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AUTOMATIC RIVER QUALITY MONITORING

A thesis submitted for the degree of Doctor of Philosophy

Volume 2 Appendices.

by

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APPENDIX 2

Griffiths, 1988. River Quality Monitoring by Satellite.

River quality monitoring by satellite

Martin Griffiths

THREE MOBILE automatic river quality monitoring stations used by Thames Water to monitor pollution problems have been fitted with satellite communication equipment.

The stations, built to the authority's specification by pHox Systems UK, have proved useful in monitoring a variety of problems which include the commissioning of sewage treatment works, the tracing of intermittent pollution problems, an investigation of rising sludge in a flood relief channel and monitoring the effects of a malfunctioning sewage treatment works on the river. Detailed information can be collected at problem areas, during pollution incidents, for project works and in areas of high or intermittent pollution risk. Their deployment has been particularly useful in studying short to medium term problems, especially where unpredictable variations in river quality can be characterised only by 24 hour monitoring. They have become a valuable supplement to the manual sampling effort and the existing network of fixed automatic water quality monitors.

Dissolved oxygen, temperature, conductivity, pH, suspended solids, nitrate and ammonia are monitored. Water is drawn via a submersible pump through a wedgewire filter before being monitored. The equipment is mounted on a twin axled box trailer which can be towed by a medium sized car or Landrover. The stations require a 240volt power supply.

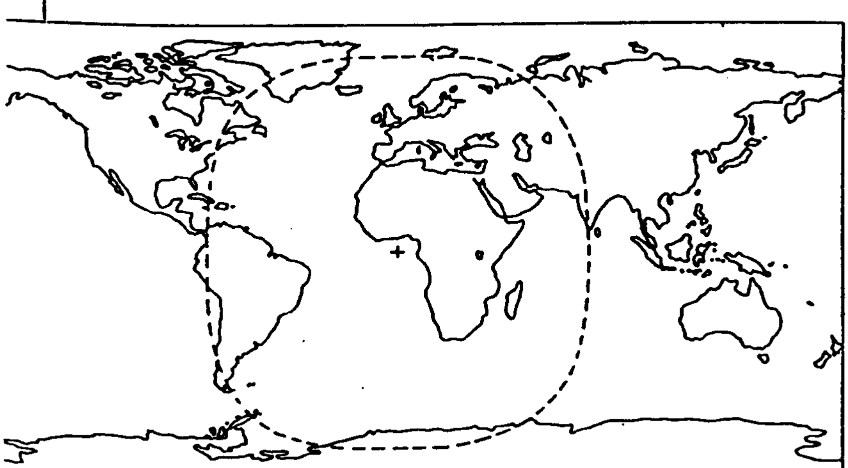
The stations operate in an intermittent sampling mode, normally sampling at hourly intervals. This principle has been developed by the authority and offers significant advantages over conventional continuous operation. Pump wear and blockages are minimised and sensor fouling is reduced. The reagent consumption of the specific ion monitors, which measure ammonia and nitrate, is reduced significantly. This not only lengthens the servicing intervals but also increases reliability. Running costs, of which manpower is most significant, are reduced considerably. This mode of operation has been applied to all fixed and mobile river monitoring sites operated by Thames Water.

The intermittent operation is controlled by a sequencer/timer. Instruments are kept in a standby condition but are turned on before a measurement is taken. The pump is triggered for five minutes, at the end of which time readings are taken from the sensors and logged. Sampling interval is usually one hour but can be varied according to the inherent variability of the river. The sequencer also initiates an autoclean and calibration cycle at 12.15hrs each day. If a satellite communication system is being used the sequencer can be synchronised by electrical pulses generated by the accurate satellite clock. This coordinates the sampling and data logging.

The satellite data transmission system is proving to be very useful for this application and has considerable potential for other related projects. Telemetry from remote sites, usually in river valleys which are often screened by trees and buildings, is a common problem for the water industry. At such temporary sites telephone lines are rarely available and tall radio telemetry masts are not practicable. The satellite systems can overcome this by directing a relatively low power signal skywards to a satellite which then reflects the signal back to a receiving station. A small omni-directional aerial 40cm long by 8cm diameter is mounted on the roof of the monitor.

This requires no alignment and is not as vulnerable to vandalism as a conventional satellite aerial. The mobile monitors use a communication system produced by Space Technology Systems Limited based in Hampshire. This uses a geostationary satellite, normally Meteosat, to relay the data, via the European Space Agency ground station in Germany to a receiver dish on the roof of the authority's Reading headquarters. Here a satellite receiver/decoder collects the information and passes it to a printer and microcomputer.

The satellite's primary function is to produce the familiar weather pictures but it also has a number of communications transponder facilities. In simplistic terms the system

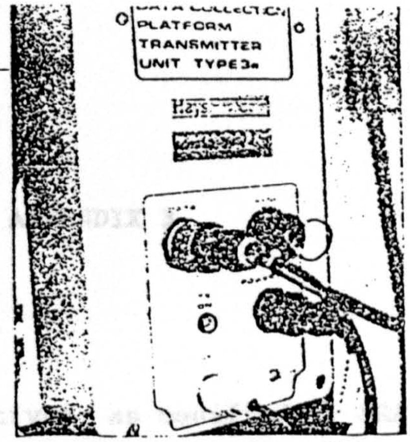


The Meteosat satellite telemetry coverage area uses the satellite as a mirror, reflecting signals back to receivers on earth. The data transmissions are separated by accurate time slots which are controlled by ESA. For this application Thames Water has requested time slots at approximately 04.00 and 16.00 GMT. This enables data to be available at the start, and before the end, of the normal working day and has proved adequate for all applications to date.

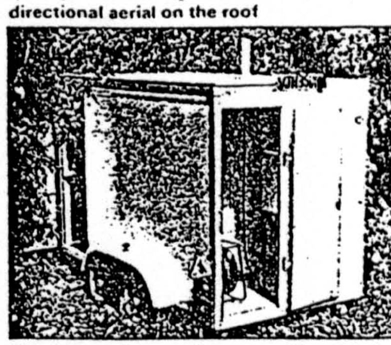
WATER QUALITY information, measured by the sensors at hourly intervals, is collected by a data collection platform prior to transmission. The DCP can collect data from five analogue channels. The five parameters to be transmitted are chosen according to the nature of the investigation. Data is stored by the DCP prior to transmission at the specified timeslot.

An accurate clock within the DCP transmits the stored data at the allocated time precisely. Station addresses, sampling frequency and transmission times can be changed using a synchronising device. The synchroniser can also be used to programme 'alert' thresholds which override set time slots. With this facility alarm messages can be transmitted as soon as an alarm condition (eg low dissolved oxygen or high ammonia) is detected, enabling appropriate action to be taken.

Before opting for this system a survey of other satellite systems was undertaken. The Argos system, often used for marine research, was the other major contender. It uses two Noaa satellites in polar orbit and can be used to track floating buoys and collect quality information. The data is continuously transmitted from the outstations and is collected by the satellites when overhead. The data is then retransmitted when the satellite passes the ground station. Because two satellites in different orbits are used positional information can be calculated. The Argos system does not restrict transmission of information to time slots but availability of data is dependent upon the orbiting times of the satellites. The DCP is less complicated and is cheaper but there is a substantial cost for using the system. Because Britain contributes to ESA, use of the Meteosat system is free for the capture of environmental data by 'Government services'. This system is one of the valuable 'spin-offs' from our contribution to the



Above: Data collection platform which logs and transmits data. Below: Mobile water quality monitoring station with omni-directional aerial on the roof



European Space Agency. Should the UK Government withdraw support then projects such as this may be jeopardised.

Meteosat is located over the equator and the Greenwich meridian. It is interesting to speculate that should Thames Water International consultancy service require water quality data from Europe, Africa, the Middle East or South America, a mobile monitor fitted with a satellite transmission system could transmit data directly to a receiver in Reading.

Over the past three years the mobile monitors have made a valuable contribution to our understanding of sensitive pollution problems. The addition of the satellite telemetry system not only provides daily access to river quality information but also enables faults to be recognised and rectified, thus improving reliability. The principles of operation have been well tried in the network of fixed monitoring stations and an effective, minimum maintenance system is now operational. Early problems with the satellite system have been largely overcome and future developments to consolidate the system will include integration with the regional telemetry system and improvements in data presentation.

Martin Griffiths is technical coordinator, quality control, regulation and monitoring, Thames Water.

APPENDIX 3

River Quality Objectives, as modified by NRA-TR.

River Quality Standards, as modified by NRA-TR.

River Quality Objectives

Class 1A – High quality waters

1. Suitable for potable supply at defined abstraction points, and
2. Suitable for all other abstractions, and
3. Suitable for game or other high class fisheries, (complying with the requirements of Directive 78/659/EEC for salmonid waters), and
4. Of high amenity value.

Class 1B – High quality waters

1. Used for the transport of high proportions of sewage effluent, trade effluent or urban run–off, and
2. Suitable for potable supply at defined abstraction points, and
3. Suitable for all other abstractions, and
4. Suitable for game or other high class fisheries, (complying with the requirements of Directive 78/659/EEC for salmonid waters), and
5. Of high amenity value.

Class 2A – Fair quality waters

1. Suitable for potable supply after advanced treatment at defined abstraction points, and
2. Suitable for agricultural uses, and
3. Capable of supporting good coarse fisheries, (complying with Directive 78/659/EEC for cyprinid waters), and
4. Of moderate amenity value.

Class 2B – Fair quality waters

1. Suitable for potable supply after advanced treatment at defined abstraction points, and
2. Suitable for agricultural uses, and
3. Capable of supporting reasonably good coarse fisheries, and
4. Of moderate amenity value.

Class 3 – Poor quality waters

1. Suitable for low grade industrial use, and
2. Not anaerobic or likely to cause a nuisance, and
3. Capable of supporting a restricted aquatic flora and fauna.

N.B. Not required to be capable of supporting a viable fishery.

Class 4 – Bad quality waters

1. Likely to cause a nuisance.
2. Flora and fauna absent or restricted to pollution tolerant organisms.

Class X – Insignificant watercourses

1. Watercourses, not usable, and not placed in Classes 1A to 4 above.
2. Capable of supporting a restricted flora and fauna, and
3. Not likely to cause a nuisance.

NATIONAL RIVERS AUTHORITY, THAMES REGION

RIVER QUALITY STANDARDS (FRESH WATER)

Notes:

1. Figures in parenthesis are guidelines only, to be used in setting discharge quality standards.
2. Standards are expressed in the units specified in source documents.
3. Where standards for zinc and copper are given for specific levels of hardness rather than for a range of hardness, standards for intermediate values of hardness should be calculated by linear interpolation between the tabulated figures.
4. An asterisk (*) denotes values interpolated as above from values in the source document.

Sources of Standards:

Standards have been drawn from the following sources:

a) National Water Council Classification of River Quality (1978).

b) European Inland Fisheries Advisory Commission (EIFAC)

c) European Community Directive 78/659/EEC on the quality of fresh waters needing protection or improvement in order to support fish life.

d) European Community Directive 76/464/EEC on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community, and related Directives.

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NATIONAL RIVERS AUTHORITY, THAMES REGION - RIVER QUALITY STANDARDS (FRESH WATER)

DETERMINAND		UNITS	CLASS 1A MEAN	50%ile	95%ile	MAX	
Dissolved oxygen (min)		%sat.			80		
Dissolved oxygen (min)		mg/l		9			
BOD (ATU) 5 day		mg/l	(1.5)		3		
Ammonia as NH4		mg/l			0.4		
Ammonia, non-ionized as NH3		mg/l			0.025		
Suspended solids (105 deg C)		mg/l		(25)			
pH					6-9		
Nitrite as NO2		mg/l			(0.2)		
Cadmium		ug/l	5				LIST 1 substances
Mercury		ug/l	1				
Hexachlorocyclohexane		ug/l	0.1				
Carbon tetrachloride		ug/l	12				
Para-para DDT		ng/l	10				
DDT		ng/l	25				
Pentachlorophenol		ug/l	2				
Hexachlorobenzene		ug/l	0.03	from 01/1990			
Hexachlorobutadiene		ug/l	0.1	from 01/1990			
Chloroform		ug/l	12	from 01/1990			
Aldrin		ng/l	10	from 01/1994		) 1/1989 total 'drins	
Dieldrin		ng/l	10	from 01/1994		) <- 30ng/l	
Endrin		ng/l	5	from 01/1994		) & endrin	
Isodrin		ng/l	5	from 01/1994		) <- 5 ng/l	
Arsenic		ug/l	50				LIST 2 substances
Chromium	hardness 0-50	ug/l	5				
	50-100	ug/l	10				
	100-200	ug/l	20				
	>200	ug/l	50				
Copper	hardness 0	ug/l	1				
	10	ug/l	*2		(5)		
	50	ug/l	6		(22)		
	100	ug/l	10		(40)		
	200	ug/l	10		*(76)		
	250	ug/l	28		*(94)		
	>300	ug/l	28		(112)		
Lead	hardness 0-50	ug/l	4				
	50-150	ug/l	10				
	>150	ug/l	20				
Nickel	hardness 0-50	ug/l	50				
	50-100	ug/l	100				
	100-200	ug/l	150				
	>200	ug/l	200				
Zinc	hardness 0	ug/l	8				
	10	ug/l	*16		30		
	50	ug/l	50		200		
	100	ug/l	75		300		
	200	ug/l	75		*350		
	250	ug/l	125		*375		
	>500	ug/l	125		500		

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NATIONAL RIVERS AUTHORITY. THAMES REGION - RIVER QUALITY STANDARDS (FRESH WATER)

CLASS 1B

DETERMINAND		UNITS	MEAN	50%ile	95%ile	MAX	
Dissolved oxygen (min)		%sat.			60		
Dissolved oxygen (min)		mg/l		9			
BOD (ATU) 5 day		mg/l	(2)		5		
Ammonia as NH4		mg/l	(0.5)		0.9		
Ammonia, non-ionized as NH3		mg/l			0.025		
Suspended solids (105 deg C)		mg/l		(25)			
pH					6-9		
Nitrite as NO2		mg/l			(0.2)		
Cadmium		ug/l	5				LIST 1 substances
Mercury		ug/l	1				
Hexachlorocyclohexane		ug/l	0.1				
Carbon tetrachloride		ug/l	12				
Para-para DDT		ng/l	10				
DDT		ng/l	25				
Pentachlorophenol		ug/l	2				
Hexachlorobenzene		ug/l	0.03	from 01/1990			
Hexachlorobutadiene		ug/l	0.1	from 01/1990			
Chloroform		ug/l	12	from 01/1990			
Aldrin		ng/l	10	from 01/1994		) 1/1989 total 'drins	
Dieldrin		ng/l	10	from 01/1994		) <= 30ng/l	
Endrin		ng/l	5	from 01/1994		) & endrin	
Isodrin		ng/l	5	from 01/1994		) <= 5 ng/l	
Arsenic		ug/l	50				LIST 2 substances
Chromium	hardness 0-50	ug/l	5				
	50-100	ug/l	10				
	100-200	ug/l	20				
	>200	ug/l	50				
Copper	hardness 0	ug/l	1				
	10	ug/l	*2		(5)		
	50	ug/l	6		(22)		
	100	ug/l	10		(40)		
	200	ug/l	10		*(76)		
	250	ug/l	28		*(94)		
	>300	ug/l	28		(112)		
Lead	hardness 0-50	ug/l	4				
	50-150	ug/l	10				
	>150	ug/l	20				
Nickel	hardness 0-50	ug/l	50				
	50-100	ug/l	100				
	100-200	ug/l	150				
	>200	ug/l	200				
Zinc	hardness 0	ug/l	8				
	10	ug/l	*16		30		
	50	ug/l	50		200		
	100	ug/l	75		300		
	200	ug/l	75		*350		
	250	ug/l	125		*375		
	>500	ug/l	125		500		

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NATIONAL RIVERS AUTHORITY, THAMES REGION - RIVER QUALITY STANDARDS (FRESH WATER)

DETERMINAND		UNITS	CLASS 2A MEAN	 50%ile	 95%ile	 MAX	
Dissolved oxygen (min)		%sat.			40		
Dissolved oxygen (min)		mg/l		7			
BOD (ATU) 5 day		mg/l	(5)		9(8)		
Ammonia as NH4		mg/l			3		
Ammonia, non-ionized as NH3		mg/l			0.025		
Suspended solids (105 deg C)		mg/l		(25)			
pH					6-9		
Nitrite as NO2		mg/l			(0.5)		
Cadmium		ug/l	5				LIST 1 substances
Mercury		ug/l	1				
Hexachlorocyclohexane		ug/l	0.1				
Carbon tetrachloride		ug/l	12				
Para-para DDT		ng/l	10				
DDT		ng/l	25				
Pentachlorophenol		ug/l	2				
Hexachlorobenzene		ug/l	0.03	from 01/1990			
Hexachlorobutadiene		ug/l	0.1	from 01/1990			
Chloroform		ug/l	12	from 01/1990			
Aldrin		ng/l	10	from 01/1994		) 1/1989	total 'drins
Dieldrin		ng/l	10	from 01/1994		) <- 30ng/l	
Endrin		ng/l	5	from 01/1994		) & endrin	
Isodrin		ng/l	5	from 01/1994		) <- 5 ng/l	
Arsenic		ug/l	50				LIST 2 substances
Chromium	hardness 0-50	ug/l	150				
	50-100	ug/l	175				
	100-200	ug/l	200				
	>200	ug/l	250				
Copper	hardness 0	ug/l	1				
	10	ug/l	*2		(5)		
	50	ug/l	6		(22)		
	100	ug/l	10		(40)		
	200	ug/l	10		*(76)		
	250	ug/l	28		*(94)		
	>300	ug/l	28		(112)		
Lead	hardness 0-50	ug/l	50				
	50-150	ug/l	125				
	>150	ug/l	250				
Nickel	hardness 0-50	ug/l	50				
	50-100	ug/l	100				
	100-200	ug/l	150				
	>200	ug/l	200				
Zinc	hardness 0	ug/l	75				
	10	ug/l	*95		300		
	50	ug/l	175		700		
	100	ug/l	250		1000		
	200	ug/l	250		*1250		
	250	ug/l	500		*1375		
	>500	ug/l	500		2000		

NATIONAL RIVERS AUTHORITY, THAMES REGION - RIVER QUALITY STANDARDS (FRESH WATER)

CLASS 2B

DETERMINAND		UNITS	MEAN	50%ile	95%ile	MAX	
Dissolved oxygen (min)		%sat.			40		
Dissolved oxygen (min)		mg/l		(5)			
BOD (ATU) 5 day		mg/l	5		9		
Ammonia as NH4		mg/l					
Ammonia, non-ionized as NH3		mg/l		0.025			
Suspended solids (105 deg C)		mg/l		(80)			
pH					5-9.5		
Nitrite as NO2		mg/l					
Cadmium		ug/l	5				LIST 1 substances
Mercury		ug/l	1				
Hexachlorocyclohexane		ug/l	0.1				
Carbon tetrachloride		ug/l	12				
Para-para DDT		ng/l	10				
DDT		ng/l	25				
Pentachlorophenol		ug/l	2				
Hexachlorobenzene		ug/l	0.03	from 01/1990			
Hexachlorobutadiene		ug/l	0.1	from 01/1990			
Chloroform		ug/l	12	from 01/1990			
Aldrin		ng/l	10	from 01/1994			) 1/1989 total 'drins
Dieldrin		ng/l	10	from 01/1994			) <- 30ng/l
Endrin		ng/l	5	from 01/1994			) & endrin
Isodrin		ng/l	5	from 01/1994			) <- 5 ng/l
Arsenic		ug/l	50				LIST 2 substances
Chromium	hardness 0-50	ug/l	150				
	50-100	ug/l	175				
	100-200	ug/l	200				
	>200	ug/l	250				
Copper	hardness 0	ug/l	1				
	10	ug/l					
	50	ug/l	6				
	100	ug/l	10	hardness 100-200			
	200	ug/l					
	250	ug/l	28	hardness >250			
	>300	ug/l					
Lead	hardness 0-50	ug/l	50				
	50-150	ug/l	125				
	>150	ug/l	250				
Nickel	hardness 0-50	ug/l	50				
	50-100	ug/l	100				
	100-200	ug/l	150				
	>200	ug/l	200				
Zinc	hardness 0	ug/l	75				
	10	ug/l					
	50	ug/l	175				
	100	ug/l	250	hardness 100-200			
	200	ug/l					
	250	ug/l	500	hardness >250			
	>500	ug/l					

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NATIONAL RIVERS AUTHORITY, THAMES REGION - RIVER QUALITY STANDARDS (FRESH WATER)

CLASS 3

DETERMINAND		UNITS	MEAN	50%ile	95%ile	MAX	
Dissolved oxygen (min)		%sat.			10		
Dissolved oxygen (min)		mg/l					
BOD (ATU) 5 day		mg/l			17		
Ammonia as NH4		mg/l					
Ammonia, non-ionized as NH3		mg/l					
Suspended solids (105 deg C)		mg/l					
pH					5-9.5		
Nitrite as NO2		mg/l					
Cadmium		ug/l	5				LIST 1 substances
Mercury		ug/l	1				
Hexachlorocyclohexane		ug/l	0.1				
Carbon tetrachloride		ug/l	12				
Para-para DDT		ng/l	10				
DDT		ng/l	25				
Pentachlorophenol		ug/l	2				
Hexachlorobenzene		ug/l	0.03	from 01/1990			
Hexachlorobutadiene		ug/l	0.1	from 01/1990			
Chloroform		ug/l	12	from 01/1990			
Aldrin		ng/l	10	from 01/1994		) 1/1989 total 'drins	
Dieldrin		ng/l	10	from 01/1994		) <= 30ng/l	
Endrin		ng/l	5	from 01/1994		) & endrin	
Isodrin		ng/l	5	from 01/1994		) <= 5 ng/l	
Arsenic		ug/l	50				LIST 2 substances
Chromium	hardness 0-50	ug/l	150				
	50-100	ug/l	175				
	100-200	ug/l	200				
	>200	ug/l	250				
Copper	hardness 0	ug/l	1				
	10	ug/l					
	50	ug/l	6				
	100	ug/l	10	hardness 100-200			
	200	ug/l					
	250	ug/l	28	hardness >250			
	>300	ug/l					
Lead	hardness 0-50	ug/l	50				
	50-150	ug/l	125				
	>150	ug/l	250				
Nickel	hardness 0-50	ug/l	50				
	50-100	ug/l	100				
	100-200	ug/l	150				
	>200	ug/l	200				
Zinc	hardness 0	ug/l	75				
	10	ug/l					
	50	ug/l	175				
	100	ug/l	250	hardness 100-200			
	200	ug/l					
	250	ug/l	500	hardness >250			
	>500	ug/l					

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NATIONAL RIVERS AUTHORITY, THAMES REGION - RIVER QUALITY STANDARDS (FRESH WATER)

CLASS 4

DETERMINAND		UNITS	MEAN	50%ile	95%ile	MAX
Dissolved oxygen (min)		%sat.				
Dissolved oxygen (min)		mg/l				
BOD (ATU) 5 day		mg/l				
Ammonia as NH4		mg/l				
Ammonia, non-ionized as NH3		mg/l				
Suspended solids (105 deg C)		mg/l				
pH						
Nitrite as NO2		mg/l				
Cadmium		ug/l				
Mercury		ug/l				
Hexachlorocyclohexane		ug/l				
Carbon tetrachloride		ug/l				
Para-para DDT		ng/l				
DDT		ng/l				
Pentachlorophenol		ug/l				
Hexachlorobenzene		ug/l				
Hexachlorobutadiene		ug/l				
Chloroform		ug/l				
Aldrin		ng/l				
Dieldrin		ng/l				
Endrin		ng/l				
Isodrin		ng/l				
Arsenic		ug/l				
Chromium	hardness 0-50	ug/l				
	50-100	ug/l				
	100-200	ug/l				
	>200	ug/l				
Copper	hardness 0	ug/l				
	10	ug/l				
	50	ug/l				
	100	ug/l				
	200	ug/l				
	250	ug/l				
	>300	ug/l				
Lead	hardness 0-50	ug/l				
	50-150	ug/l				
	>150	ug/l				
Nickel	hardness 0-50	ug/l				
	50-100	ug/l				
	100-200	ug/l				
	>200	ug/l				
Zinc	hardness 0	ug/l				
	10	ug/l				
	50	ug/l				
	100	ug/l				
	200	ug/l				
	250	ug/l				
	>500	ug/l				

There are no quality standards that apply, BUT

Discharges containing dangerous substances, i.e. List 1 and List 2 substances, must not cause concentrations in the receiving water to exceed those set for Class 3 or to increase the existing levels if these are greater.

LIST 1 substances (Cadmium to Isodrin)

LIST 2 substances (Arsenic to Zinc)

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NATIONAL RIVERS AUTHORITY, THAMES REGION - RIVER QUALITY STANDARDS (FRESH WATER)

DETERMINAND		UNITS	CLASS X MEAN	50%ile	95%ile	MAX	
Dissolved oxygen (min)		%sat.			10		
Dissolved oxygen (min)		mg/l					
BOD (ATU) 5 day		mg/l			(17)		
Ammonia as NH4		mg/l					
Ammonia, non-ionized as NH3		mg/l					
Suspended solids (105 deg C)		mg/l					
pH					5-9.5		
Nitrite as NO2		mg/l					
Cadmium		ug/l	5				LIST 1 substances
Mercury		ug/l	1				
Hexachlorocyclohexane		ug/l	0.1				
Carbon tetrachloride		ug/l	12				
Para-para DDT		ng/l	10				
DDT		ng/l	25				
Pentachlorophenol		ug/l	2				
Hexachlorobenzene		ug/l	0.03	from 01/1990			
Hexachlorobutadiene		ug/l	0.1	from 01/1990			
Chloroform		ug/l	12	from 01/1990			
Aldrin		ng/l	10	from 01/1994		) 1/1989	total 'drins
Dieldrin		ng/l	10	from 01/1994		) <- 30ng/l	
Endrin		ng/l	5	from 01/1994		) & endrin	
Isodrin		ng/l	5	from 01/1994		) <- 5 ng/l	
Arsenic		ug/l					LIST 2 substances
Chromium	hardness 0-50	ug/l					
	50-100	ug/l					
	100-200	ug/l					
	>200	ug/l					
Copper	hardness 0	ug/l					
	10	ug/l					
	50	ug/l					
	100	ug/l					
	200	ug/l					
	250	ug/l					
	>300	ug/l					
Lead	hardness 0-50	ug/l					
	50-150	ug/l					
	>150	ug/l					
Nickel	hardness 0-50	ug/l					
	50-100	ug/l					
	100-200	ug/l					
	>200	ug/l					
Zinc	hardness 0	ug/l					
	10	ug/l					
	50	ug/l					
	100	ug/l					
	200	ug/l					
	250	ug/l					
	>500	ug/l					

Printed 17/09/90

APPENDIX 4

Frequency distribution plots	4.A.1 - 4.A.12.
	4.B.1. - 4.B.10.
	4.C.1. - 4.C.6.
	4.D.1. - 4.D.3.
	4.E.1. - 4.E.15.
	4.F.1. - 4.F.9.
	4.G.1. - 4.G.3.

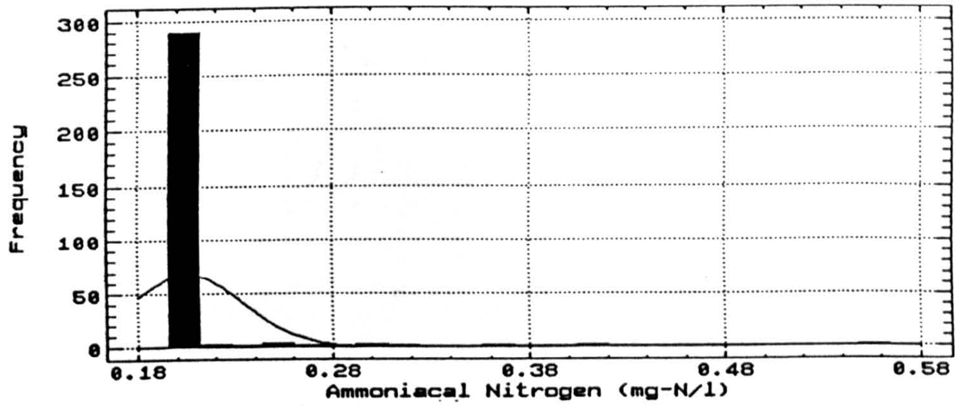


Figure 4.A.1 : Normal distribution fit for ammoniacal nitrogen as N at Northmoor (daily midday values)

n is large, D= 0.5055, D_{crit}= 0.0000 at the 5% significance level

As $D>D_{crit}$, frequency distribution significantly different form normal distribution at the 5% significance level.

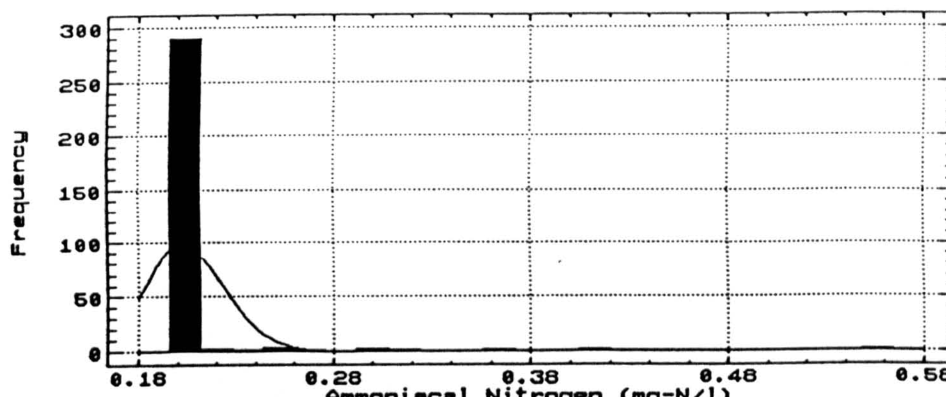


Figure 4.A.2 : Log normal distribution fit for ammoniacal nitrogen as N at Northmoor (daily midday values)

n is large, D= 0.5139, D_{crit}= 0.0000 at the 5% significance level

As $D>D_{crit}$, frequency distribution significantly different form log normal distribution at the 5% significance level.

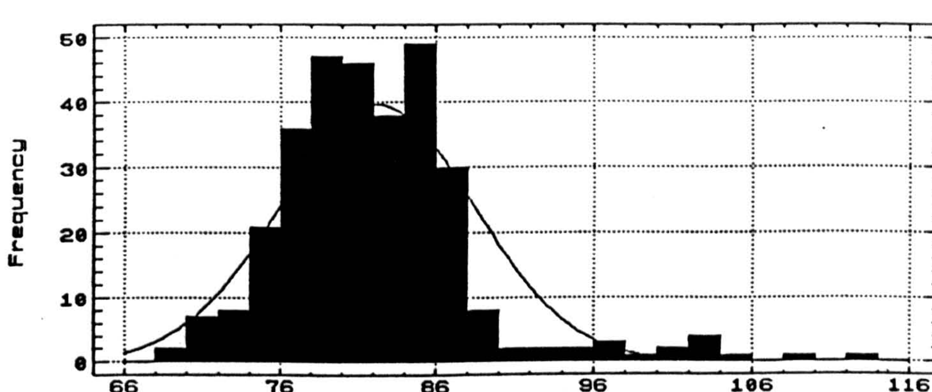


Figure 4.A.3 : Normal distribution fit for dissolved oxygen at Northmoor (daily midday values)

n is large, D= 0.0976, D_{crit}= 0.0054 at the 5% significance level

As $D>D_{crit}$, frequency distribution significantly different form normal distribution at the 5% significance level.

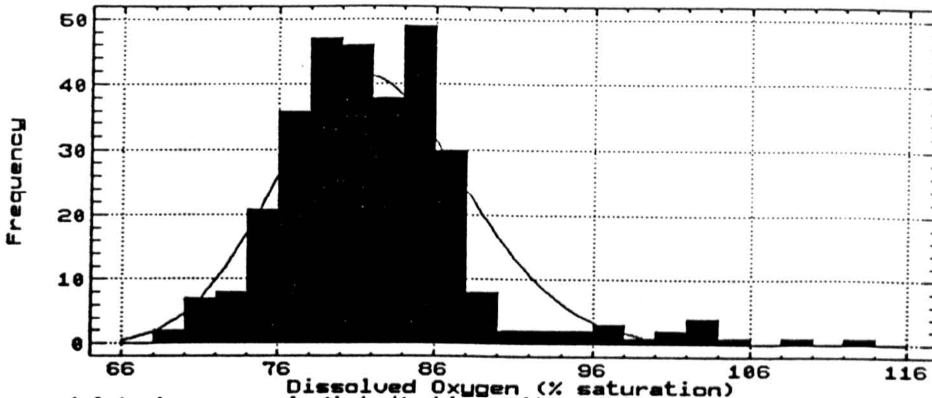


Figure 4.A.4 : Log normal distribution fit of dissolved oxygen at Northmoor (daily midday values)

n is large, D= 0.0833, D_{crit}= 0.0267 at the 5% significance level

As D>D_{crit}, frequency distribution significantly different form log normal distribution at the 5% significance level.

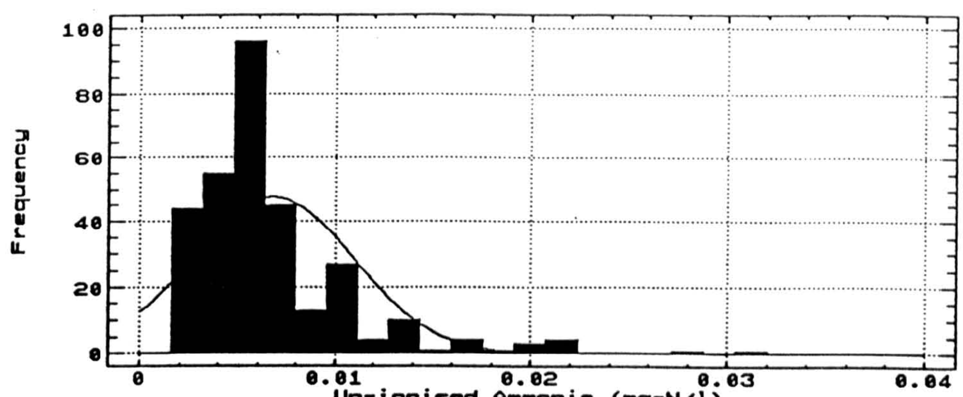


Figure 4.A.5 :Normal distribution fit for un-ionised ammonia as N at Northmoor (daily midday values)

n is large, D= 0.2061, D_{crit}= 0.0000 at the 5% significance level

As D>D_{crit}, frequency distribution significantly different form log normal distribution at the 5% significance level.

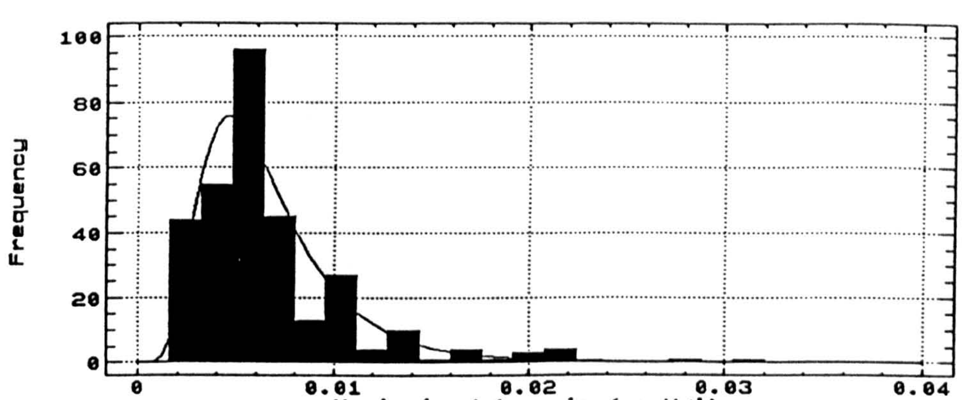


Figure 4.A.6 : Log normal distribution fit for un-ionised ammonia as N at Northmoor (daily midday values)

n is large, D= 0.1202, D_{crit}= 0.0003 at the 5% significance level

As D>D_{crit}, frequency distribution significantly different form log normal distribution at the 5% significance level.

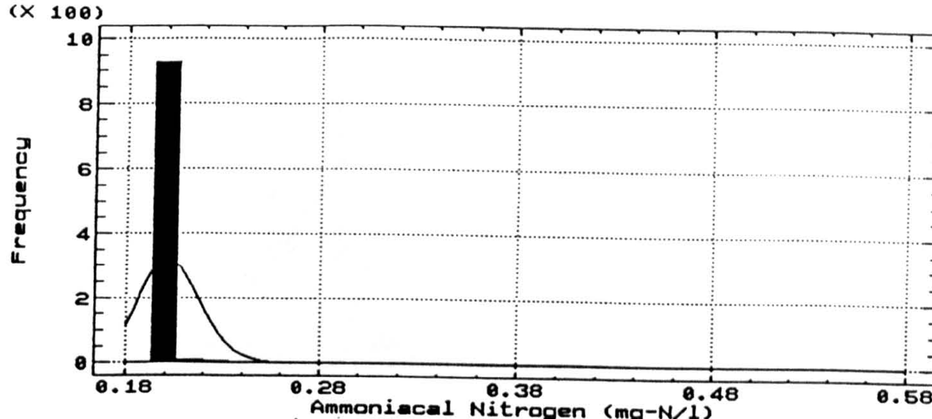


Figure 4.A.7: Log normal distribution fit for ammoniacal nitrogen as N at Northmoor (8th day, 24 hourly values)

n is large, D= 0.1547, D_{crit}= 0.0000 at the 5% significance level

As D>D_{crit}, frequency distribution significantly different form log normal distribution at the 5% significance level.

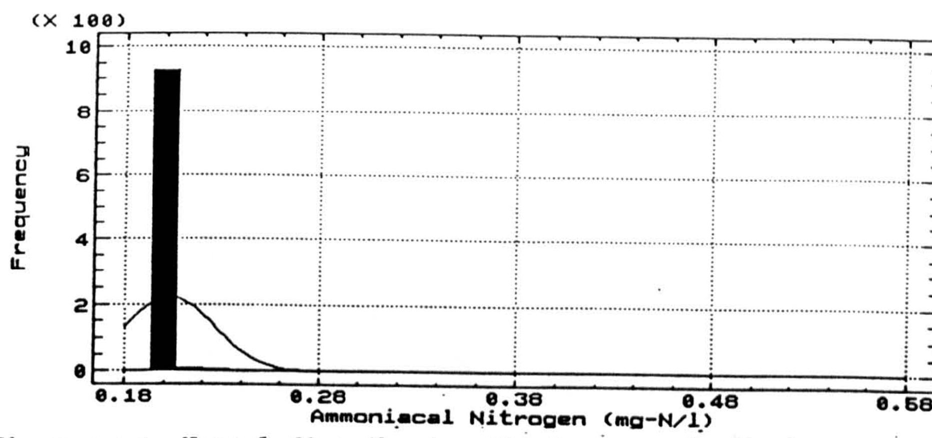


Figure 4.A.8: Normal distribution fit for ammoniacal nitrogen as N at Northmoor (8th day, 24 hourly values)

n is large, D= 0.1316, D_{crit}= 0.0000 at the 5% significance level

As D>D_{crit}, frequency distribution significantly different form log normal distribution at the 5% significance level.

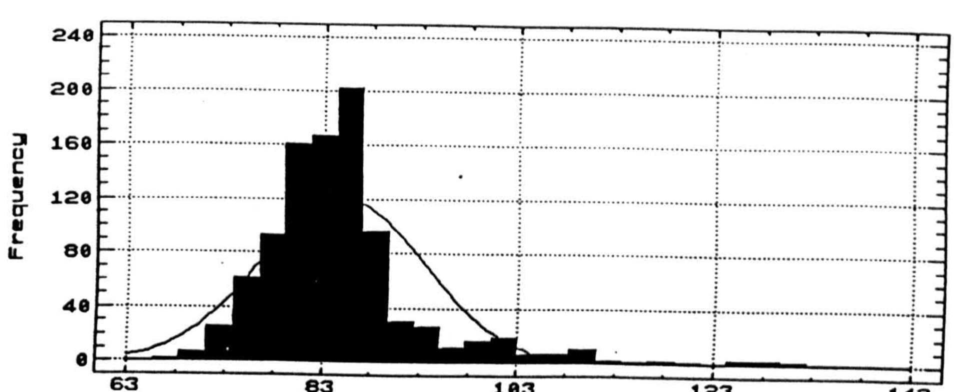


Figure 4.A.9 : Normal distribution fit for dissolved oxygen at Northmoor (8th day, 24 hourly values)

n is large, D= 0.1568, D_{crit}= 0.0000 at the 5% significance level

As D>D_{crit}, frequency distribution significantly different form log normal distribution at the 5% significance level.

