - 20 percentile range.
In general the changes are very small.

Temperature

At the high percentile end of the range (80 - 99) the changes are less than 10%.
At the low percentile end of the range (1 - 20) there is an increase which exceeds 10% at Pixton only. This percentage change appears to be a spurious effect related to one sample.

pH

There are no excursions beyond 10% across the whole percentile range. The maximum excursion is approximately 1%.

4.1.1.2 1990

The relevant figures are in appendix B.

Flow

At Hartford there are large increases in flow from the 20th to 80th percentile, as more water is released from the reservoir.
From Pixton to Thorverton, there are increases in the percentile range from 1 to approximately 40, as reservoir releases progress through the system. From Stafford Bridge to Trews Weir there are negligible changes at the lower percentiles. These sites lie below the Northbridge Abstraction.

BOD

There are no excursions above 10% in the 80 - 99 percentile range.
In general there are improvements in this range. These improvements are correlated with the flow profiles and hence are related to the increased dilution at low flows.

Ammonia

There are no excursions above 10% in the 80 - 99 percentile range, except at Hartford at the 99th percentile where there is an 11% change associated with the reduced flow. However the absolute ammonia concentrations are small, approximately 0.15 mg/l at the 95th percentile.
In general there are slight improvements in this range above the Northbridge Abstraction. These improvements are correlated with the flow profiles and hence are related to the increased dilution at low flows. Below Northbridge there are slight increases.

Nitrates

There are no excursions above 10% in the 80 - 99 percentile range.
In general the relative changes in concentration are small.

Dissolved Oxygen

There are no excursions above 10% in 1 – 20 percentile range.
In general the relative changes in concentration are very small.

Temperature

At the high percentile end of the range (80 - 99) the changes are less than 10%.
At low percentile end of the range (1 - 20) there are no excursions above 10%.

pH

There are no excursions beyond 10% across the whole percentile range. The maximum excursion is approximately 1%.

4.1.2 Synthetically Based Scenarios

The relevant figures are in appendix C.

4.1.2.1 1976

Flow

At Hartford there are large increases in flow from the 20th to 80th percentile as more water is released from the reservoir.
From Pixton to Thorverton there are increases in the percentile range from 1 to approximately 40 as reservoir releases progress through the system.
From Stafford Bridge to Trews Weir there are slight decreases at the lower percentiles. These sites lie below the Northbridge Abstraction.

BOD

There are no excursions above 10% in the 80 - 99 percentile range.

Ammonia

Collipriest and Thorverton sites show excursions above 10% in the 80 - 99 percentile range.

Nitrates

There are no excursions above 10% in the 80 - 99 percentile range.
In general the relative changes in concentrations are small.

Dissolved Oxygen

There are no excursions below 10% in 1 - 20 percentile range
In general the changes are very small except at Thorverton.

Temperature

At the high percentile end of the range (80 - 99) the changes are less than 10%.
At low percentile end of the range (1 - 20) the changes are less than 10%.

pH

There are no excursions beyond 10% across the whole percentile range. The maximum excursion is approximately 1%.

4.1.2.2 1986

Flow

At Hartford there are large increases in flow from the 20th to 80th percentile as more water is released from the reservoir.
From Pixton to Thorverton there are increases in the percentile range from 1 to approximately 40 as reservoir releases progress through the system.
From Stafford Bridge to Trews Weir there are very slight changes at the lower percentiles. These sites lie below the Northbridge Abstraction.

BOD

There are no excursions above 10% in the 80 - 99 percentile range.

Ammonia

There are no excursions above 10% in the 80 - 99 percentile range.

Nitrates

There are no excursions above 10% in the 80 - 99 percentile range.
In general the changes are small.

Dissolved Oxygen

There are no excursions above 10% in 1 - 20 percentile range.
In general the changes are very small.

Temperature

At the high percentile end of the range (80 - 99) the changes are less than 10%.
At low percentile end of the range (1 - 20) there are no excursions above 10%.

pH

There are no excursions beyond 10% across the whole percentile range. The maximum excursion is approximately 1%.

4.2 NWC River Classification Change

For all scenarios, there is no change in the NWC River Classification for any of the reaches.

4.3 Summary

4.3.1 Relative Impact

For the 1989 scenario there are no deteriorations greater than 10%, in the 80-99 percentile range.

For the 1990 scenario there is one deterioration greater than 10%, in the 80-99 percentile range. It is for ammonia at Hartford, where the 99th percentile is 11%.

For the 1976 scenario there are two deteriorations, for ammonia, above 10%, in the 80-99 percentile range.
The deteriorations are at Collipriest, at the 97 -99th percentiles with a maximum 19% deterioration of a background value of 0.15mg/l at the 95th percentile, and at Thorverton with a 11% deterioration, for a similar background value, at the 97 - 98th percentiles.

For the 1986 scenario there are no deteriorations greater than 10%, in the 80-99 percentile range.

4.3.2 River Classification Impact

For the scenarios modelled, the Scheme has no impact on NWC River Classification.

References

1. QUASAR Technical Manual, Institute of Hydrology, Wallingford, UK

2. Exe Freshwater Model: QUASAR Model Design, NRA Document Ref. RP-NRA 1981AA-1001(01), C Doidge and N Murdoch 1992.

3. Exe Freshwater Model: QUASAR Validation/Calibration, NRA Document Ref. RP-NRA 1981AA-1002(01), C Doidge and N Murdoch 1992

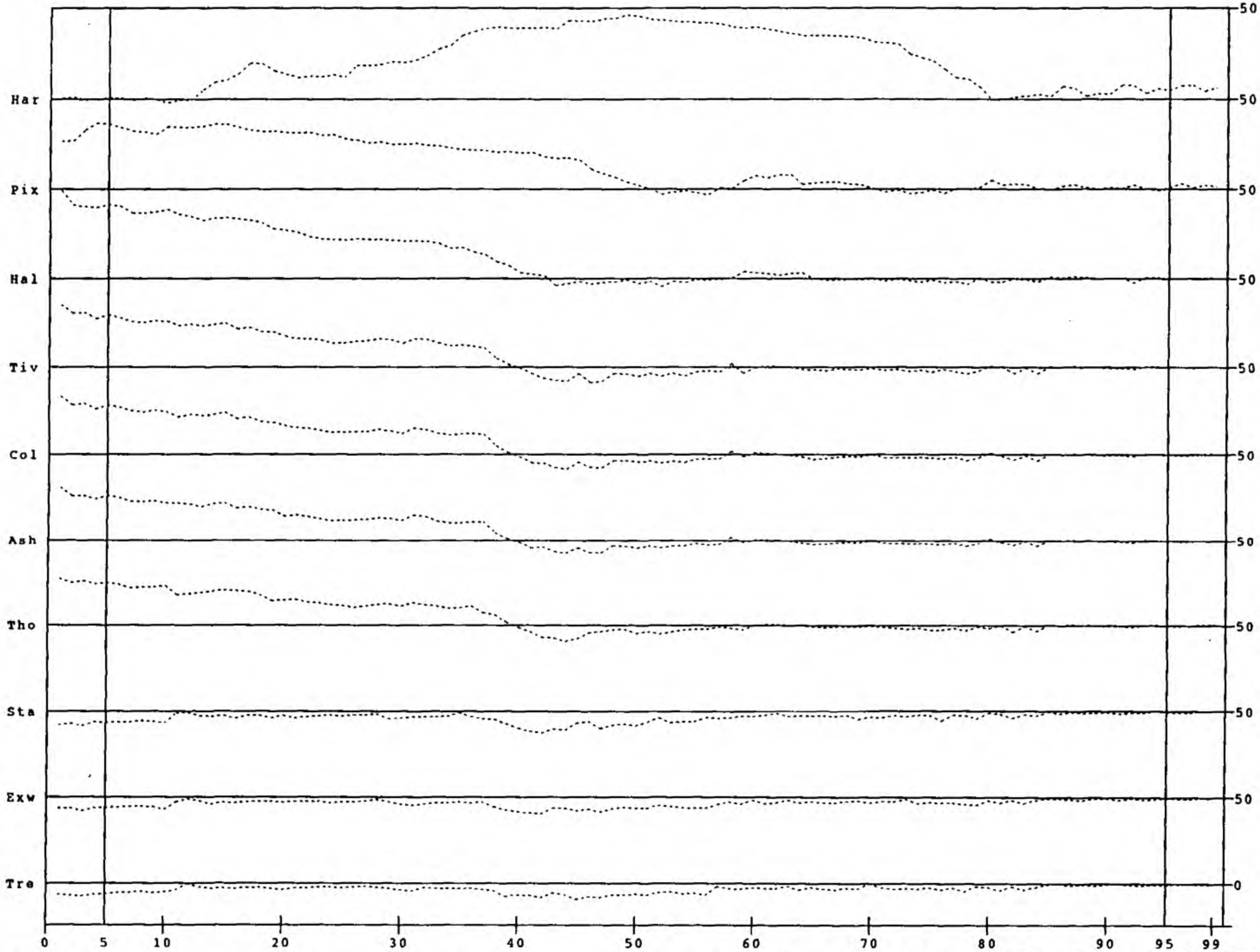
4. A Note on the Estimation of Percentiles within SWW. A Heathwood and N. Morris, South West Water, Feb. 1988.

5. East Devon Water Resources, Wimbleball Pumped Storage Scheme, Water Resources Appendix, Water Resources Model: Calibration and Development, A6, (ref RP-PLA-1981-034(01))

Appendix A Profiles for 1989

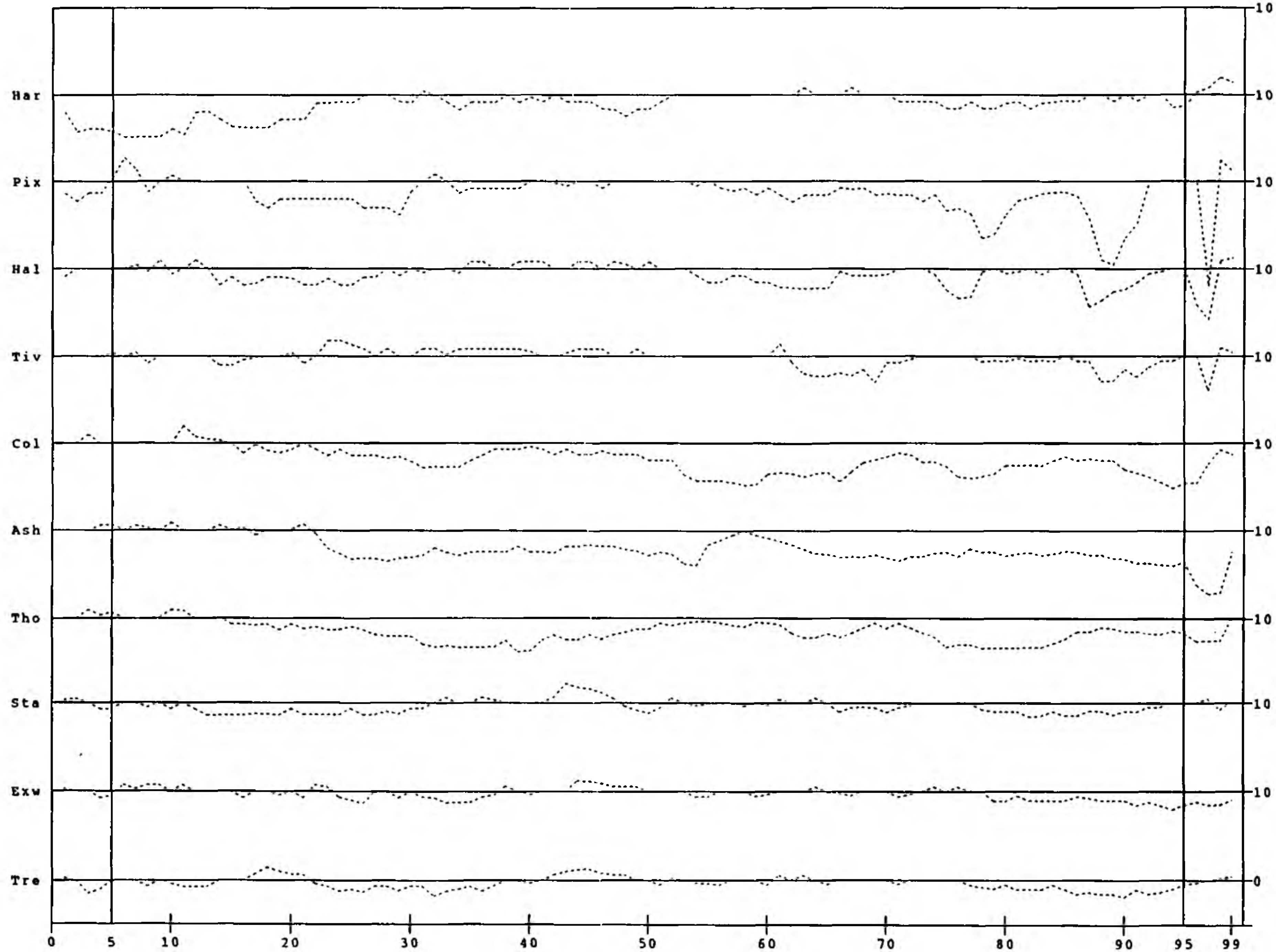
Flow
BOD
Ammonia
Nitrate
DO
Temperature
pH

Flow 1989

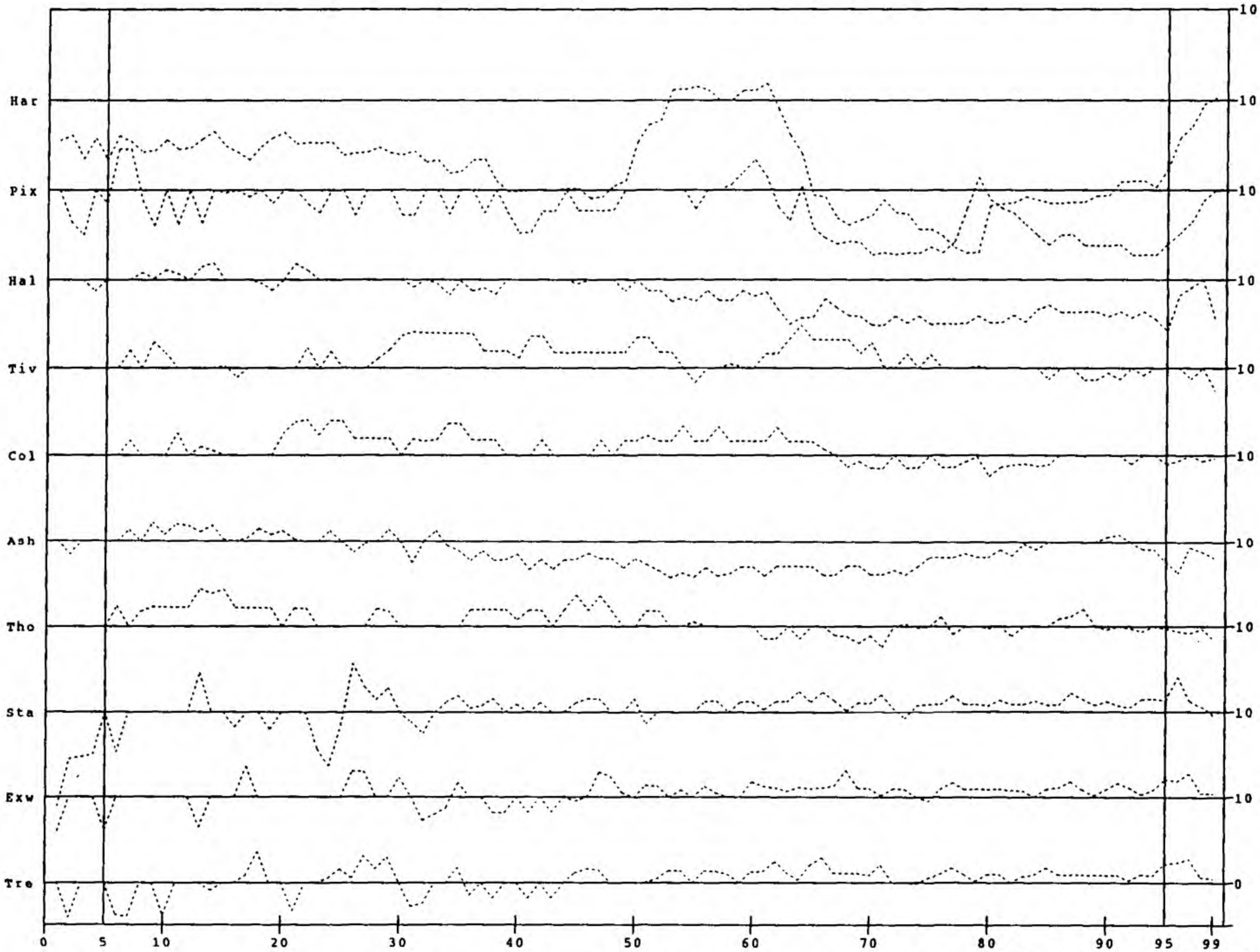


Har
Pix
Hal
Tiv
Col
Ash
Tho
Sta
Exw
Tre
50
50
50
50
50
50
50
50
50
50
0
0
5
10
20
30
40
50
60
70
80
90
95
99