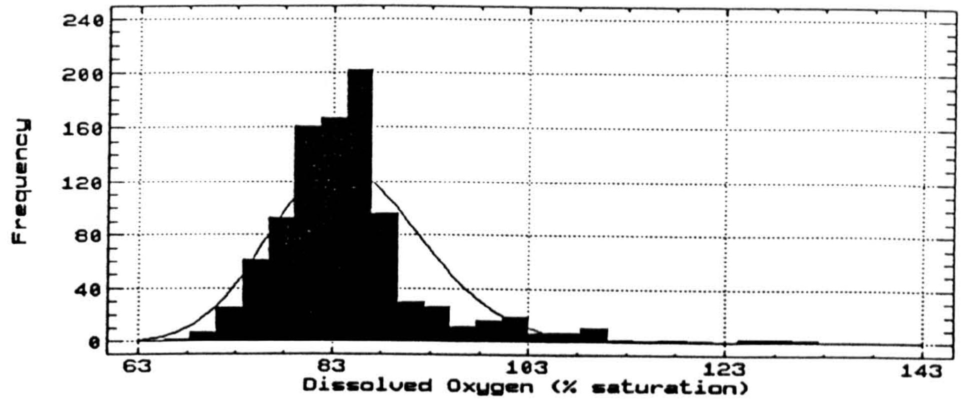


Figure 4.A.10: Log normal distribution fit for dissolved oxygen at Northmoor (8th day, 24 hourly values)

n is large, D= 0.1316, D_{crit}= 0.0000 at the 5% significance level

As D>D_{crit}, frequency distribution significantly different form normal distribution at the 5% significance level.

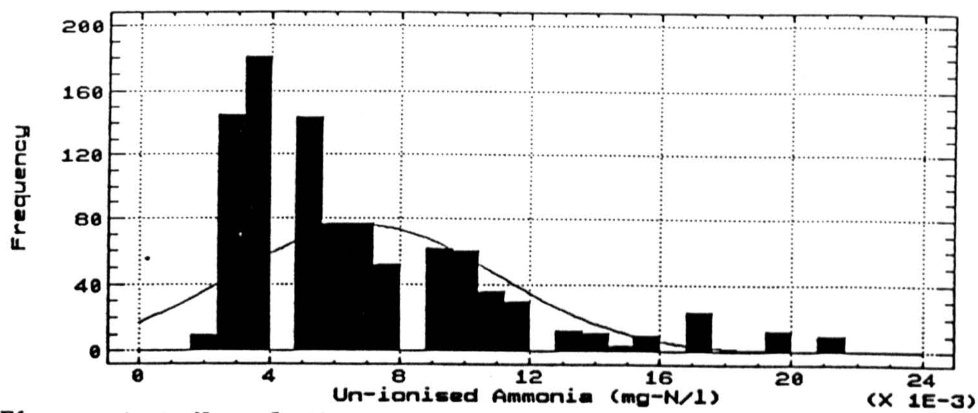


Figure 4.A.11: Normal distribution fit for un-ionised ammonia as N at Northmoor (8th day, 24 hourly values)

n is large, D= 0.1844, D_{crit}= 0.0000 at the 5% significance level

As D>D_{crit}, frequency distribution significantly different form normal distribution at the 5% significance level.

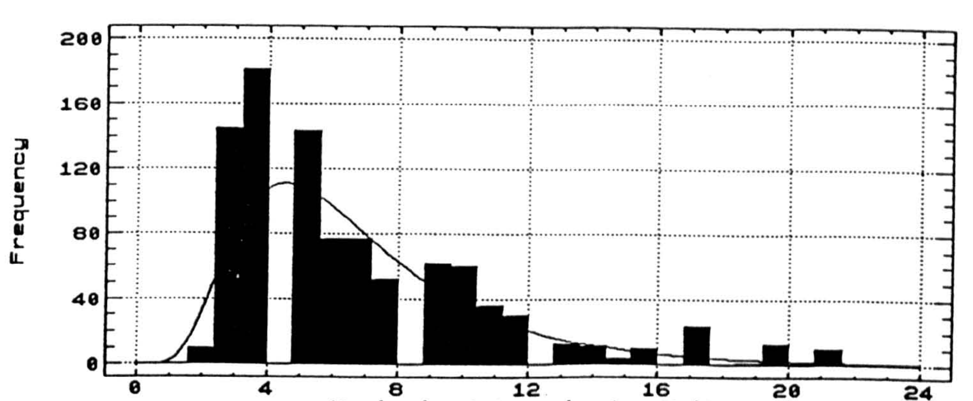


Figure 4.A.12: Log normal distribution for un-ionised ammonia as N at Northmoor (8th day, 24 hourly values)

n is large, D= 0.1362, D_{crit}= 0.0000 at the 5% significance level

As D>D_{crit}, frequency distribution significantly different form log normal distribution at the 5% significance level.

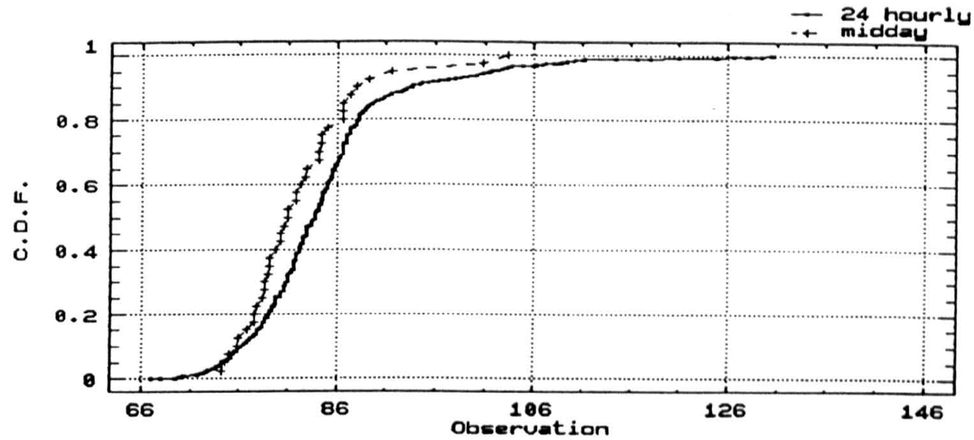


Figure 4.B.1 : Cumulative distribution functions (C.D.F.) for dissolved oxygen (Annual: 8th day, 24 hourly and midday values)

n= 38, D= 0.2260, D_{crit}= 0.0925 at a 5% significance level

As D>D_{crit}, the dissolved oxygen data sets for 24 hourly and midday values (8th day) are significantly different at the 5% significance level.

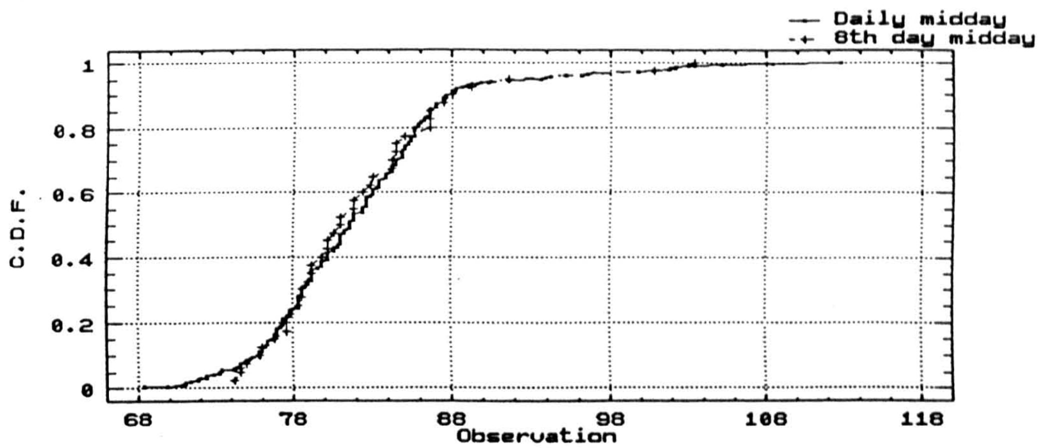


Figure 4.B.2 : Cumulative distribution functions (C.D.F.) for dissolved oxygen (Annual: daily midday and 8th day midday values)

n= 27, D= 0.0877, D_{crit}= 0.9480 at a 5% significance level

As D<D_{crit}, the dissolved oxygen data sets for daily and 8th day midday values are not significantly different at the 5% significance level.

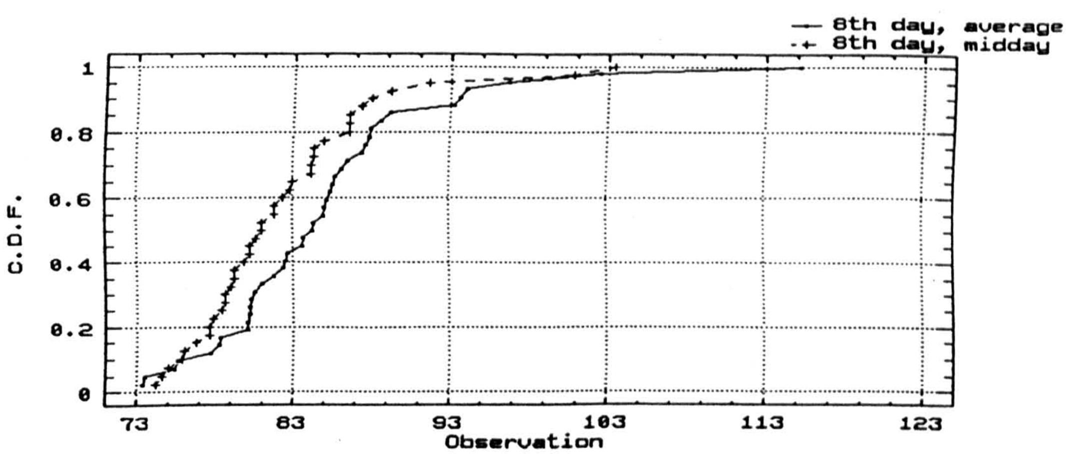


Figure 4.B.3 : Cumulative distribution functions (C.D.F.) for dissolved oxygen (Annual: 8th day, midday and average values)

n= 39, D= 0.2333, D_{crit}= 0.2146 at a 5% significance level

As D>D_{crit}, the dissolved oxygen data sets for midday and average values (8th day) are significantly different at the 5% significance level. It should be noted that the values of D and D_{crit} are almost equal, it is difficult to state the above without reservations.

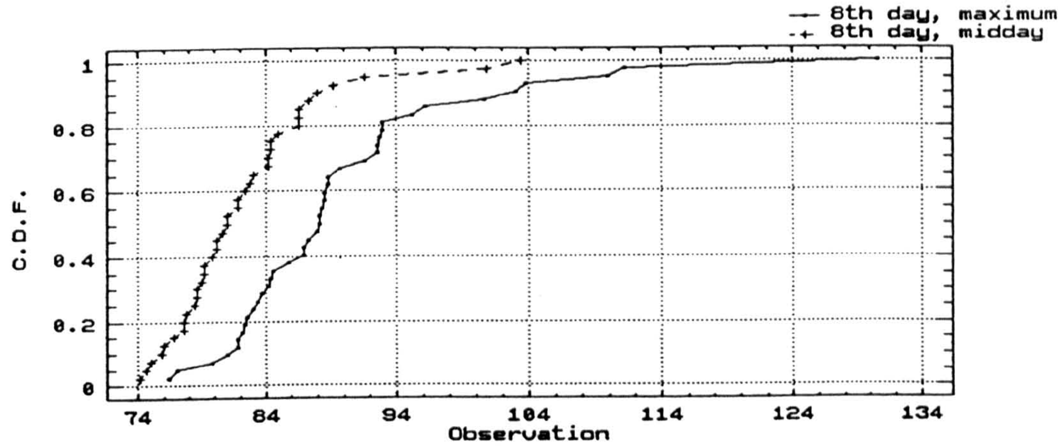


Figure 4.B.4 : Cumulative distribution functions (C.D.F.) for dissolved oxygen (Annual: 8th day, midday and maximum values)

n= 39, D= 0.4691, D_{crit}= 0.0002 at a 5% significance level

As $D>D_{crit}$, the dissolved oxygen data sets for midday and maximum values (8th day) are significantly different at the 5% significance level.

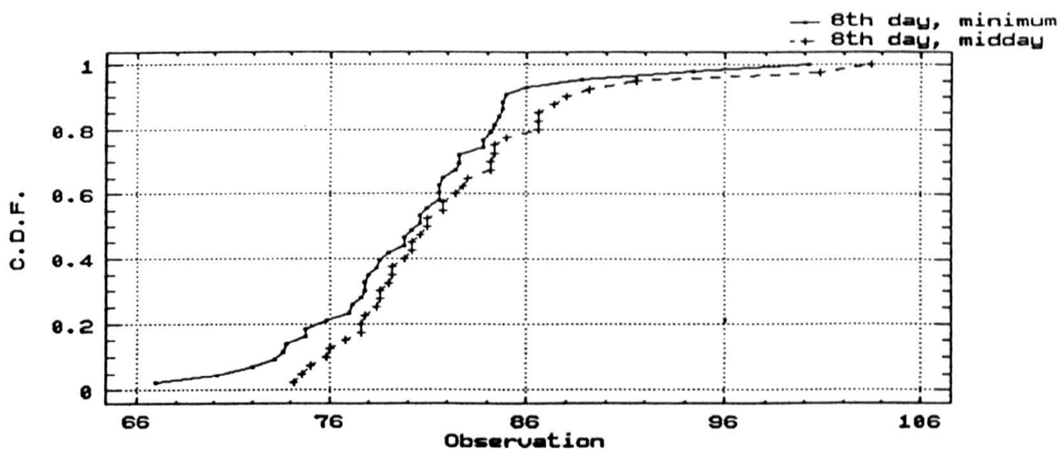


Figure 4.B.5 : Cumulative distribution functions (C.D.F.) for dissolved oxygen (Annual: 8th day, midday and mimimum values)

n= 39, D= 0.1570, D_{crit}= 0.6868 at a 5% significance level

As $D<D_{crit}$, the dissolved oxygen data sets for midday and minimum values (8th day) are not significantly different at the 5% significance level.

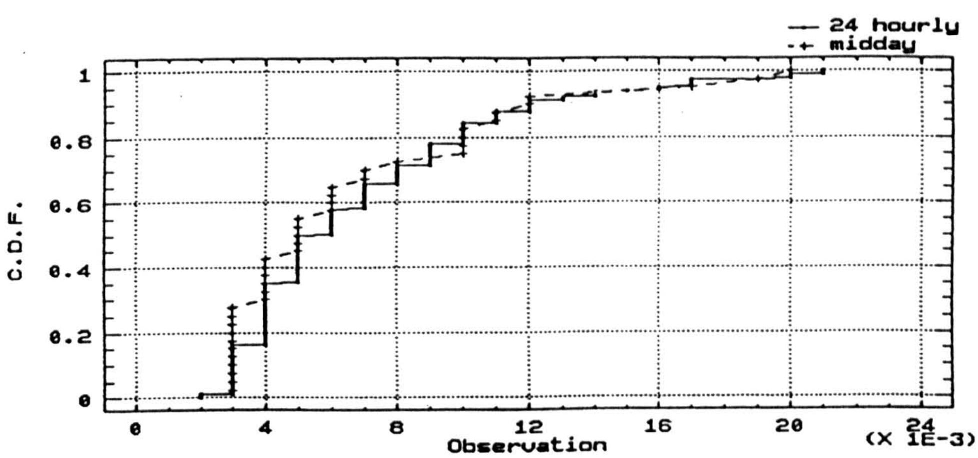


Figure 4.B.6 : Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Annual: 8th day, 24 hourly and midday values)

n= 38, D= 0.2694, D_{crit}= 0.1615 at a 5% significance level

As $D>D_{crit}$, the un-ionised ammonia (N) data sets for 24 hourly and midday values (8th day) are significantly different at the 5% significance level.

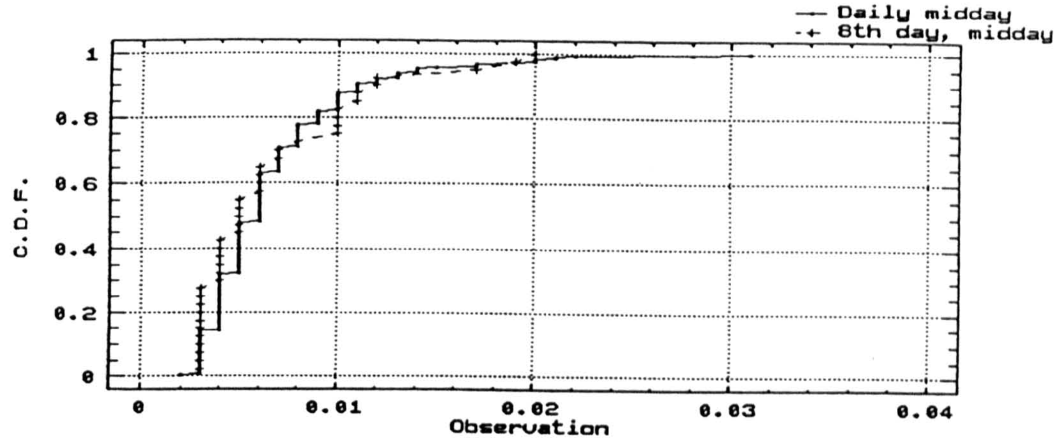


Figure 4.B.7 : Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Annual: daily midday and 8th day midday values)

n= 27, D= 0.1520, D_{crit}= 0.3863 at a 5% significance level

As D<D_{crit}, the un-ionised ammonia (N) data sets for daily and 8th day midday values are not significantly different at the 5% significance level.

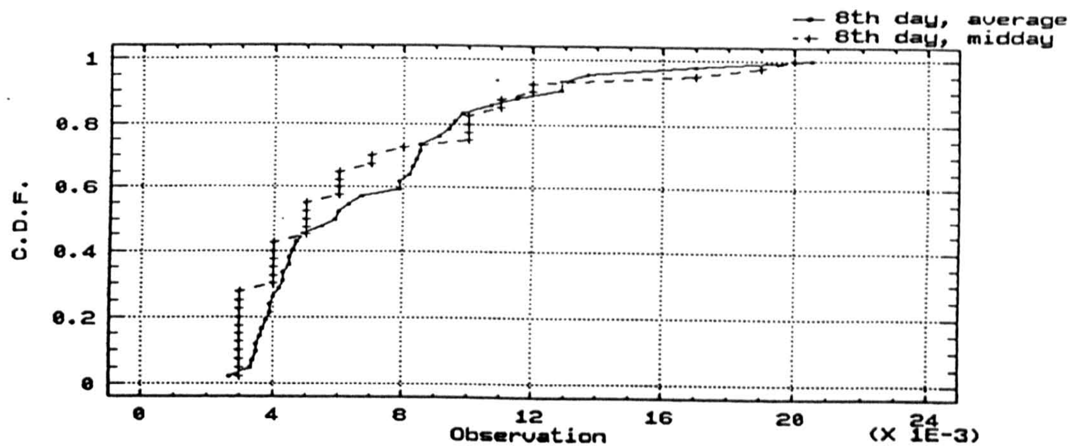


Figure 4.B.8 : Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Annual: 8th day, midday and average values)

n= 39, D= 0.2512, D_{crit}= 0.1507 at a 5% significance level

As D>D_{crit}, the un-ionised ammonia (N) oxygen data sets for midday and average values (8th day) are significantly different at the 5% significance level.

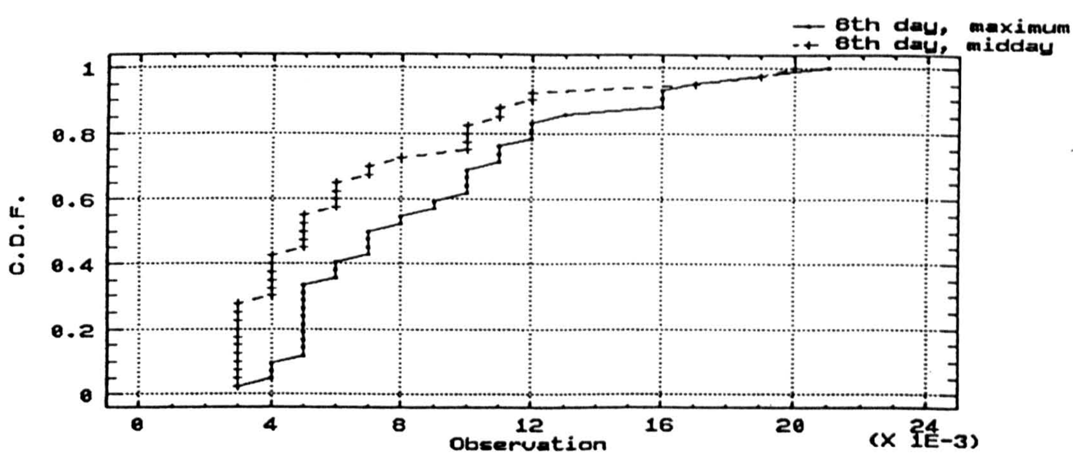


Figure 4.B.9 : Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Annual: 8th day, midday and maximum values)

n= 39, D= 0.3298, D_{crit}= 0.0232 at a 5% significance level

As D>D_{crit}, the un-ionised ammonia (N) data sets for midday and maximum values (8th day) are significantly different at the 5% significance level.

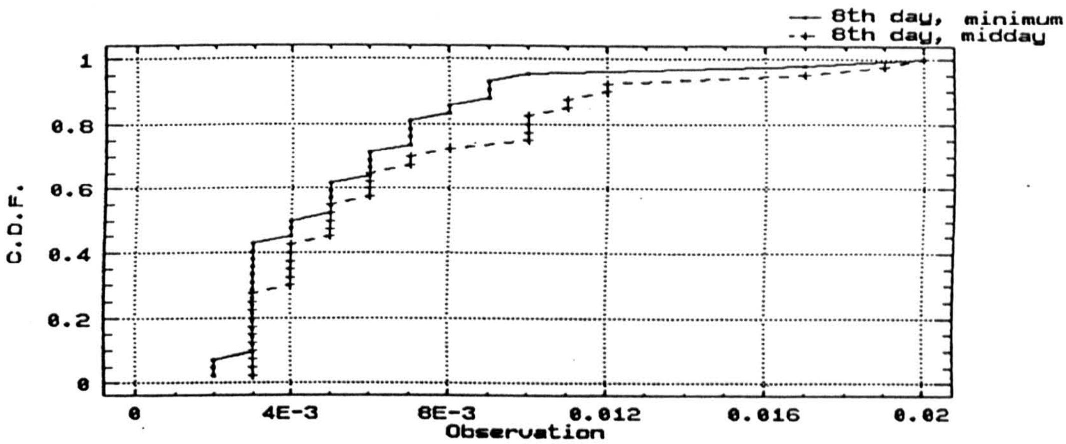


Figure 4.B.10: Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Annual: 8th day, midday and minimum values)

n= 39, D= 0.3298, D_{crit}= 0.0232 at a 5% significance level

As D>D_{crit}, the un-ionised ammonia (N) data sets for midday and minimum values (8th day) are significantly different at the 5% significance level.

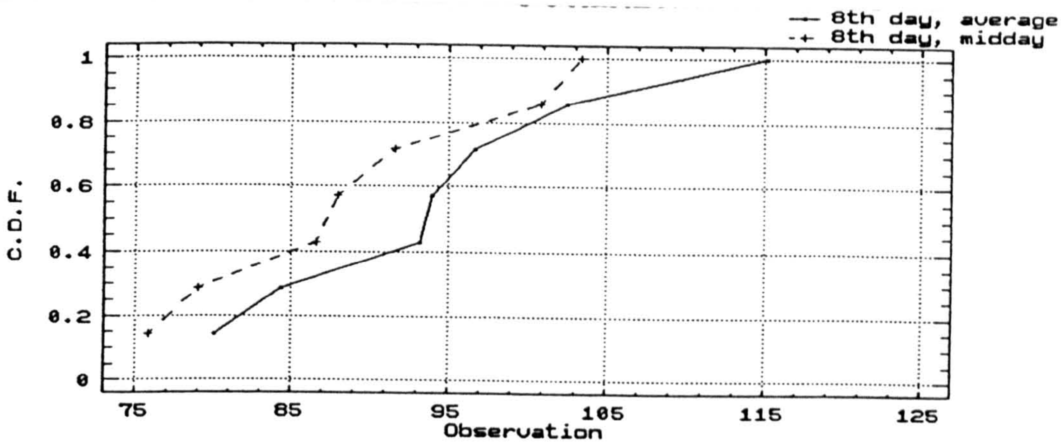


Figure 4.C.1 : Cumulative distribution functions (C.D.F.) for dissolved oxygen (Seasonal: 8th day, midday and average values)

n= 7, D= 0.4286, D_{crit}= 0.4860 at a 5% significance level

As $D<D_{crit}$, the dissolved oxygen data sets for midday and average values (8th day) are not significantly different at the 5% significance level.

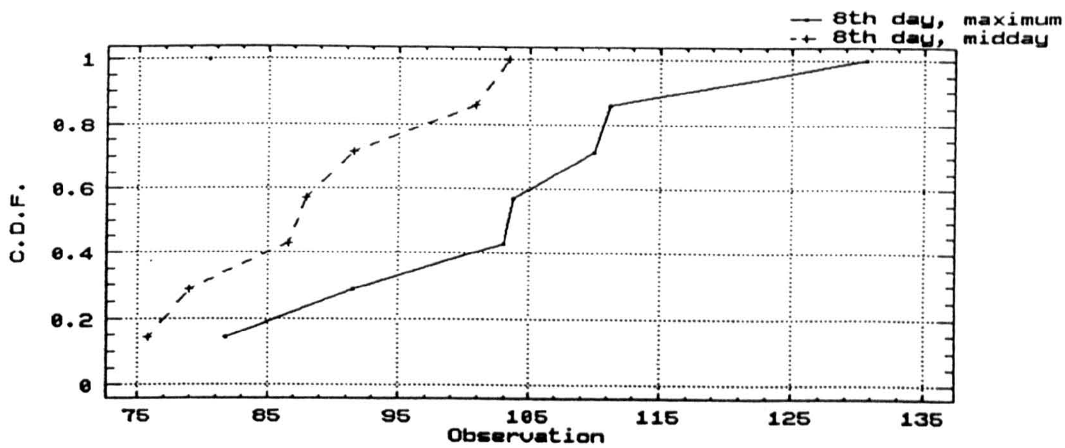


Figure 4.C.2 : Cumulative distribution functions (C.D.F.) for dissolved oxygen (Seasonal: 8th day, midday and maximum values)

n= 7, D= 0.5714, D_{crit}= 0.4860 at a 5% significance level

As $D>D_{crit}$, the dissolved oxygen data sets for midday and maximum values (8th day) are significantly different at the 5% significance level.

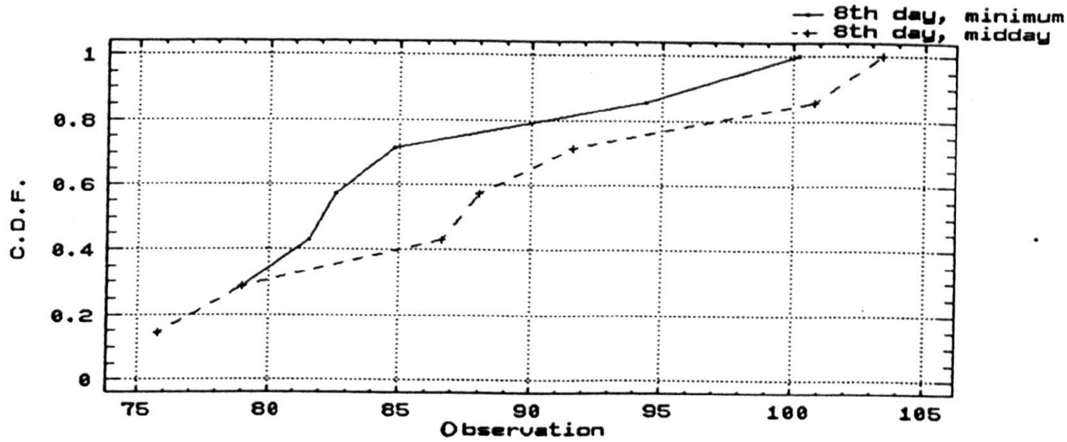


Figure 4.C.3 : Cumulative distribution functions (C.D.F.) for dissolved oxygen (Seasonal: 8th day, midday and minimum values)

n= 7, D= 0.4285, D_{crit}= 0.4860 at a 5% significance level

As $D<D_{crit}$, the dissolved oxygen data sets for midday and minimum values (8th day) are not significantly different at the 5% significance level.

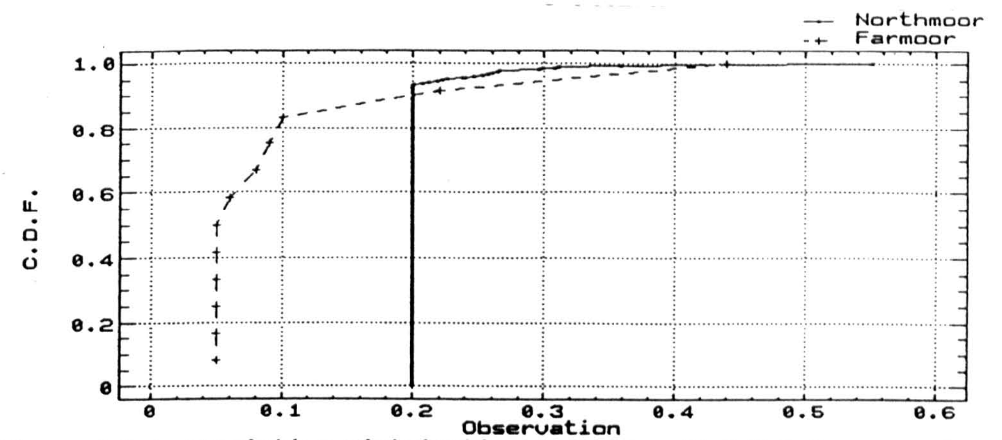


Figure 4.D.1 : Cumulative distribution functions (C.D.F.) for ammoniacal nitrogen as N at Northmoor and Farmoor

n= 12, D= 0.8333, D_{crit}= 0.3750 at a 5% significance level

As $D>D_{crit}$, the data sets at Northmoor and Farmoor are significantly different for ammoniacal nitrogen as N at a 5% significance level.

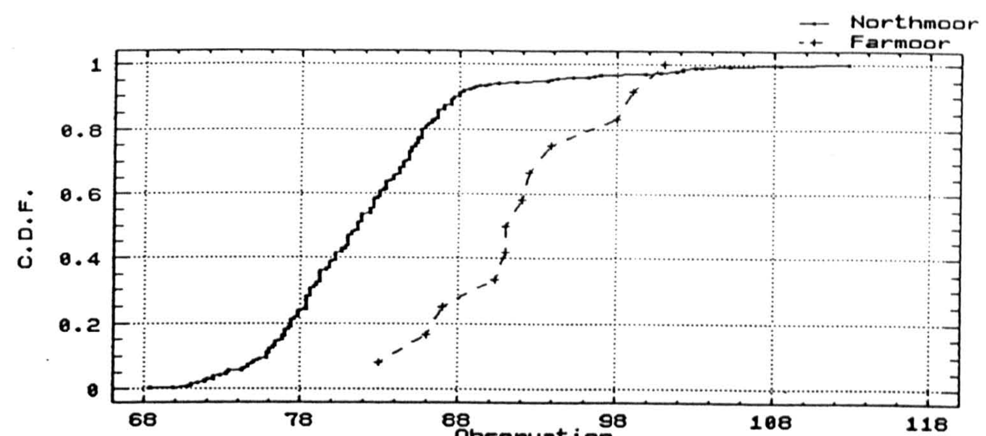


Figure 4.D.2: Cumulative distribution functions (C.D.F.) for dissolved oxygen at Northmoor and Farmoor

n= 12, D= 0.7334, D_{crit}= 0.3750 at a 5% significance level

As $D>D_{crit}$, the data sets at Northmoor and Farmoor are significantly different for dissolved oxygen at a 5% significance level.

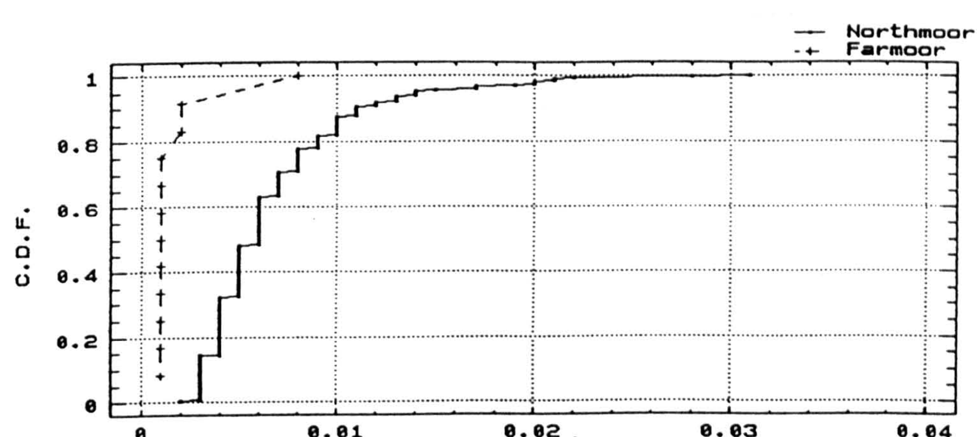


Figure 4.D.3 :Cumulative distribution functions (C.D.F.) for unionised ammonia as N at Northmoor and Farmoor

n= 12, D= 0.9102, D_{crit}= 0.3750 at a 5% significance level

As $D>D_{crit}$, the data sets at Northmoor and Farmoor are significantly different for unionised ammonia as N at a 5% significance level.

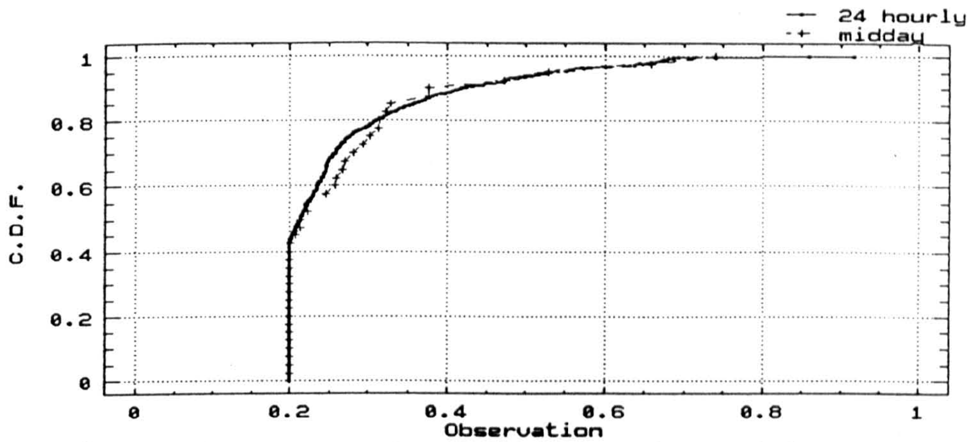


Figure 4.E.1 : Cumulative distribution functions (C.D.F.) for ammoniacal nitrogen as N (Annual: 8th day, 24 hourly and midday values)

n= 38, D= 0.4370, D_{crit}= 0.0000 at a 5% significance level

As $D>D_{crit}$, the ammoniacal nitrogen (N) data sets for 24 hourly and midday values (8th day) are significantly different at the 5% significance level.

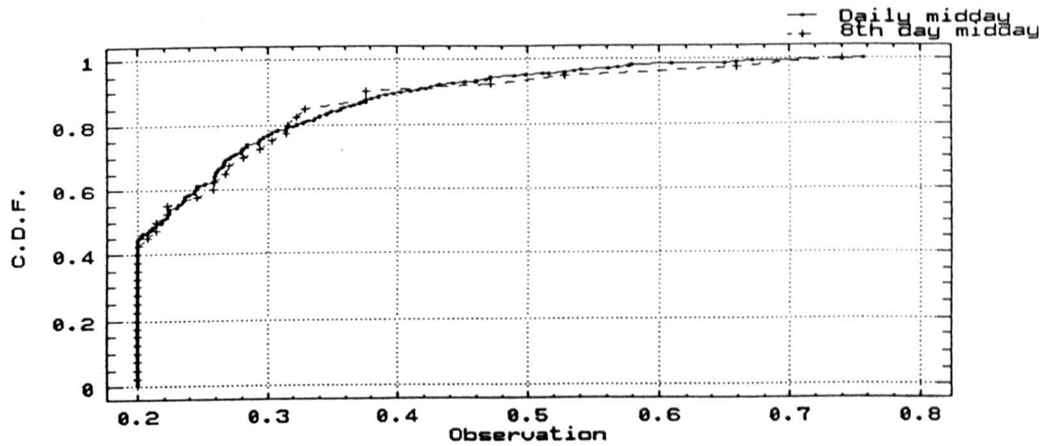


Figure 4.E.2 : Cumulative distribution functions (C.D.F.) for ammoniacal nitrogen as N (Annual: daily midday and 8th day midday values)

n= 38, D= 0.4481, D_{crit}= 0.0000 at a 5% significance level

As $D>D_{crit}$, the ammoniacal nitrogen (N) data sets for daily and 8th day midday values are significantly different at the 5% significance level.

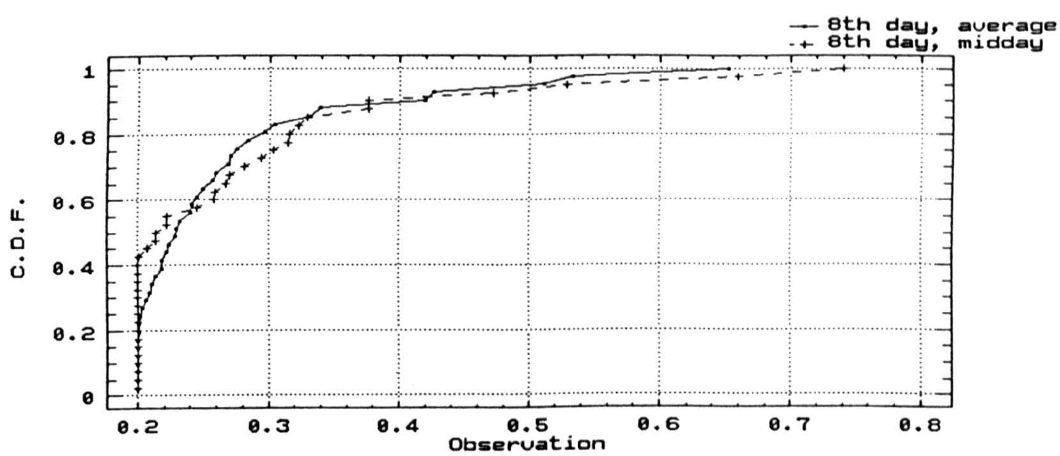


Figure 4.E.3 : Cumulative distribution functions (C.D.F.) for ammoniacal nitrogen as N (Annual: 8th day, midday and average values)

n= 38, D= 0.2537, D_{crit}= 0.1477 at a 5% significance level

As $D>D_{crit}$, the ammoniacal nitrogen (N) data sets for midday and average values (8th day) are significantly different at the 5% significance level.