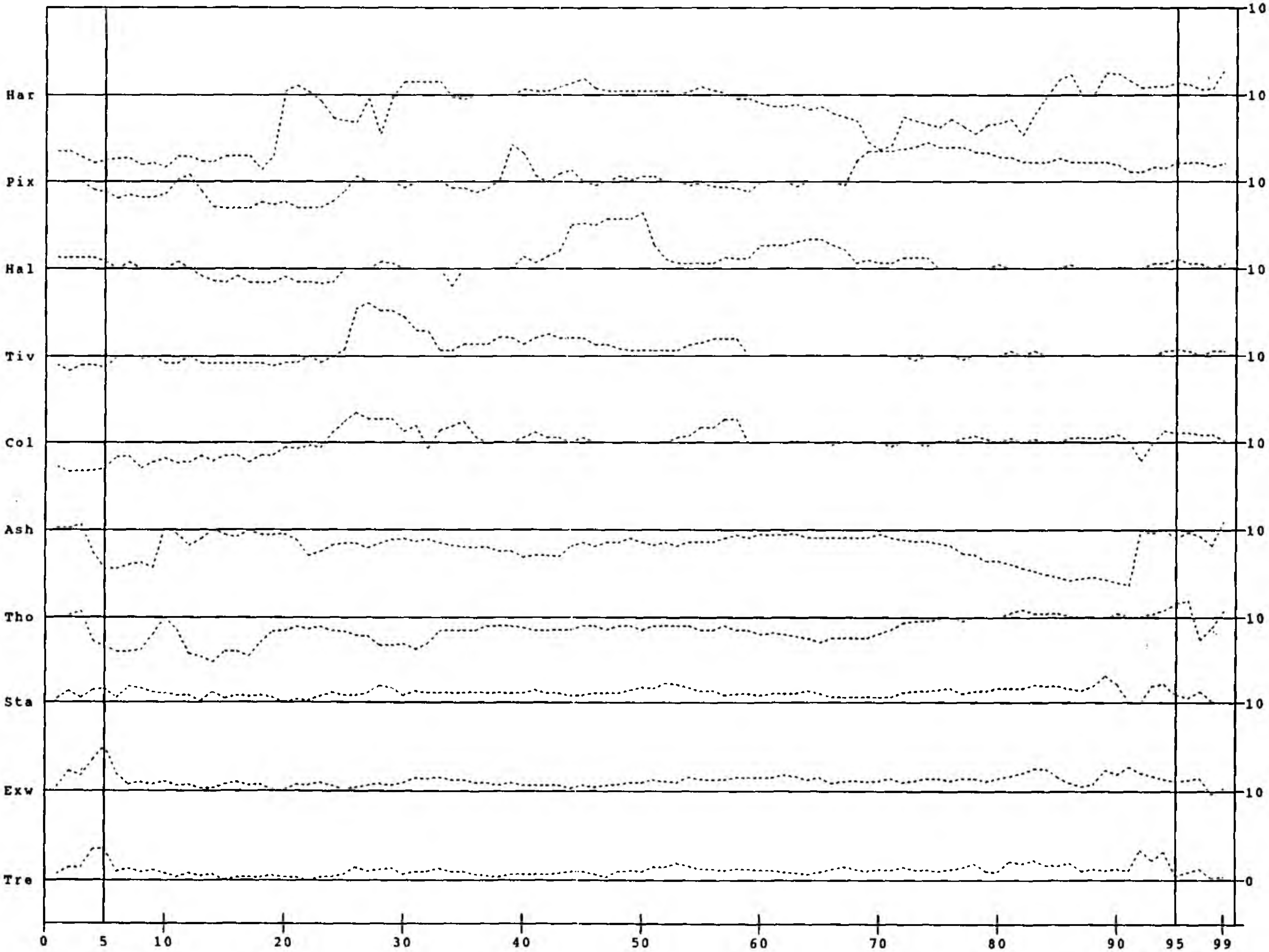
BOD 1989


Har
Pix
Hal
Tiv
Col
Ash
Tho
Sta
Exw
Tre
0
5
10
20
30
40
50
60
70
80
90
95
99

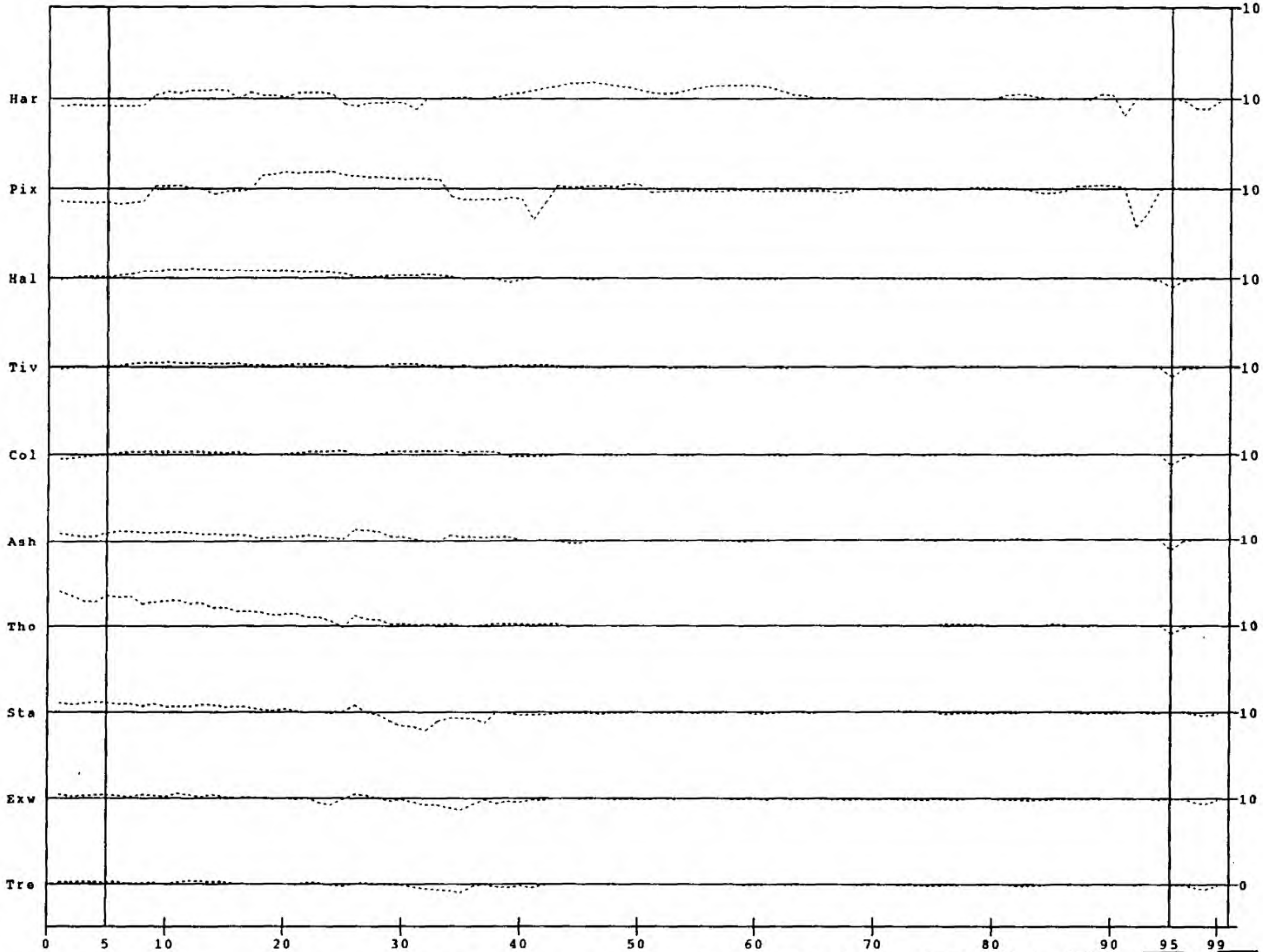
Ammonia 1989



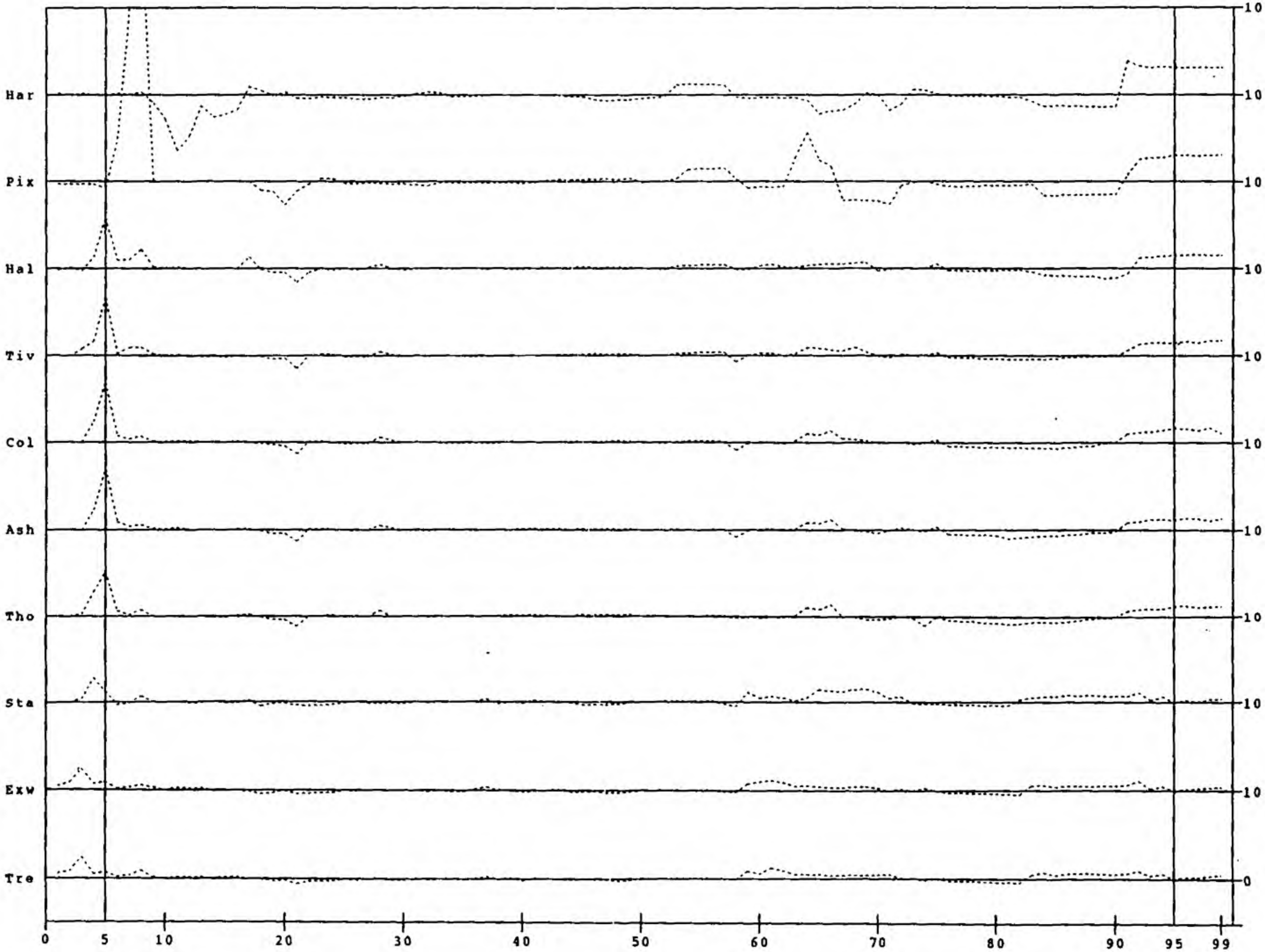
Nitrate 1989



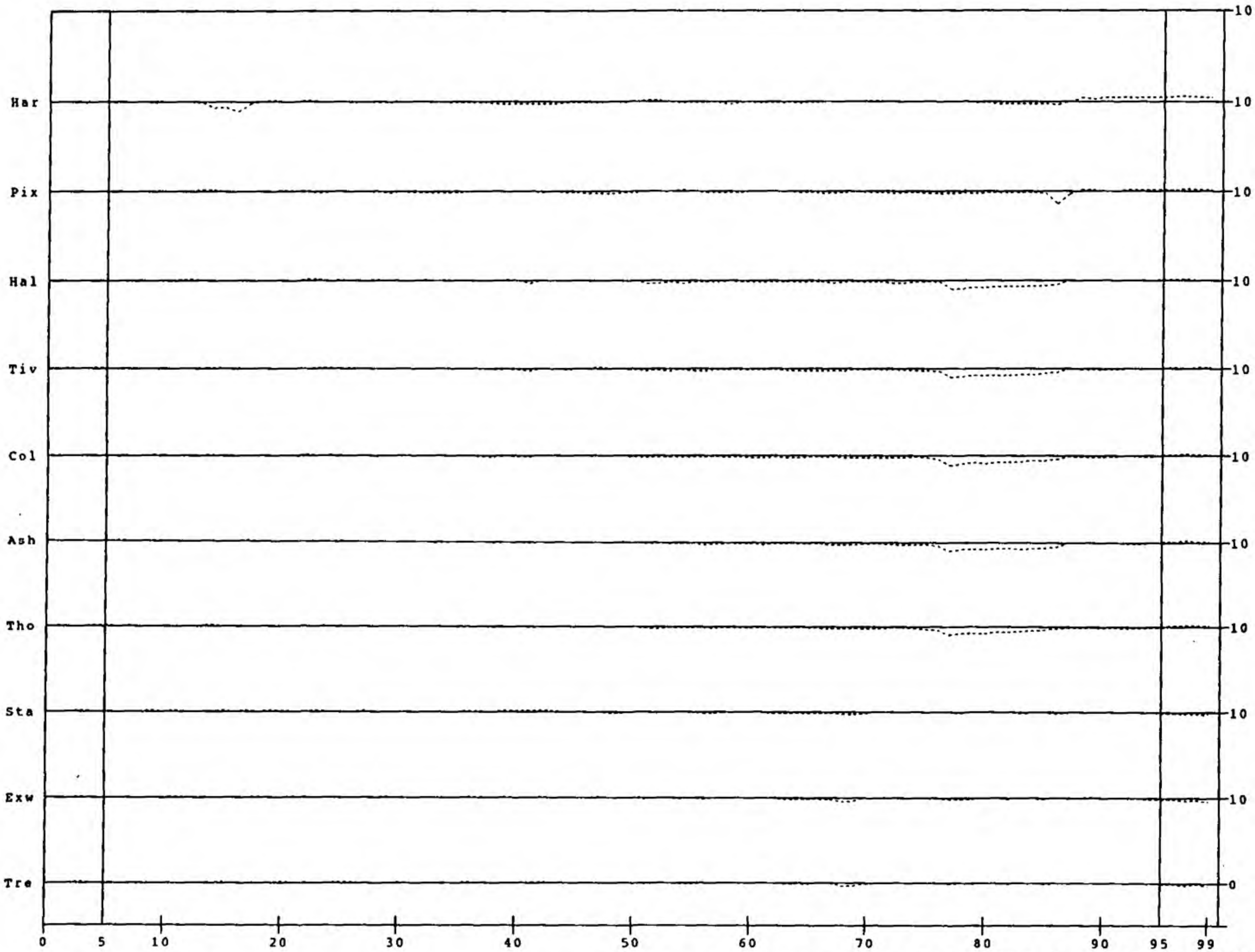
Dissolved Oxygen 1989



Temperature 1989



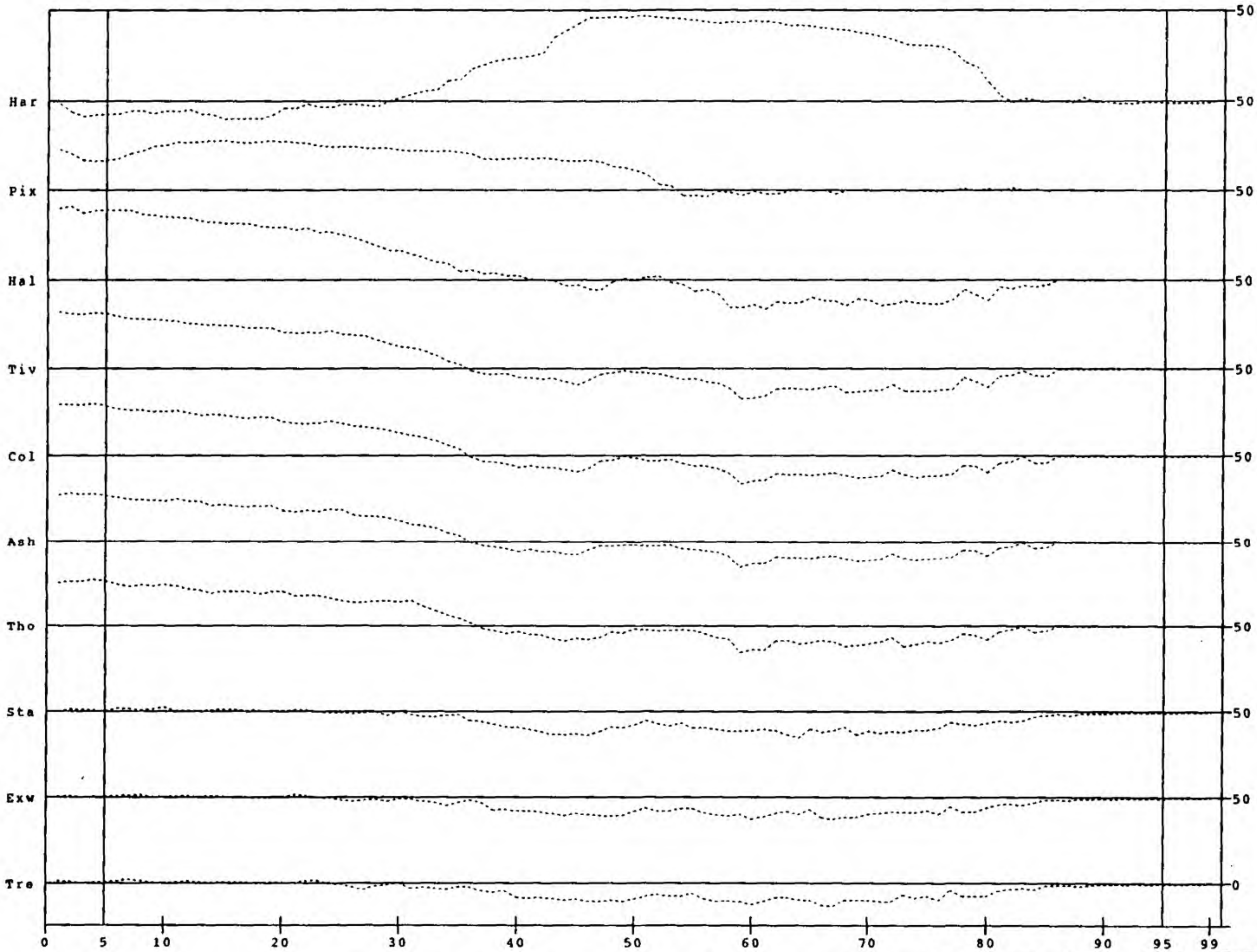
pH 1989


Har
Pix
Hal
Tiv
Col
Ash
Tho
Sta
Exw
Tre
0
5
10
20
30
40
50
60
70
80
90
95
99

Appendix B **Profiles for 1990**

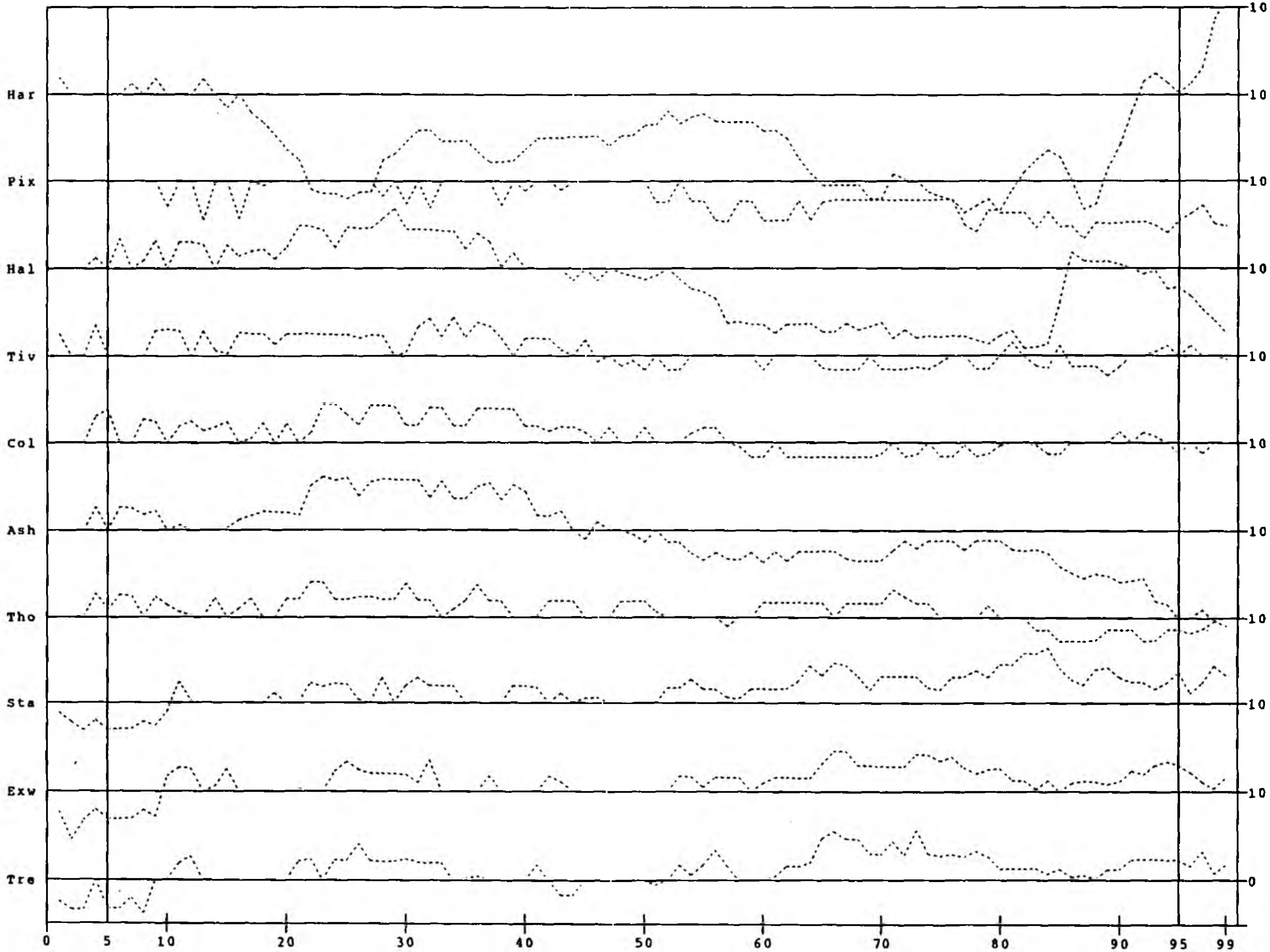
Flow
BOD
Ammonia
Nitrate
DO
Temperature
pH

Flow 1990

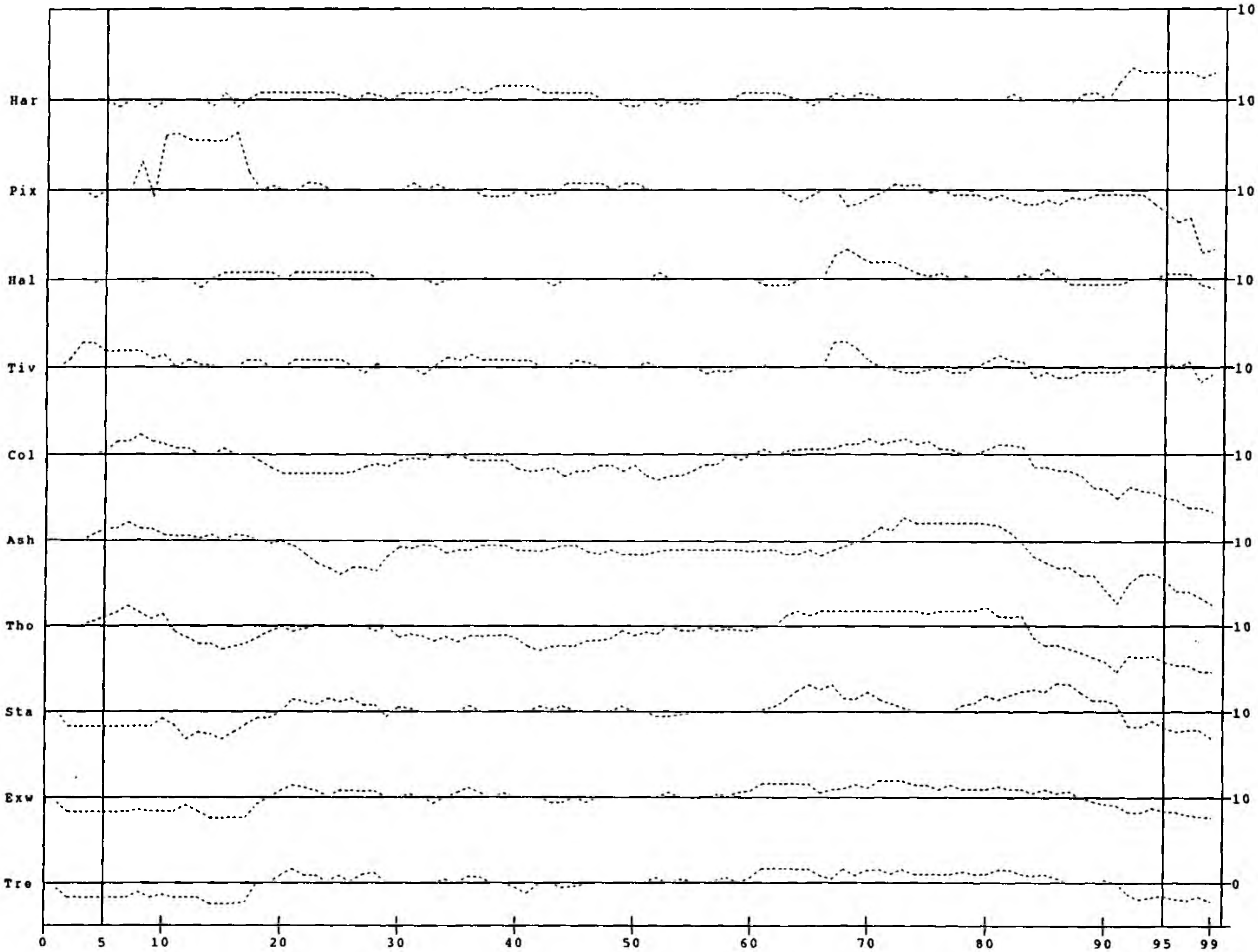


Har
Pix
Hal
Tiv
Col
Ash
Tho
Sta
Exw
Tre
50
50
50
50
50
50
50
50
50
50
0
0
5
10
20
30
40
50
60
70
80
90
95
99

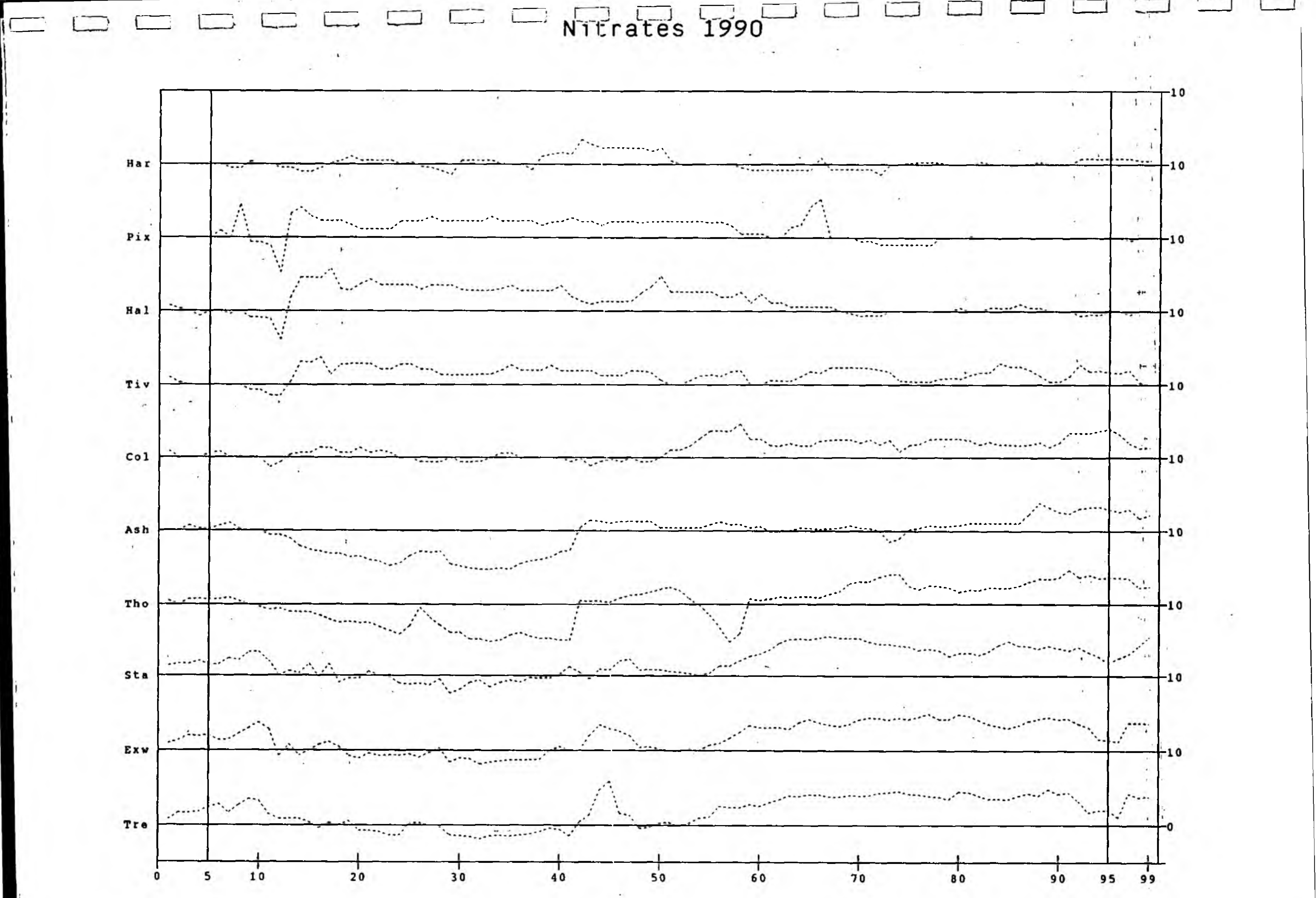
Ammonia 1990



BOD 1990

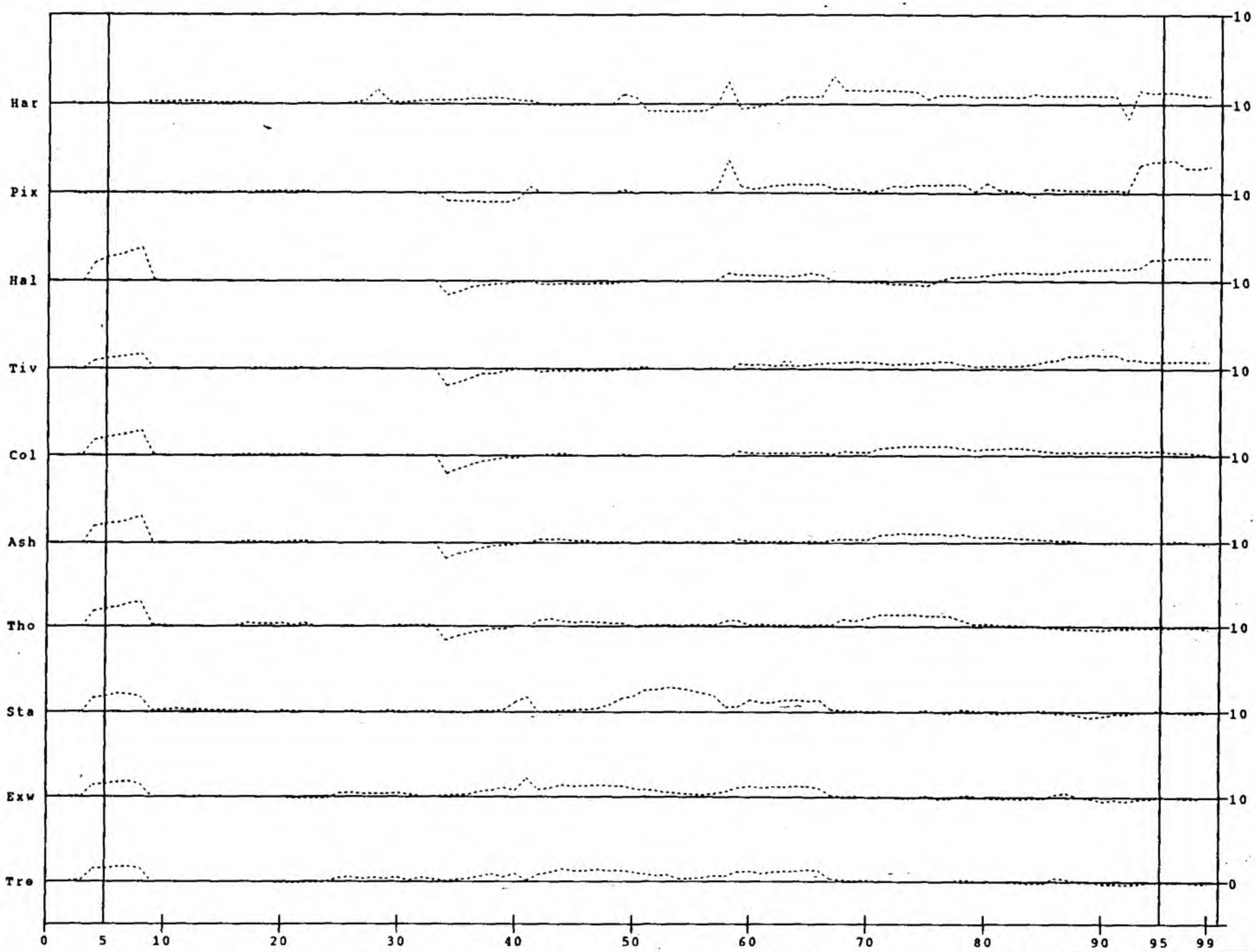


10
Har
10
Pix
10
Hal
10
Tiv
10
Col
10
Ash
10
Tho
10
Sta
10
Exw
10
Tre
0
0
5
10
20
30
40
50
60
70
80
90
95
99



Nitrates 1990
Har
Pix
Hal
Tiv
Col
Ash
Tho
Sta
Exw
Tre
10
0
0 5 10 20 30 40 50 60 70 80 90 95 99