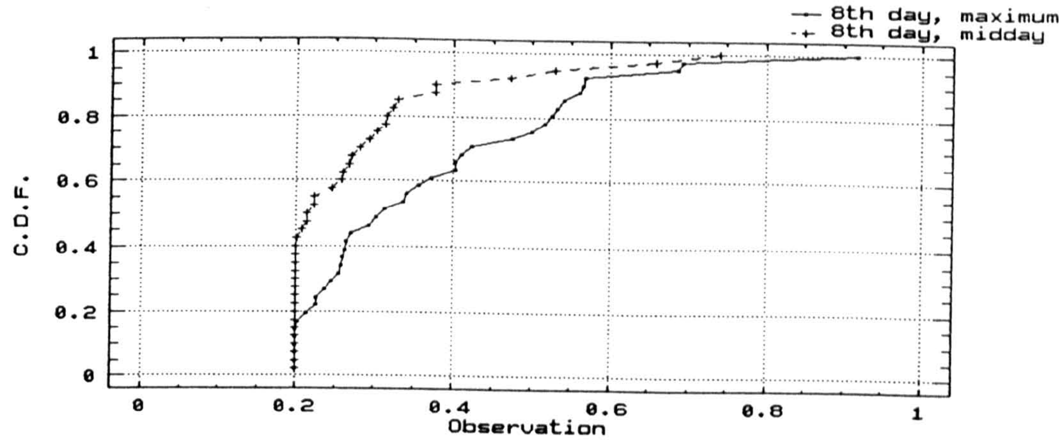


Figure 4.E.4 : Cumulative distribution functions (C.D.F.) for ammoniacal nitrogen as N (Annual: 8th day, midday and maximum values)

n= 38, D= 0.3549, D_{crit}= 0.0122 at a 5% significance level

As $D>D_{crit}$, the ammoniacal nitrogen (N) data sets for midday and maximum values (8th day) are significantly different at the 5% significance level.

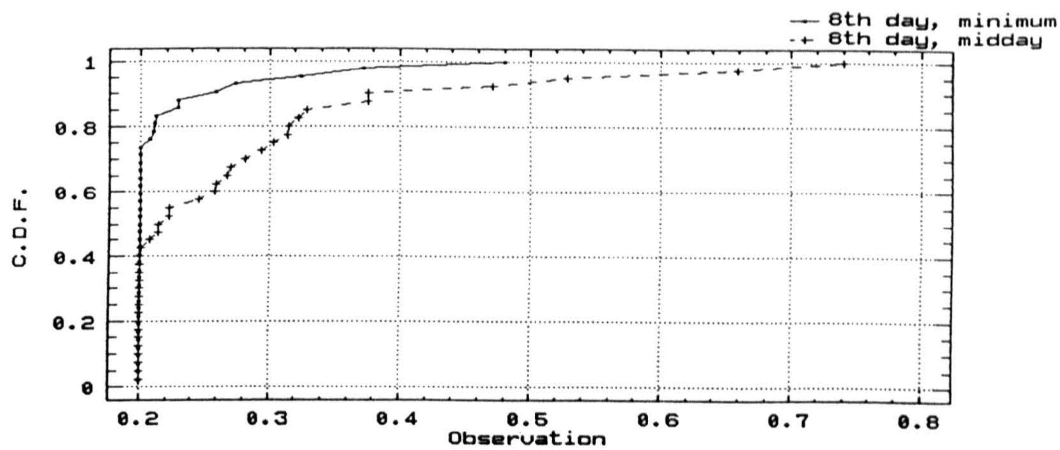


Figure 4.E.5 : Cumulative distribution functions (C.D.F.) for ammoniacal nitrogen as N (Annual: 8th day, midday and minimum values)

n= 39, D= 0.7381, D_{crit}= 0.0000 at a 5% significance level

As $D>D_{crit}$, the ammoniacal nitrogen (N) data sets for midday and minimum values (8th day) are significantly different at the 5% significance level.

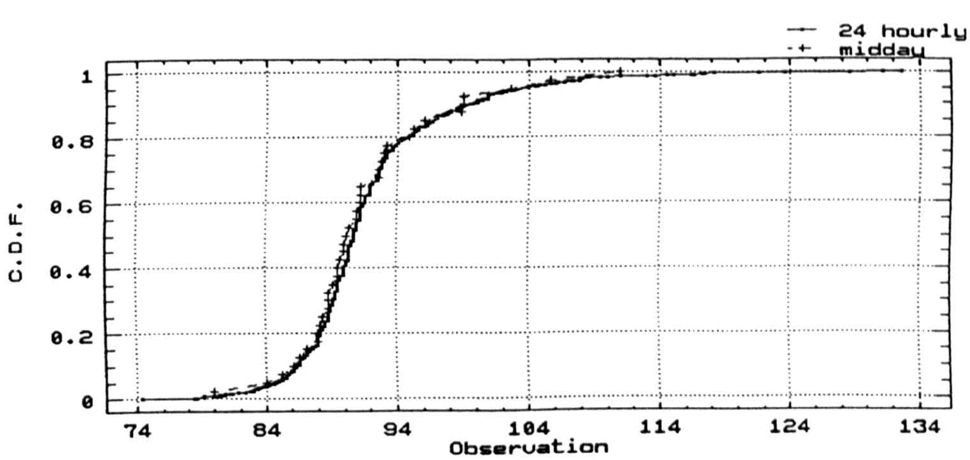


Figure 4.E.6 : Cumulative distribution functions (C.D.F.) for dissolved oxygen (Annual: 8th day, 24 hourly and midday values)

n= 38, D= 0.0784, D_{crit}= 0.9724 at a 5% significance level

As $D<D_{crit}$, the dissolved oxygen data sets for 24 hourly and midday values (8th day) are not significantly different at the 5% significance level.

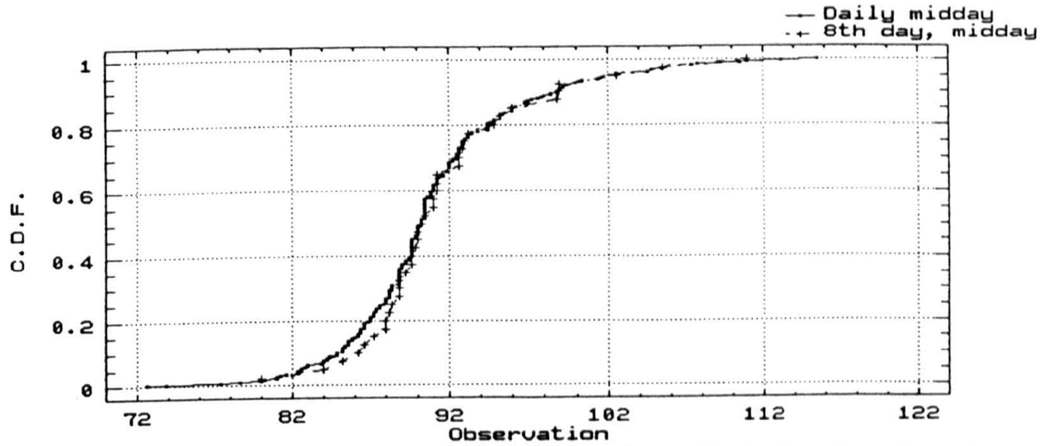


Figure 4.E.7 : Cumulative distribution functions (C.D.F.) for dissolved oxygen (Annual: daily midday and 8th day midday values)

n= 38, D= 0.1195, D_{crit}= 0.6930 at a 5% significance level

As $D<D_{crit}$, the dissolved oxygen data sets for daily and 8th day midday values are not significantly different at the 5% significance level.

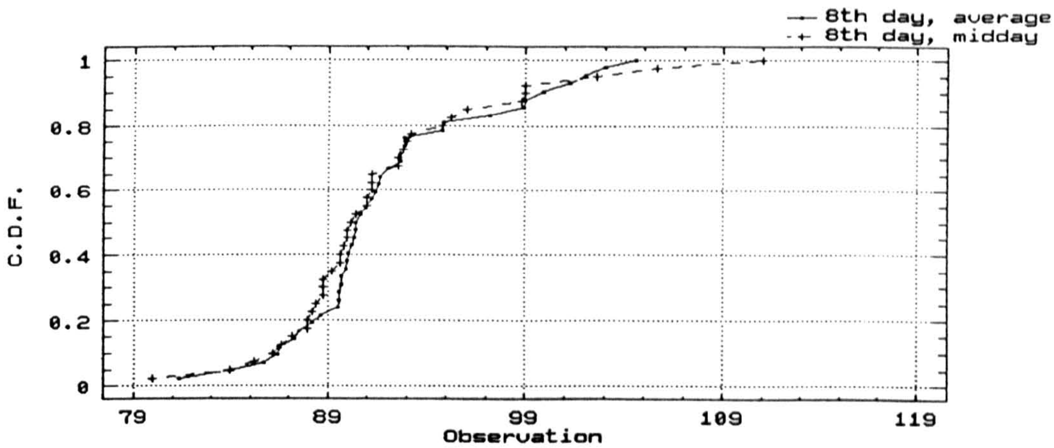


Figure 4.E.8 :Cumulative distribution functions (C.D.F.) for dissolved oxygen (Annual: 8th day, midday and average values)

n= 39, D= 0.1357, D_{crit}= 0.8448 at a 5% significance level

As $D<D_{crit}$, the dissolved oxygen data sets for midday and average values (8th day) are not significantly different at the 5% significance level.

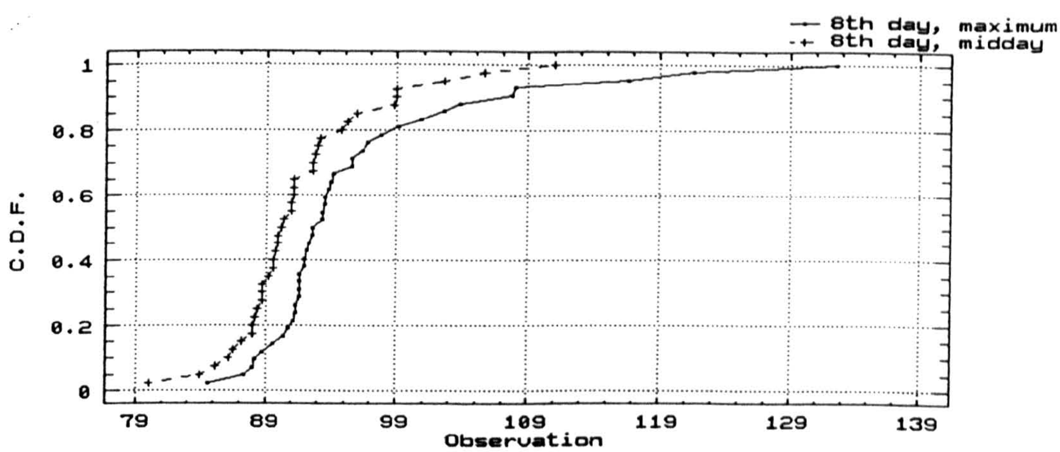


Figure 4.E.9 : Cumulative distribution functions (C.D.F.) for dissolved oxygen (Annual: 8th day, midday and maximum values)

n= 39, D= 0.4357, D_{crit}= 0.0008 at a 5% significance level

As $D>D_{crit}$, the dissolved oxygen data sets for midday and maximum values (8th day) are significantly different at the 5% significance level.

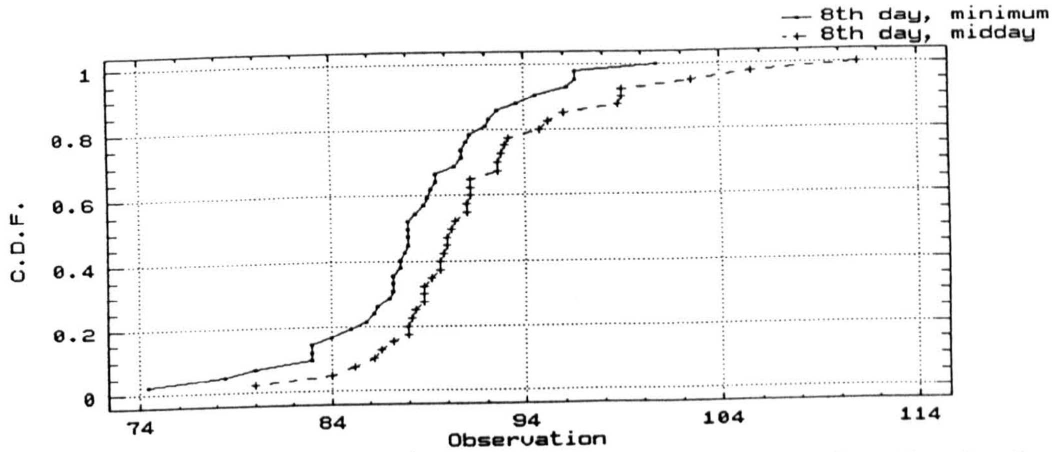


Figure 4.E.10: Cumulative distribution functions (C.D.F.) for dissolved oxygen (Annual: 8th day, midday and minimum values)

n= 39, D= 0.3738, D_{crit}= 0.0065 at a 5% significance level

As $D>D_{crit}$, the dissolved oxygen data sets for midday and minimum values (8th day) are significantly different at the 5% significance level.

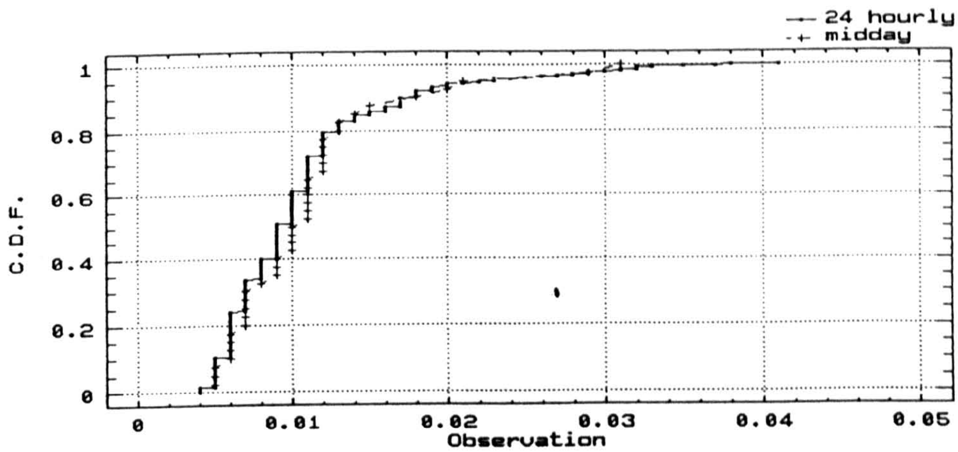


Figure 4.E.11: Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Annual: 8th day, 24 hourly and midday values)

n= 38, D= 0.2211, D_{crit}= 0.0468 at a 5% significance level

As $D>D_{crit}$, the un-ionised ammonia (N) data sets for 24 hourly and midday values (8th day) are significantly different at the 5% significance level.

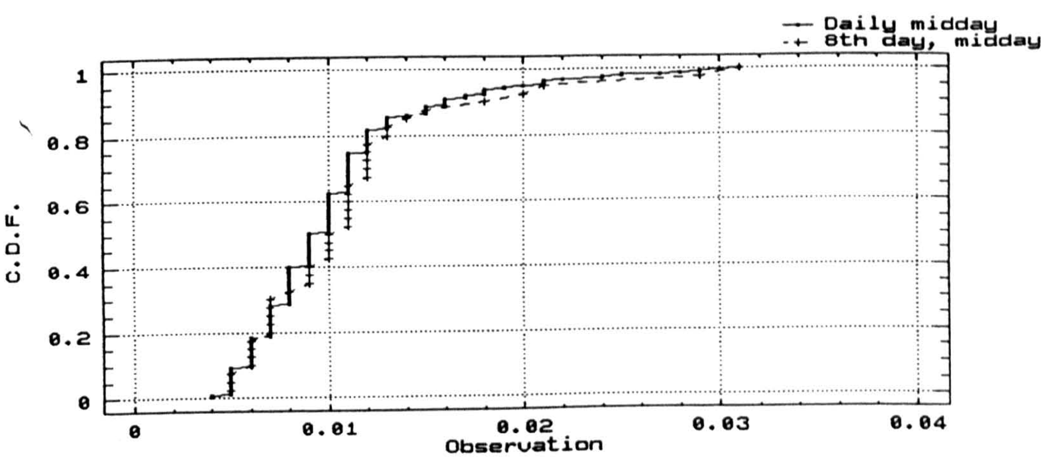


Figure 4.E.12: Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Annual: daily midday and 8th day midday values)

n= 38, D= 0.2459, D_{crit}= 0.0279 at a 5% significance level

As $D>D_{crit}$, the un-ionised ammonia (N) data sets for daily and 8th day midday values are significantly different at the 5% significance level.

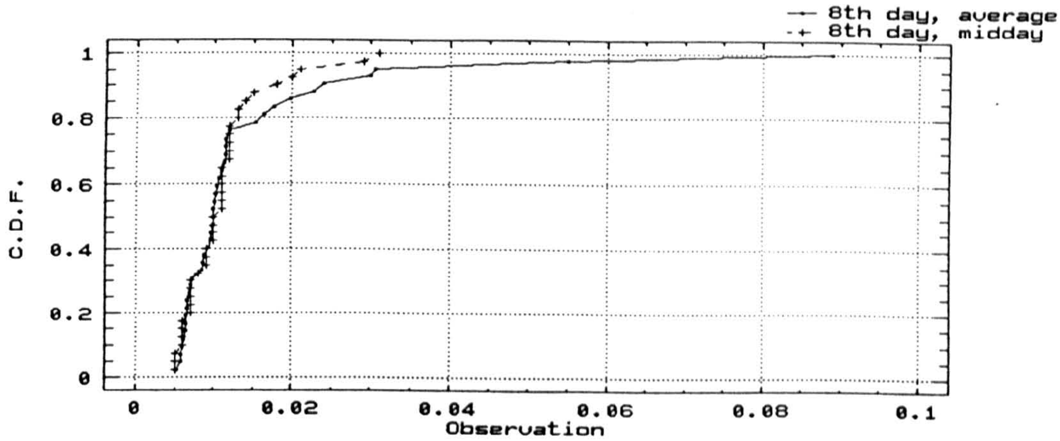


Figure 4.E.13: Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Annual: 8th day, midday and average values)

n= 39, D= 0.1429, D_{crit}= 0.7972 at a 5% significance level

As $D<D_{crit}$, the un-ionised ammonia (N) data sets for midday and average values (8th day) are not significantly different at the 5% significance level.

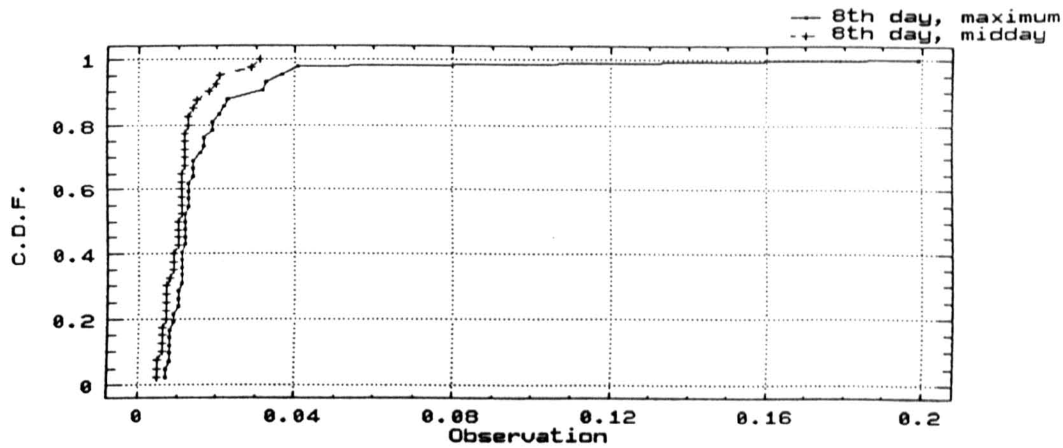


Figure 4.E.14: Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Annual: 8th day, midday and maximum values)

n= 39, D= 0.2524, D_{crit}= 0.1470 at a 5% significance level

As $D>D_{crit}$, the un-ionised ammonia (N) data sets for midday and maximum values (8th day) are significantly different at the 5% significance level.

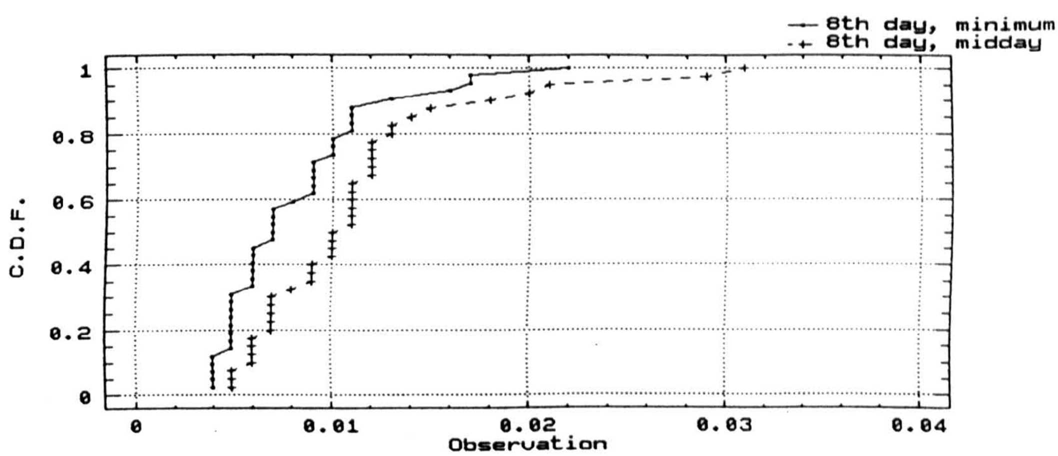


Figure 4.E.15: Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Annual: 8th day, midday and minimum values)

n= 39, D= 0.3964, D_{crit}= 0.0032 at a 5% significance level

As $D>D_{crit}$, the un-ionised ammonia (N) data sets for midday and minimum values (8th day) are significantly different at the 5% significance level.

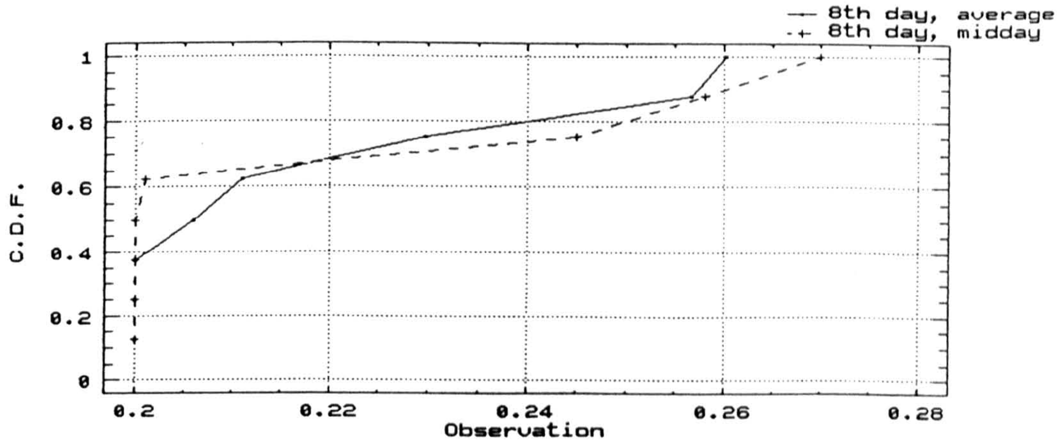


Figure 4.F.1 : Cumulative distribution functions (C.D.F.) for ammoniacal nitrogen as N (Seasonal: 8th day, midday and average values)

n= 7, D= 0.3750, D_{crit}= 0.4860 at a 5% significance level

As $D<D_{crit}$, the ammoniacal nitrogen (N) data sets for midday and average values (8th day) are not significantly different at the 5% significance level.

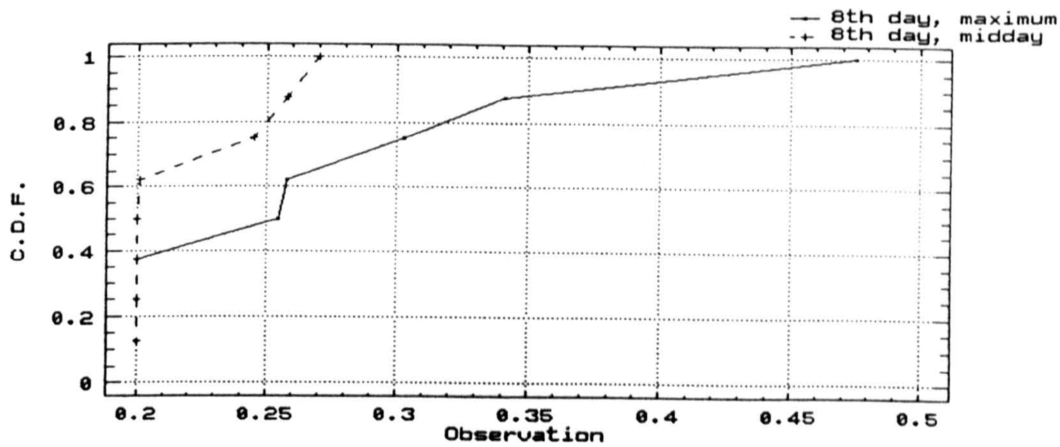


Figure 4.F.2: Cumulative distribution functions (C.D.F.) for ammoniacal nitrogen as N (Seasonal: 8th day, midday and maximum values)

n= 7, D= 0.3750, D_{crit}= 0.4860 at a 5% significance level

As $D<D_{crit}$, the ammoniacal nitrogen (N) data sets for midday and maximum values (8th day) are not significantly different at the 5% significance level.

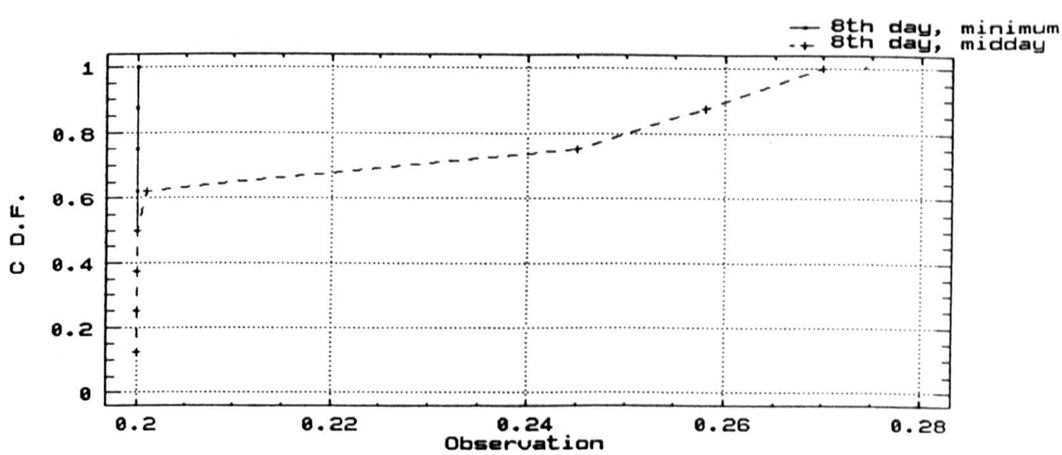


Figure 4.F.3 : Cumulative distribution functions (C.D.F.) for ammoniacal nitrogen as N (Seasonal: 8th day, midday and minimum values)

n= 7, D= 1.0000, D_{crit}= 0.4860 at a 5% significance level

As $D>D_{crit}$, the ammoniacal nitrogen (N) data sets for midday and minimum values (8th day) are significantly different at the 5% significance level.

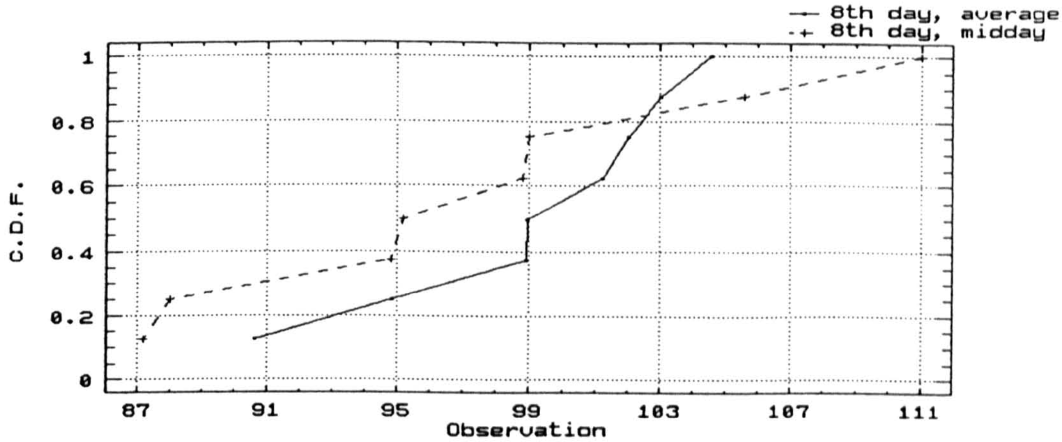


Figure 4.F.4: Cumulative distribution functions (C.D.F.) for dissolved oxygen (Seasonal: 8th day, midday and average values)

n= 7, D= 0.3750, D_{crit}= 0.4860 at a 5% significance level

As $D<D_{crit}$, the dissolved oxygen data sets for midday and average values (8th day) are not significantly different at the 5% significance level.

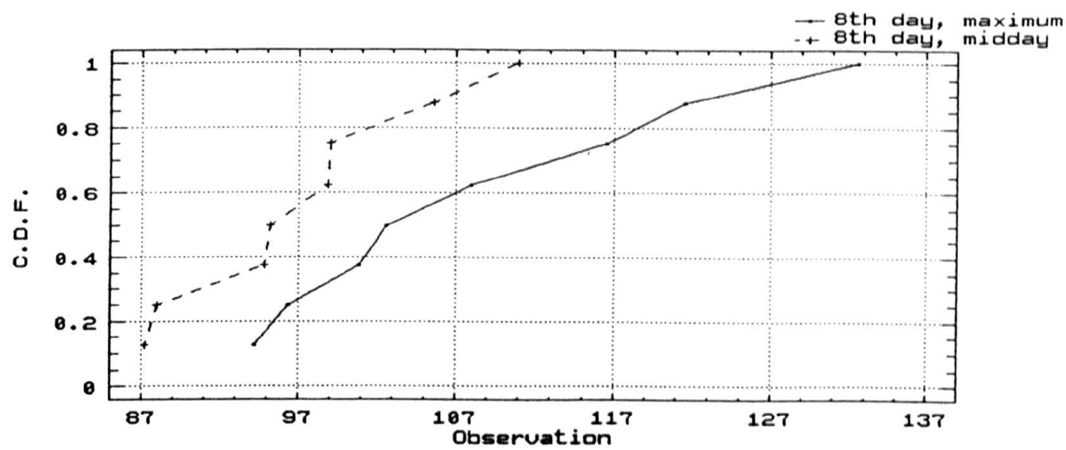


Figure 4.F.5: Cumulative distribution functions (C.D.F.) for dissolved oxygen (Seasonal: 8th day, midday and maximum values)

n= 7, D= 0.5000, D_{crit}= 0.4860 at a 5% significance level

As $D>D_{crit}$, the dissolved oxygen data sets for midday and maximum values (8th day) are significantly different at the 5% significance level. It should be noted that the values of D and D_{crit} are almost equal, it is difficult to state the above without reservations.

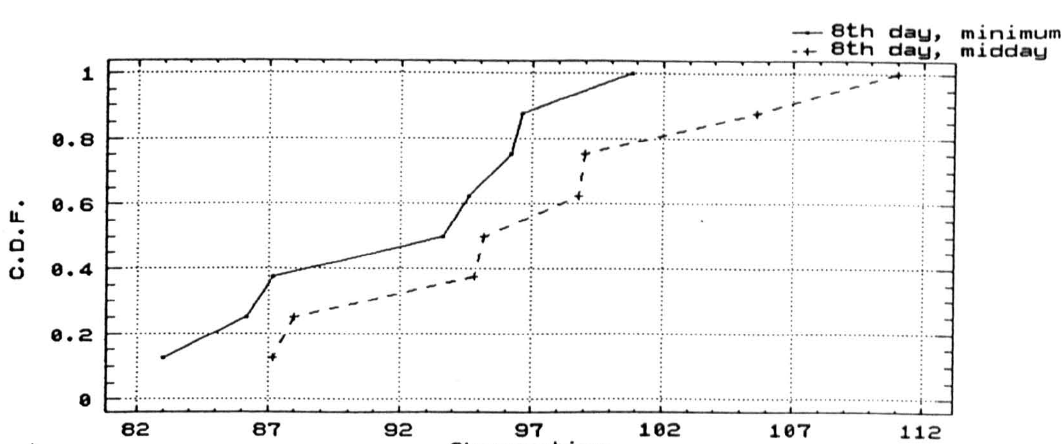


Figure 4.F.6: Cumulative distribution functions (C.D.F.) for dissolved oxygen (Seasonal: 8th day, midday and minimum values)

n= 7, D= 0.3750, D_{crit}= 0.4860 at a 5% significance level

As $D<D_{crit}$, the dissolved oxygen data sets for midday and minimum values (8th day) are not significantly different at the 5% significance level.

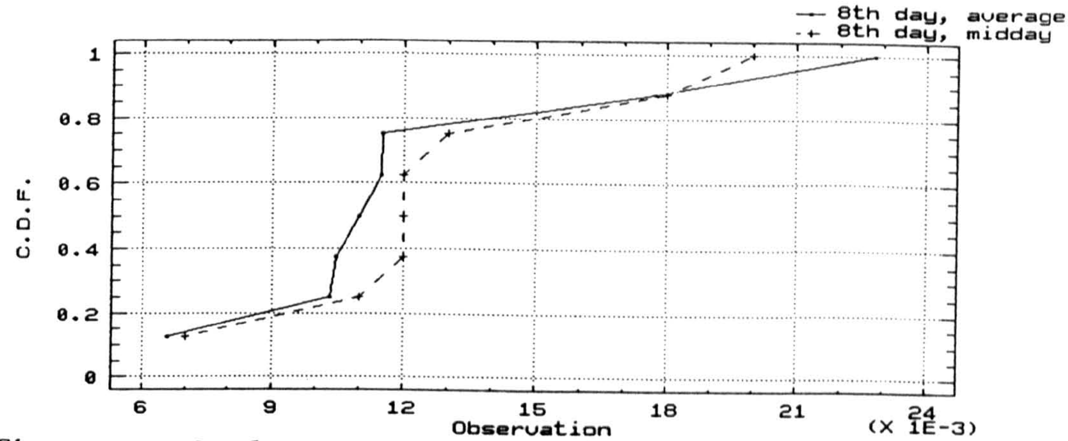


Figure 4.F.7: Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Seasonal: 8th day, midday and average values)

n= 7, D= 0.5000, D_{crit}= 0.4860 at a 5% significance level

As $D>D_{crit}$, the un-ionised ammonia (N) data sets for midday and average values (8th day) are significantly different at the 5% significance level. D and D_{crit} are almost equal and so it is difficult to state the above without reservations.

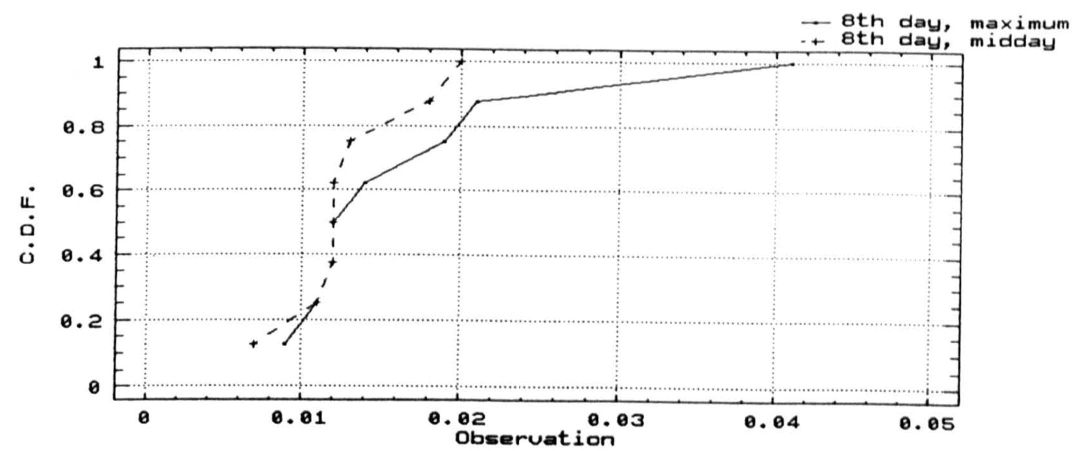


Figure 4.F.8: Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Seasonal: 8th day, midday and maximum values)

n= 7, D= 0.2500, D_{crit}= 0.4860 at a 5% significance level

As $D<D_{crit}$, the un-ionised ammonia (N) data sets for midday and maximum values (8th day) are not significantly different at the 5% significance level.

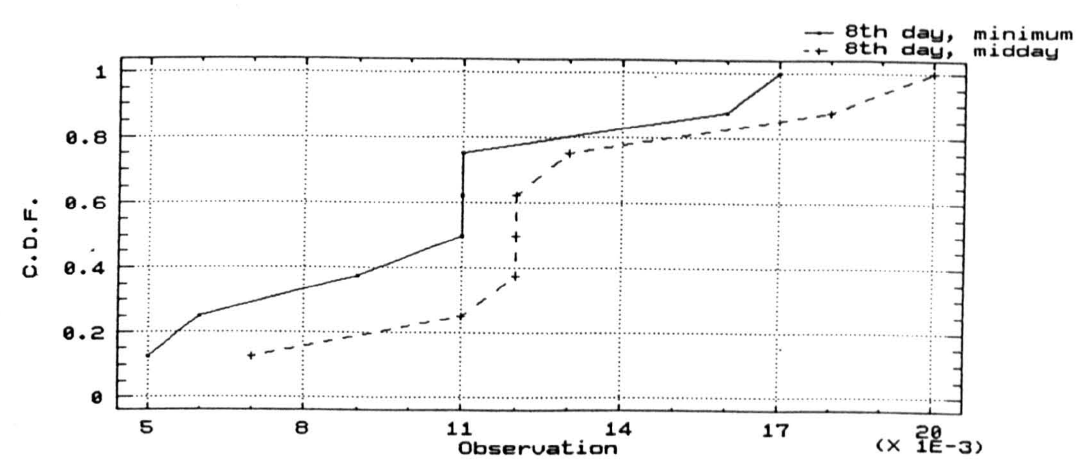


Figure 4.F.9: Cumulative distribution functions (C.D.F.) for un-ionised ammonia as N (Seasonal: 8th day, midday and minimum values)

n= 7, D= 0.6250, D_{crit}= 0.4860 at a 5% significance level

As $D>D_{crit}$, the un-ionised ammonia (N) data sets for midday and minimum values (8th day) are significantly different at the 5% significance level.

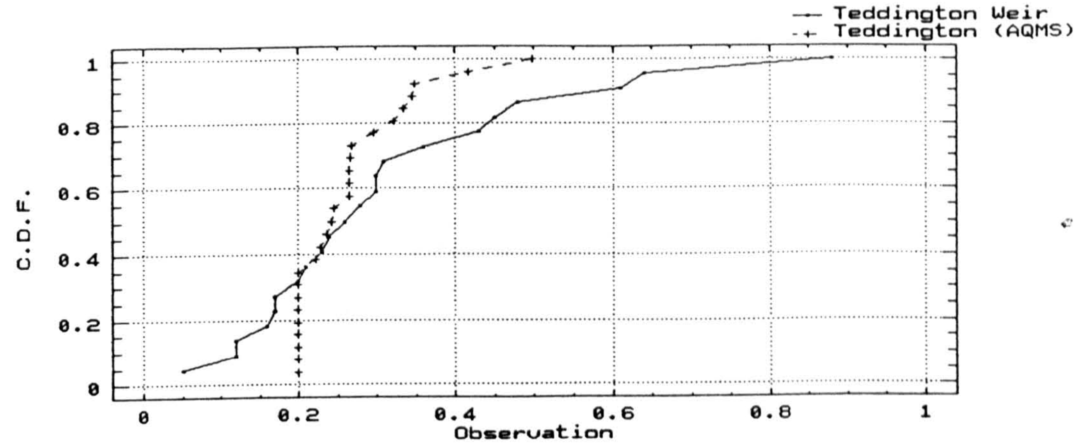


Figure 4.G.1: Cumulative distribution functions (C.D.F.) for ammoniacal nitrogen as N at Teddington (AQRM) and Teddington Weir.

n= 18, D= 0.3181, D_{crit}= 0.3090 at a 5% significance level

As $D>D_{crit}$, the data sets at Teddington (AQRM) and Teddington Weir are significantly different for ammoniacal nitrogen as N at a 5% significance level. As D and D_{crit} are close, this result t is only speculative.