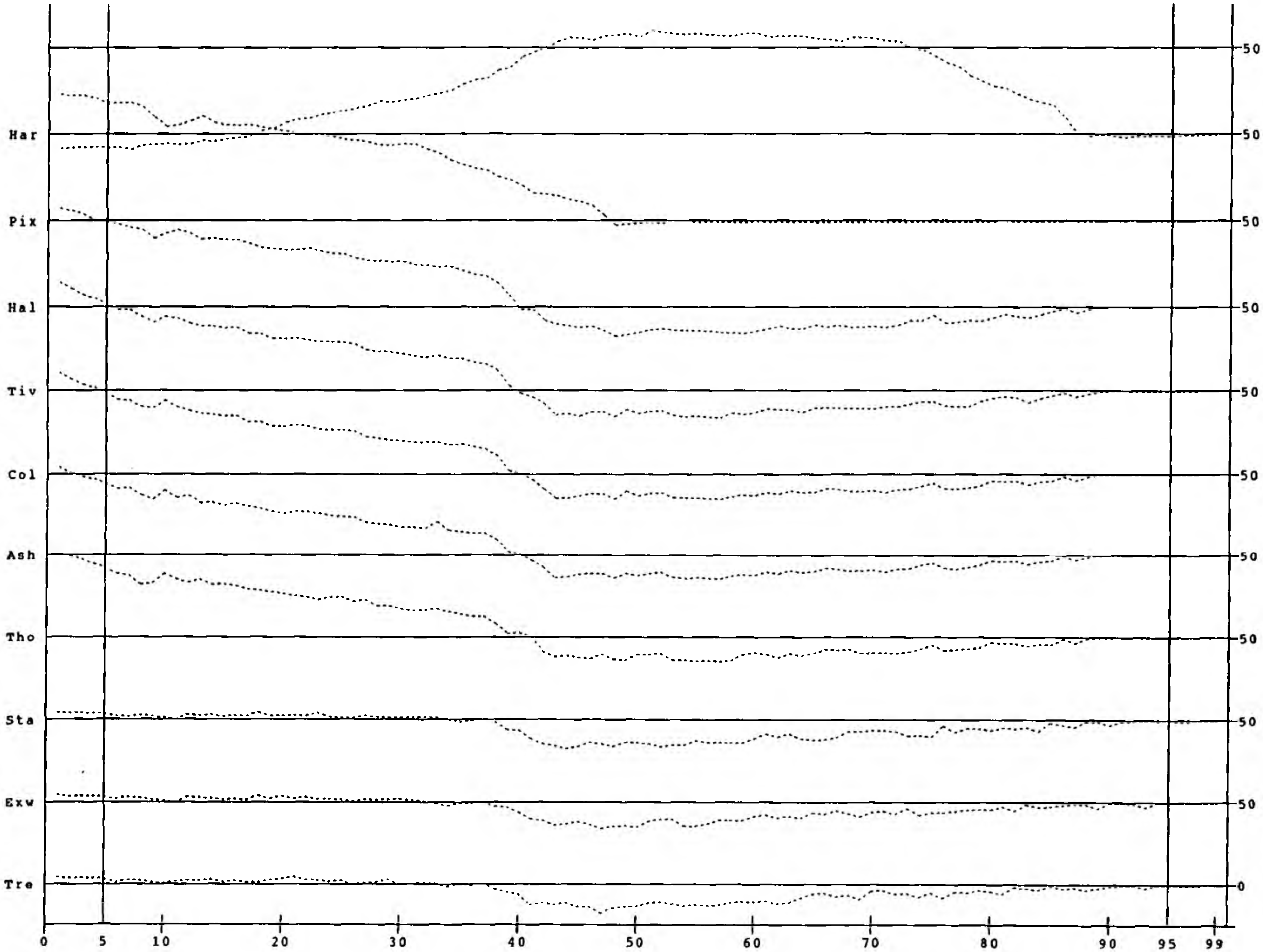
Temperature 1990



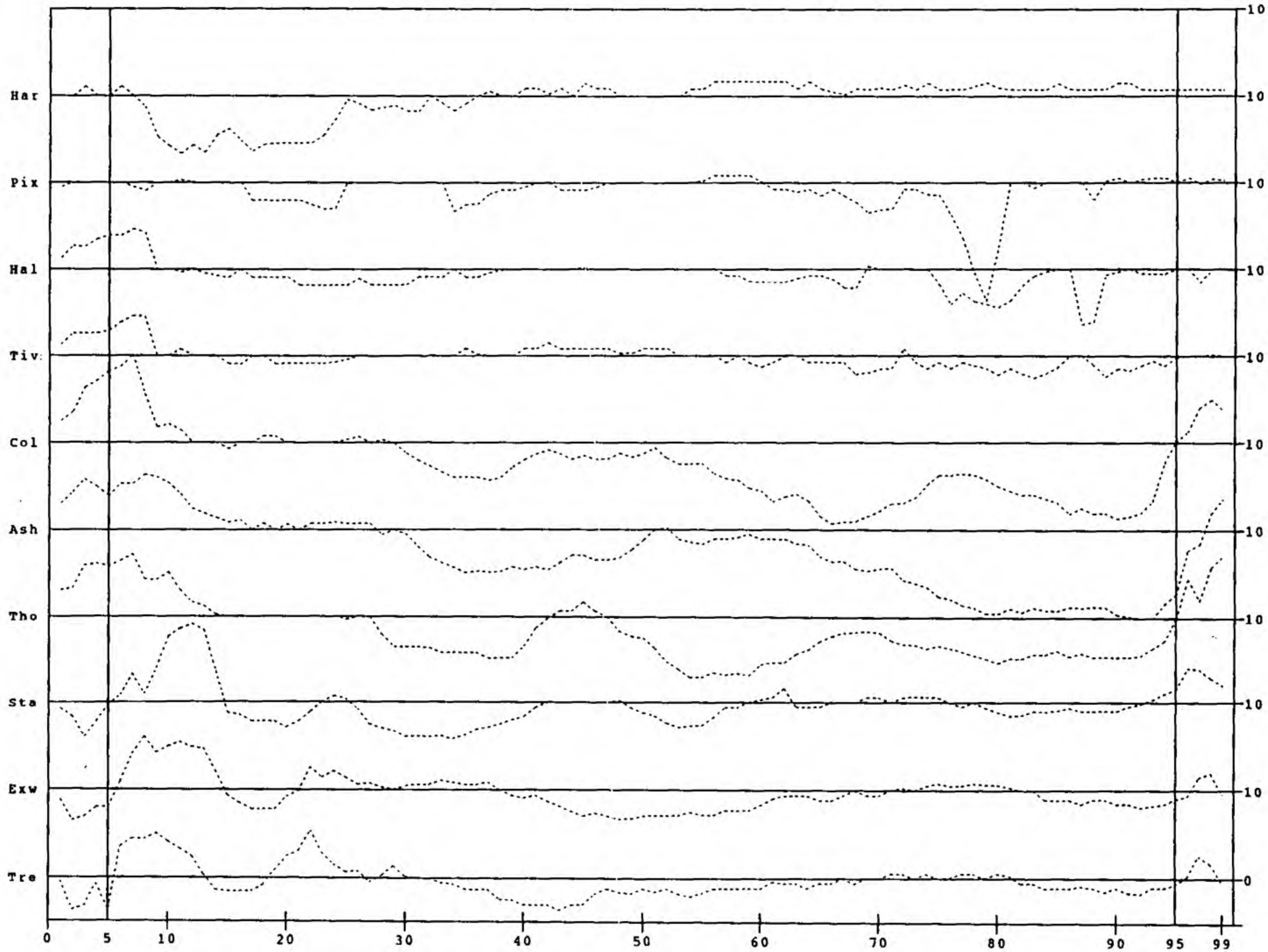
Appendix C Profiles for 1976

- Flow
- BOD
- Ammonia
- Nitrate
- DO
- Temperature
- pH

Flow 1976

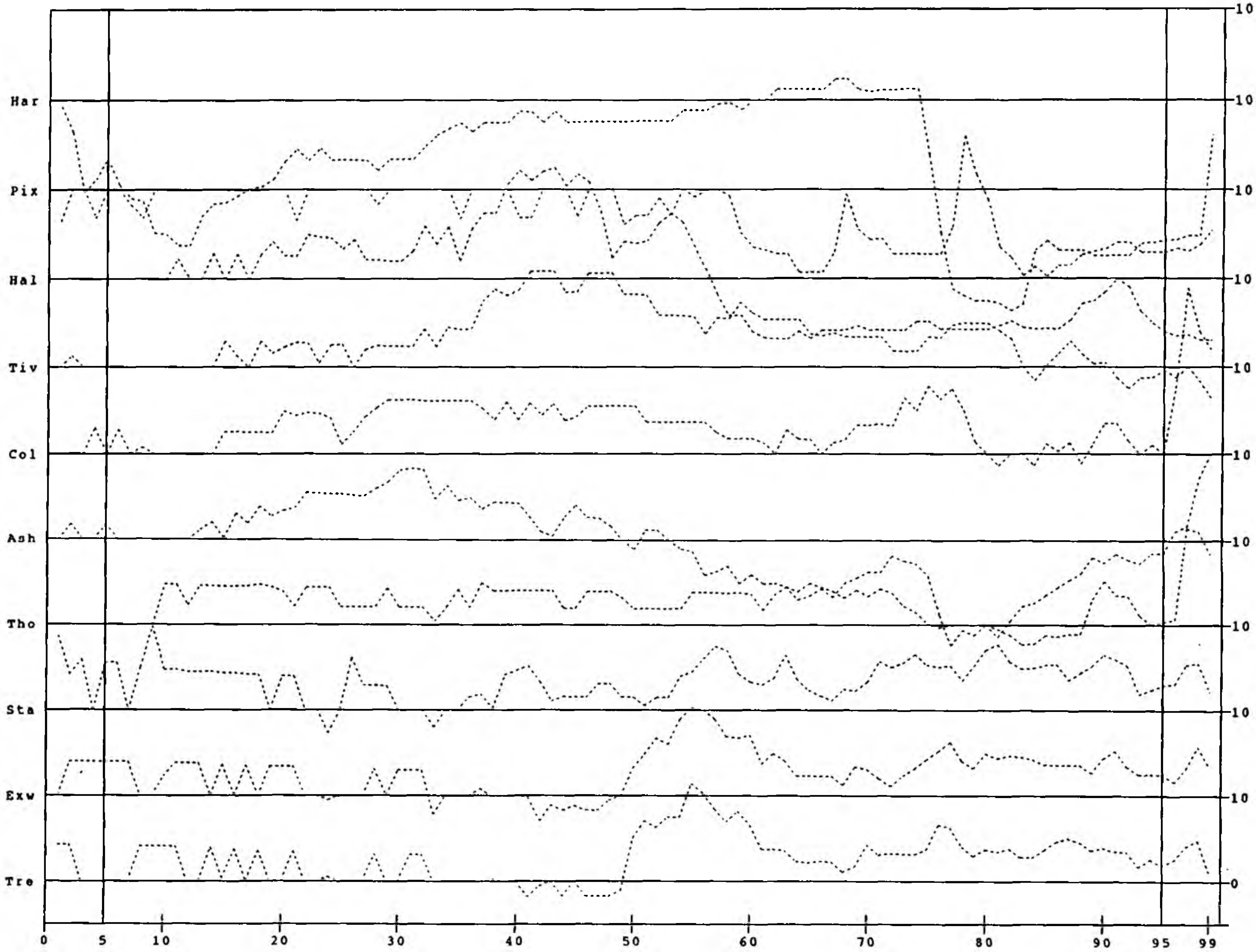

Har
Pix
Hal
Tiv
Col
Ash
Tho
Sta
Exw
Tre
50
50
50
50
50
50
50
50
50
50
0
0
5
10
20
30
40
50
60
70
80
90
95
99

BOD 1976

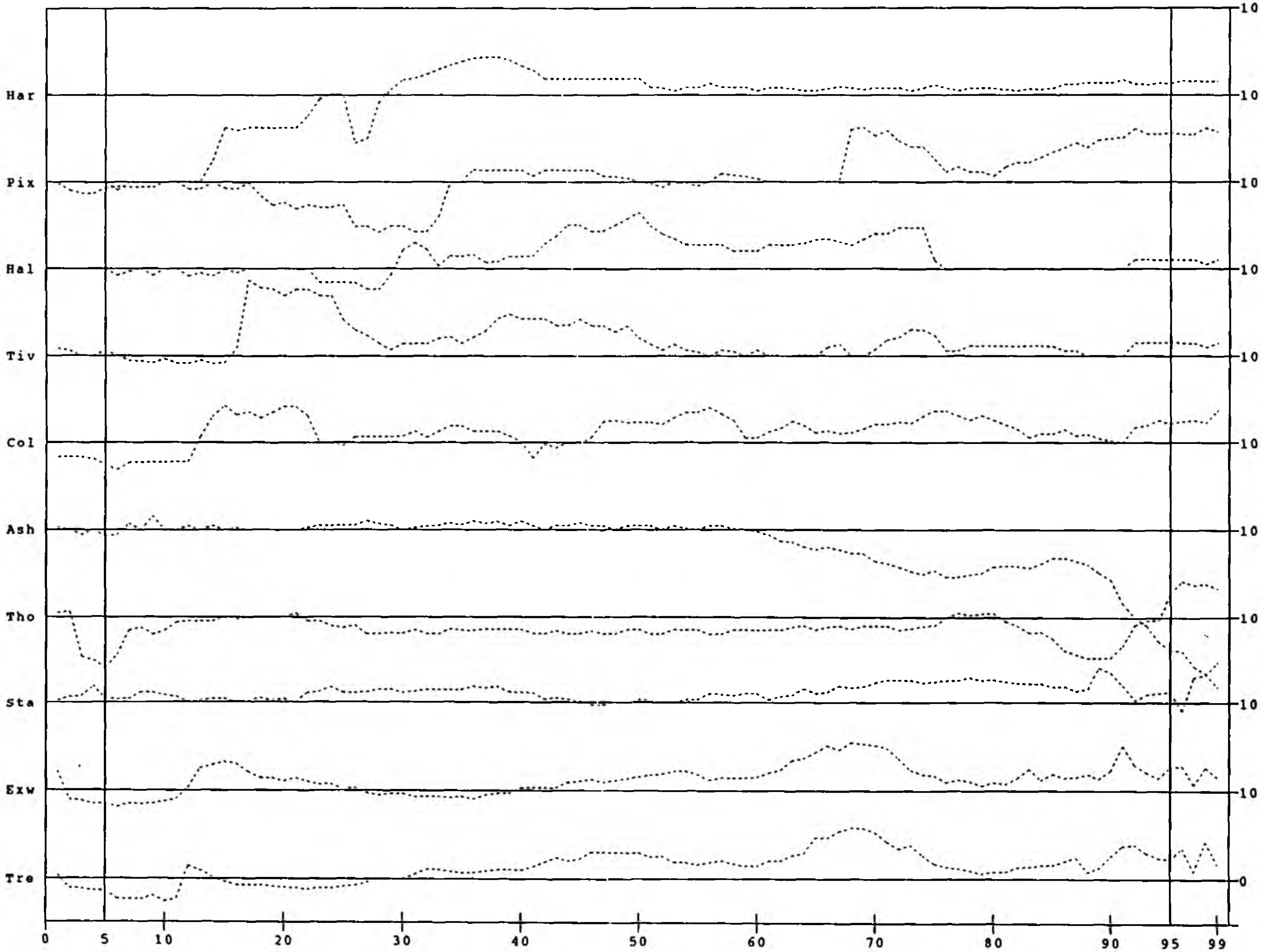


Har
Pix
Hal
Tiv
Col
Ash
Tho
Sta
Exw
Tre
0 5 10 20 30 40 50 60 70 80 90 95 99
10
10
10
10
10
10
10
10
10
10
0