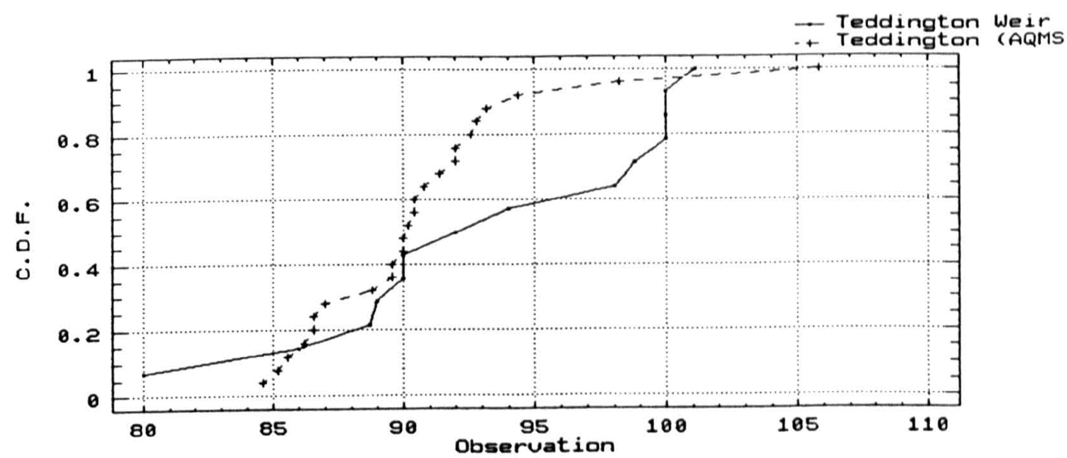


Figure 4.G.2: Cumulative distribution functions (C.D.F.) for dissolved oxygen at Teddington (AQRM) and Teddington Weir.

n= 10, D= 0.3800, D_{crit}= 0.4100 at a 5% significance level

As $D>D_{crit}$, the data sets at Teddington (AQRM) and Teddington Weir are significantly different for dissolved oxygen at a 5% significance level. As D and D_{crit} are close, this result is only speculative.

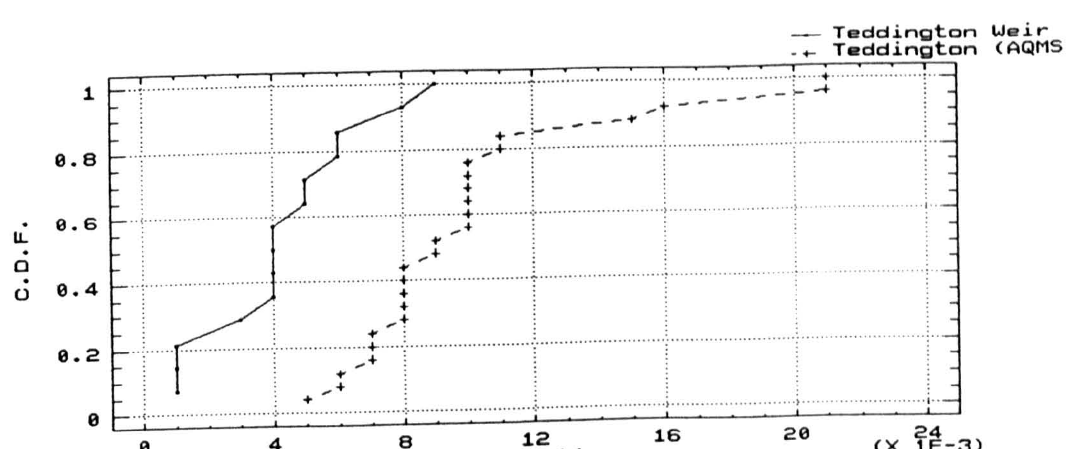
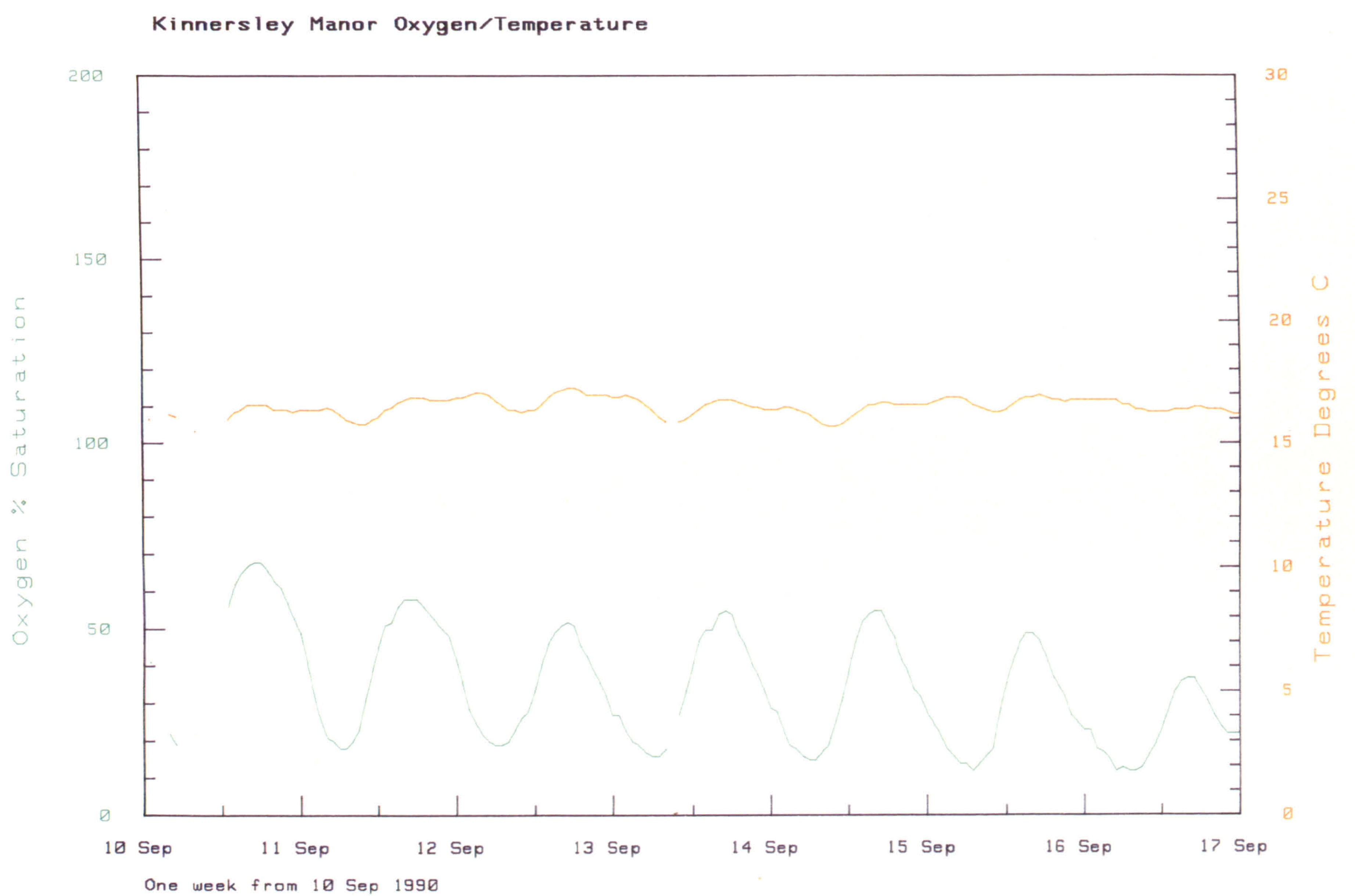


Figure 4.G.3: Cumulative distribution functions (C.D.F.) 'for un-ionised ammonia as N at Teddington (AQRM) and Teddington Weir.

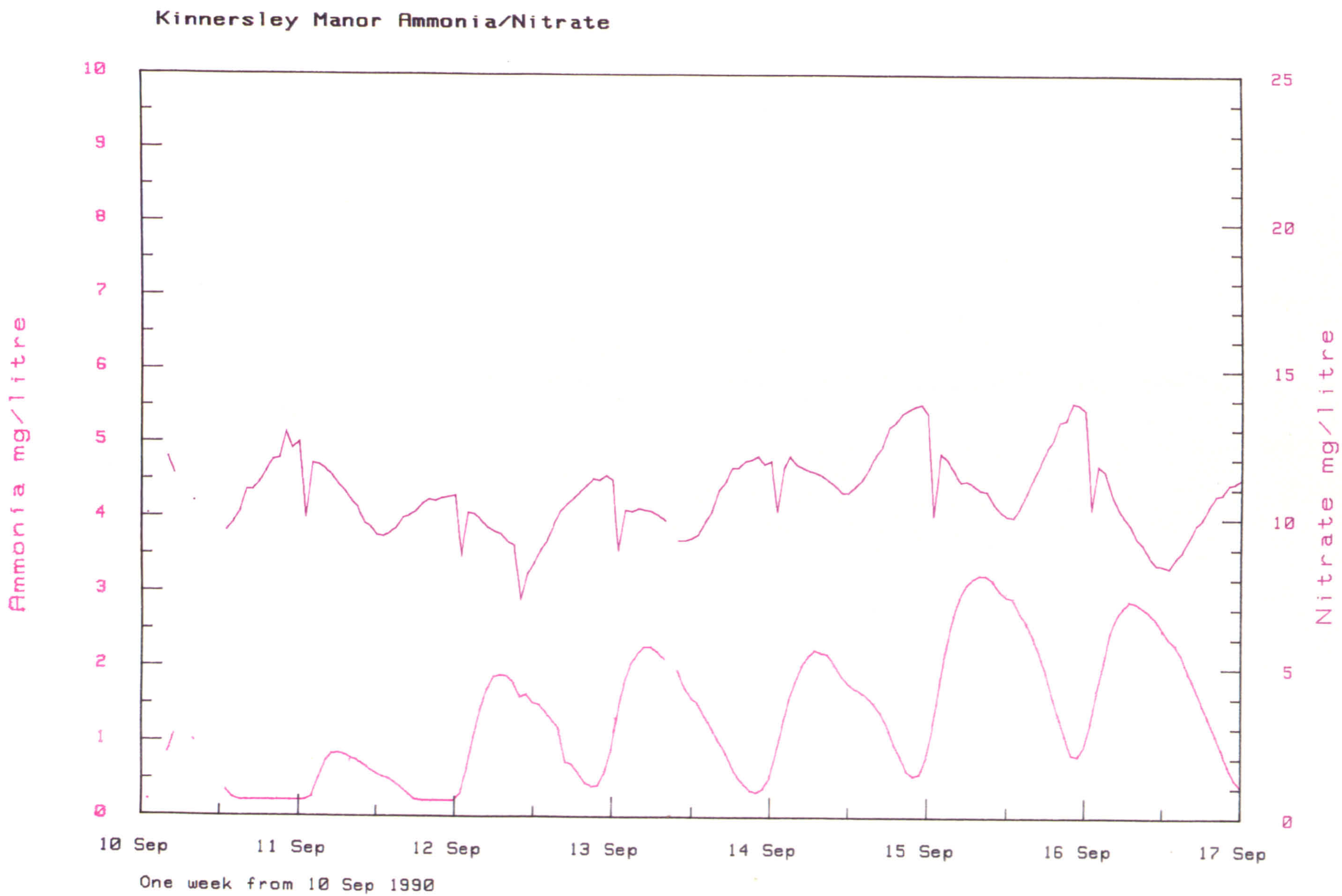
n= 10, D= 0.8171, D_{crit}= 0.4100 at a 5% significance level

As $D>D_{crit}$, the data sets at Teddington (AQRM) and Teddington Weir are significantly different for un-ionised ammonia as N at a 5% significance level.

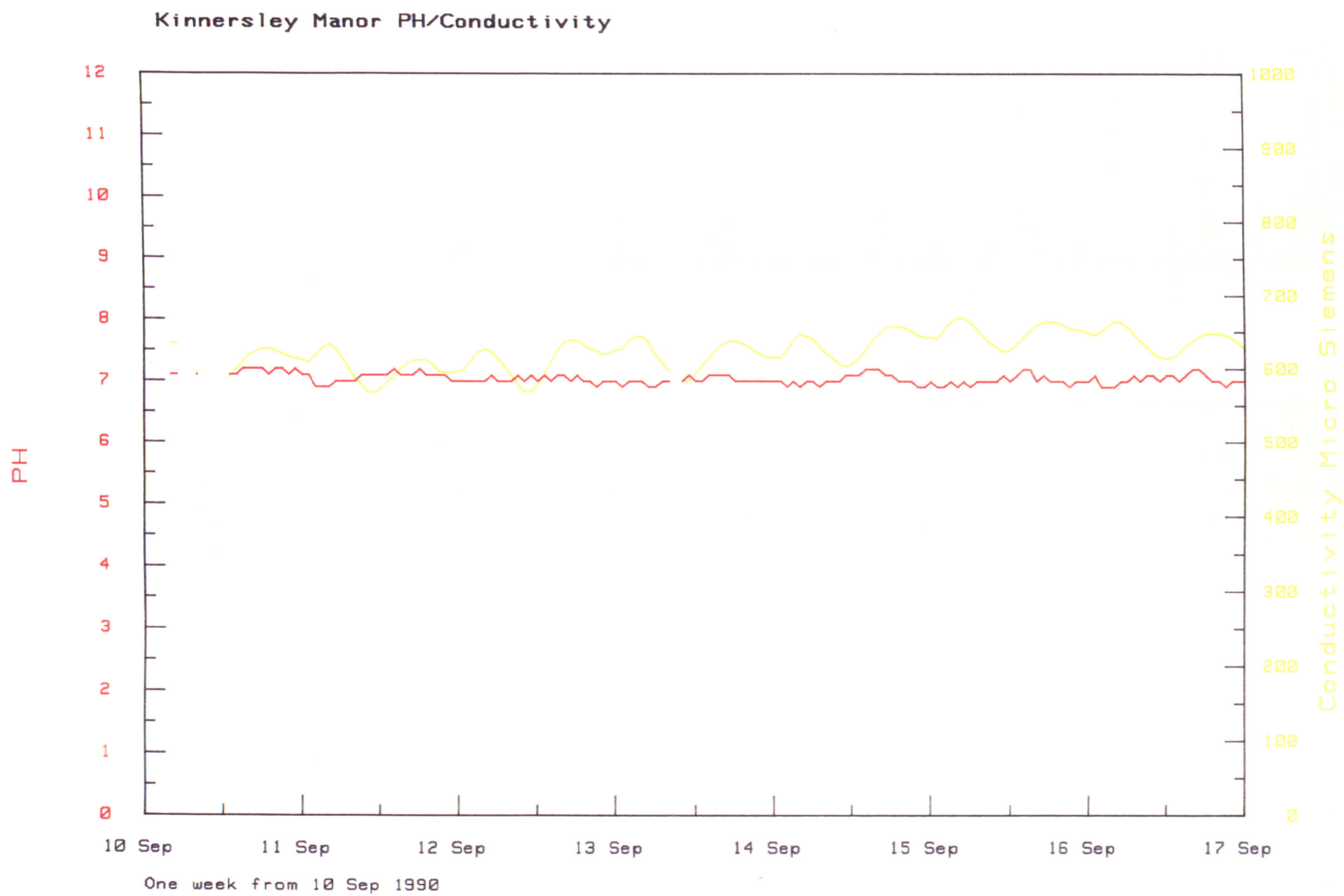
APPENDIX 5.



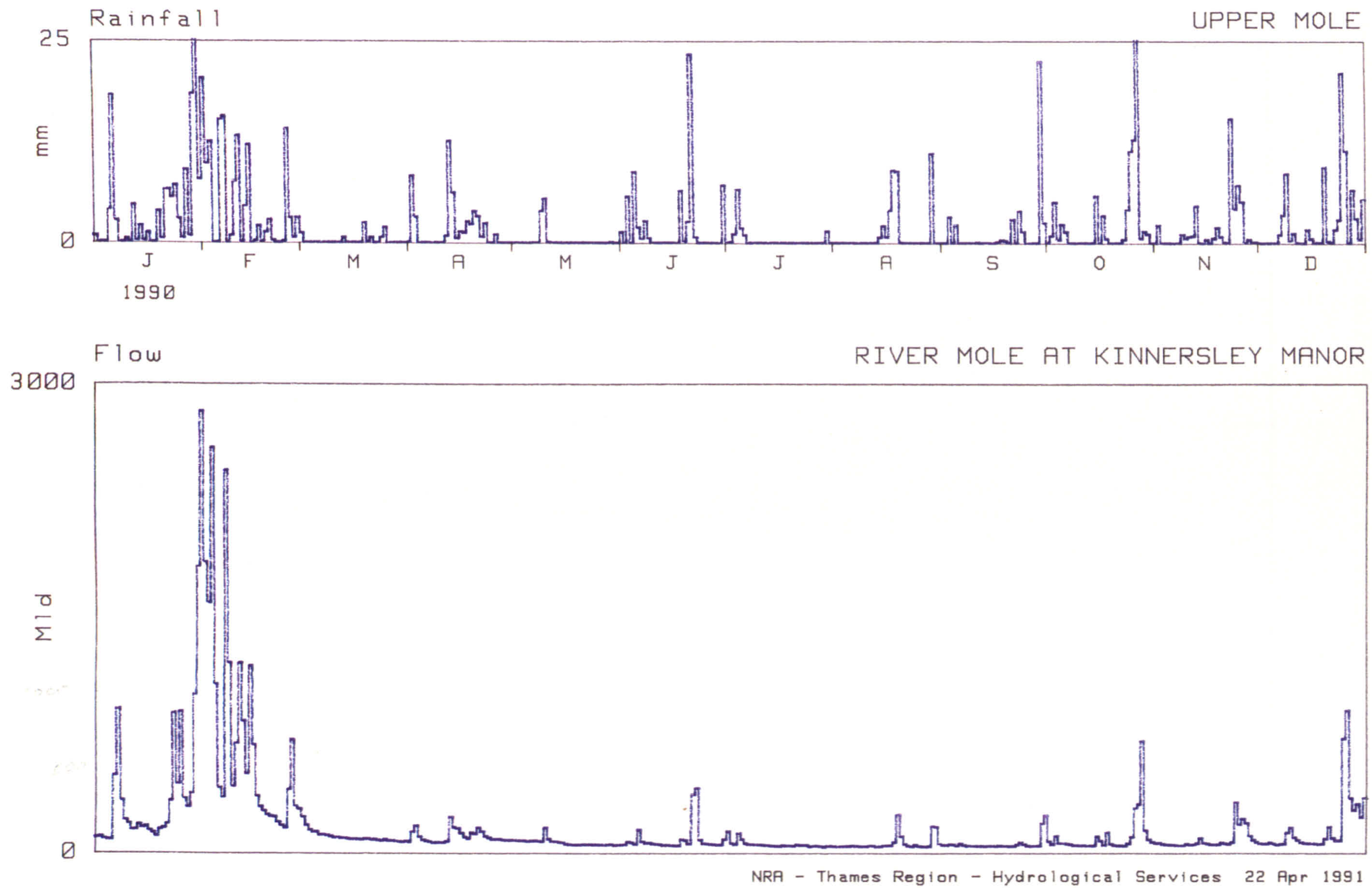
App 5. Fig 1. Kinnersley Manor, River Mole - Dissolved oxygen and temperature, week beginning 10th September 1990.



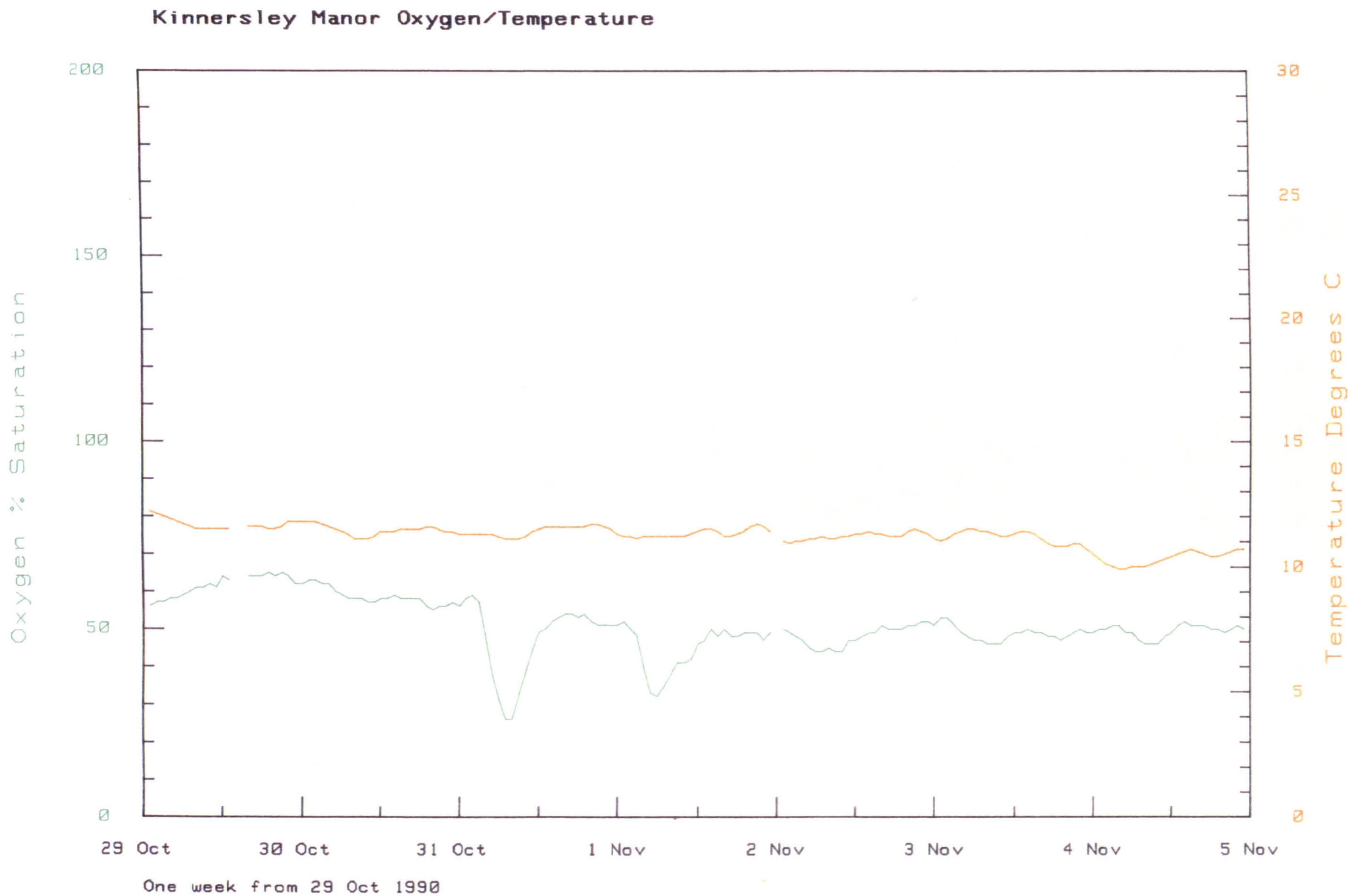
App 5. Fig 2. Kinnersley Manor, River Mole - Ammonia and nitrate, week beginning 10th September 1990.



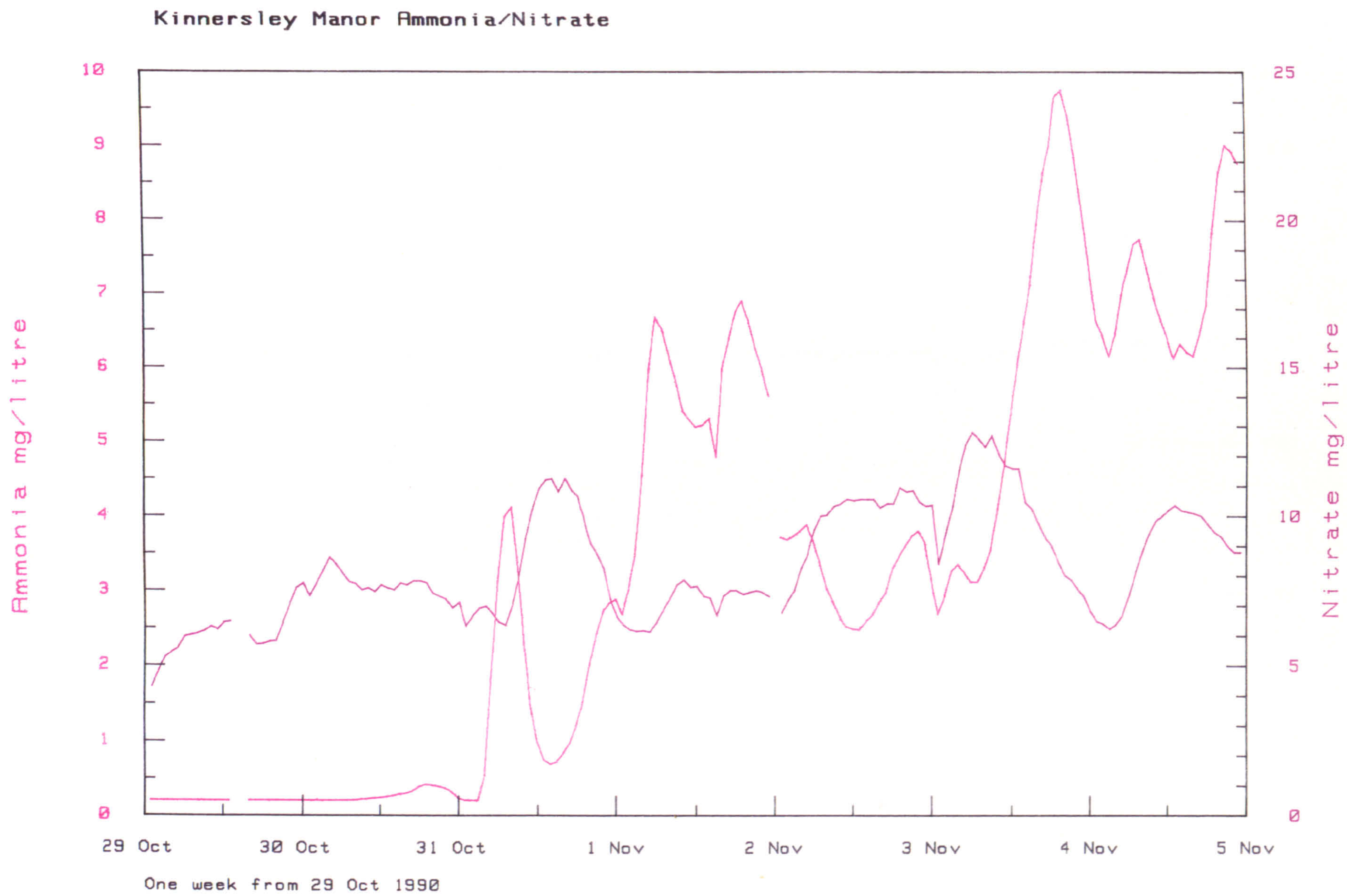
App 5. Fig 3. Kinnersley Manor, River Mole - pH and conductivity, week beginning 10th September 1990.



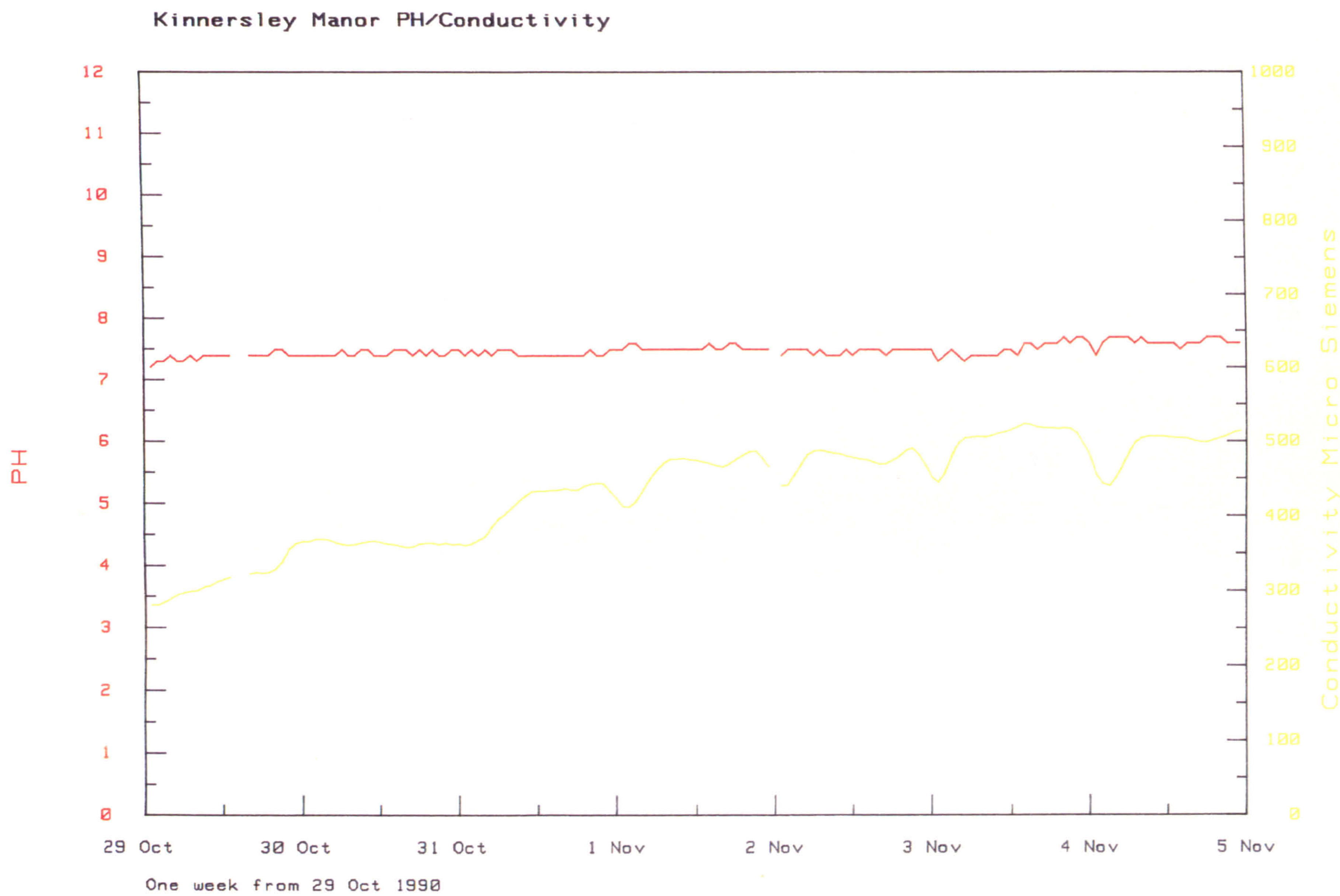
App 5. Fig 4. Kinnersley Manor, River Mole - Flow Hydrograph, 1990.



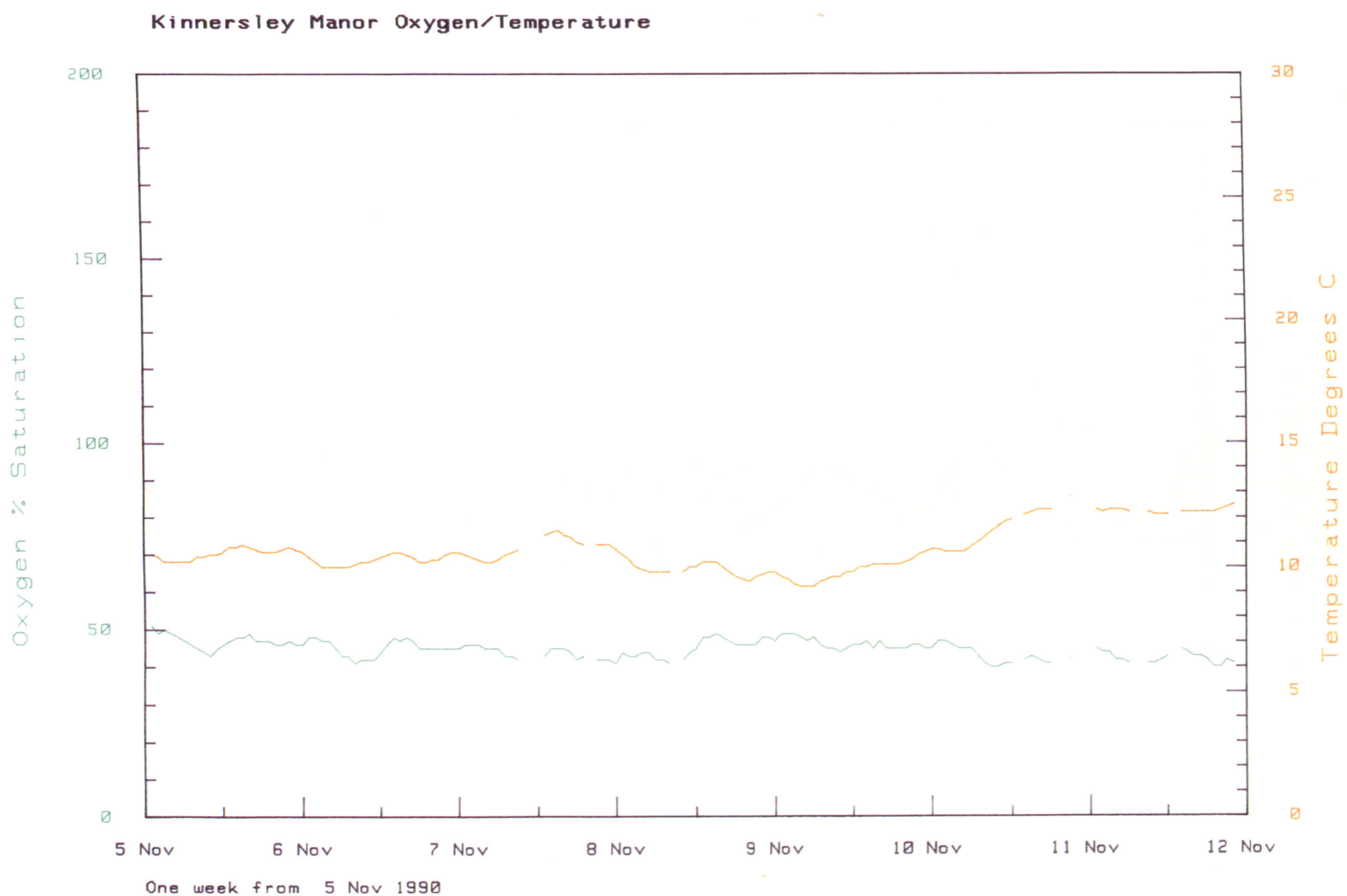
App 5. Fig 5. Kinnersley Manor, River Mole - Dissolved oxygen and temperature, week beginning 29th October 1990.



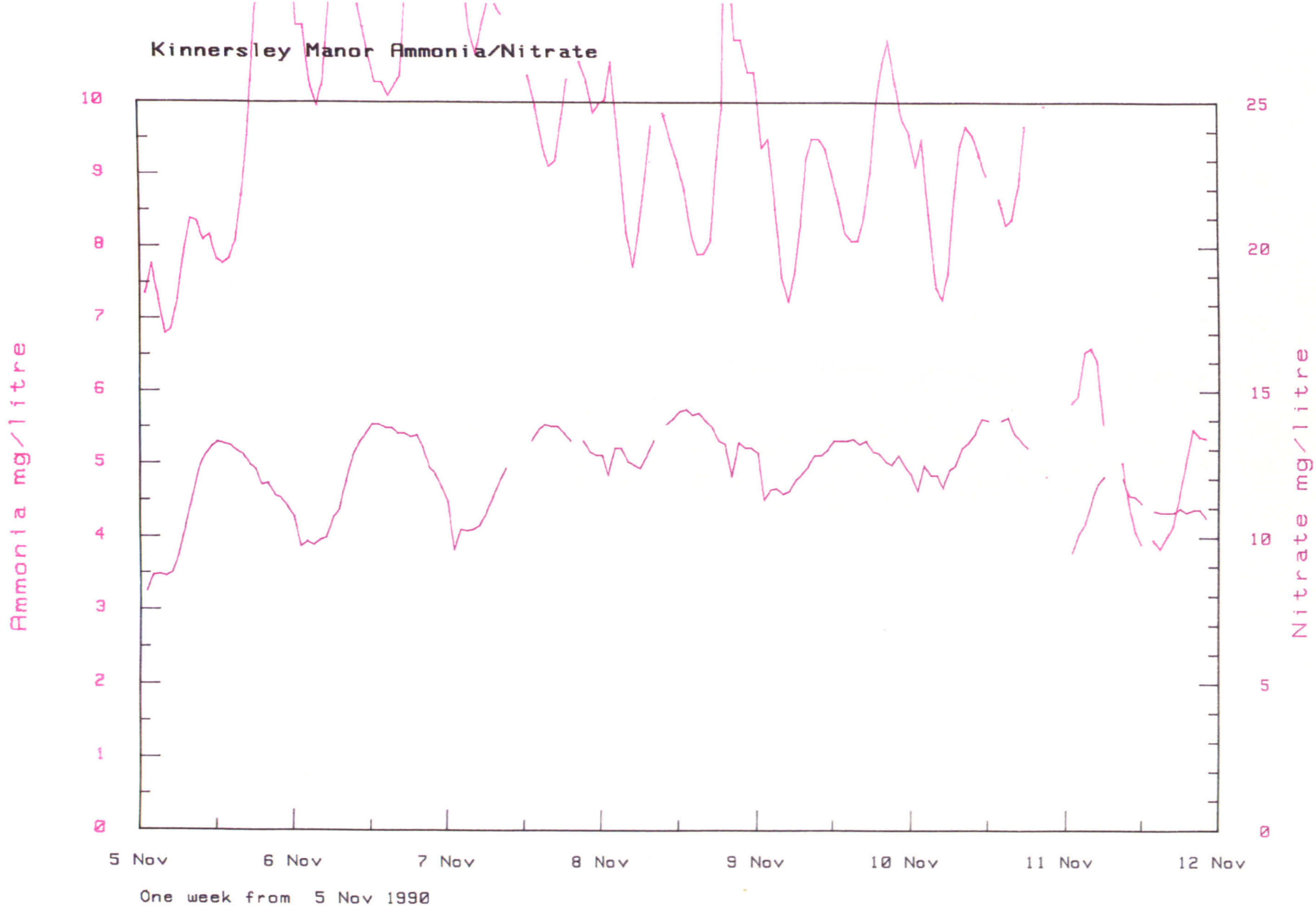
App 5. Fig 6. Kinnersley Manor, River Mole - Ammonia and nitrate, week beginning 29th October 1990.



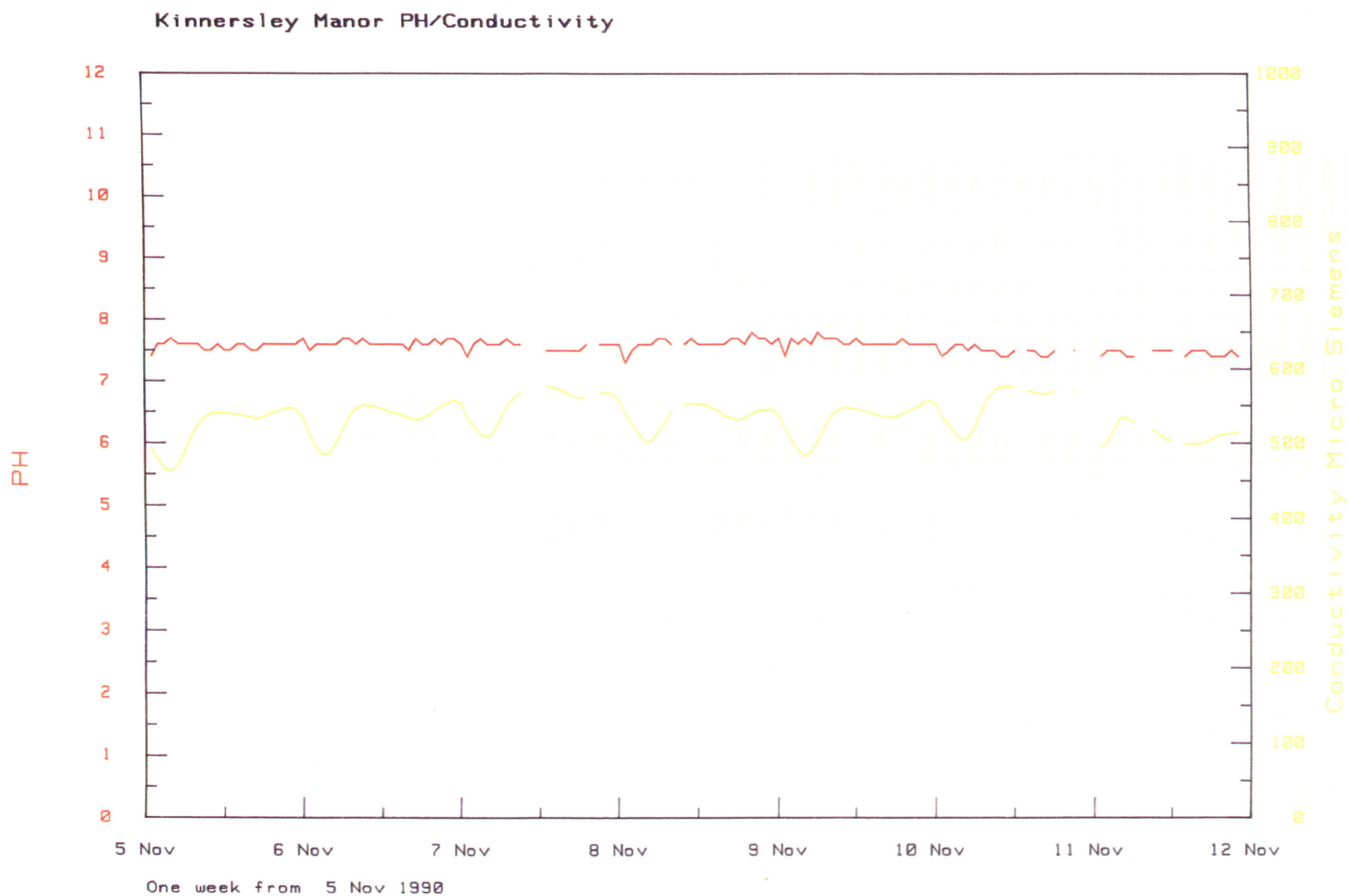
App 5. Fig 7. Kinnersley Manor, River Mole - pH and conductivity, week beginning 29th October 1990.



App 5. Fig 8. Kinnersley Manor, River Mole - Dissolved oxygen and temperature, week beginning 5th November 1990.



App 5. Fig 9. Kinnersley Manor, River Mole - Ammonia and nitrate, week beginning 5th November 1990.



App 5. Fig 10. Kinnersley Manor, River Mole - pH and conductivity, week beginning 5th November 1990.

PHLE.0053 CRAWLEY STW NO.1					SOLIDS	BOD	AMMONIA	SOLIDS	BOD	AMMONIA
09/01/90	1034	R--D	11	AA054	35.0	11.0	3.37	PASS	PASS	PASS
25/01/90	1215	R--D	11	RK085	42.0	18.2	3.24	PASS	PASS	PASS
05/02/90	1105	R--D	11	RK122	7.0	3.9	2.30	PASS	PASS	PASS
22/02/90	1050	R--D	11	RK232	7.5	3.8	6.34	PASS	PASS	PASS
28/02/90	1310	R--D	11	RK260	6.0	3.4	5.42	PASS	PASS	PASS
15/03/90	1300	R--D	11	IG275	5.0	3.6	2.35	PASS	PASS	PASS
04/04/90	1120	R--D	11	RK468	< 1.0	3.6	5.64	PASS	PASS	PASS
17/04/90	0920	R--D	11	RK513	1.0	1.6	0.97	PASS	PASS	PASS
23/04/90	1340	R--D	11	IG403	7.5	2.4	4.19	PASS	PASS	PASS
26/04/90	1245	R--D	10	IG443	0.0	3.4	7.81	PASS	PASS	PASS
09/05/90	1235	R--D	11	IG515	12.0	6.7	7.99	PASS	PASS	PASS
14/05/90	1030	R--D	11	ND127	20.0	7.9	3.79	PASS	PASS	PASS
19/05/90	0945	R--D	11	IG584	12.0	4.9	6.53	PASS	PASS	PASS
24/05/90	1245	R--D	11	RK663	5.5 <	5.0	7.36	PASS	PASS	PASS
31/05/90	1335	-L-X	02	LS158	60.0	121.0	7.20	PASS	FAIL	PASS
[illegible]4/06/90	2000	--SR	12	ND150	24.5	14.7	28.90	PASS	PASS	FAIL
[illegible]5/06/90	0001	--SR	10	PG071				PASS	PASS	PASS
05/06/90	1002	--SR	12	PG031	12.0	9.2	22.90	PASS	PASS	FAIL
05/06/90	1201	--SR	11	PG041	13.5	5.7	19.40	PASS	PASS	PASS
05/06/90	1404	--SR	12	PG051	13.0	5.1	22.20	PASS	PASS	FAIL
05/06/90	2010	--SR	12	IC047	27.0	10.6	30.10	PASS	PASS	FAIL
06/06/90	0001	--SR	10	RK739				PASS	PASS	PASS
06/06/90	1000	--SR	12	IG665	32.0	15.3	20.50	PASS	PASS	FAIL
06/06/90	1200	--SR	10	RK710				PASS	PASS	PASS
06/06/90	2015	--SR	12	JN051	75.0	30.9	17.90	FAIL	PASS	PASS
07/06/90	0410	--SR	12	ND200	388.0 >	38.9	16.30	FAIL	PASS	PASS
07/06/90	0415	-L-X	02	LS162	350.0	202.0	14.60	FAIL	FAIL	PASS
07/06/90	1400	--SR	11	RK720	55.0	26.9	19.80	PASS	PASS	PASS
07/06/90	1600	--SR	12	RK730	248.0 >	38.9	20.70	FAIL	PASS	FAIL
17/06/90	1230	R--D	11	RK805	2.5	10.2	9.09	PASS	PASS	PASS
20/06/90	0730	R--D	10	RK856				PASS	PASS	PASS
22/06/90	1615	R--D	11	IG773	8.0	3.0	3.88	PASS	PASS	PASS
03/07/90	1035	R--D	11	ND307	30.0	7.7	7.61	PASS	PASS	PASS
[illegible]6/08/90	1315	I--R	11	ND462	11.0	4.8	13.60	PASS	PASS	PASS
30/08/90	1045	IL-X	02	LS244	121.0	94.0	10.40	FAIL	FAIL	PASS
12/09/90	1035	RL-X	01	LS252	8.0	8.5	4.00	PASS	PASS	PASS
03/10/90	1643	IL-X	02	LS299	20.0	51.0	13.60	PASS	FAIL	PASS
03/01/91	1055	R--D	11	IG242	11.0	6.2 <	0.50	PASS	PASS	PASS
10/01/91	1140	RL-X	01	LS517	12.0	11.0	0.12	PASS	PASS	PASS
23/01/91	1150	R--D	10	ML074				PASS	PASS	PASS
30/01/91	1100	R--D	10	ML141				PASS	PASS	PASS
11/02/91	1040	-L-X	01	LS580	10.0	12.0	6.20	PASS	PASS	PASS
15/02/91	1030	IL-X	02	LS621	274.0	156.0	2.40	FAIL	FAIL	PASS
18/04/91	1500	RL-X	00	ML381				PASS	PASS	PASS
02/05/91	1250	RL-X	01	ML408	22.8	9.0	0.64	PASS	PASS	PASS
23/05/91	1140	RL-X	02	ML448	63.0		5.84	FAIL	PASS	PASS
13/06/91	1240	RL-X	01	ML477	9.2	8.8 <	0.50	PASS	PASS	PASS
18/06/91	0950	RL-X	02	ML480	63.8	39.7	2.23	FAIL	FAIL	PASS

App 5. Tab 1. Performance statistice for Crawley STW.

PHLE.0054 CRAWLEY STW NO.2					SOLIDS	BOD	AMMONIA	SOLIDS	BOD	AMMONIA
02/01/90	1150	R--D	12	RK009	21.5	9.0	4.97	FAIL	FAIL	PASS
09/01/90	1039	R--D	11	AA055	2.5	2.4	3.30	PASS	PASS	PASS
15/01/90	1405	R--D	11	RK047	8.0	2.2	6.01	PASS	PASS	PASS
25/01/90	1215	R--D	10	RK086				PASS	PASS	PASS
30/01/90	1125	R--R	10	RK107				PASS	PASS	PASS
05/02/90	1100	R--D	11	RK123	< 1.0	1.3	1.53	PASS	PASS	PASS
13/02/90	1045	R--D	11	AA244	2.0	1.2	0.98	PASS	PASS	PASS
22/02/90	1045	R--D	11	RK231	2.0	1.9	5.51	PASS	PASS	PASS
28/02/90	1315	R--D	11	RK261	1.0	1.4	4.84	PASS	PASS	PASS
15/03/90	1305	R--D	11	IG276	1.5	1.8	0.72	PASS	PASS	PASS
26/03/90	0924	R--D	11	AA526	2.0	2.2	1.07	PASS	PASS	PASS
04/04/90	1125	R--D	12	RK469	2.0	14.1	5.80	PASS	FAIL	PASS
17/04/90	0925	R--D	11	RK514	4.0	3.9	1.38	PASS	PASS	PASS
23/04/90	1345	R--D	11	IG404	2.5	1.7	2.43	PASS	PASS	PASS
26/04/90	1250	R--D	10	IG444		1.2	5.47	PASS	PASS	PASS
01/05/90	0842	R--D	11	AA720	3.0	2.3	9.34	PASS	PASS	PASS
09/05/90	1240	R--D	11	IG516	1.0	2.1	6.46	PASS	PASS	PASS
14/05/90	1025	R--D	11	ND126	2.0	2.4	4.34	PASS	PASS	PASS
19/05/90	0950	R--D	11	IG585	6.0	1.8	5.61	PASS	PASS	PASS
24/05/90	1240	R--D	12	RK664	12.0	9.7	8.71	FAIL	FAIL	PASS
31/05/90	1330	R--D	11	RK702	7.0	4.2	7.14	PASS	PASS	PASS
04/06/90	0400	--SR	12	IG640	2.0	5.1	26.70	PASS	PASS	FAIL
04/06/90	2005	--SR	12	ND151	7.5	10.9	26.10	PASS	FAIL	FAIL
04/06/90	2155	--SR	12	ND153	7.0	10.9	29.30	PASS	FAIL	FAIL
05/06/90	1000	--SR	12	PG030	4.5	5.8	18.30	PASS	PASS	FAIL
05/06/90	1201	--SR	12	PG040	4.0	4.5	21.10	PASS	PASS	FAIL
05/06/90	1403	--SR	12	PG050	5.0	5.4	21.70	PASS	PASS	FAIL
05/06/90	1600	--SR	12	PG060	4.5	5.7	23.40	PASS	PASS	FAIL
05/06/90	1800	--SR	12	PG070	5.5	5.7	25.40	PASS	PASS	FAIL
05/06/90	2012	--SR	12	IC048	5.0	6.0	26.80	PASS	PASS	FAIL
05/06/90	2200	--SR	12	IC056	4.0	5.1	29.40	PASS	PASS	FAIL
06/06/90	0001	--SR	12	IC065	2.5	7.2	29.60	PASS	FAIL	FAIL
06/06/90	0205	--SR	12	IC073	3.0	5.4	29.00	PASS	PASS	FAIL
06/06/90	0600	--SR	12	IG648	4.0	3.0	25.30	PASS	PASS	FAIL
06/06/90	0755	--SR	12	IG657	5.0	2.4	24.60	PASS	PASS	FAIL
06/06/90	1005	--SR	12	IG666	7.0	2.7	20.40	PASS	PASS	FAIL
06/06/90	1200	--SR	12	RK711	25.0	10.8	18.60	FAIL	FAIL	FAIL
06/06/90	2020	--SR	12	JN052	17.0	9.7	19.30	FAIL	FAIL	FAIL
07/06/90	0210	--SR	12	JN080	13.0	3.6	16.70	FAIL	PASS	FAIL
07/06/90	0605	--SR	12	ND209	4.0	3.7	14.60	PASS	PASS	FAIL
07/06/90	0800	--SR	12	ND218	19.0	8.2	14.80	FAIL	FAIL	FAIL
07/06/90	1000	--SR	12	ND226	15.0	6.2	13.10	FAIL	PASS	FAIL
07/06/90	1405	--SR	12	RK721	2.0	4.5	19.70	PASS	PASS	FAIL
07/06/90	1610	--SR	12	RK731	19.0	6.4	20.30	FAIL	PASS	FAIL
07/06/90	1750	--SR	12	RK740	52.0	19.9	19.80	FAIL	FAIL	FAIL
17/06/90	1235	R--D	11	RK806	2.5	4.0	9.16	PASS	PASS	PASS
20/06/90	0730	R--D	12	RK857	9.0	2.6	15.50	PASS	PASS	FAIL
22/06/90	1620	R--D	11	IG774	1.0	2.0	2.40	PASS	PASS	PASS
28/06/90	1540	V--D	30	DV000				PASS	PASS	PASS
03/07/90	1030	R--D	11	ND306	5.5	3.5	7.99	PASS	PASS	PASS
16/07/90	1030	-L-X	02	LS171	14.0	19.0	10.70	FAIL	FAIL	PASS

PMLE.0054	CRAWLEY	STW	NO.2		SOLIDS		BOD		AMMONIA	SOLIDS	BOD	AMMONIA
16/07/90	1725	I--R	12	ND405	13.0		16.7		12.20	FAIL	FAIL	FAIL
17/07/90	0950	I--R	11	ND406	3.0		2.0		8.41	PASS	PASS	PASS
02/08/90	1600	R--D	11	IG850	6.0		3.7		6.72	PASS	PASS	PASS
15/08/90	1400	IL-X	01	LS228	6.0		3.5		11.10	PASS	PASS	PASS
28/08/90	1310	I--R	11	ND461	6.0		3.9		11.10	PASS	PASS	PASS
02/09/90	1645	-L-X	01	LS306	7.0		4.0		8.50	PASS	PASS	PASS
02/09/90	1646	R--D	10	RK973						PASS	PASS	PASS
12/09/90	1030	RL-X	01	LS251	3.0		2.5		4.10	PASS	PASS	PASS
28/09/90	0915	RL-X	01	LS278 <	2.0		2.0		10.30	PASS	PASS	PASS
28/09/90	0916	R--D	10	RK035						PASS	PASS	PASS
03/10/90	1640	IL-X	02	LS298	2.0		11.5		12.70	PASS	FAIL	FAIL
31/10/90	1235	ILSX	02	LS330	7.0		8.0		11.40	PASS	FAIL	PASS
05/11/90	0930	IL-X	02	LS329	9.0		9.5		25.20	PASS	FAIL	FAIL
09/11/90	1040	RL-X	02	LS394	2.0		4.5		18.50	PASS	PASS	FAIL
13/11/90	0945	RL-X	01	LS350	5.0		2.5		5.10	PASS	PASS	PASS
[illegible]5/11/90	1215	RL-X	02	LS389	10.0		7.5		16.90	PASS	FAIL	FAIL
[illegible]0/11/90	1120	RL-X	01	LS385	6.0		3.0		3.70	PASS	PASS	PASS
05/12/90	0950	RL-X	01	LS431	4.0		5.0		5.50	PASS	PASS	PASS
13/12/90	1145	RL-X	01	LS460	7.0		5.0		0.23	PASS	PASS	PASS
03/01/91	1100	RL-X	01	LS493	3.0		3.0		1.40	PASS	PASS	PASS
10/01/91	1100	RL-X	02	LS516	15.0		12.5		0.11	FAIL	FAIL	PASS
16/01/91	0940	RL-X	01	LS505	3.0		2.5		0.47	PASS	PASS	PASS
23/01/91	1150	RL-X	01	LS531	4.0		5.0		1.91	PASS	PASS	PASS
30/01/91	1045	RL-X	01	LS561 <	2.0		4.0		2.20	PASS	PASS	PASS
05/02/91	1035	RL-X	01	LS584	8.0		4.5		4.70	PASS	PASS	PASS
07/03/91	1140	RL-X	01	LS653 <	2.0		1.5		0.08	PASS	PASS	PASS
21/03/91	1150	RL-X	01	LS663 <	2.0		2.0		4.80	PASS	PASS	PASS
15/04/91	1040	RL-X	00	ND120	2.4		0.0	<	0.50	PASS	PASS	PASS
18/04/91	1430	RL-X	00	ML380						PASS	PASS	PASS
07/05/91	1210	RL-X	01	ML411	7.2	<	2.0	<	0.50	PASS	PASS	PASS
23/05/91	1045	RL-X	02	ML447	34.0				5.87	FAIL	PASS	PASS
30/05/91	0945	RL-X	01	ML465	6.0		2.0	<	0.50	PASS	PASS	PASS
18/06/91	1010	RL-X	02	ML481	17.5		16.9		1.83	FAIL	FAIL	PASS

PMLE.0091 HORLEY STW

				SOLIDS	BOD	AMMONIA	SOLIDS	BOD	AMMONIA
02/01/90	1100	R--D	12 RK005	19	21	26.11	PASS	PASS	FAIL
09/01/90	1225	R--D	12 AA064	32	37	17.2	PASS	FAIL	PASS
15/01/90	1205	R--D	12 RK042	41	50	24.1	PASS	FAIL	PASS
15/01/90	1300	-L-X	02 LS070	35	51	24.6	PASS	FAIL	PASS
25/01/90	1415	R--D	12 RK093	143	32.2	10.5	FAIL	FAIL	PASS
30/01/90	1040	R--D	11 RK102	28	18.2	9.25	PASS	PASS	PASS
05/02/90	1010	R--D	11 RK119	16.5	14	10.1	PASS	PASS	PASS
13/02/90	1026	R--D	12 AA251	30	30.3	12	PASS	FAIL	PASS
22/02/90	1200	--SR	12 RK235	46	91.5	27.4	PASS	FAIL	FAIL
28/02/90	1355	R--D	12 RK263	28	38.3	14.1	PASS	FAIL	PASS
15/03/90	1345	R--D	10 IG278	16	9	24.56	PASS	PASS	PASS
26/03/90	1104	R--D	10 AA534	13	10	15.2	PASS	PASS	PASS
04/04/90	1210	R--D	11 RK472	9	11.1	1.3	PASS	PASS	PASS
17/04/90	1200	R--R	11 RK523	10.5	3.1	0.5	PASS	PASS	PASS
23/04/90	1210	R--D	11 IG397	21.5	5.7	9.78	PASS	PASS	PASS
26/04/90	1130	R--R	11 IG437	7.5	3.9	11.3	PASS	PASS	PASS
26/04/90	1240	--SR	31 AC705	14.4	10.3	4.54	PASS	PASS	PASS
01/05/90	1030	R--D	11 AA729	7.5	6.5	19.81	PASS	PASS	PASS
09/05/90	1110	R--D	11 IG510	9.5	12.7	20.8	PASS	PASS	PASS
14/05/90	1335	R--D	11 RK586	18	12.3	13.8	PASS	PASS	PASS
19/05/90	1020	R--D	11 IG586	11	9.7	19.2	PASS	PASS	PASS
24/05/90	1025	R--D	10 RK655	20	17.7	16.9	PASS	PASS	PASS
31/05/90	1200	R--D	11 RK695	12	12.4	15.5	PASS	PASS	PASS
04/06/90	2030	--SR	10 ND152	14.5	13.7	14.7	PASS	PASS	PASS
04/06/90	2225	--SR	10 ND154	11	13.7	12.8	PASS	PASS	PASS
05/06/90	1050	--SR	10 PG035	8.5	11.5	7.06	PASS	PASS	PASS
05/06/90	1223	--SR	10 PG045	8	10.6	6.44	PASS	PASS	PASS
05/06/90	1435	--SR	10 PG055	7	11.4	10.7	PASS	PASS	PASS
05/06/90	1627	--SR	10 PG065	11	12	11.1	PASS	PASS	PASS
05/06/90	1830	--SR	10 PG075	11	12.9	11.3	PASS	PASS	PASS
05/06/90	2040	--SR	10 IC050	11	12.3	11.8	PASS	PASS	PASS
05/06/90	2325	--SR	10 IC059	9	12	12.5	PASS	PASS	PASS
06/06/90	0035	--SR	10 IC067	11	13.8	12.9	PASS	PASS	PASS
06/06/90	0055	--SR	10 JN073	5	10.5	12.7	PASS	PASS	PASS
06/06/90	0230	--SR	10 IC076	9	12.6	13.6	PASS	PASS	PASS
06/06/90	0445	--SR	10 IG643	12	13.5	13.9	PASS	PASS	PASS
06/06/90	0451	--SR	10 ND203	8	10.5	14.4	PASS	PASS	PASS
06/06/90	0645	--SR	10 IG652	19	12	13.6	PASS	PASS	PASS
06/06/90	0820	--SR	10 IG660	12	15.9	13.7	PASS	PASS	PASS
06/06/90	1040	--SR	10 IG670	17	15.6	12.8	PASS	PASS	PASS
06/06/90	1225	--SR	10 RK712	12	14	10	PASS	PASS	PASS
06/06/90	2105	--SR	10 JN056	21	10.8	8.8	PASS	PASS	PASS
06/06/90	2300	--SR	10 JN064	11	10	9.63	PASS	PASS	PASS
07/06/90	0305	--SR	10 JN084	11	11.5	13.8	PASS	PASS	PASS
07/06/90	0637	--SR	10 ND211	3	11.6	15.5	PASS	PASS	PASS
07/06/90	0823	--SR	10 ND220	6.5	14.6	14.7	PASS	PASS	PASS

App 5. Tab 2. Performance statistics for Horley STW.

PWLE.0091 HORLEY STW

					SOLIDS	BOD	AMMONIA	SOLIDS	BOD	AMMONIA
07/06/90	1050	--SR	10	WD229	8	14.9	16	PASS	PASS	PASS
07/06/90	1445	--SR	10	RK723	10	10.9	8.96	PASS	PASS	PASS
07/06/90	1645	--SR	10	RK732	20	10	9.12	PASS	PASS	PASS
07/06/90	1820	--SR	10	RK743	10	8.5	9.26	PASS	PASS	PASS
17/06/90	1425	R--D	10	RK812	2	4.6	15.9	PASS	PASS	PASS
20/06/90	0640	R--D	10	RK852	8	4.4	17.3	PASS	PASS	PASS
20/06/90	1820	R--D	10	IG755	8	4.8	17.5	PASS	PASS	PASS
22/06/90	1545	R--D	11	IG772	11	8.3	24.3	PASS	PASS	PASS
28/06/90	1000	R--D	10	WD300	4.8	3	19.7	PASS	PASS	PASS
03/07/90	1050	R--D	10	WD308	7.5	5.6	14.5	PASS	PASS	PASS
16/07/90	1250	I--R	10	WD404	4	2	10.6	PASS	PASS	PASS
24/07/90	1010	R--D	11	RK896	7.6	4.8	5.04	PASS	PASS	PASS
26/07/90	0630	I--D	10	RK900	6	2.8	3.67	PASS	PASS	PASS
28/07/90	0920	I--D	10	RK902	5	2.8	3.56	PASS	PASS	PASS
02/08/90	1710	R--D	11	IG854	5	16.9	3.75	PASS	PASS	PASS
03/08/90	1440	R--D	10	IG865	8	1	3.38	PASS	PASS	PASS
15/08/90	1340	IL-X	00	LS227	6	4	3.5	PASS	PASS	PASS
28/08/90	1345	I--R	10	WD460	3.5	3.4	5.81	PASS	PASS	PASS
02/09/90	1610	R--D	10	RK971				PASS	PASS	PASS
02/09/90	1615	-L-X	00	LS246	8	4.5	3.8	PASS	PASS	PASS
12/09/90	1115	RL-X	01	LS249	5	4	3.7	PASS	PASS	PASS
27/09/90	1755	RL-X	00	LS279	3	2.5	4.4	PASS	PASS	PASS
27/09/90	1756	R--D	10	RK030				PASS	PASS	PASS
31/10/90	1135	RL-X	02	LS331	11	29	3.1	PASS	FAIL	PASS
05/11/90	1055	RL-X	01	LS338	5	2.5	3.6	PASS	PASS	PASS
09/11/90	1000	RL-X	01	LS393	3	2	2.8	PASS	PASS	PASS
16/11/90	1105	RL-X	01	LS388	9	3	2.2	PASS	PASS	PASS
20/11/90	1020	RL-X	01	LS384	5	3	2.4	PASS	PASS	PASS
13/12/90	1105	RL-X	01	LS461	7	2	1.13	PASS	PASS	PASS

LUTON SEWAGE WORKS 1988 - 1990

CONSENT : 20/10/10 up to 14th Dec 1989, 45/25/10 from 15th Dec 1989 to date.

DATE					SOLIDS	BOD	AMMONIA	S.S.	BOD	AmN
08/08/90	1210	R--D	31	RB144	3.6	2.2	0.05	PASS	PASS	PASS
14/08/90	1315	R--D	31	RB186	3.6	11.3	0.16	PASS	PASS	PASS
21/08/90	1105	R--D	31	RB220	1.2	3.3	2.51	PASS	PASS	PASS
30/08/90	1130	R--D	31	RB279	1.6	2.3	0.05	PASS	PASS	PASS
06/09/90	1230	R--D	31	RB316	1.6	2	0.05	PASS	PASS	PASS
11/09/90	1000	R--D	31	SR020	0.8	2.4	0.09	PASS	PASS	PASS
18/09/90	1335	R--D	31	RB369	1	2	4.25	PASS	PASS	PASS
27/09/90	1155	R--D	31	RB435	9	3.3	1.67	PASS	PASS	PASS
29/09/90	2000	RL-X	02	LS293	245	79	6	FAIL	FAIL	PASS
02/10/90	1125	R--D	31	RB459	8.4	5.6	3.21	PASS	PASS	PASS
09/10/90	1345	RL-X	01	LS297	2	1.5		PASS	PASS	PASS
18/10/90	1035	RL-X	01	LS322	2	2	15.1	PASS	PASS	FAIL
18/10/90	1830	RL-D	01	LS321	75	52	19	FAIL	FAIL	FAIL
26/10/90	1450	RL-D	01	LS313	2	2	9.5	PASS	PASS	PASS
01/11/90	1205	RL-X	02	LS371	2	2	15.7	PASS	PASS	FAIL
13/11/90	1405	RL-X	02	LS396	9	4.5	18	PASS	PASS	FAIL
14/11/90	1700	-L-X	02	LS391	33	38	20.6	PASS	FAIL	FAIL
21/11/90	1100	RL-X	02	LS397	5	5.5	22.1	PASS	PASS	FAIL
28/11/90	1210	RL-X	02	LS407	25	5.5	17.1	PASS	PASS	FAIL
05/12/90	1325	RL-X	02	LS440	4	1.5	20.6	PASS	PASS	FAIL
07/12/90	0930	RL-X	02	LS449	3	2.5	21.3	PASS	PASS	FAIL
10/12/90	1125	RL-X	01	LS438	2	2	7.2	PASS	PASS	PASS
12/12/90	1040	RL-X	02	LS437	2	8	12.5	PASS	PASS	FAIL
02/01/91	1125	RL-D	02	LS509	2	1.4	0.46	PASS	PASS	PASS
08/01/91	1040	RL-D	02	LS510	2	2.5	2	PASS	PASS	PASS
18/01/91	1445	RL-X	01	LS544	2		6.9	PASS	PASS	PASS
23/01/91	1500	RL-X	01	LS543	2		4.7	PASS	PASS	PASS

App 5. Tab 3. Performance statistics for Luton STW.

LUTON SEWAGE WORKS 1988 - 1990

CONSENT : 20/10/10 up to 14th Dec 1989, 45/25/10 from 15th Dec 1989 to date.

DATE					SOLIDS	BOD	AMMONIA	S.S.	BOD	AmN
06/01/89	0830	R--D	91	DV023	9.6	4.1	0.1	PASS	PASS	PASS
12/01/89	1000	R--D	91	DV018	19.6	6.3	0.3	PASS	PASS	PASS
18/01/89	1100	R--D	91	DV004	8.2	6.3	1.2	PASS	PASS	PASS
18/01/89	1400	---R	12	DM025	22	8.1	0.98	FAIL	PASS	PASS
24/01/89	1200	R--D	91	DV004	10.8	6.1	0.9	PASS	PASS	PASS
30/01/89	1300	R--D	91	DV009	9.8	7.7	0.4	PASS	PASS	PASS
07/02/89	1400	R--D	91	DV003	6.6	5.3	5.2	PASS	PASS	PASS
15/02/89	1500	R--D	91	DV023	10.8	7.6	4.8	PASS	PASS	PASS
23/02/89	0900	R--D	91	DV004	7.4	4.8	2.9	PASS	PASS	PASS
03/03/89	0830	R--D	91	DV014	9.8	4.8	0.9	PASS	PASS	PASS
09/03/89	1100	R--D	91	DV004	7.4	3.9	0.5	PASS	PASS	PASS
14/03/89	1200	R--D	91	DV018	8.8	4.4	0.1	PASS	PASS	PASS
22/03/89	1300	R--D	91	DV008	6.2	4	3.1	PASS	PASS	PASS
28/03/89	1400	R--D	91	DV011	12	7.5	5.1	PASS	PASS	PASS
03/04/89	1500	R--D	91	DV012	15.2	9	2.6	PASS	PASS	PASS
05/04/89	1030	---R	12	DM120	21	13.2	2.28	FAIL	FAIL	PASS
12/04/89	0900	R--D	91	DV008	17.2	7.3	0.5	PASS	PASS	PASS
20/04/89	1000	R--D	91	DV016	13	5.3	0.1	PASS	PASS	PASS
28/04/89	0900	R--D	91	DV009	12.8	4.2	0.4	PASS	PASS	PASS
04/05/89	1200	R--D	91	DV005	13.5	7.5	0.1	PASS	PASS	PASS
10/05/89	1300	R--D	91	DV005	9.8	4.8	0.5	PASS	PASS	PASS
16/05/89	1400	R--D	91	DV025	11.2	4	0.3	PASS	PASS	PASS
22/05/89	1500	R--D	91	DV034	10	4.1	1.2	PASS	PASS	PASS
30/05/89	0900	R--D	91	DV052	4.6	1.9	0.1	PASS	PASS	PASS
07/06/89	1000	R--D	91	DV029	9.2	4.1	0.8	PASS	PASS	PASS
15/06/89	1100	R--D	91	DV014	7.2	3.4	1.7	PASS	PASS	PASS
23/06/89	0900	R--D	91	DV011	12.8	6.1	3.4	PASS	PASS	PASS
28/06/89	1000	R--R	11	PR200	5	6	0.55	PASS	PASS	PASS
29/06/89	1300	R--D	91	DV010	6.8	3.6	0.9	PASS	PASS	PASS
04/07/89	0900	R--R	11	TB232	4.4	5.4	0.12	PASS	PASS	PASS
05/07/89	1400	R--D	91	DV008	7.4	4.6	2.4	PASS	PASS	PASS
11/07/89	1500	R--D	91	DV021	15.8	8.5	4.5	PASS	PASS	PASS
13/07/89	1030	R--R	11	DM221	9	4.7	1.64	PASS	PASS	PASS
17/07/89	0900	R--D	91	DV002	5.2	3.6	0.1	PASS	PASS	PASS
20/07/89	0855	R--R	01	TB278	6.8	2.9	0.38	PASS	PASS	PASS
25/07/89	1000	R--D	91	DV007	3.2	3.5	0.6	PASS	PASS	PASS
27/07/89	1040	R--R	01	SM261	12.8	2.5	0.43	PASS	PASS	PASS
02/08/89	1100	R--D	91	DV001	5.8	3.6	0.1	PASS	PASS	PASS
02/08/89	1335	R--R	01	SM270	3	3.7	0.39	PASS	PASS	PASS
09/08/89	1140	R--R	01	KD292	0.4	5.7	0.05	PASS	PASS	PASS
10/08/89	1200	R--D	91	DV013	6.8	3.3	0.1	PASS	PASS	PASS
14/08/89	1325	R--R	01	SM290	3.6	4	1.15	PASS	PASS	PASS
18/08/89	0830	R--D	91	DV020	1.6	3	0.1	PASS	PASS	PASS
22/08/89	0900	R--R	01	TB320	0.8	3	0.07	PASS	PASS	PASS
24/08/89	1400	R--D	91	DV008	3.8	1.5	0.5	PASS	PASS	PASS
30/08/89	1500	R--D	91	DV007	4	2.7	0.3	PASS	PASS	PASS
01/09/89	1155	R--R	01	KD345	6.8	3.3	1.74	PASS	PASS	PASS

LUTON SEWAGE WORKS 1988 - 1990

CONSENT : 20/10/10 up to 14th Dec 1989, 45/25/10 from 15th Dec 1989 to date.

DATE					SOLIDS	BOD	AMMONIA	S.S.	BOD	AMN
04/09/89	1125	R--D	01	DH279	2.4	4.9	2.65	PASS	PASS	PASS
14/09/89	1510	R--D	01	DH291	2	6.1	2.03	PASS	PASS	PASS
19/09/89	1020	R--D	00	SH326	2.8	2	2.76	PASS	PASS	PASS
27/09/89	1230	R--D	02	KD409	5.2	11.8	8.5	PASS	FAIL	PASS
05/10/89	1025	R--D	01	KW031	2.4	4.9	1.02	PASS	PASS	PASS
07/10/89	1245	-L-X	01	LS005	7	5	7.1	PASS	PASS	PASS
11/10/89	1400	R--D	01	DE017	10	8.3	4.22	PASS	PASS	PASS
17/10/89	1005	R--D	01	DH327	6	3.9	1.85	PASS	PASS	PASS
26/10/89	1415	R-PD	01	JA126	5.2	3.8	5.3	PASS	PASS	PASS
31/10/89	1405	R--D	02	KW075	8	11.4	15.1	PASS	FAIL	FAIL
07/11/89	1200	-L-X	02	LS022	5	4.5	15.3	PASS	PASS	FAIL
14/11/89	1415	-L-X	00	LS023	11	6	7.7	PASS	PASS	PASS
22/11/89	1415	-L-X	01	LS024	5	3	2.6	PASS	PASS	PASS
29/11/89	1415	-L-X	01	LS026	25	5	4.9	FAIL	PASS	PASS
06/12/89	1225	-L-X	01	LS025	6	3.5	3.7	PASS	PASS	PASS
13/12/89	1400	-L-X	01	LS041	25	9	4.9	FAIL	PASS	PASS
04/01/90	1345	-L-X	01	LS060	22	8.5	2.1	PASS	PASS	PASS
10/01/90	1125	-L-X	01	LS061	24	12	3.9	PASS	PASS	PASS
16/01/90	1130	-L-X	01	LS064	18	9	3.5	PASS	PASS	PASS
26/01/90	1150	R--D	30	DH039	20	7.8	7.65	PASS	PASS	PASS
29/01/90	1240	R--D	31	RB235	14	5.4	4.94	PASS	PASS	PASS
09/02/90	1050	R--D	31	RB274	41	6.4	3.41	PASS	PASS	PASS
11/02/90	1615	I--R	32	KD027	79	15.5	6.2	FAIL	PASS	PASS
14/02/90	1350	R--D	31	RB308	12	3.5	5.5	PASS	PASS	PASS
18/02/90	1735	R--D	31	RB336	18.4	7.8	0.71	PASS	PASS	PASS
28/02/90	1715	R--D	32	RB387	100	36.2	4.36	FAIL	FAIL	PASS
15/03/90	1040	R--D	31	SH045	25.2	11.9	1.06	PASS	PASS	PASS
23/03/90	1100	R--D	31	RB470	30.4	15.5	1.95	PASS	PASS	PASS
27/03/90	1300	R--D	31	RB490	14	7.4	3.14	PASS	PASS	PASS
06/04/90	1435	R--D	31	RB552	14	12.6	5.89	PASS	PASS	PASS
12/04/90	0635	R--D	31	RB586	24.8	5.9	0.06	PASS	PASS	PASS
20/04/90	1300	R--D	31	RB618	30	12.8	3.39	PASS	PASS	PASS
25/04/90	1100	R--D	30	DH080	23.2	22.3	4.21	PASS	PASS	PASS
04/05/90	1245	-L-X	02	LS123	17	12	12.1	PASS	PASS	FAIL
11/05/90	1315	R--D	31	RB734	8.8	5	0.05	PASS	PASS	PASS
16/05/90	1340	R--D	31	RB754	9.6	6.8	4.91	PASS	PASS	PASS
22/05/90	1220	R--D	31	RB783	4.4	7	4.59	PASS	PASS	PASS
04/06/90	2130	R--D	31	RB848	11.6	5.5	6.02	PASS	PASS	PASS
07/06/90	1450	R--D	31	RB885	10	6.3	7.06	PASS	PASS	PASS
14/06/90	0850	R--D	31	RB919	1.6	3.7	0.15	PASS	PASS	PASS
20/06/90	1140	R--D	30	DH103	5.6	6.9	9.06	PASS	PASS	PASS
06/07/90	1145	R--D	31	RB038	15.2	9.5	0.05	PASS	PASS	PASS
11/07/90	1235	IL-X	02	LS178	22	17	10.7	PASS	PASS	FAIL
14/07/90	1400	IL-X	02	LS201	40	28	10.4	PASS	FAIL	FAIL
16/07/90	1425	IL-X	02	LS202	14	17	14.5	PASS	PASS	FAIL
17/07/90	0840	R--D	31	RB099	3.6	2.1	2.63	PASS	PASS	PASS
25/07/90	1115	R--D	31	DH129	6	4.1	1.82	PASS	PASS	PASS

05/03/91

APPENDIX 9

Computer code for half tide corrections and tideway data transformations.

Comparisons of ARQM data with data from the research vessel (launch Thames Water). From Radford and Bruderer, 1989.