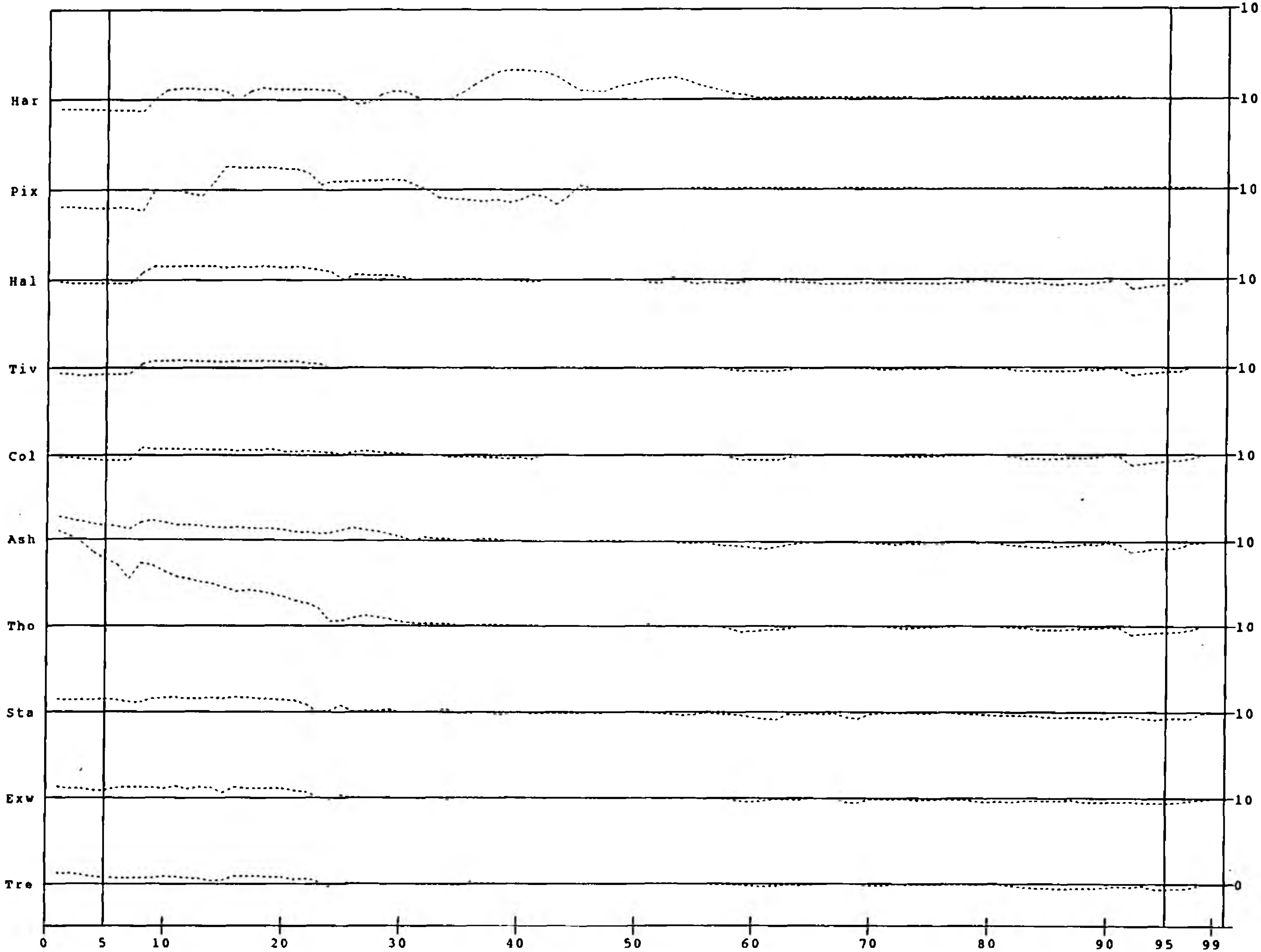
Ammonia 1976



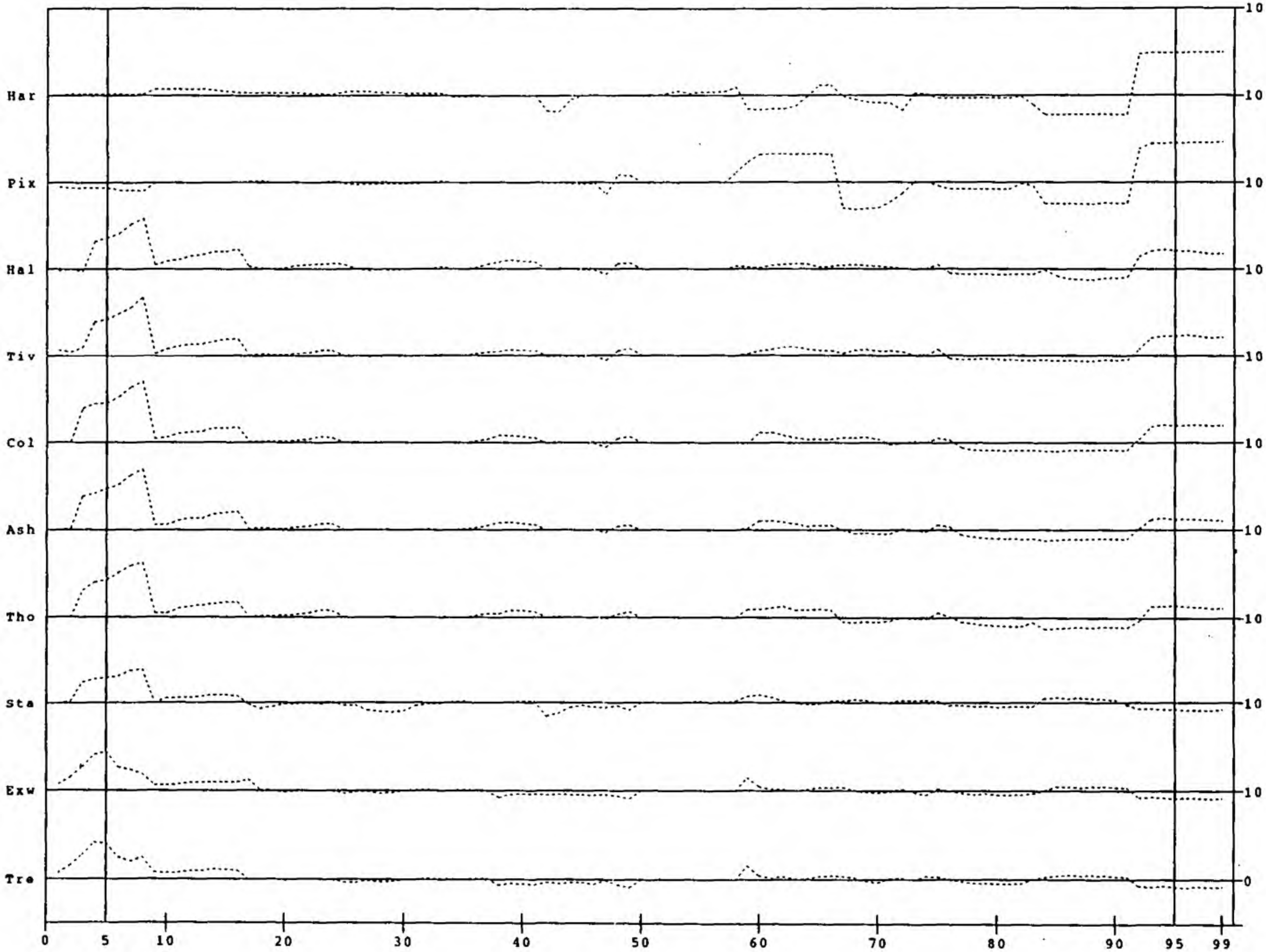
Nitrates 1976



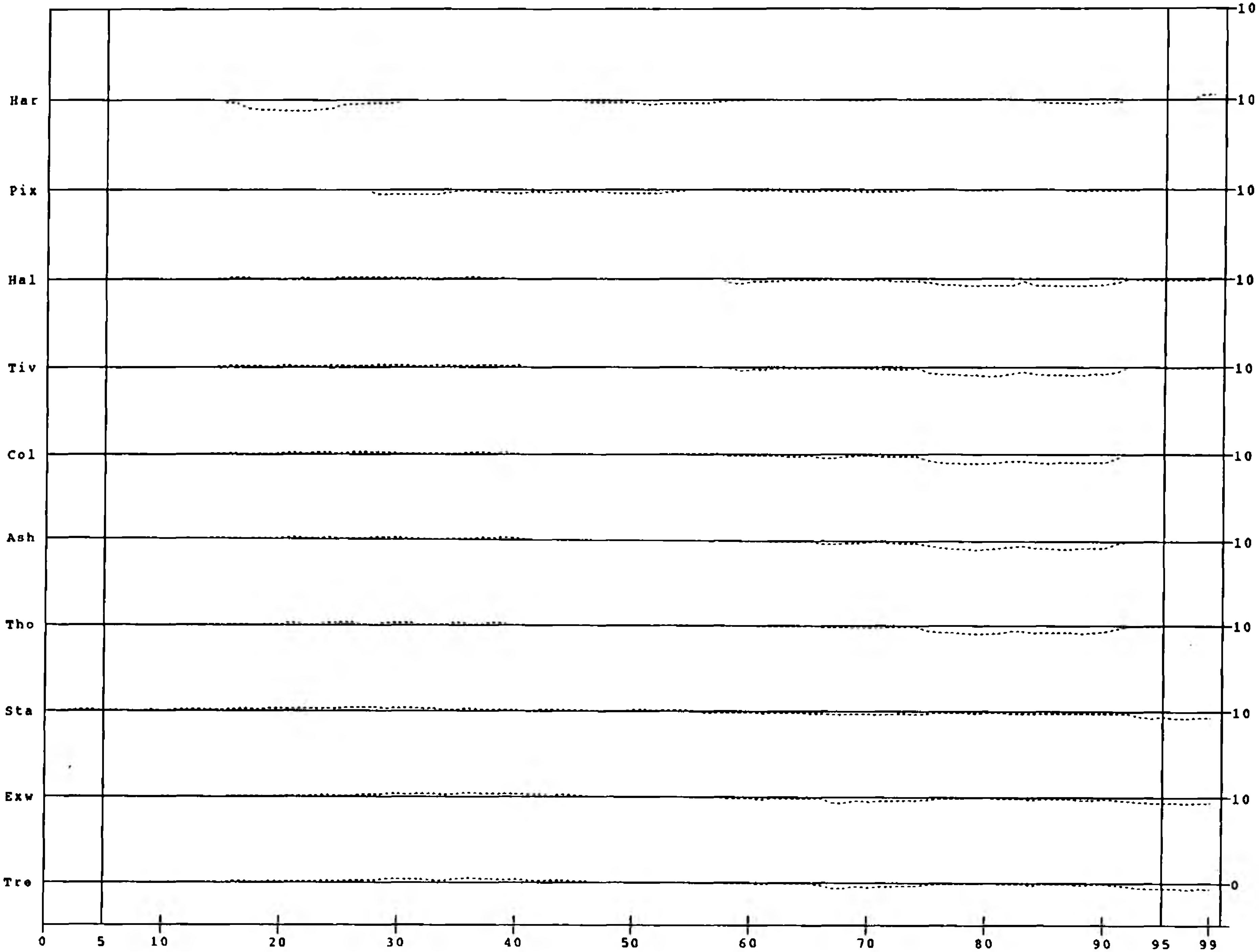
Dissolved Oxygen 1976



Temperature 1976



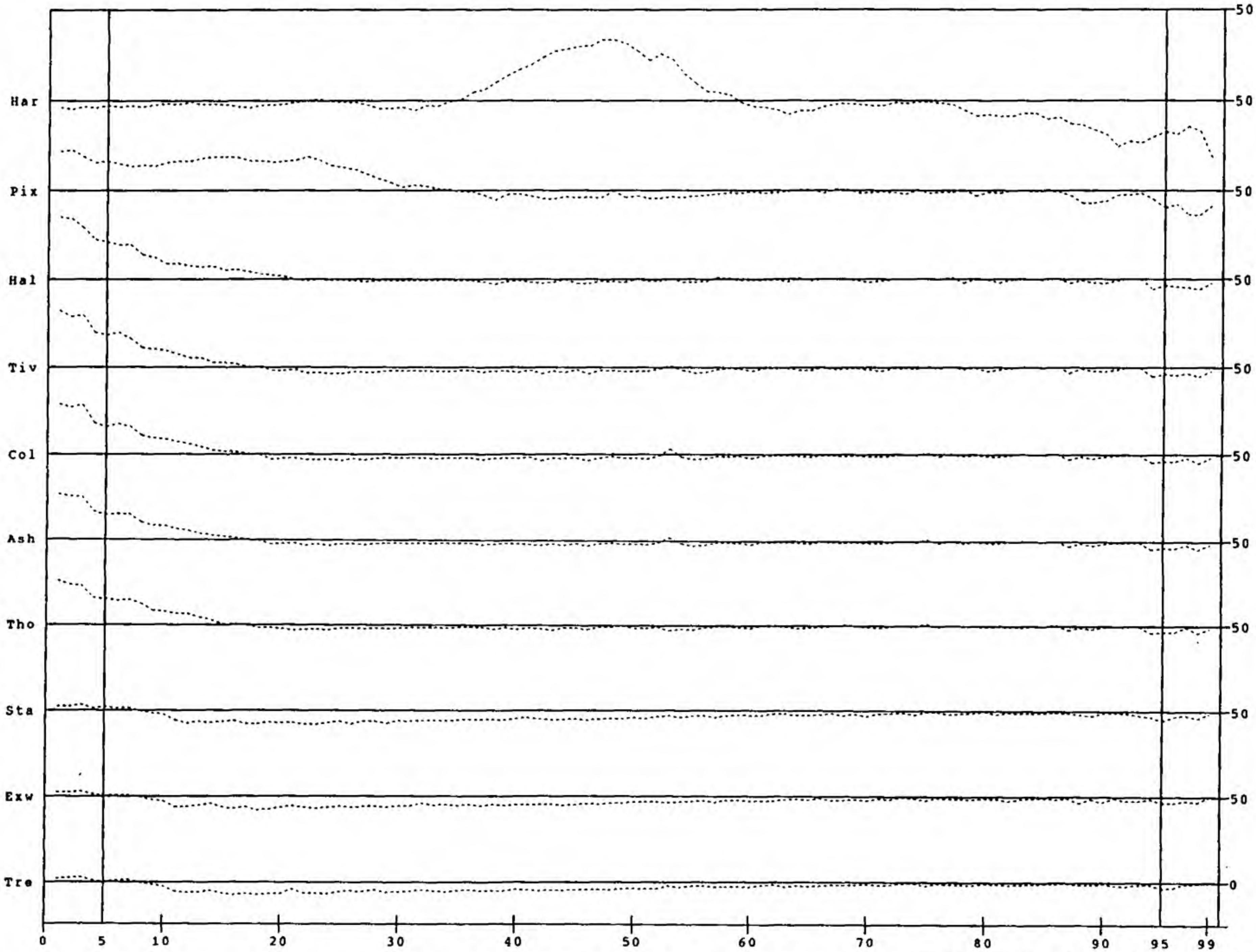
pH 1976

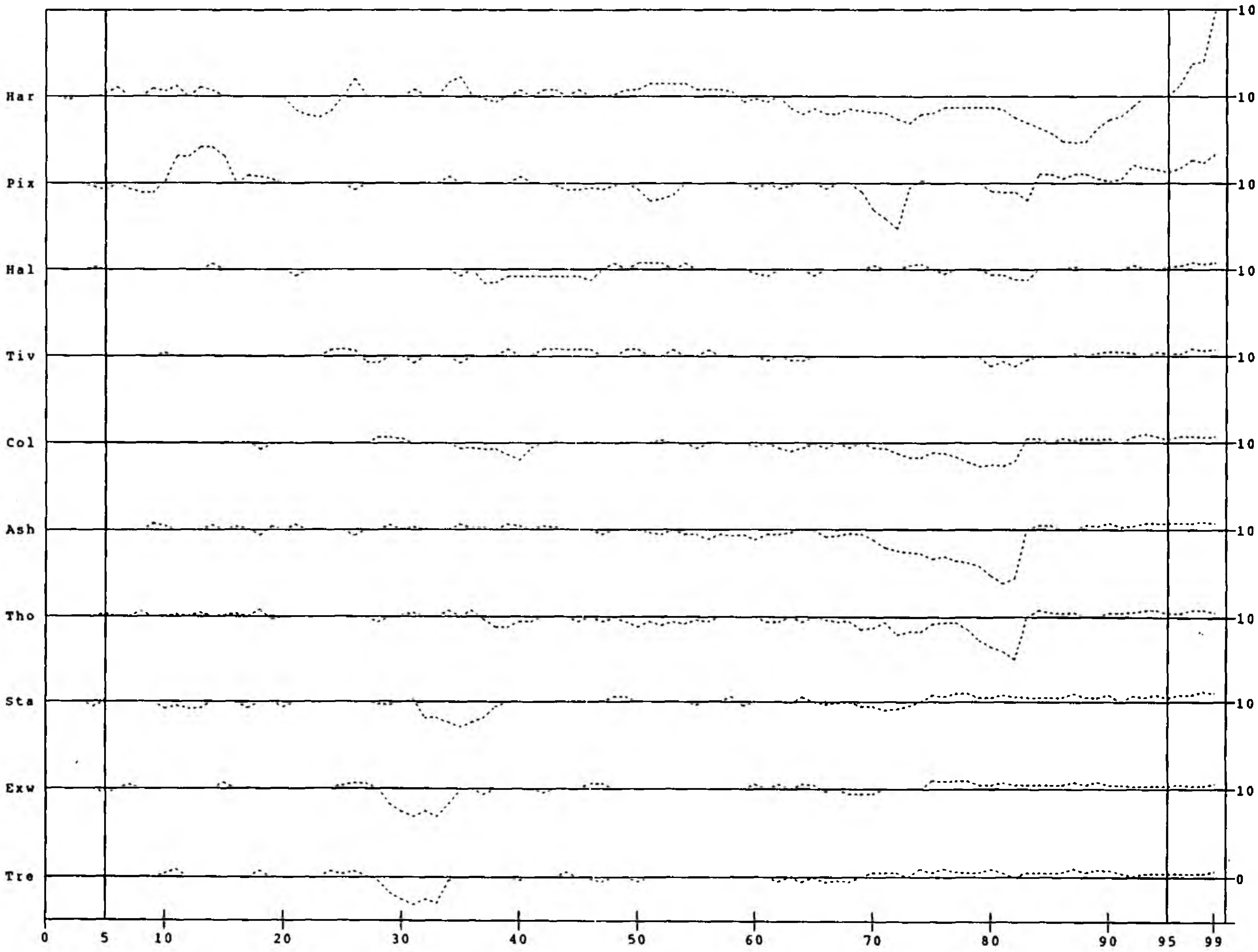

Har
Pix
Hal
Tiv
Col
Ash
Tho