Computer code for half tide corrections and tideway data transformations.

```
3099 ! Processes Tidal Data
3100 !
3101  COM /Drives1/ P_drive$[11],D_drive$[11],Tape_drive$[11]
3102  COM /Enhance1/ En_off$[1],Inv$[1],Blink$[1],Inv_blink$[1],Und$[1]
3103  COM /Enhance2/ Und_inv$[1],Und_blink$[1],Und_inv_blink$[1]
3104  COM /Boolean/ INTEGER True,False
3105  !
3106  !
3107 ON KBD ALL,15 GOSUB Get_key
3108 !
3109 ! Arrays
3110 ! ------
3111 !
3112 ! Tides
3113 ! -----
3114 DIM Tides$(12)[44]              ! Initially will hold yesterdays,
3115                                 ! todays & tommorrows tides.
3116                                 ! After Processing will hold the
3117                                 ! the 5 tides that cover today.
3118 DIM Lb_tides$(12)[44]           ! Holds tide times at London Bridge
3119 !
3120 ! Sites
3121 ! -----
3122 DIM Site$(10)[512]            ! Room for the 10 tidal Sites
3123 DIM Site_name$[20]            ! Holds Site name
3124 DIM Status$[1]                ! Status on or off
3125 DIM Site_code$[1]             ! Site Code
3126 REAL Cal_a3,Cal_a4,Cal_a8     ! Calibration Factors
3127 !
3128 ! Tide adjustments to London Bridge
3129 !
3130 DIM Hw_adj$[5]                ! High water adjustment
3131 DIM Lw_adj$[5]                ! Low Water Adjustment
3132 DIM Adj$[5]                   ! Working variable
3133 !
3134 !
3135 DIM File_name$[10]            ! Site Log file name
3136 DIM Today_file$[10]           ! File name for todays log file
3137 DIM Yest_file$[10]            ! File name for yesterdays log file
3138 DIM Yesterday$[20]            ! Variable to hold yesterdays date
3139 !
3140 ! Half Tide Correction
3141 !
3142 DIM Ebb_flood$[5]
3143 DIM Segment$[4]
3144 !
3145 INTEGER Htc_ebb(15,2)         ! Half tide correction factors (seg,dist) EBB
3146 INTEGER Htc_flood(15,2)       ! Half tide correction factors (seg,dist) FLO
3147 INTEGER Htc(15,2)             ! Either of the above 2 will be moved into th
3148 !
3149 ! Log data
3150 ! --------
3151 DIM Log$(128)[128]
3152 !
3153 ! Processed Data
3154 ! --------------
3155 DIM P_data$(560)[44]          ! Will hold processed data for all sites
3156                               ! This array will be written to archive
3157 DIM S_data$(100)[44]        ! Holds processed data for each site
3158 !
3159 DIM D$[255]                   ! General Purpose string
3160 DIM Record$[64]               ! I/O record buffer
3161 DIM Upper$[4]
3162 DIM Lower$[4]
```

```
3163 DIM Date$[20]
3164 !
3165 INTEGER Site_number,Count,Matched,Pointer,I,J,K,L,Proc_pointer
3166 !
3167 REAL Reference,Julian          ! Used for calculating Julian days
3168 REAL Record,R,Start,Finish
3169 REAL Oxygen,Cond,Temp,Xcon,Xcond,Xtemp,Kappa,Xk,F,Kk,Xoxy,Ppm,Xchl
3170 !
3171 !
3172 D$=Blink$&"Processing Data"&En_off$
3173 Display(13,10,D$)
3174 GOSUB Get_sites                ! Reads in All ten tidal site files to Site$
3175 !
3176 GOSUB Get_tides                !
3177 Proc_pointer=0                 ! Points to the P_data$() Array element to
3178                                ! accept processed data
3179 FOR Site_number=1 TO 10        ! Do ten sites
3180    GOSUB Parse_data            ! Parse site data into appropriate variables
3181                                ! Defined above
3182    IF Status$="0" THEN
3183       DISP "Working on ";Site_name$
3184       GOSUB Adj_tides          ! Gets tides, adjusts for site, picks 6 tides
3185       GOSUB Get_log            ! Loads todays log and last 32 of yesterdays
  86       GOSUB Process            ! Applies Htc, calibration & puts in S_data$
3187       !
3188       ! Update P_data$()
3189       !
3190       FOR I=1 TO VAL(S_data$(0))
3191           Proc_pointer=Proc_pointer+1
3192           P_data$(Proc_pointer)=S_data$(I)
3193       NEXT I
3194    END IF
3195    !
3196 NEXT Site_number
3197 !
3198 D$="                   "            ! Clear Message
3199 Display(13,10,D$)                   !
3200 !
3201 DISP "Storing Processed Data"
3202 !
3203 P_data$(0)=VAL$(Proc_pointer)       ! Store Total
3204 !
  05 ! Everything is now in P_data$() so write it to disk
3206 !
3207 ! Get the file name and Start record Number
3208 !
3209 Date$=Ref_d_t$[1;11]
3210 Get_tidal_file(Date$,File_name$,Record)
3211 !
3212 ! Write the data to file
3213 !
3214 GOSUB Write
3215 !
3216 OFF CYCLE
3217 OFF KBD
3218 SUBEXIT
3219  !
3220  ! =====================================================================
3221  !                    Sub-routines for Process_t_data
3222  ! =====================================================================
3223  !
3224 Write:  !
3225!==========
3226  !
3227  ! Writes Processed data to File
3228  !
3229  ASSIGN @Path1 TO File_name$
```

```
3229  ASSIGN @Path1 TO File_name$
3230  !
3231  !
3232  !
3233  ! Store the Total Number in Record
3234  !
3235  OUTPUT @Path1,Record;P_data$(0)
3236  !
3237  Count=0
3238  Start=Record+1
3239  Finish=Record+VAL(P_data$(0))
3240  !
3241  FOR R=Start TO Finish
3242     Count=Count+1
3243     OUTPUT @Path1,R;P_data$(Count)
3244  NEXT R
3245  !
3246  ! Store the Date of the Plot in Record+600
3247  !
3248  OUTPUT @Path1,Record+600;Date$
3249  !
3250  ! Also store the London Bridge Tides and their numbers for the plot
3251  !
  52  ! These can Go from Record+601
3253  !
3254  Start=Record+601
3255  Finish=Record+612                ! There are 12 tides to store
3256  Count=0
3257  FOR R=Start TO Finish            !
3258     Count=Count+1
3259     OUTPUT @Path1,R;Lb_tides$(Count)
3260  NEXT R
3261  !
3262  ! Done
3263  !
3264  ASSIGN @Path1 TO *
3265  !
3266  !
3267  RETURN
3268  !
3269  ! ------------------------------------------------------------------
3270  !
 .71 Get_key: !
3272!===========
3273  !
3274  ! Reads Keyboard Buffer if Pause has been pressed returns Pause True
3275  !
3276  Key$=KBD$                            ! Read Keyboard Buffer
3277  IF Key$=CHR$(255)&CHR$(80) THEN      ! Check for Pause key value
3278     Pause=True                        ! Set Pause
3279     Display(51,3,Inv_blink$&"Interrupted. Please Wait.."&En_off$)   ! Mes
e
3280  ELSE                                 ! Wrong key pressed
3281     Pause=False                       ! Reset Pause
3282  END IF
3283  RETURN
3284 !
3285 ! ------------------------------------------------------------------
3286 !
3287 Get_tides:  !
3288!============
3289 !
3290 DISP "Reading Tides"
3291 !
3292 ! Subroutine to get yesterdays,todays & tommorows London Bridge tides
3293 !
3294 ! and remove any gaps from the days that only have 3 tides
```

```
3295 !
3296 ! First work out todays Julian Number
3297 !
3298 D$=Ref_d_t$[1;11]                                ! Todays date
3299 Julian=(DATE(D$) DIV 86400)                      ! Work out julian days
3300 Julian=Julian-2447161                            ! Subtract our tide start date
3301                                                  ! which is 1st Jan 88 (-1)
3302 I=INT(Julian)                                    ! Todays record number
3303 !
3304 ! Now read them in
3305 !
3306 ! Assign an I/O path to the file
3307 !
3308 ASSIGN @Path9 TO "RDOMTABLES"&D_drive$
3309 !
3310 ! Read in Data and add or subtract Adjustments
3311 ! Also store the London Bridge tide times.
3312 ! -----------------------------------------
3313 !
3314 ! Yesterdays Tides
3315 ! ----------------
3316 ENTER @Path9,(I-1);Record$
3317 Pointer=1
3318 FOR J=1 TO 4                    ! Format of Tides$ "0536L00111 JAN 1988"
3319      Julian=(I-1+2447161)*86400
3320      Lb_tides$(J)=Record$[Pointer;8]&DATE$(Julian)
3321      Pointer=Pointer+8
3322 NEXT J
3323 !
3324 ! Todays Tides
3325 ! ------------
3326 ENTER @Path9,I;Record$
3327 Pointer=1
3328 FOR J=5 TO 8
3329      Julian=(I+2447161)*86400
3330      Lb_tides$(J)=Record$[Pointer;8]&DATE$(Julian)
3331      Pointer=Pointer+8
3332 NEXT J
3333 !
3334 ! Tomorrows Tides
3335 ! ---------------
3336 ENTER @Path9,(I+1);Record$
3337 Pointer=1
3338 FOR J=9 TO 12
3339      Julian=(I+1+2447161)*86400
3340      Lb_tides$(J)=Record$[Pointer;8]&DATE$(Julian)
3341      Pointer=Pointer+8
3342 NEXT J
3343 !
3344 ! Explicitly Close File
3345 !
3346 ASSIGN @Path9 TO *
3347 !
3348 ! Clear Empty tides
3349 !
3350 Count=0
3351 FOR J=1 TO 12
3352    IF Lb_tides$(J)[1;8]<>"........" THEN
3353       Count=Count+1
3354       Lb_tides$(Count)=Lb_tides$(J)
3355    END IF
3356 NEXT J
3357 Tide_count=Count
3358 !
3359 RETURN
```

```
3360 !
3361 ! ----------------------------------------------------------------
3362 !
3363 Adj_tides:        !
3364!==========
3365 !
3366 ! Subroutine to read the london bridge tides & apply the adjustments
3367 ! for the particular site.
3368 ! Then select the 6 tides that cover todays 24 hours
3369 !
3370 ! First copy the London Bridge Tides into Tides$()
3371 !
3372 FOR J=1 TO Tide_count                        ! Previously worked out shoulc
3373     Tides$(J)=Lb_tides$(J)[1;8]             ! be 11 or 12
3374 NEXT J
3375 !
3376 ! Apply the Adjustments to the tide times
3377 !
3378 FOR J=1 TO Tide_count
3379     !
3380     ! First Find out if tide is High or Low
3381     !
3382     IF Tides$(J)[5;1]="L" THEN
3383        Adj$=Lw_adj$
3384     ELSE
3385        Adj$=Hw_adj$
3386     END IF
3387     !
3388     ! Then work out sign (+/-) of the Adjustment
3389     !
3390     IF Adj$[1;1]="+" THEN
3391        Tides$(J)[1;4]=FNAdd_times$(Tides$(J)[1;4],Adj$[2;4])
3392     ELSE
3393        Tides$(J)[1;4]=FNSub_times$(Tides$(J)[1;4],Adj$[2;4])
3394     END IF
3395 NEXT J
3396 !
3397 !
3398 ! To find the first tide which will cover 0000 for today
3399 !
3400 ! Check 1st Tide of Today to see if Midnight
3401 !
3402 ! 1st look at positions 3 & 4
3403 !
3404 Y$=Tides$(3)[1;4]
3405 X$=Tides$(4)[1;4]
3406 IF X$="0000" THEN                  ! If tide 4 is midnight start there
3407    Start=4                         !
3408 ELSE                               ! Otherwise
3409    IF X$>"1200" THEN               ! If there are 4 tides yesterday
3410       Start=4                      ! start with last tide of yesterday
3411    ELSE                            ! Otherwise we had only 3 tides
3412       Start=3                      ! yesterday and want to start on
3413    END IF                          ! the last tide yesterday
3414 END IF
3415 !
3416 ! Then select the next 4 or 5 tides to cover all 24 hours
3417 ! Tides$() will be re-used for the chosen ones
3418 !
3419 J=Start                            ! Three days tides pointer
3420 K=0                                ! Chosen Tides Pointer
3421 REPEAT
3422    K=K+1
3423    Tides$(K)=Tides$(J)
3424    IF J>6 AND Tides$(J)[1;2]<"10" THEN     ! We are looking for the 1st
3425       J=Start+5                            ! tide after midnight then
```

```
3426    END IF                                  ! stop.
3427    J=J+1
3428 UNTIL J=Start+6
3429 Chosen_tides=K
3430 !
3431 ! We now should have the chosen tides in Tides$(1-K)
3432 !
3433 RETURN
3434 !
3435 ! ----------------------------------------------------------------------
3436 !
3437 Get_sites:  !
3438!==========
3439  !
3440  ! Reads Tidal Sites file into Site$()
3441  !
3442  ! Open File
3443  !
3444  ASSIGN @Path1 TO "RDOMSITES"&D_drive$
3445  !
3446  FOR I=1 TO 10                    ! Tidal Sites Records 1 - 10
3447  !
3448     ENTER @Path1,I;Site$(I)
3449  NEXT I
3450  !
3451  ! Close File
3452  !
3453  ASSIGN @Path1 TO *
3454  !
3455  RETURN
3456  !
3457  ! ---------------------------------------------------------------------
3458  !
3459 Parse_data:  !
3460!=============
3461  !
3462  ! Parse out data from Site$(i) into the variables used.
3463  !
3464  Site_name$=Site$(Site_number)[8;20]                   ! Site Name
3465  Status$=Site$(Site_number)[7;1]                       ! Status on or of
ine
3466  Site_code$=Site$(Site_number)[1;1]                    ! Site code (NB c
  st char)
3467  !
3468  ! Tidal Corrections to London Bridge
3469  !
3470  Hw_adj$=Site$(Site_number)[102;5]                     ! High Water +/-H
3471  !
3472  Lw_adj$=Site$(Site_number)[107;5]                     ! Low Water +/-HH
3473  !
3474  !
3475  ! Calibration Factors
3476  !
3477  Cal_a3=FNVal(Site$(Site_number)[144;4])               ! Temperature
3478  Cal_a4=FNVal(Site$(Site_number)[148;4])               ! Oxygen
3479  Cal_a8=FNVal(Site$(Site_number)[164;4])               ! Conductivity
3480  !
3481  ! Half Tide Correction
3482  !
3483  ! EBB
3484  !
3485  Htc_ebb(0,0)=FNVal(Site$(Site_number)[200;2])         ! Number of EBB s
ents
3486  Pointer=202                                 ! String position HTC start
3487  FOR J=1 TO 15                               ! Allocate all 15 although
3488                                              ! there may be less
3489     Htc_ebb(J,1)=FNVal(Site$(Site_number)[Pointer;2])    ! Segment
```

```
3490     Htc_ebb(J,2)=FNVal(Site$(Site_number)[Pointer+2;3])   ! Distance
3491     Pointer=Pointer+5
3492  NEXT J
3493  !
3494  ! FLOOD
3495  !
3496  Htc_flood(0,0)=FNVal(Site$(Site_number)[277;2])          ! Number of FLOO
segments
3497  Pointer=279                                   ! String position HTC star
3498  FOR J=1 TO 15                                 ! Allocate all 15 althougł
3499                                                ! there may be less
3500     Htc_flood(J,1)=FNVal(Site$(Site_number)[Pointer;2])   ! Segment
3501     Htc_flood(J,2)=FNVal(Site$(Site_number)[Pointer+2;3])! Distance
3502     Pointer=Pointer+5
3503  NEXT J
3504  !
3505  RETURN
3506  !
3507 Get_log:!
3508!=========
3509  !
3510  ! Reads in log data for Site_number
3511  !
3512  ! For Site_number work out start & finish records
3513  !
3514  Start=(Site_number*100)+1
3515  Finish=Start+95              ! 96 Entries per day
3516  !
3517  ! Work out which file we should be looking at. Quite simply if the
3518  ! reference day is even then RDOMSITED1 is used otherwise RDOMSITED2
3519  ! for todays log.
3520  ! The system loads all of todays readings into log$
3521  !
3522  D$=Ref_d_t$[1;11]
3523  Julian=DATE(D$) DIV 86400
3524  Reference=Julian-2446436
3525  IF Reference/2=INT(Reference/2) THEN
3526     Today_file$="RDOMSITED1"
3527     Yest_file$="RDOMSITED2"
3528  ELSE
3529     Today_file$="RDOMSITED2"
3530     Yest_file$="RDOMSITED1"
3531  END IF
3532  !
3533  ! Work out what yesterday should be
3534  !
3535  Julian=Julian-1
3536  Yesterday$=DATE$(Julian*86400)
3537  Convert_date(Yesterday$)          ! Converts to uppercase pads leading
3538  !
3539  ! Do Todays
3540  !
3541  ASSIGN @Path1 TO Today_file$&D_drive$
3542  !
3543  Count=0
3544  !
3545  ! The data is read for every allocated time. If there is no data or a
3546  ! gap then 999s are filled in. THese are carried right through to
3547  ! the Archive File so that they can be looked for and gaps can be left
3548  ! in the plot.
3549  !
3550  FOR I=Start TO Finish            ! All records
3551      ENTER @Path1,I;D$
3552      Count=Count+1
3553      IF D$[17;1]="1" THEN         ! Good data flag
3554         Log$(Count)=D$[1:4]&D$[18:20]    ! Extract the time & data only
```

```
3555       ELSE                           ! Bad data fill with 999999
3556          Log$(Count)=D$[1;4]&RPT$("9",20)
3557       END IF
3558    NEXT I
3559    !
3560    ! Close File
3561    !
3562    ASSIGN @Path1 TO *
3563    !
3564    Log$(0)=VAL$(Count)
3565    !
3566 RETURN
3567 !
3568 ! ------------------------------------------------------------------
3569 !
3570 Process:   !
3571!===========
3572 !
3573 ! Perform Half Tide Correction, apply Calibration factors
3574 ! and Calculate Conuctivity etc
3575 !
3576 ! Work out first tide as EBB or Flood
3577 !
3578 IF Tides$(1)[5;1]="L" THEN
3579    Ebb_flood$="FLOOD"
3580 ELSE
3581    Ebb_flood$="EBB  "
3582 END IF
3583 !
3584 ! Do All Tides
3585 !
3586 ! Work out the segment length in MMSS
3587 !
3588 Count=0
3589 FOR K=1 TO Chosen_tides
3590    D$=FNSub_times$(Tides$(K+1)[1;4],Tides$(K)[1;4]) ! Work out period of t
de
3591    Segment$=FNSeg$(D$)                   ! Gives segment time in mins,secs
3592    !
3593    ! Now calculate times for the stored segment lengths
3594    !
3595    IF Ebb_flood$="FLOOD" THEN
3596       N=Htc_flood(0,0)
3597       FOR I=1 TO N
3598          Count=Count+1
3599          D$=FNSeg_cal$(Segment$,Htc_flood(I,1)) ! times number of segments
3600          D$=FNAdd_times$(Tides$(K)[1;4],D$)     ! Add the segment time to
3601                                                 ! the reference time
3602          !
3603          ! Build up S_data$              Field                   Position
3604          !
3605          Tide_number$=Tides$(K)[6;3]   ! Tide number             1 - 3
3606          ! Site_code$=Site_code$       ! Site Code               4 - 4
3607          A$=VAL$(Htc_flood(I,2))       ! Distance from L.B.      5 - 7
3608          IF LEN(A$)<3 THEN
3609             A$=A$&RPT$(" ",3-LEN(A$)) ! Add trailing spaces
3610          END IF
3611          !                             ! Time                    8 - 11
3612          S_data$(Count)=Tide_number$&Site_code$&A$&D$
3613       NEXT I
3614    ELSE
3615       N=Htc_ebb(0,0)
3616       FOR I=1 TO N
3617          Count=Count+1
3618          D$=FNSeg_cal$(Segment$,Htc_ebb(I,1))  ! times number of segments
3619          D$=FNAdd_times$(Tides$(K)[1;4],D$)    ! Add the seament sime to
```

```
3620                                                    ! the reference time
3621          !
3622          ! Build up S_data$             Field                   Position
3623          !
3624          Tide_number$=Tides$(K)[6;3]   ! Tide number             1 - 3
3625          ! Site_code$=Site_code$       ! Site Code               4 - 4
3626          A$=VAL$(Htc_ebb(I,2))         ! Distance from L.B.      5 - 7
3627          IF LEN(A$)<3 THEN
3628             A$=A$&RPT$(" ",3-LEN(A$)) ! Add trailing spaces
3629          END IF
3630          !                             ! Time                    8 - 11
3631          S_data$(Count)=Tide_number$&Site_code$&A$&D$
3632       NEXT I
3633    END IF
3634    IF Ebb_flood$="FLOOD" THEN                      ! Alternate Ebb & Flood
3635       Ebb_flood$="EBB  "
3636    ELSE
3637       Ebb_flood$="FLOOD"
3638    END IF
3639 NEXT K
3640 !
3641 ! Now select only the times that fit >0000 and < 2359
3642 !
3643 N=Count
3644 Start=0                                                   ! Start position
3645 Finish=0                                                  ! End Position
3646 FOR I=1 TO N
3647    IF NOT Start THEN                                      !
3648       IF S_data$(I)[8;2]<"10" THEN                        ! Start is when the
3649          Start=I                                          ! hours over 2359
3650       END IF                                              ! ie less than 10
3651    ELSE
3652       IF Start AND NOT Finish THEN                        ! Only look for the
3653          IF S_data$(I)[8;2]>S_data$(I+1)[8;2] THEN ! end after start is
3654             Finish=I                                      ! has been found. The
3655          END IF                                           ! end is when the next
3656       END IF                                              ! hour is less than the
3657    END IF                                                 ! Current one.
3658 NEXT I
3659 Count=0
3660 FOR I=Start TO Finish
3661    Count=Count+1
3662    S_data$(Count)=S_data$(I)
3663 NEXT I
3664 Selected_times=Count
3665 !
3666 ! Match the calculated times to those of the Argus readings
3667 !
3668 Pointer=1                               ! Points to the last time looked at
3669                                         ! in the Log$ Array
3670 Matched=False                           ! Becomes true when Match$ is between
3671                                         ! 2 acceptable log file times.
3672 !
3673 Count=0
3674 !
3675 !
3676 ! PRINTER IS 701
3677 !
3678 FOR I=1 TO Selected_times               !
3679    Match$=S_data$(I)[8;4]               ! Parse out the Time portion
3680    Matched=False
3681    WHILE NOT Matched AND Pointer<=VAL(Log$(0)) ! Log$(0) = Total readings
3682       !
3683       ! There is a problem when doing Putney (T7) when we have a time
3684       ! of 4 or less minutes past midnight. That time is skipped, for
3685       ! the moment I haven't done anything about it.
```

```
3686         !
3687         Lower$=Log$(Pointer)[1;4]        ! Earlier Time
3688         Upper$=Log$(Pointer+1)[1;4]      ! Later Time
3689         IF Match$>=Lower$ AND Match$<=Upper$ THEN      ! Range Check
3690            !
3691            ! Now we are in a range find out which is the nearest
3692            !
3693            IF FNSub_times$(Match$,Lower$)>FNSub_times$(Upper$,Match$) THEN
3694               !
3695               ! Simply If Match-Lower > Upper-Match Then Match is nearest
3696               ! Upper. There will be no ties as we are dealing with 15 mins
3697               ! between Upper & Lower which is odd.
3698               !
3699               Count=Count+1
3700               S_data$(Count)=S_data$(I)[1;7]&Log$(Pointer+1)[5]
3701               !
3702               ! Diagnostic Print
3703               !
3704               ! PRINT S_data$(Count),Lower$,Match$,Upper$," = ";Upper$
3705               !
3706               ! Format of S_data$
3707               ! Tide number 1-3
3708               ! Site code   4-4
3709               ! Distance    5-7
3710               ! Space       8-8
3711               ! Temperature 9-14
3712               ! Space       15-15
3713               ! Oxygen      16-21
3714               ! Space       22-22
3715               ! Conduct'y   23-28
3716               !
3717            ELSE
3718               Count=Count+1
3719               S_data$(Count)=S_data$(I)[1;7]&Log$(Pointer)[5]
3720               !
3721               ! Diagnostic
3722               !
3723               ! PRINT S_data$(Count),Lower$,Match$,Upper$," = ";Lower$
3724            END IF
3725            Matched=True
3726            Pointer=Pointer+1
3727         ELSE
3728            !
3729            ! Not in Range go onto next one
3730            !
3731            Pointer=Pointer+1
3732            Matched=False
3733            !
3734         END IF
3735      END WHILE
3736      IF NOT Matched THEN         ! If no match we must start looking
3737         Pointer=1                ! from the begining. However if
3738      END IF                      ! we have a successful match we
3739                                  ! can start looking from where the
3740                                  ! pointer is at.
3741 NEXT I
3742 !
3743 ! Diagnostic
3744 !
3745 ! PRINTER IS CRT
3746 !
3747 ! By using Count we should have filtered out any readings with
3748 ! no matching times
3749 !
3750 Selected_times=Count
3751 !
```

```
3752 ! Perform Calculations
3753 ! ===================
3754 !
3755 ! Format of S_data$
3756 ! Tide number  1-3
3757 ! Site code    4-4
3758 ! Distance     5-7
3759 ! Space        8-8
3760 ! Temperature  9-14
3761 ! Space       15-15
3762 ! Oxygen      16-21
3763 ! Space       22-22
3764 ! Conduct'y   23-28
3765 !
3766 FOR I=1 TO Selected_times
3767     !
3768     ! Parse out data and add correction Factors
3769     !
3770   IF NOT POS(S_data$(I),"999999") THEN     ! Only do good data
3771     Cond=VAL(S_data$(I)[9;6])+Cal_a3
3772     Temp=VAL(S_data$(I)[16;6])+Cal_a4
3773     Oxygen=VAL(S_data$(I)[23;6])+Cal_a8
3774     !
3775     ! The next calculations are taken from Barry Whitings
3776     ! programs and I have no idea as to the theory behind them.
3777     !
3778     Xtemp=Temp
3779     Xcond=Cond
3780     !
3781     ! Calculate conductivity corrected to 25 deg. C
3782     !
3783     Xcon=Xcond+((25-Xtemp)*.02*Xcond)
3784     Kappa=Xcon
3785     IF Kappa>=.6 THEN
3786        Kk=Kappa-.05
3787        F=.02*Kk
3788        Xk=Kk*(1-F*17/46)
3789        SELECT Xk
3790          !
3791          CASE >24.5
3792            !
3793            Ppm=405.6*Xk-1310
3794            !
3795          CASE <5.0241
3796            !
3797            Ppm=321.4*Xk-30
3798            !
3799          CASE <10.1726
3800            !
3801            Ppm=344.4*Xk-144
3802            !
3803          CASE <14.9114
3804            !
3805            Ppm=359.2*Xk-292
3806            !
3807          CASE <20.0641
3808            !
3809            Ppm=371.6*Xk-478
3810            !
3811          CASE <22.1129
3812            !
3813            Ppm=380.8*Xk-657
3814            !
3815          CASE <24.5869
3816            !
```

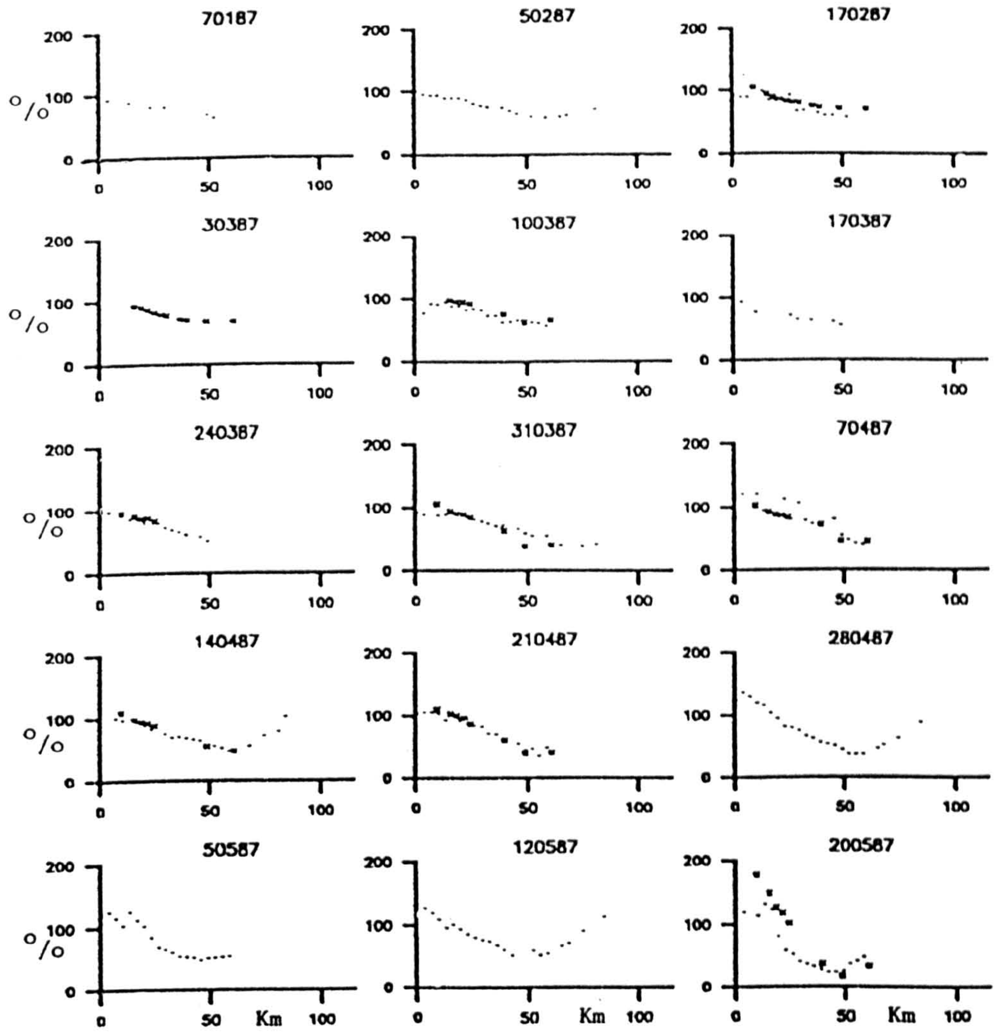
```
3817            Ppm=387*Xk-796
3818            !
3819          CASE ELSE
3820            !
3821            Ppm=321.4*Xk-30
3822            !
3823        END SELECT
3824     ELSE
3825        Ppm=Kappa*(41/.6)
3826     END IF
3827     !
3828     ! Assign Chloride as an Integer of Ppm
3829     !
3830     Xchl=INT(Ppm)
3831     !
3832     ! Ensure that Chloride is in the range 9998<= Xchl > 0
3833     ! ----------------------------------------------------
3834     !
3835     ! As there is only room  for 4 characters and it is unlikely that
3836     ! we will get a reading > 9999 OR < 0 unless there is something wrong.
3837     ! We will cut off out side those values. Actually as 9999 is used to
3838     ! indicate bad data we will cut off at 9998.
3839     !
3840     IF Xchl<0 THEN
3841        Xchl=0
3842     ELSE
3843        IF Xchl>9998 THEN
3844           Xchl=9998
3845        END IF
3846     END IF
3847     !
3848     ! Oxygen
3849     !
3850     Xcon=INT(Xcon*10)/10             ! Round to 1 decimal Corrected Cond
3851     Xoxy=Oxygen                      ! Oxygen
3852     !
3853     ! ----------------------------------------------------------------
3854     ! Calculation of % Oxygen Changed from below formula to the New one.
3855     !
3856     ! Old Formula
3857     !
3858     ! Xper=INT((Xoxy/((475.2-2.65*((Xchl/1000)*1.80655))/(33.5+Xtemp)))*100
3859     !
3860     ! ----------------------------------------------------------------
3861     ! New Formula taken from Prouse 1984. (Active from 25th May 1988)
3862     ! ==============================================================
3863     !
3864     Xper=INT(100*(Xoxy/(468/(31.6+Xtemp))))
3865     !
3866     ! Put calculations Back into S_data$()
3867     !
3868     S_data$(I)=S_data$(I)[1;7]&RPT$(" ",37)        ! Pad with spaces
3869     !
3870     S_data$(I)[8;4]=VAL$(Xper)                     ! % Oxygen
3871     S_data$(I)[12;4]=VAL$(Xchl)                    ! Chloride
3872     S_data$(I)[16;4]=VAL$(Xoxy)                    ! Oxygen Content
3873     S_data$(I)[20;4]=VAL$(Xcon)                    ! Conductivity Corrected
3874     S_data$(I)[24;5]=VAL$(Xtemp)                   ! Temperature
3875     S_data$(I)[29;5]=VAL$(Xcond)                   ! Conductivity
3876     !
3877   ELSE
3878     S_data$(I)[8;33]=RPT$("9",33)                  ! Fill in with 9s for bac
3879                                                    ! data.
3880   END IF
3881 NEXT I
3882 S_data$(0)=VAL$(Selected_times)                    ! Store the total
3883 RETURN
```

```
3883 RETURN
3884 ! --------------------------------------------------------------------
3885 !
3886 SUBEND ! Process_t_data
3887 !
```

MONITORING STATION AND RESEARCH VESSEL DATA

1987

DISSOLVED OXYGEN % SATURATION



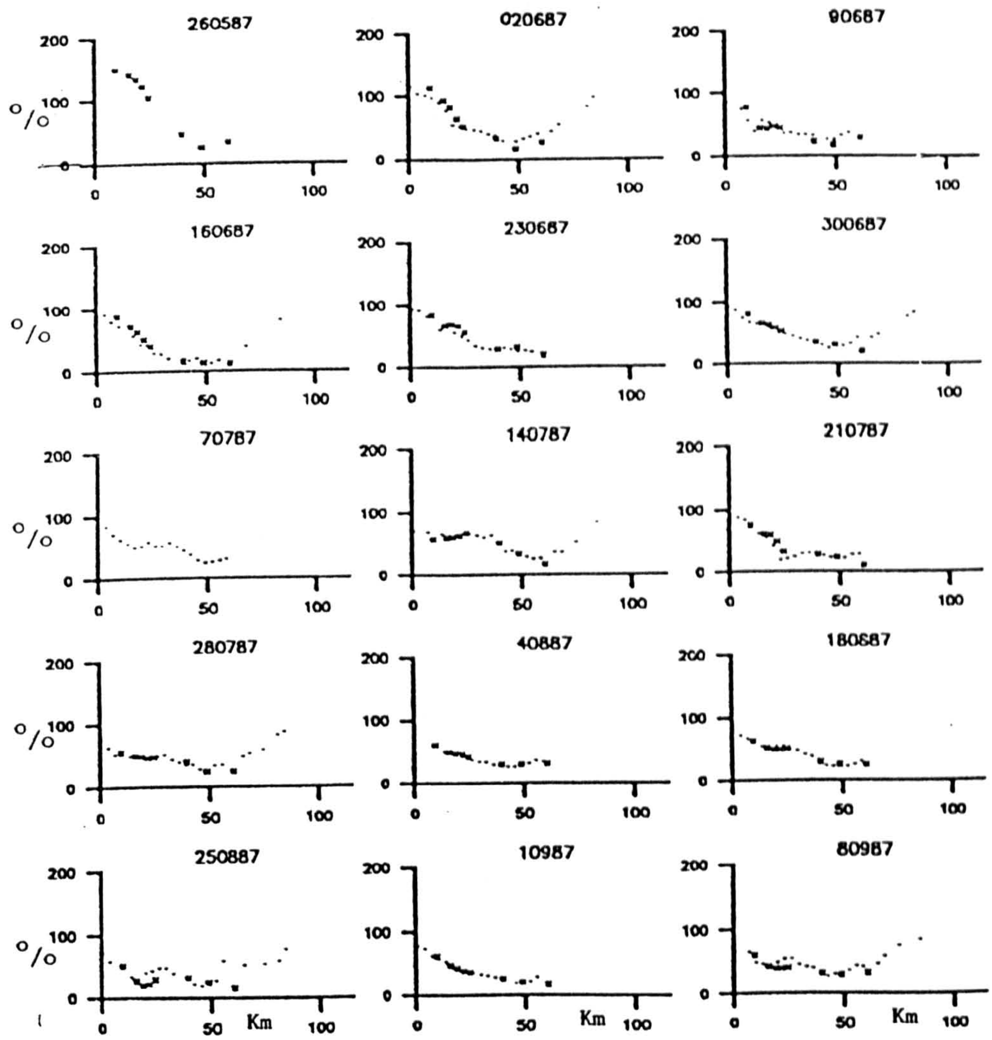
FROM TEDDINGTON

Appendix 9. A1. A comparison of measurements of dissolved oxygen made by research vessel (.) vs. automatic monitoring stations (x).

MONITORING STATION AND RESEARCH VESSEL DATA

1987

DISSOLVED OXYGEN % SATURATION



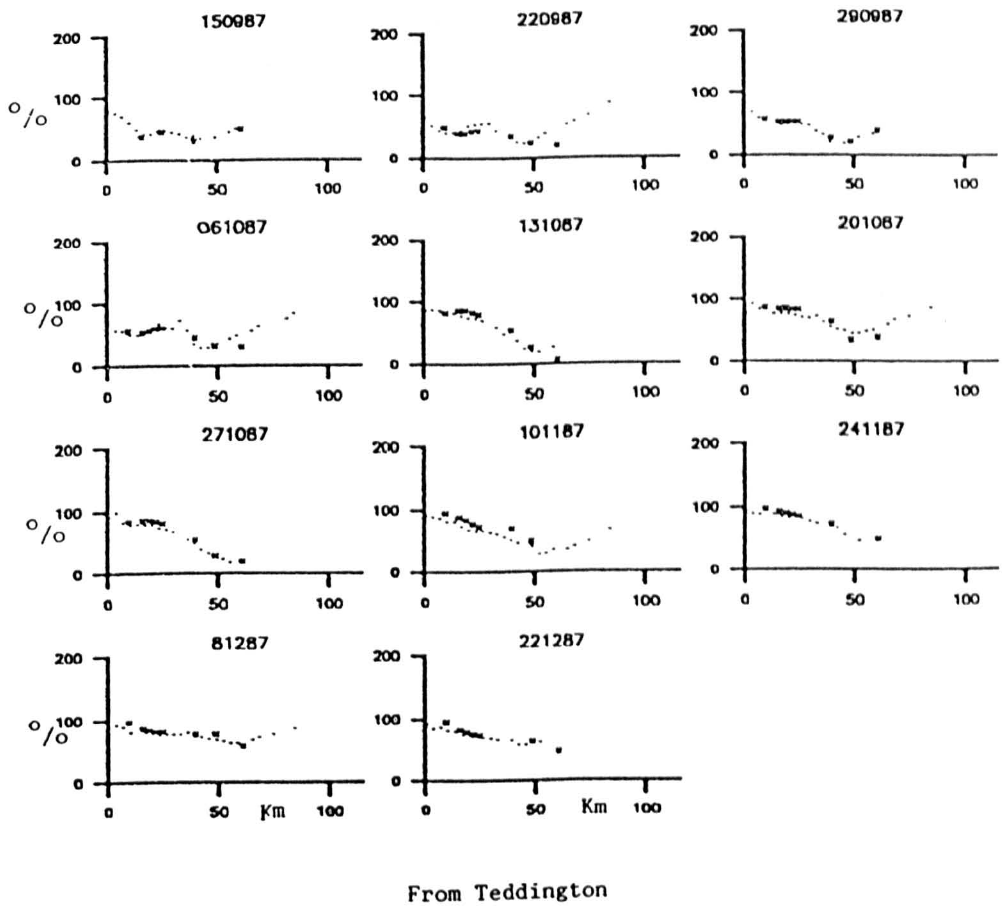
FROM TEDDINGTON

Appendix 9. A2. A comparison of measurements of dissolved oxygen made by research vessel (.) vs. automatic monitoring stations (x).

MONITORING STATION AND RESEARCH VESSEL DATA

1987

DISSOLVED OXYGEN % SATURATION



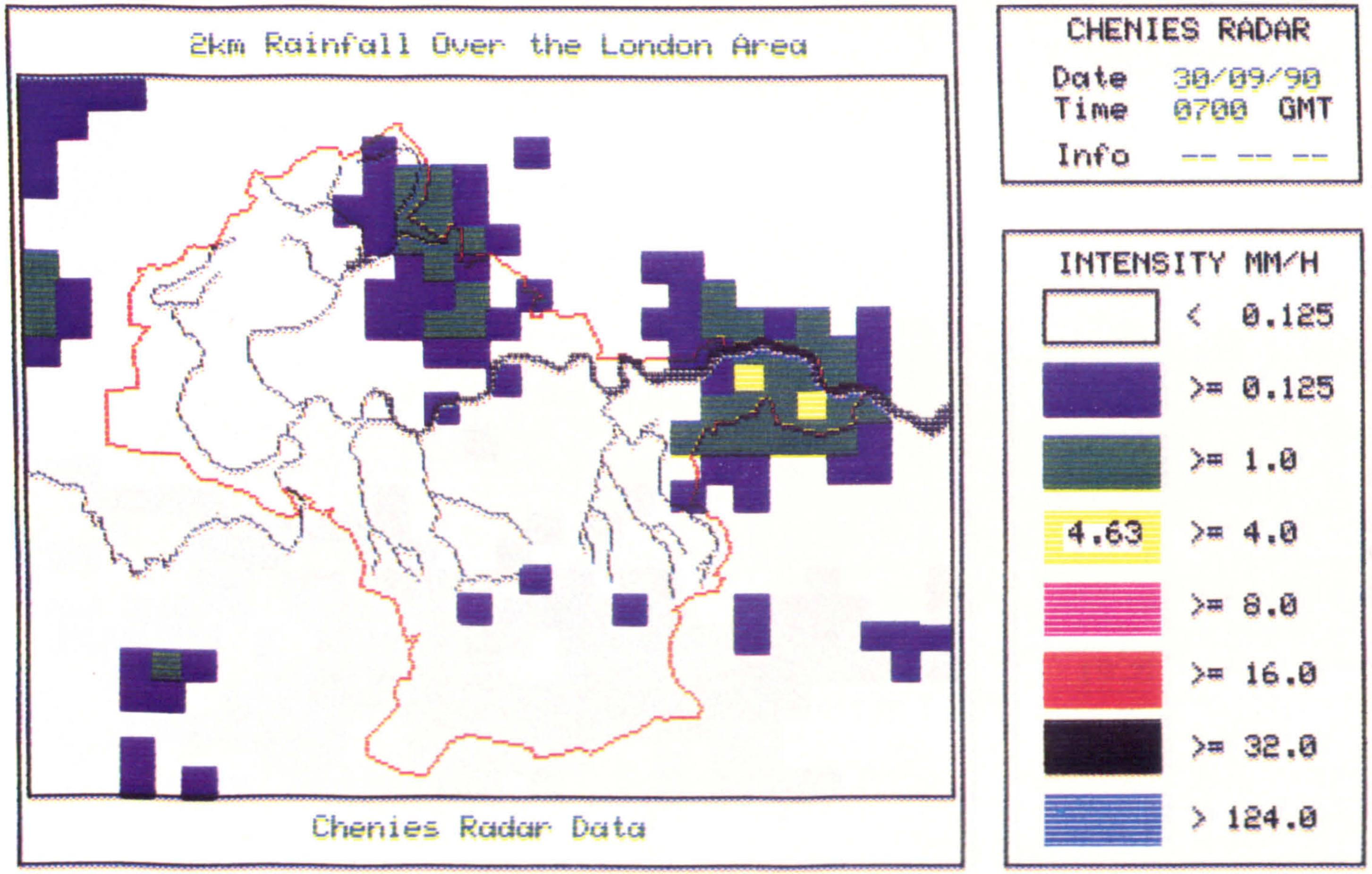
Appendix 9.A3. A comparison of measurements of dissolved oxygen made by research vessel (.) vs. automatic monitoring stations (x).