Sta
Exw
Tre
10
0
0
5
10
20
30
40
50
60
70
80
90
95
99

Appendix D Profiles for 1986

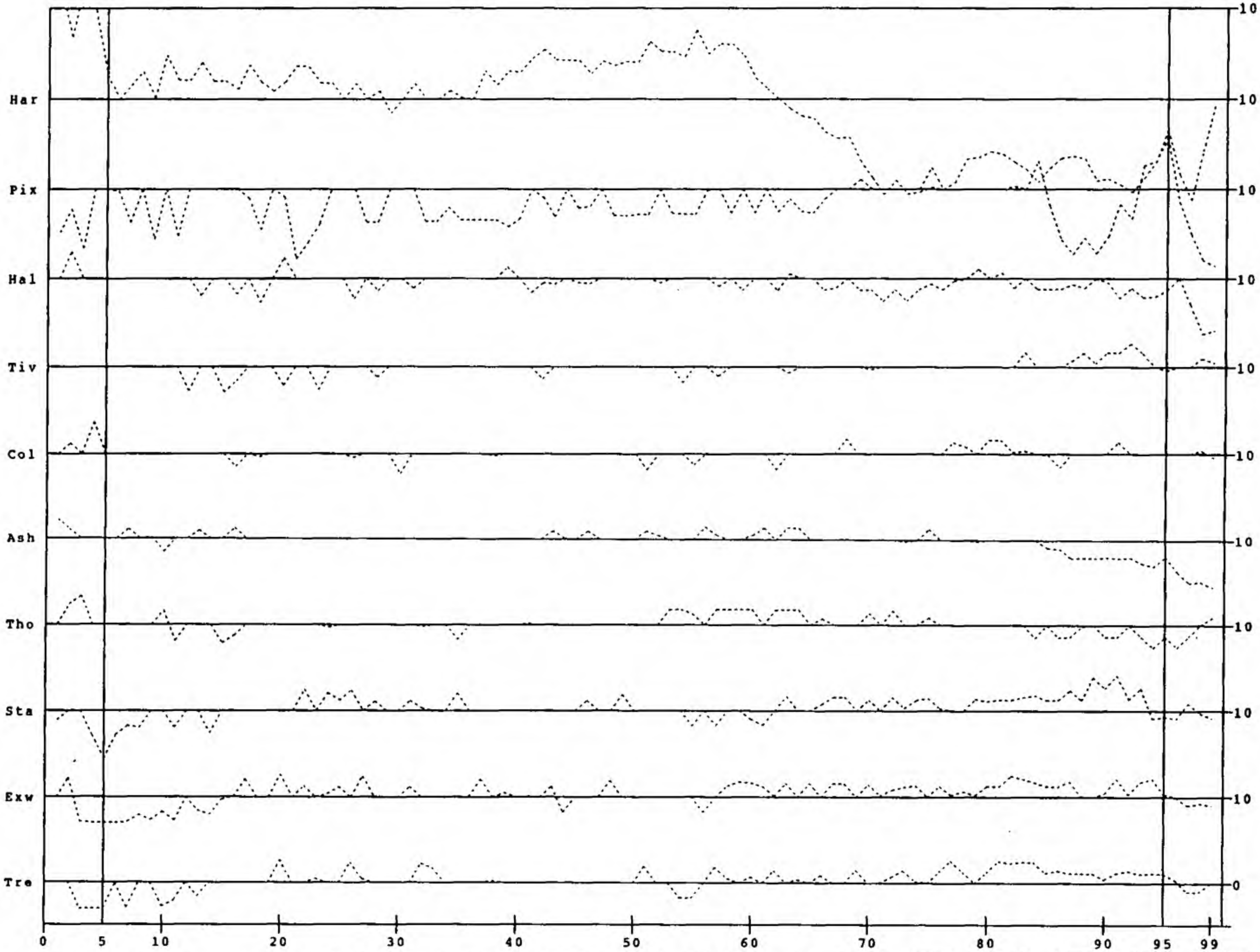
- Flow
- BOD
- Ammonia
- Nitrate
- DO
- Temperature
- pH

Flow 1986

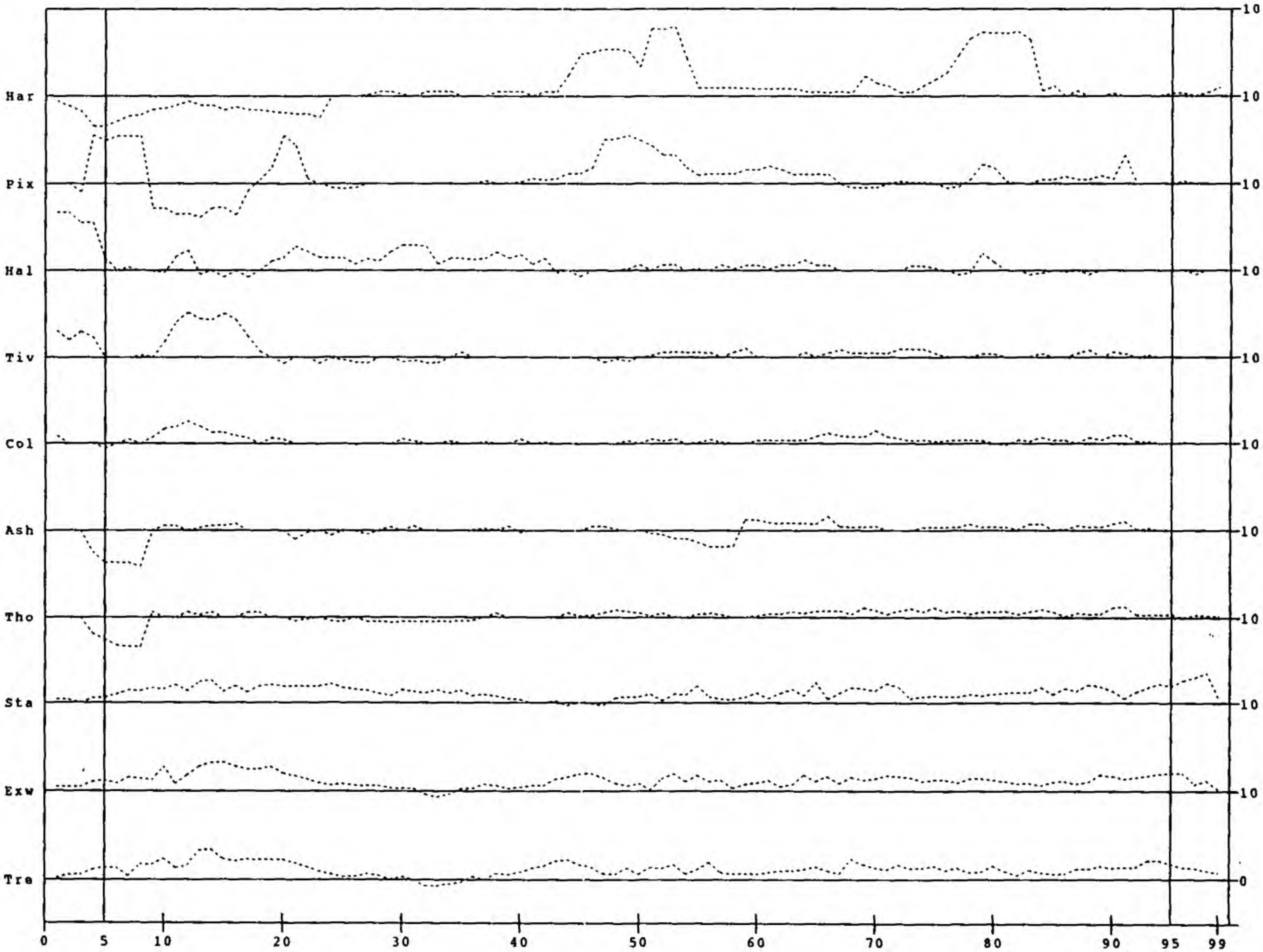

Har
Pix
Hal
Tiv
Col
Ash
Tho
Sta
Exw
Tre
50
0
0
5
10
20
30
40
50
60
70
80
90
95
99