APPENDIX 10

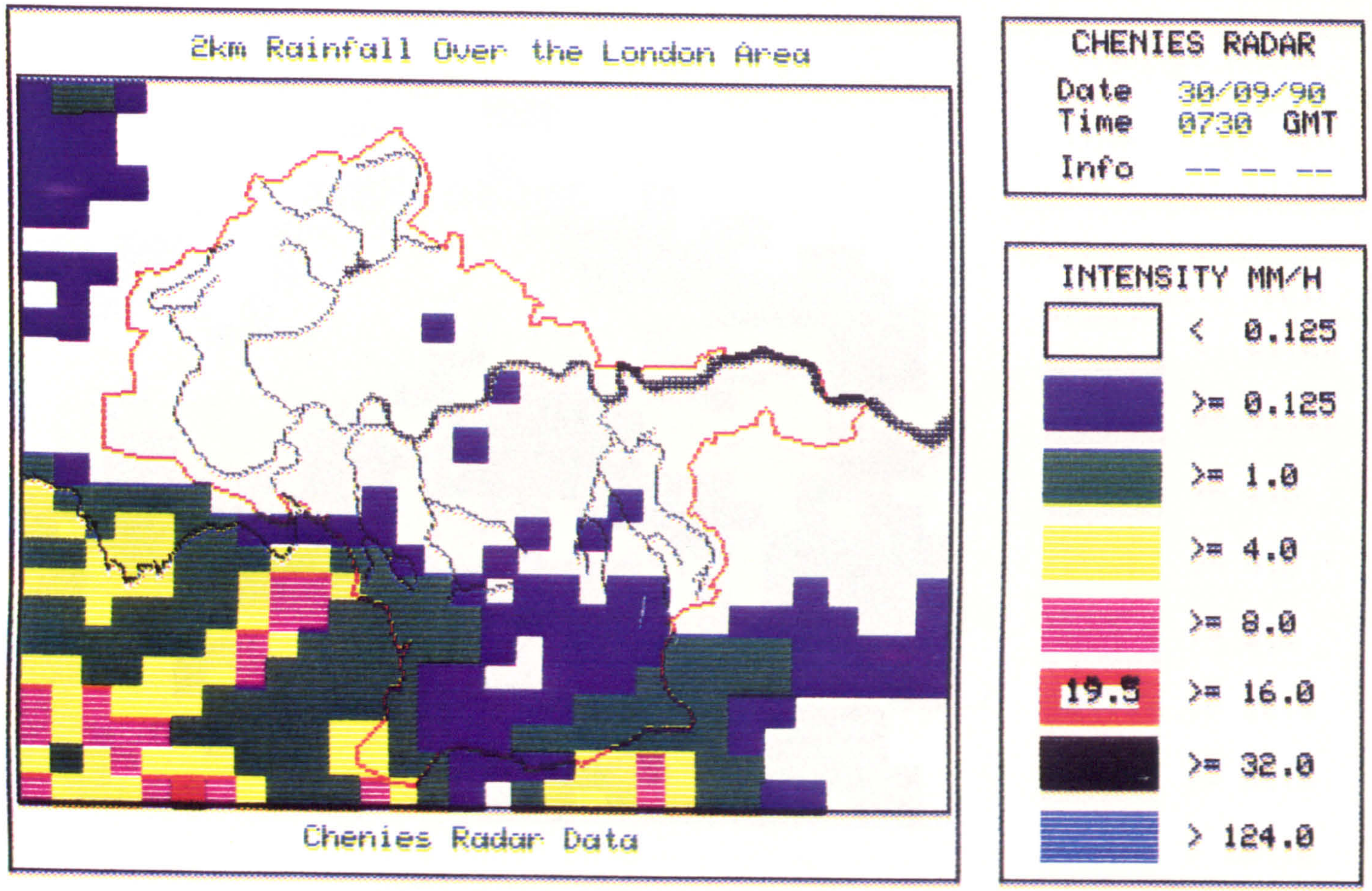
Rain radar storm sequence 30.9.1990, Figures 1-14.

Teddington Wier, Mean daily flow Aug-Sept 1990, Fig 15.

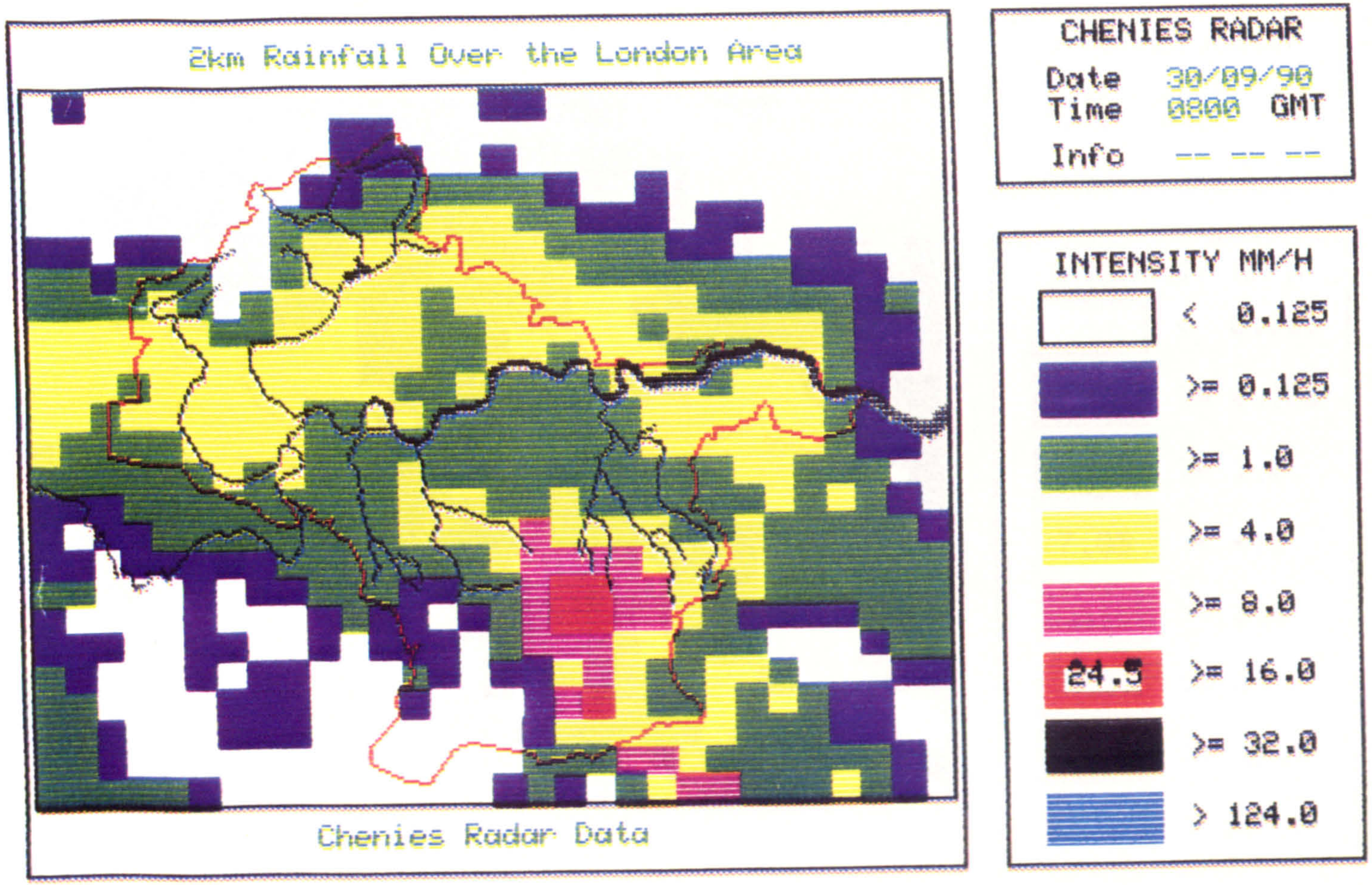
Rain radar storm sequence 8.5.1988, Figures 16-31.



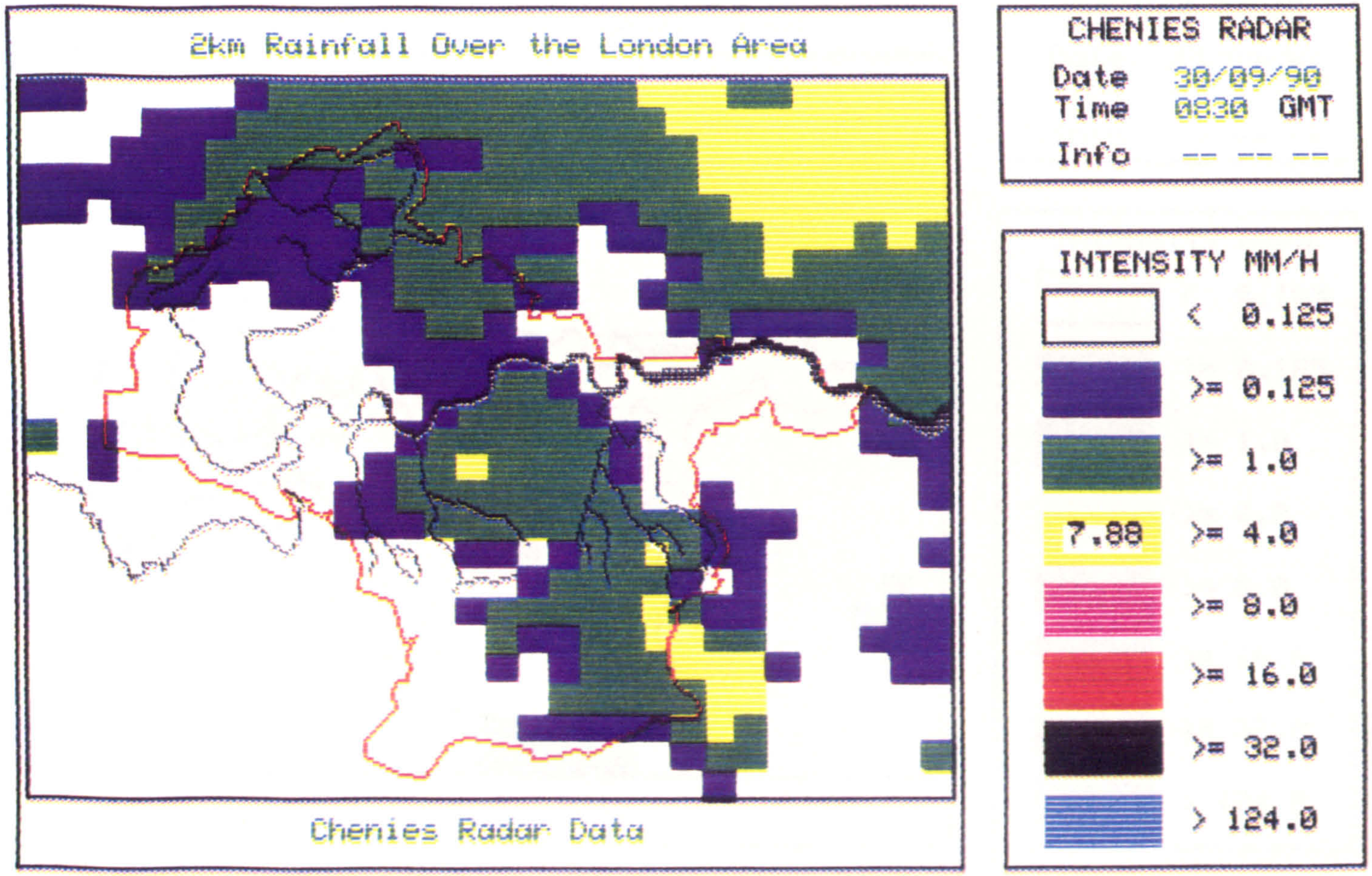
App 10. Fig 1. Rain radar sequence.



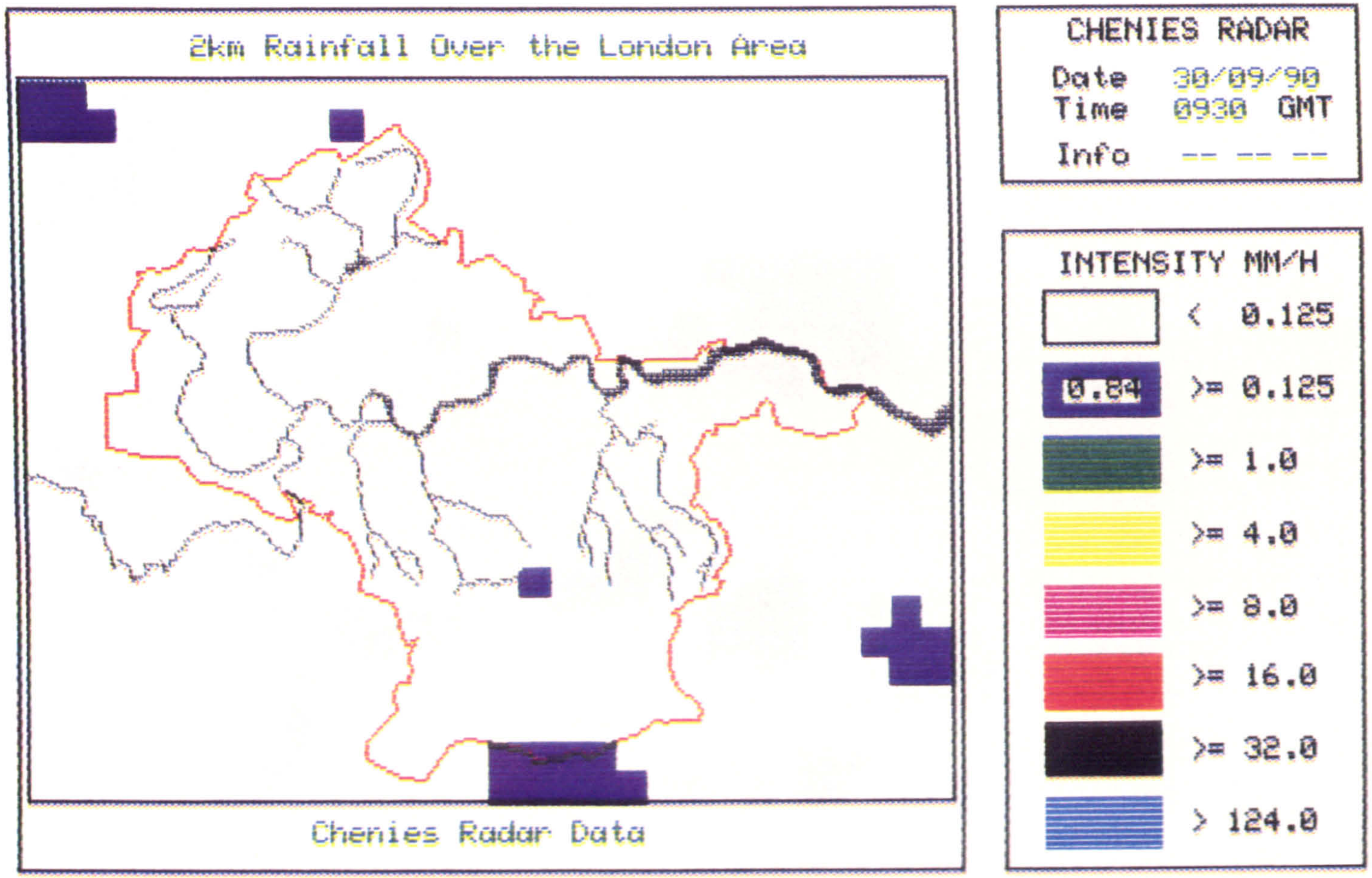
App 10. Fig 2. Rain radar sequence.



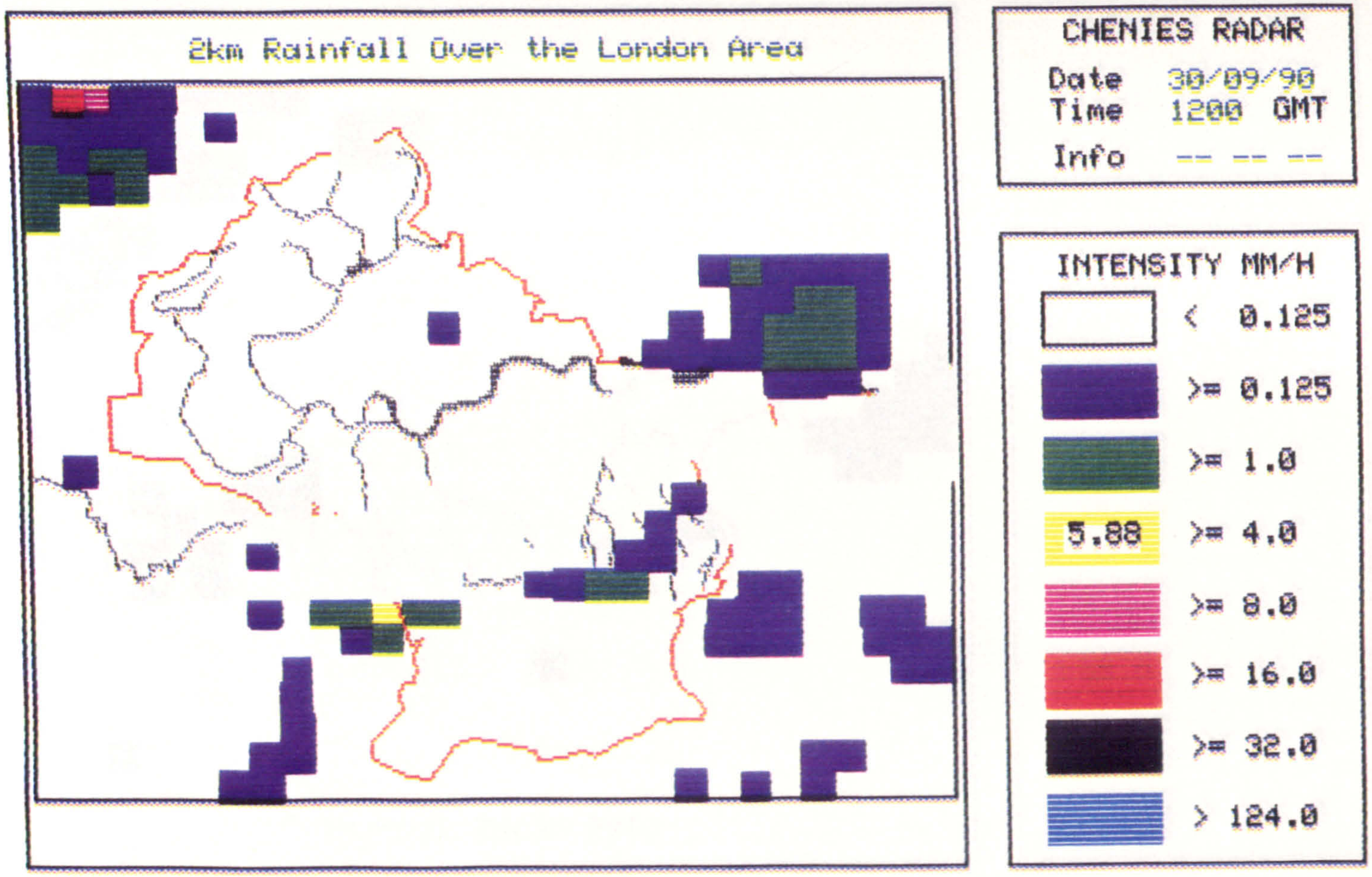
App 10. Fig 3. Rain radar sequence.



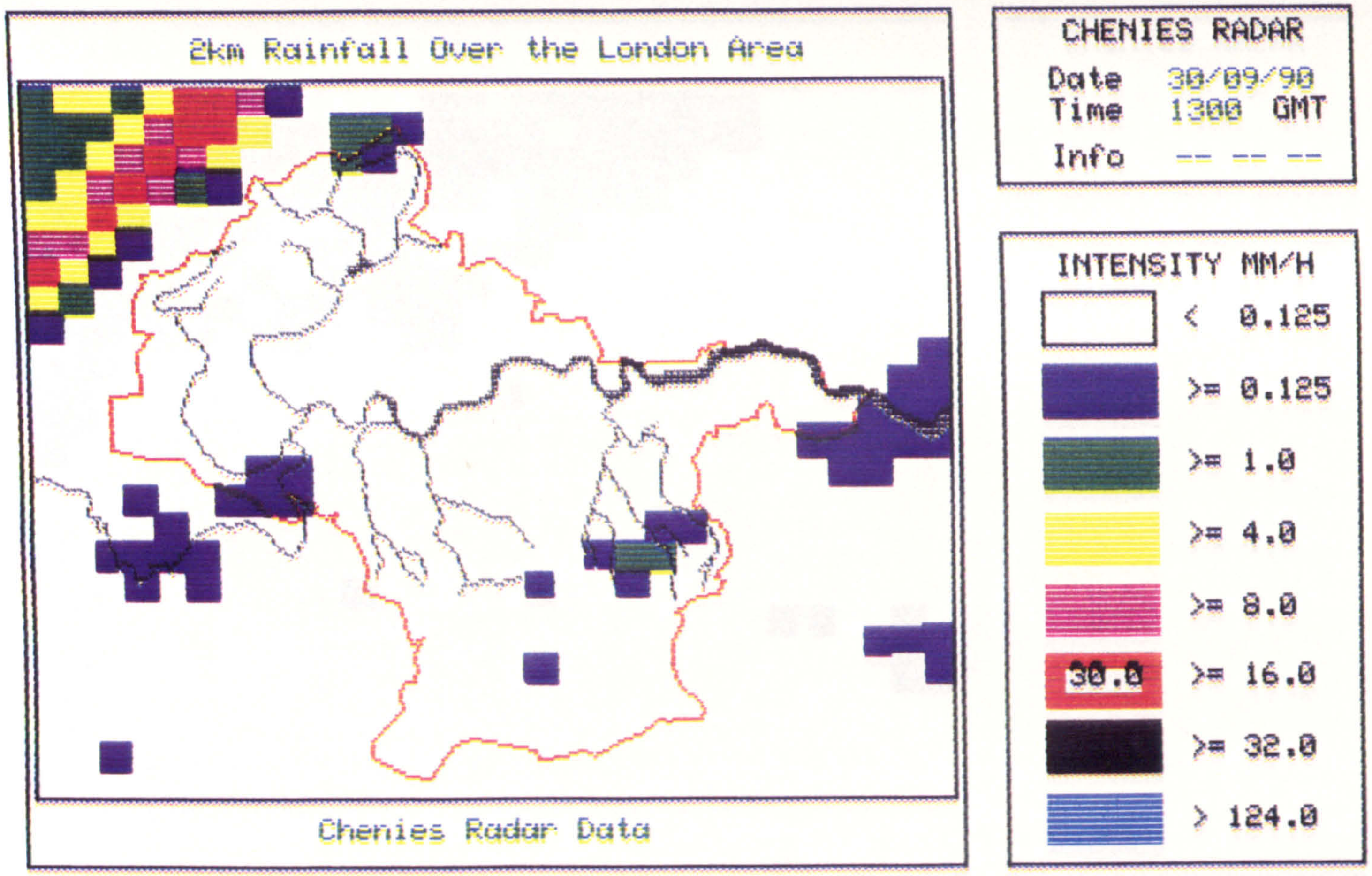
App 10. Fig 4. Rain radar sequence.



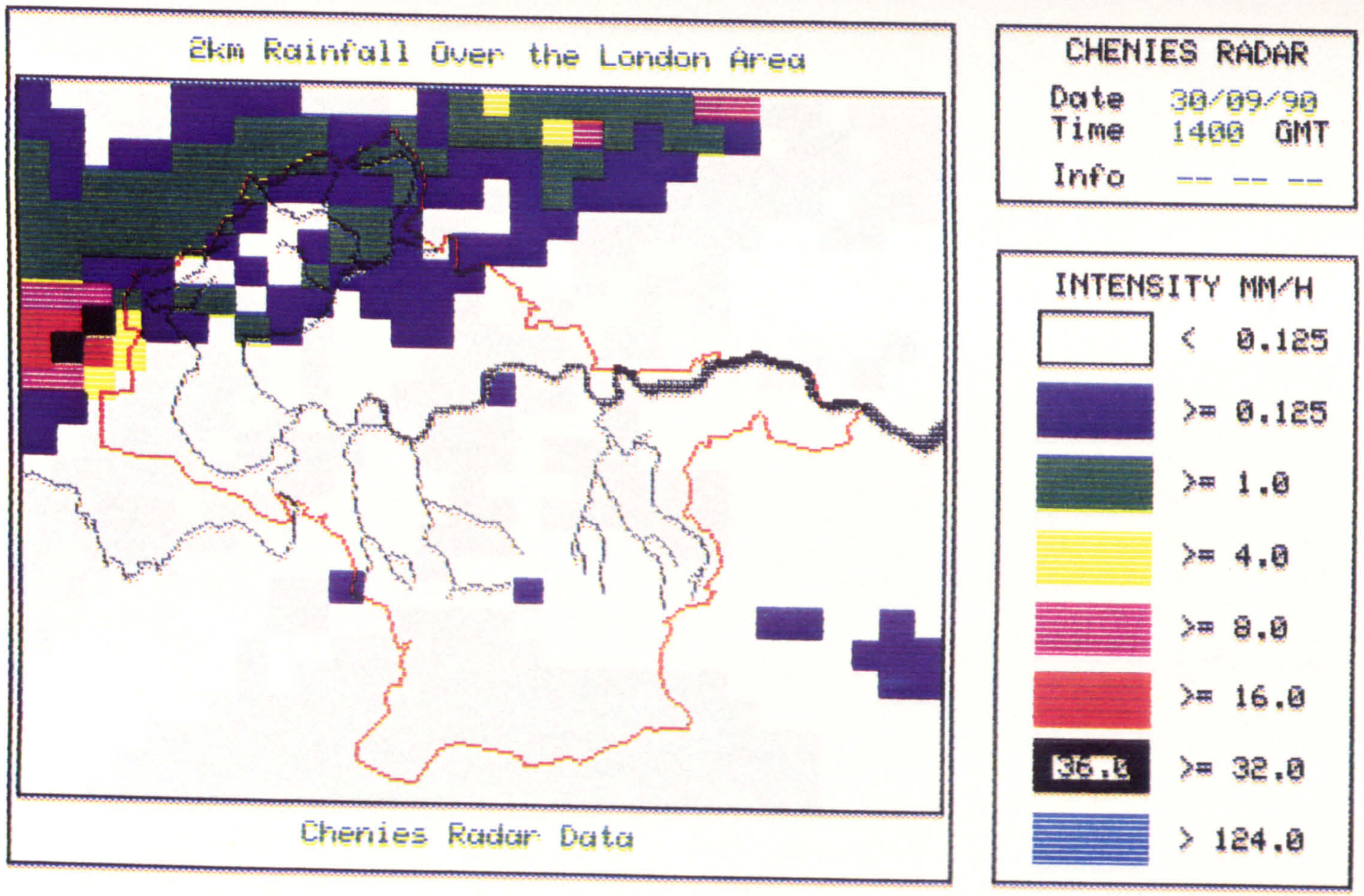
App 10. Fig 5. Rain radar sequence.



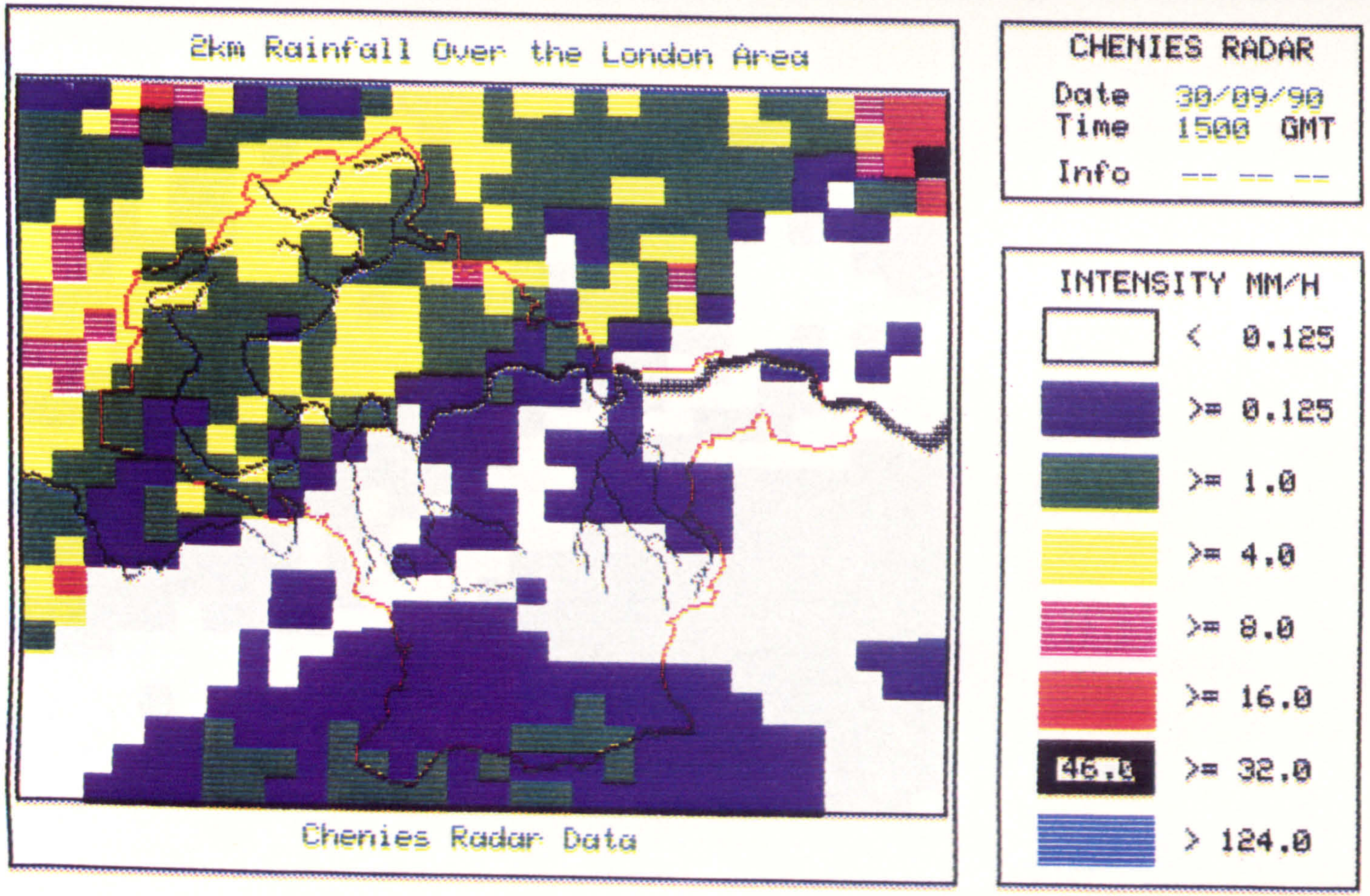
App 10. Fig 6. Rain radar sequence.



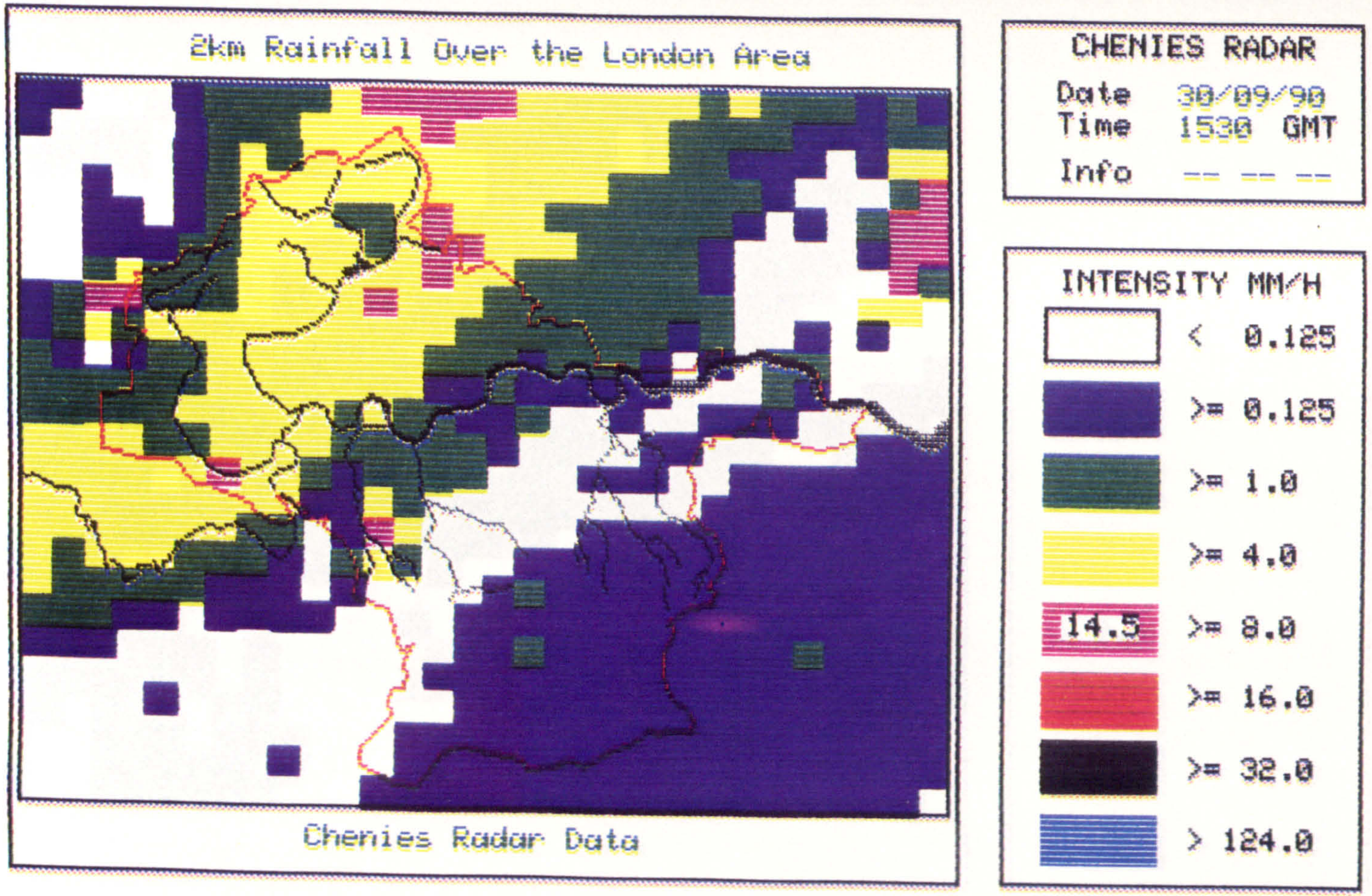
App 10. Fig 7. Rain radar sequence.



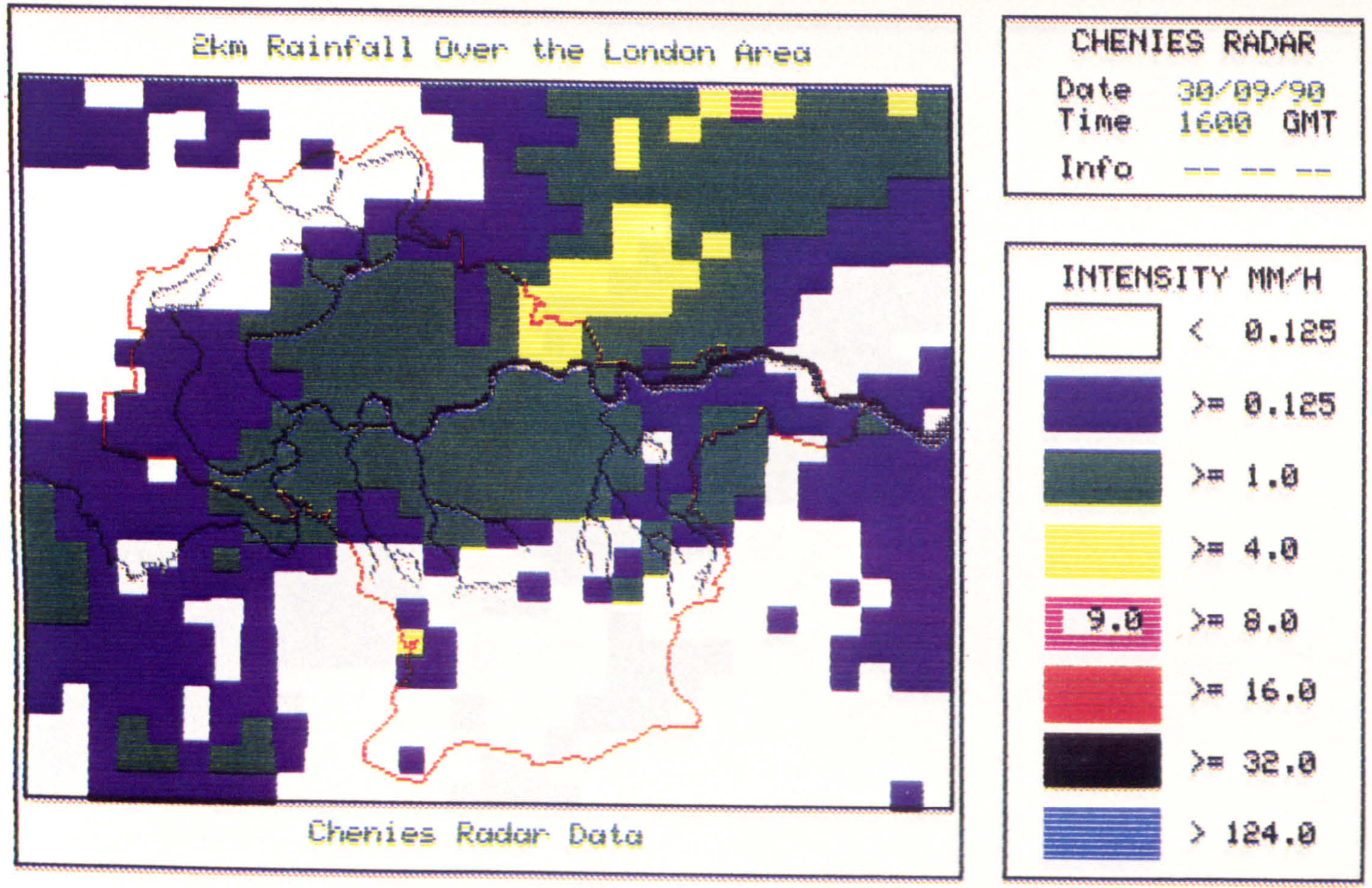
App 10. Fig 8. Rain radar sequence.