Har
Pix
Hal
Tiv
Col
Ash
Tho
Sta
Exw
Tre
10
0
0 5 10 20 30 40 50 60 70 80 90 95 99

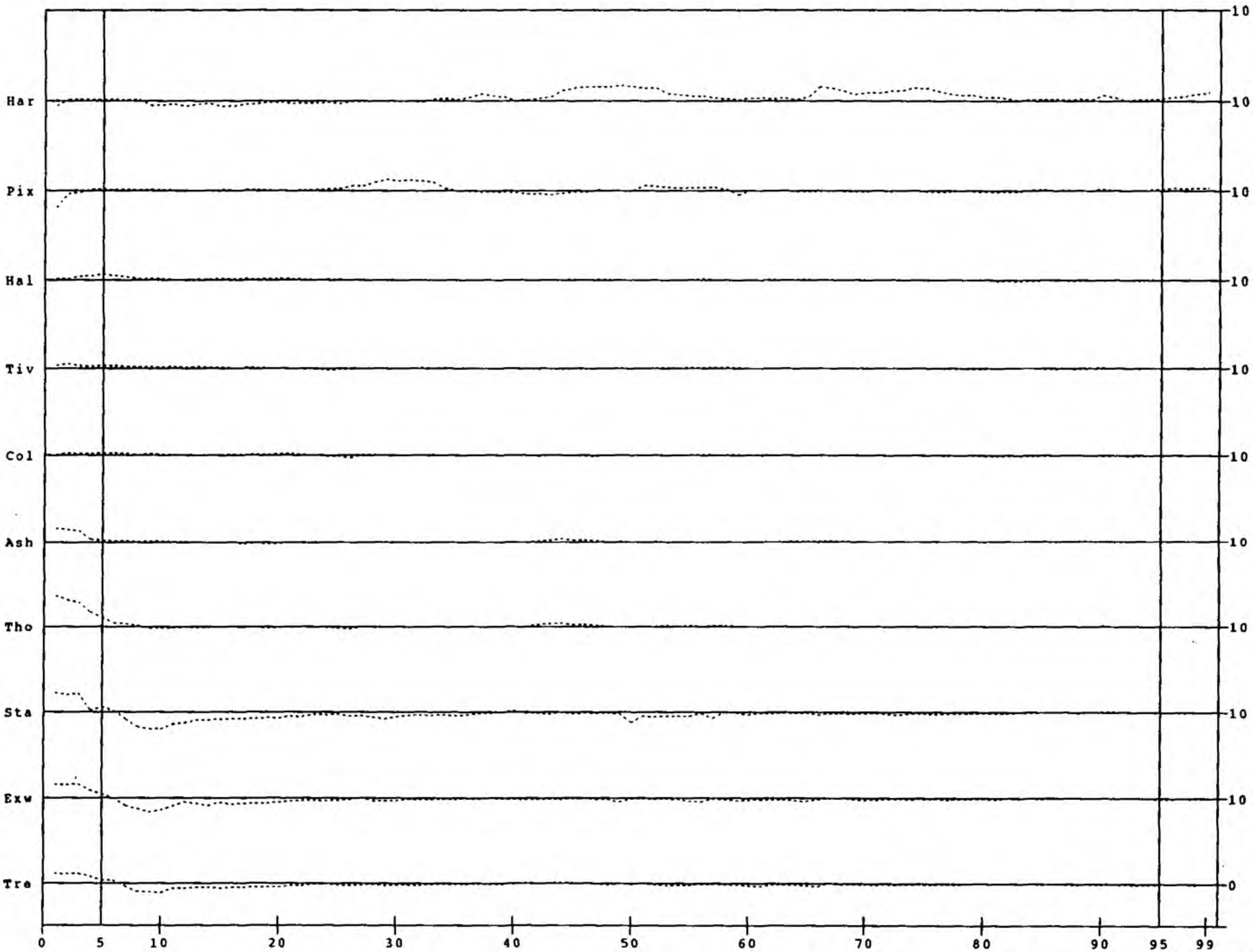
Ammonia 1986



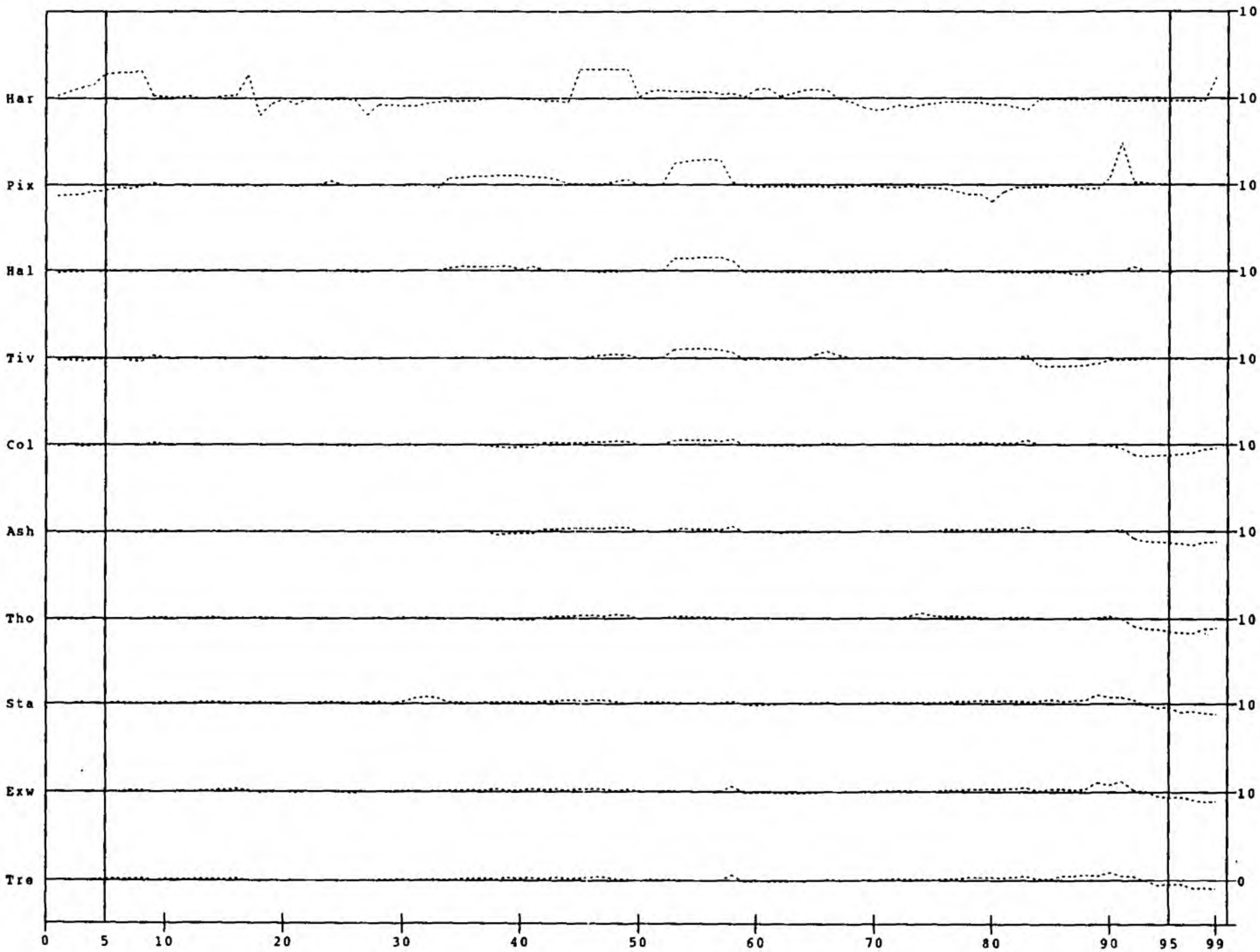
Nitrates 1986



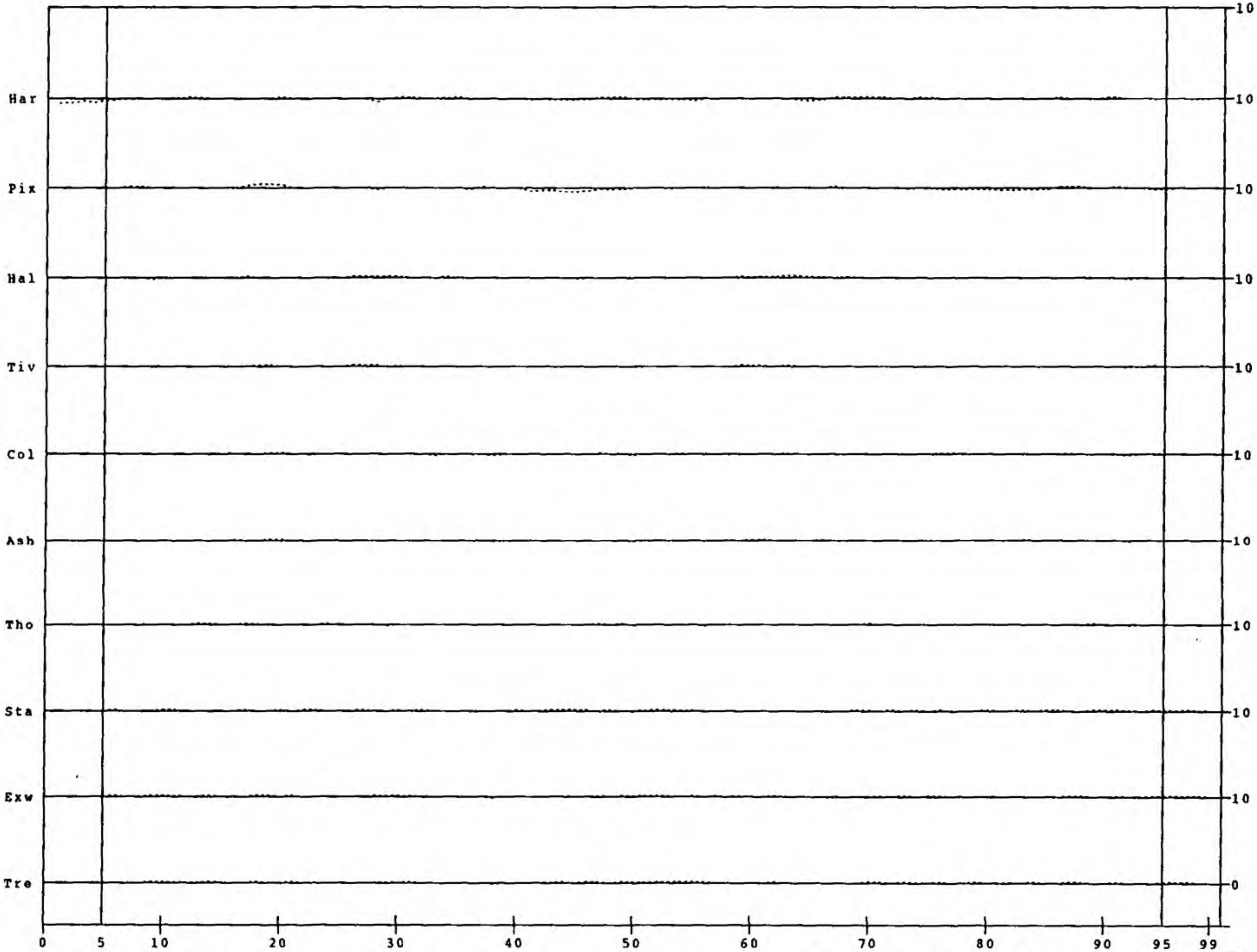
Dissolved Oxygen 1986



Temperature 1986



pH 1986


Har
Pix
Hal
Tiv
Col
Ash
Tho
Sta
Exw
Tre
10
0
0 5 10 20 30 40 50 60 70 80 90 95 99