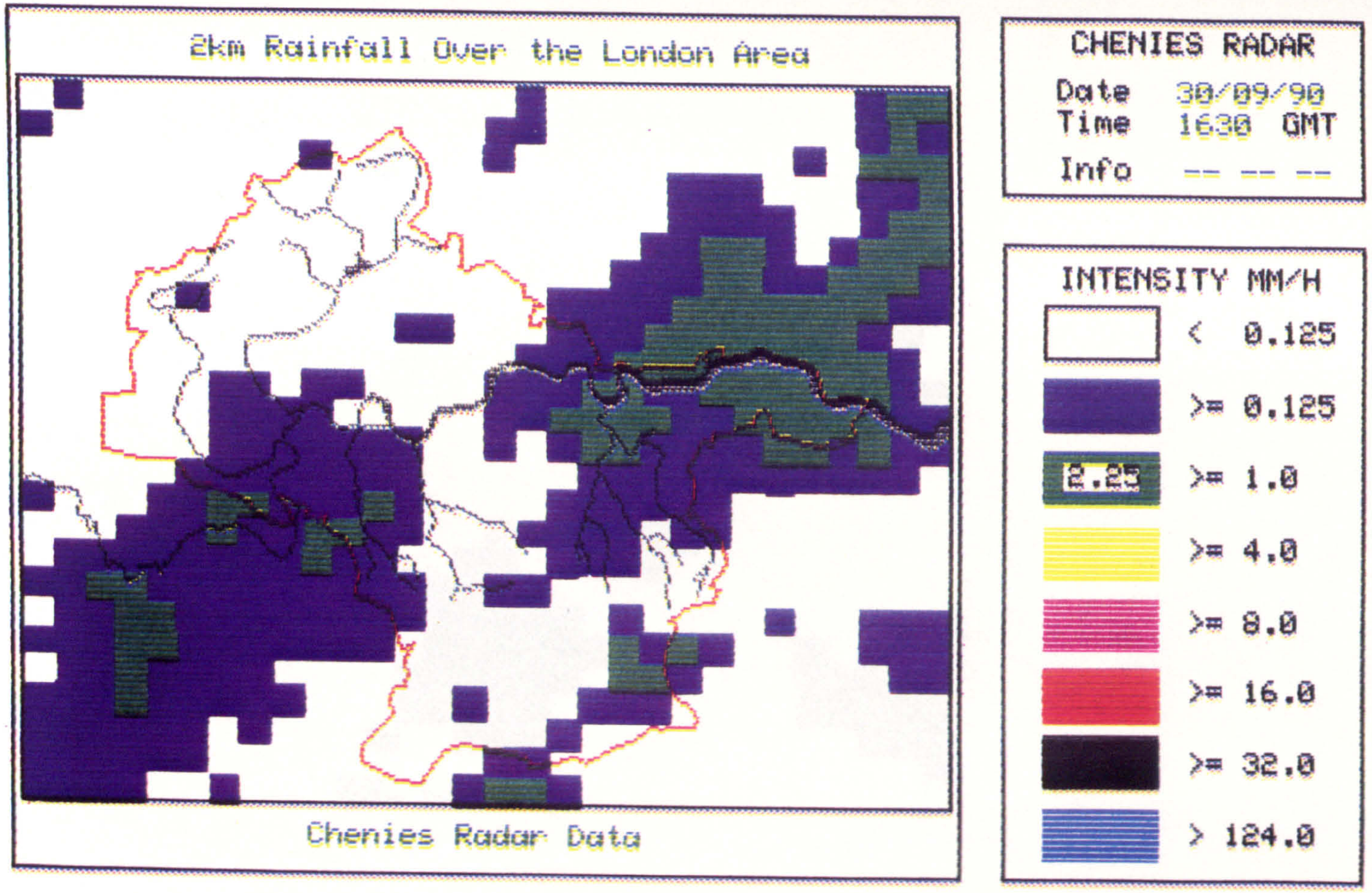
App 10. Fig 9. Rain radar sequence.



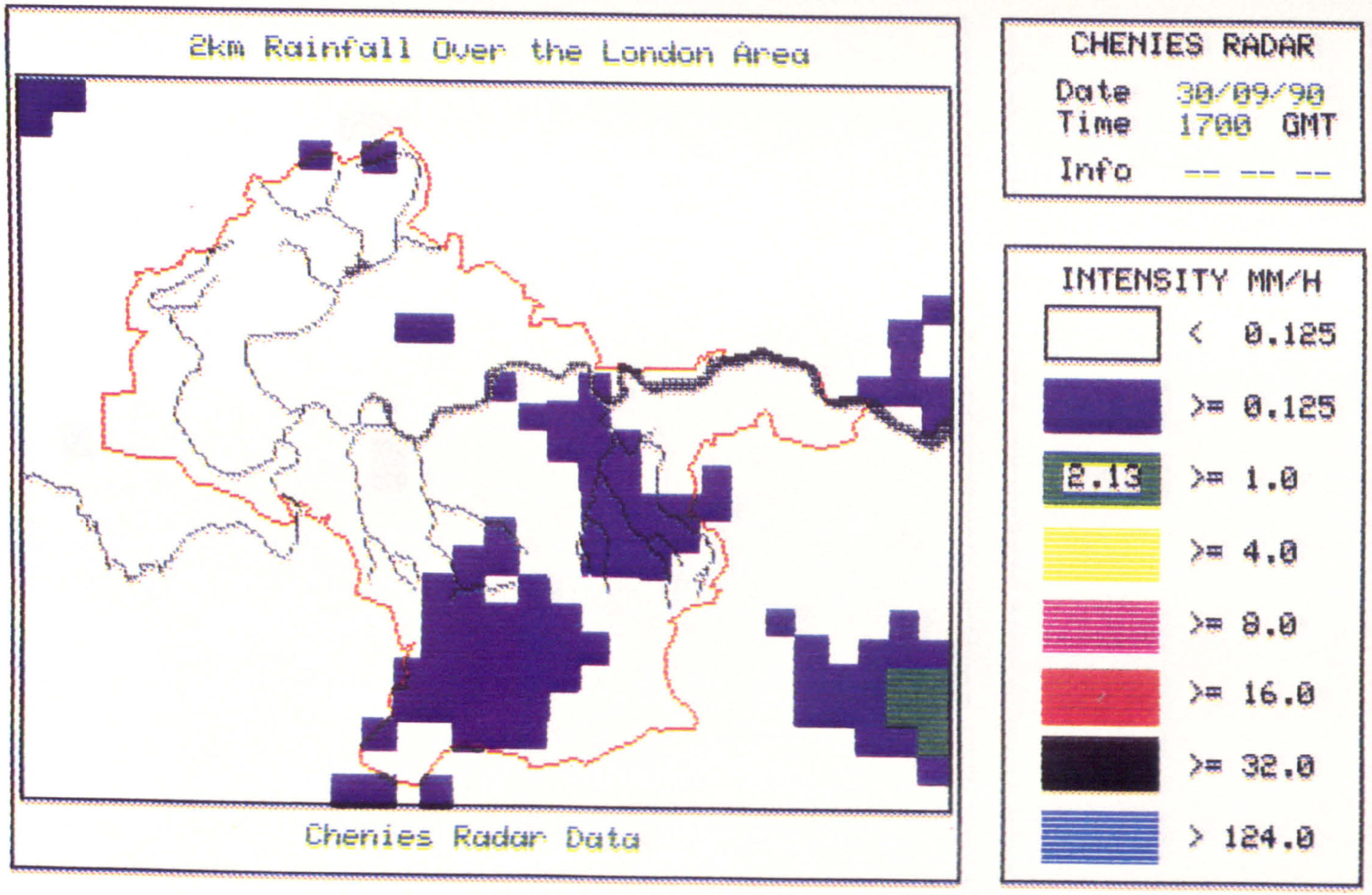
App 10. Fig 10. Rain radar sequence.



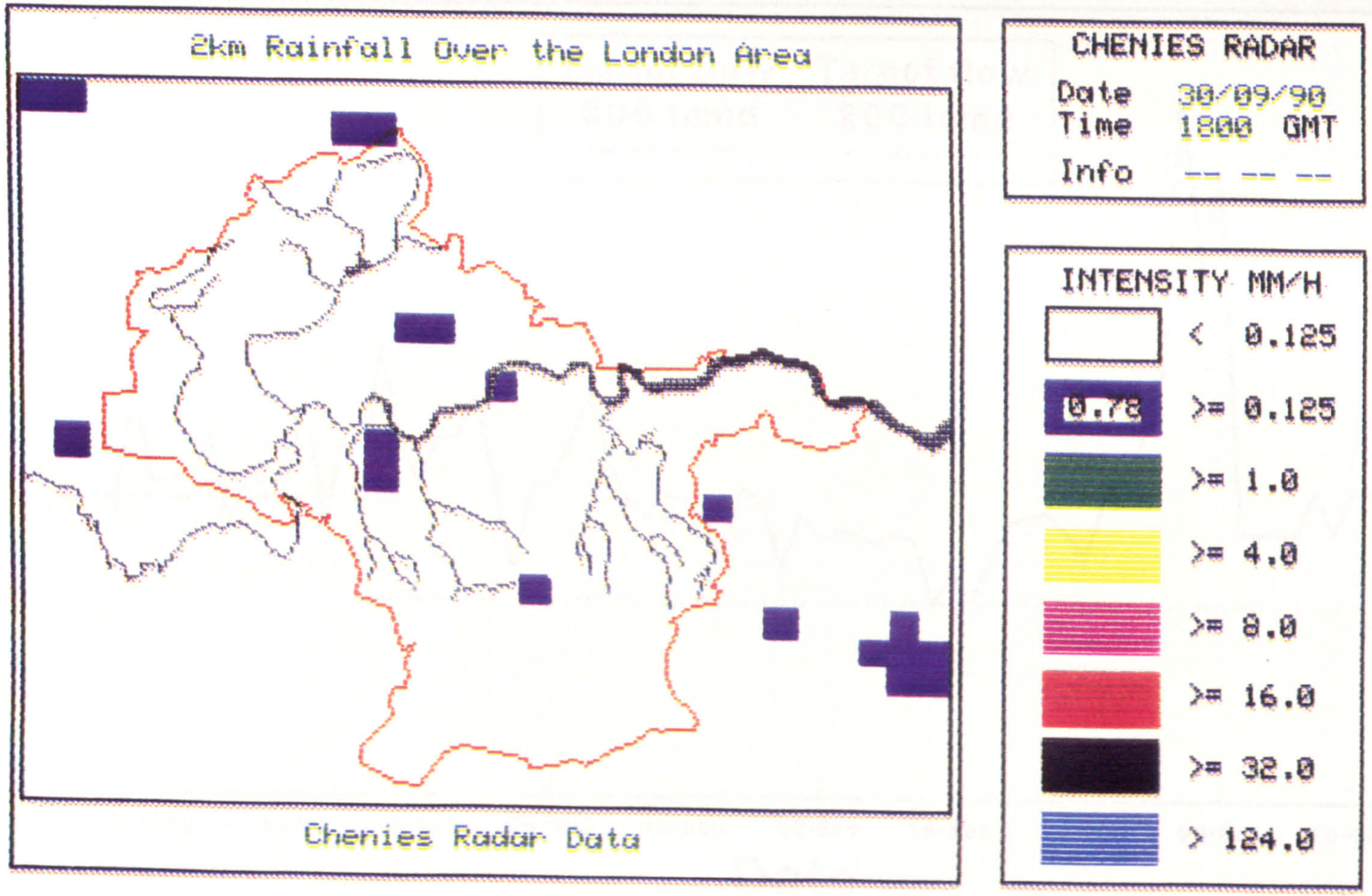
App 10. Fig 11. Rain radar sequence.



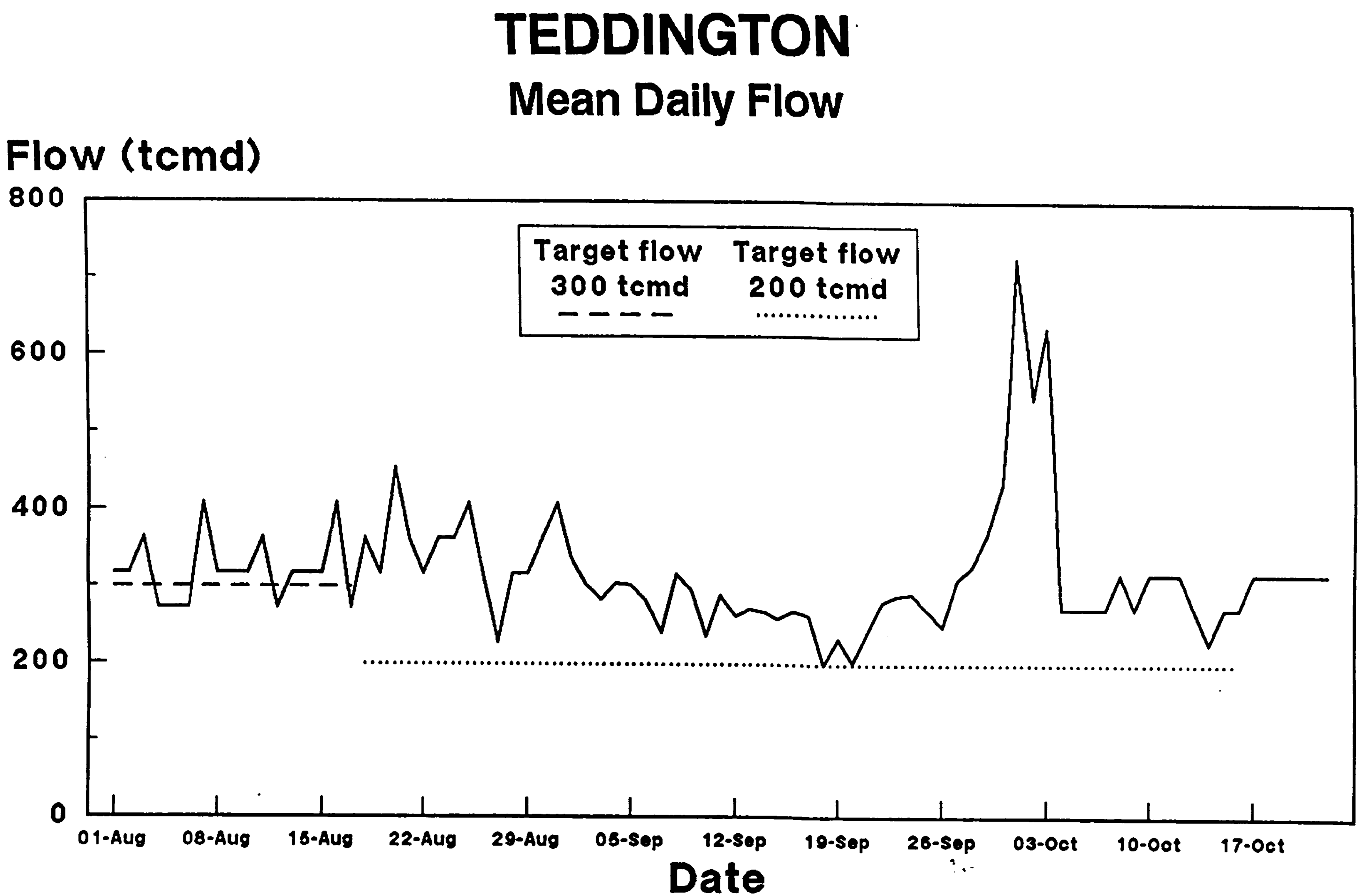
App 10. Fig 12. Rain radar sequence.



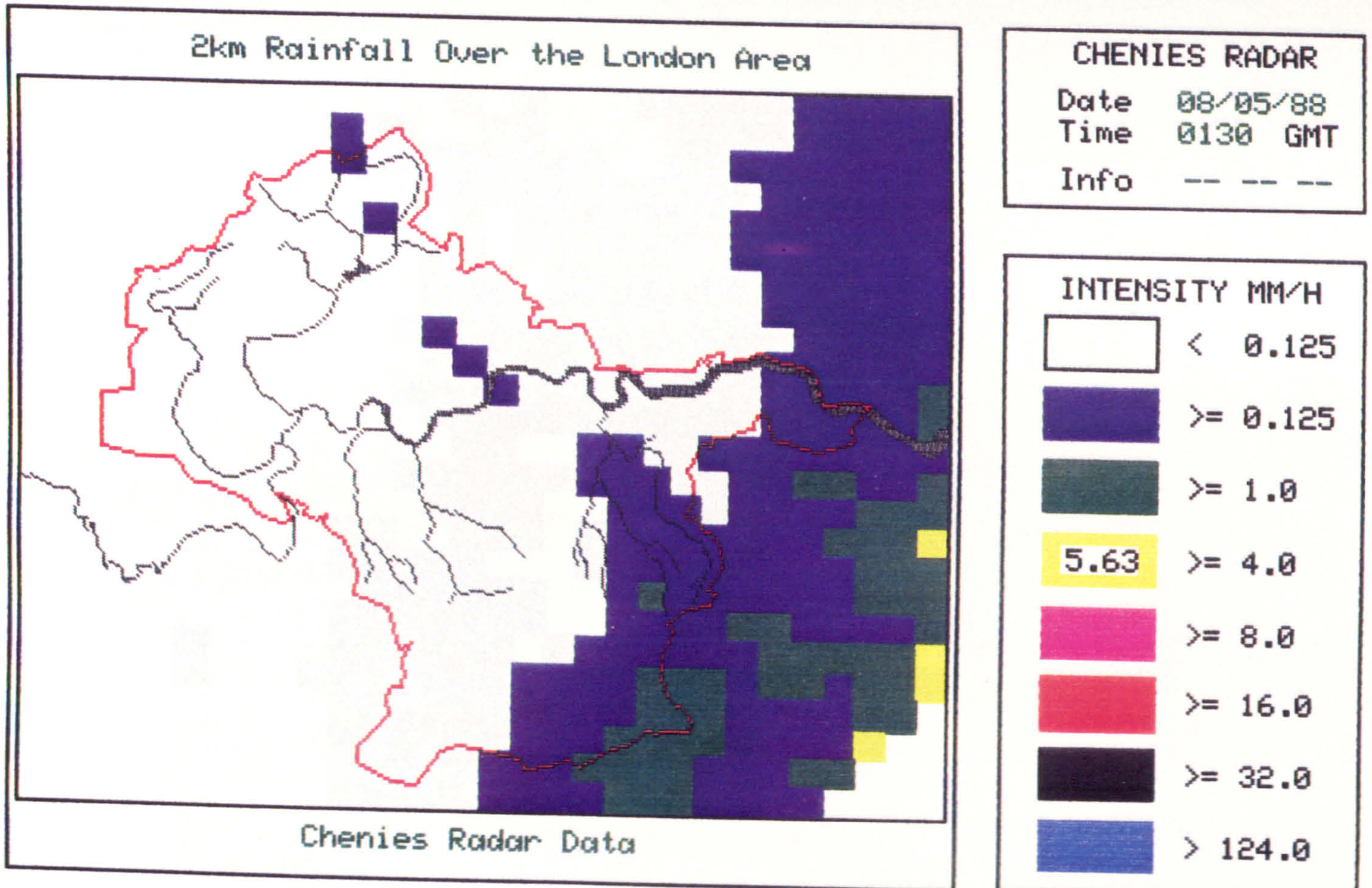
App 10. Fig 13. Rain radar sequence.



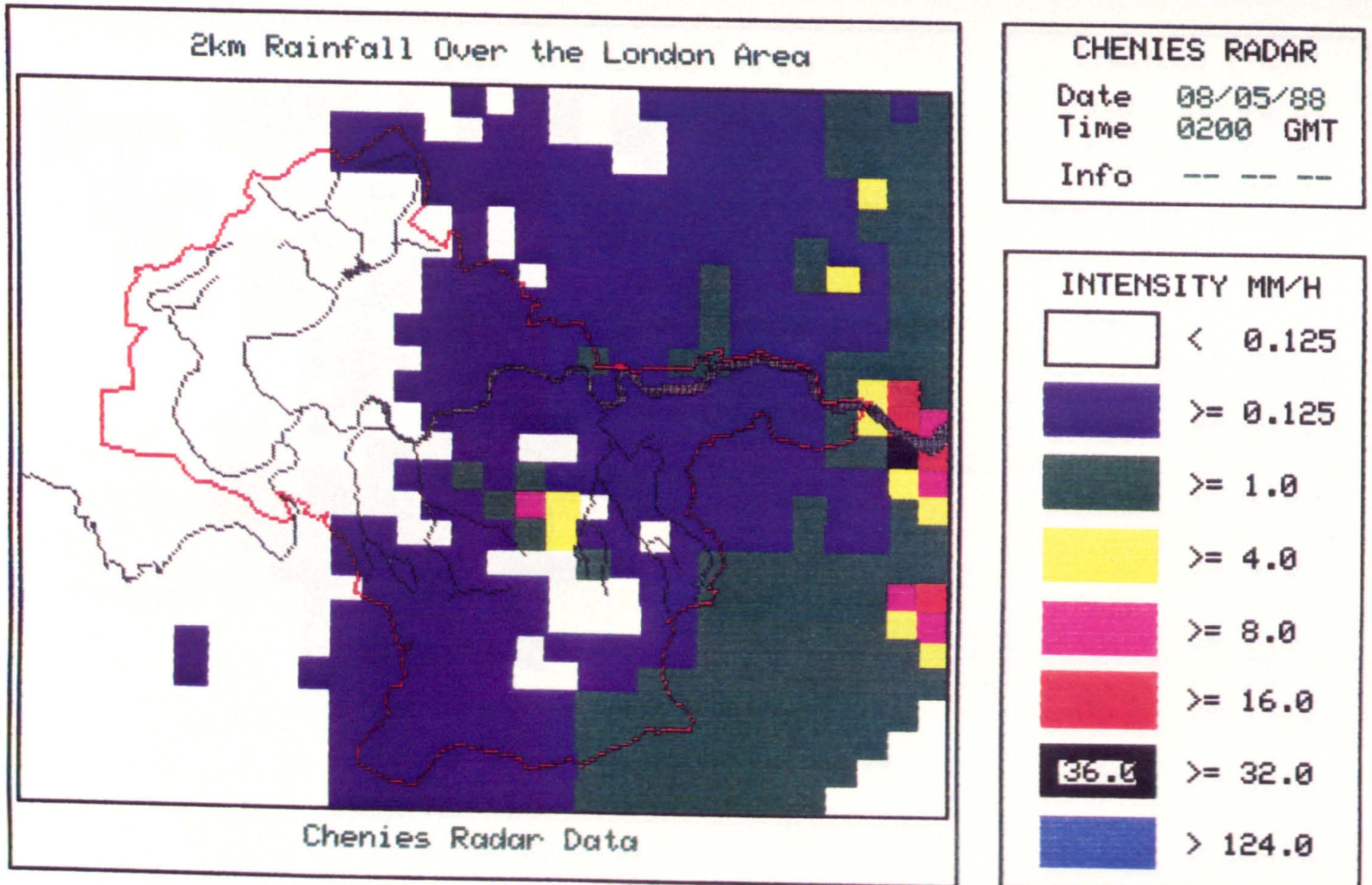
App 10. Fig 14. Rain radar sequence.



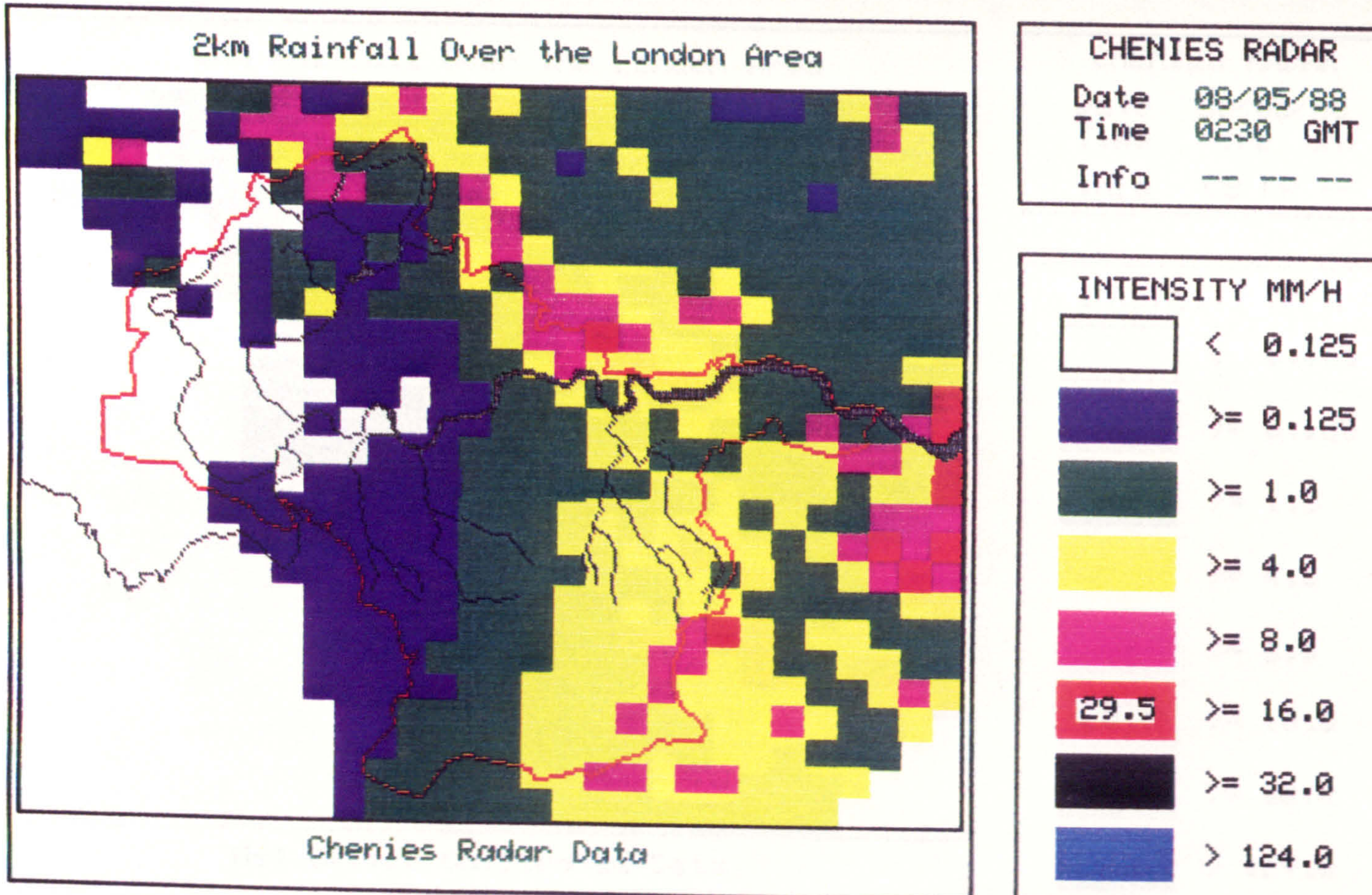
App 10. Fig 15. Teddington Flow August - October 1990.



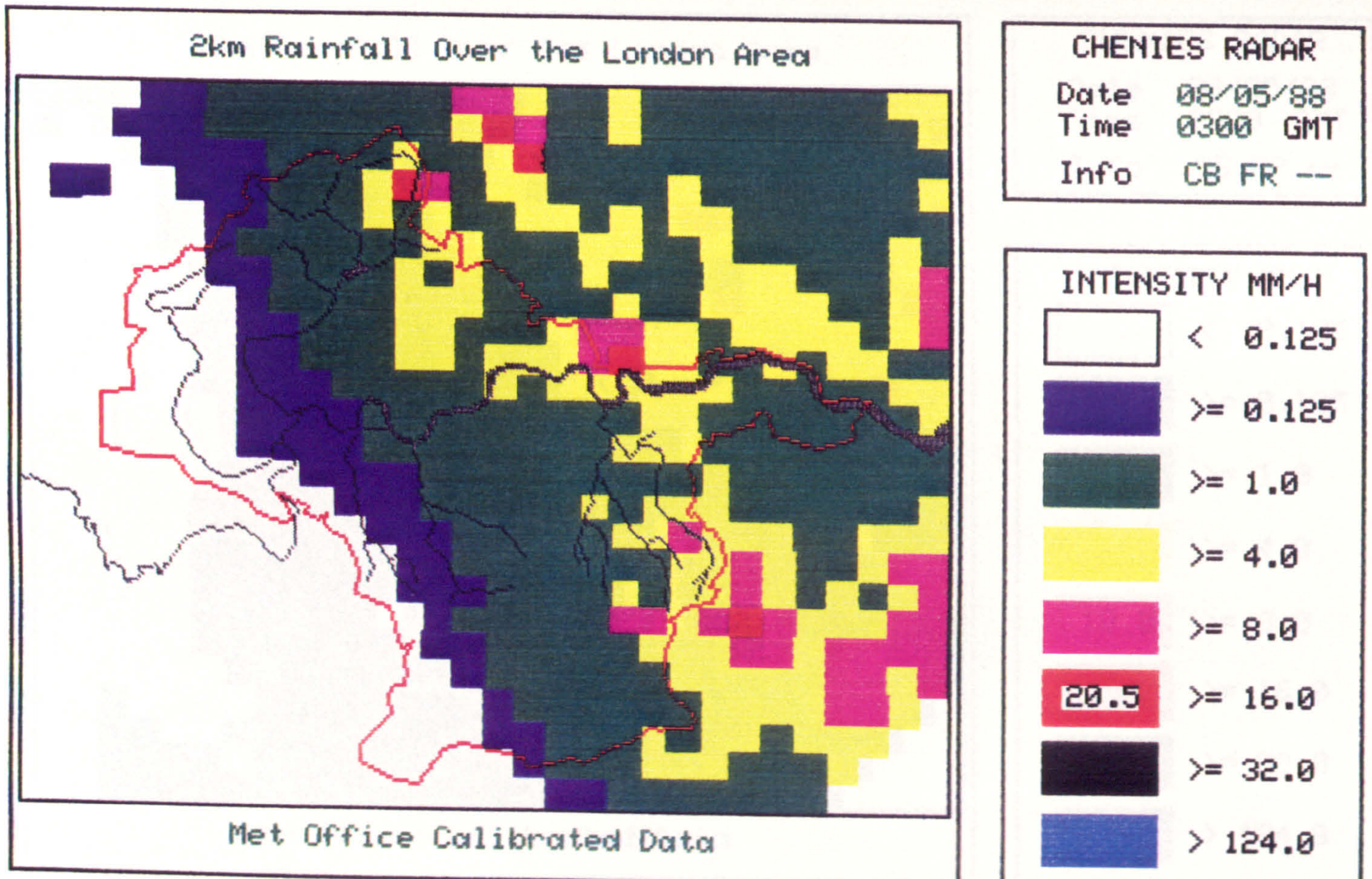
App 10. Fig 16. Rain radar sequence.



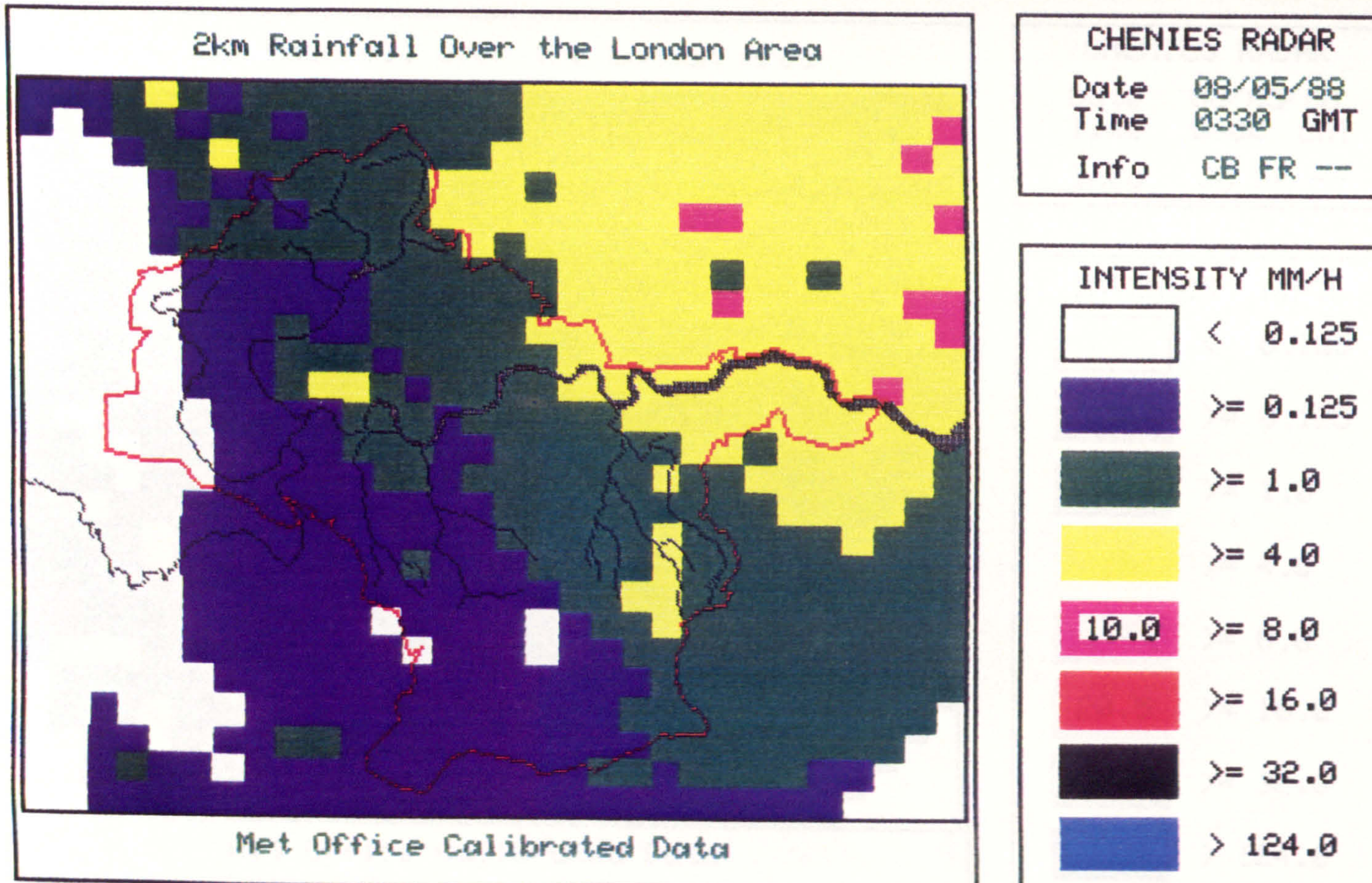
App 10. Fig 17. Rain radar sequence.



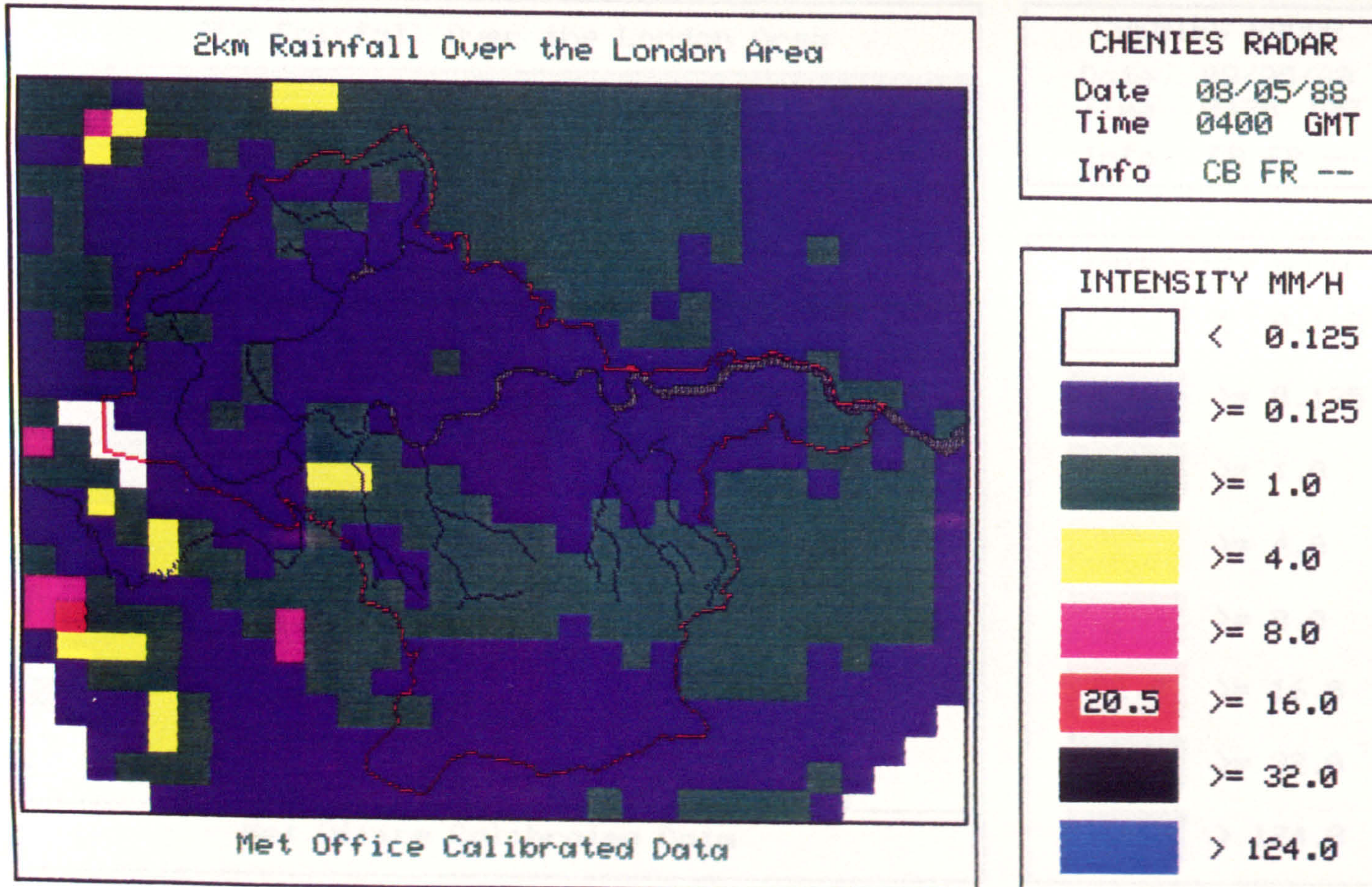
App 10. Fig 18. Rain radar sequence.



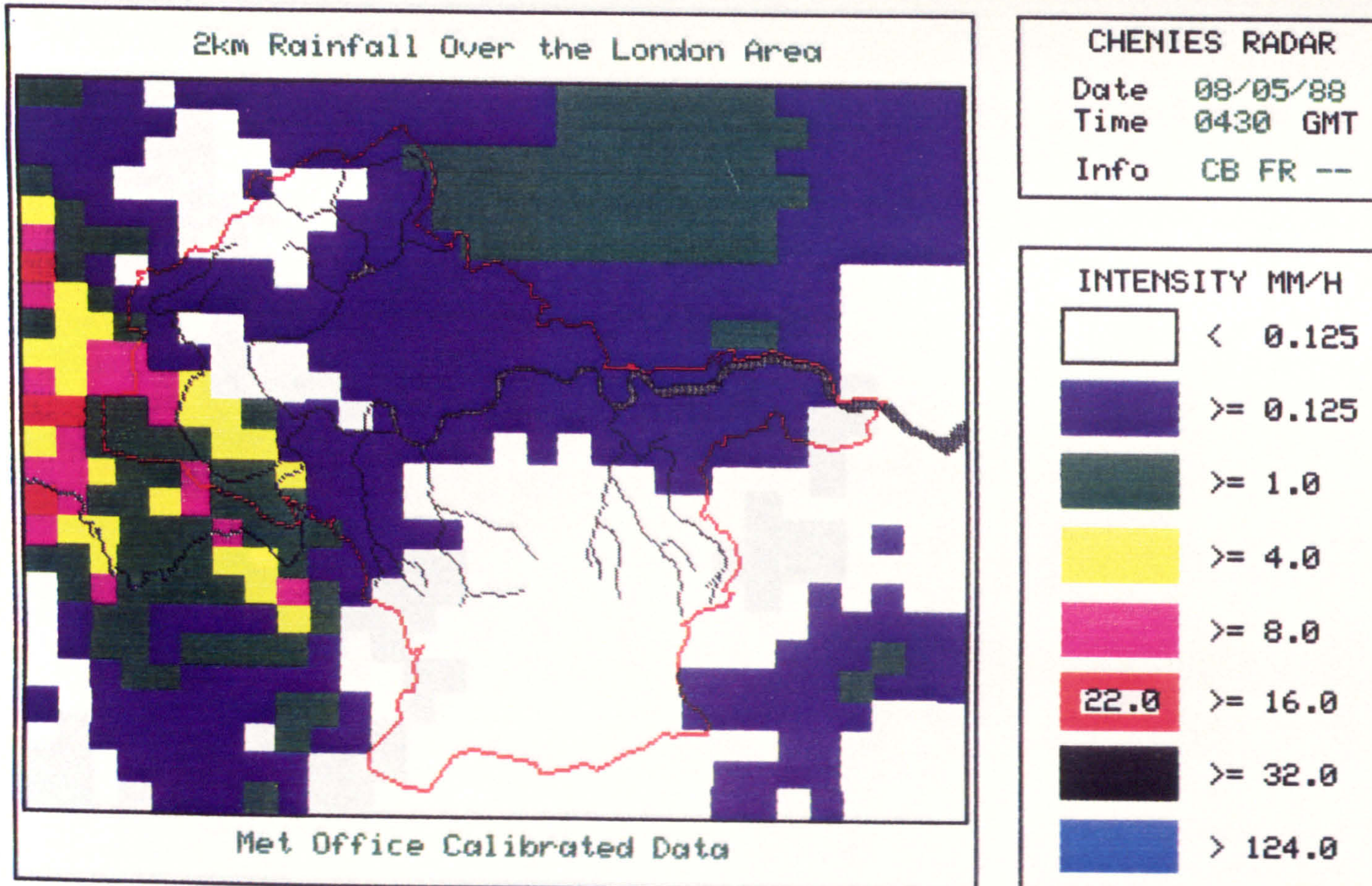
App 10. Fig 19. Rain radar sequence.



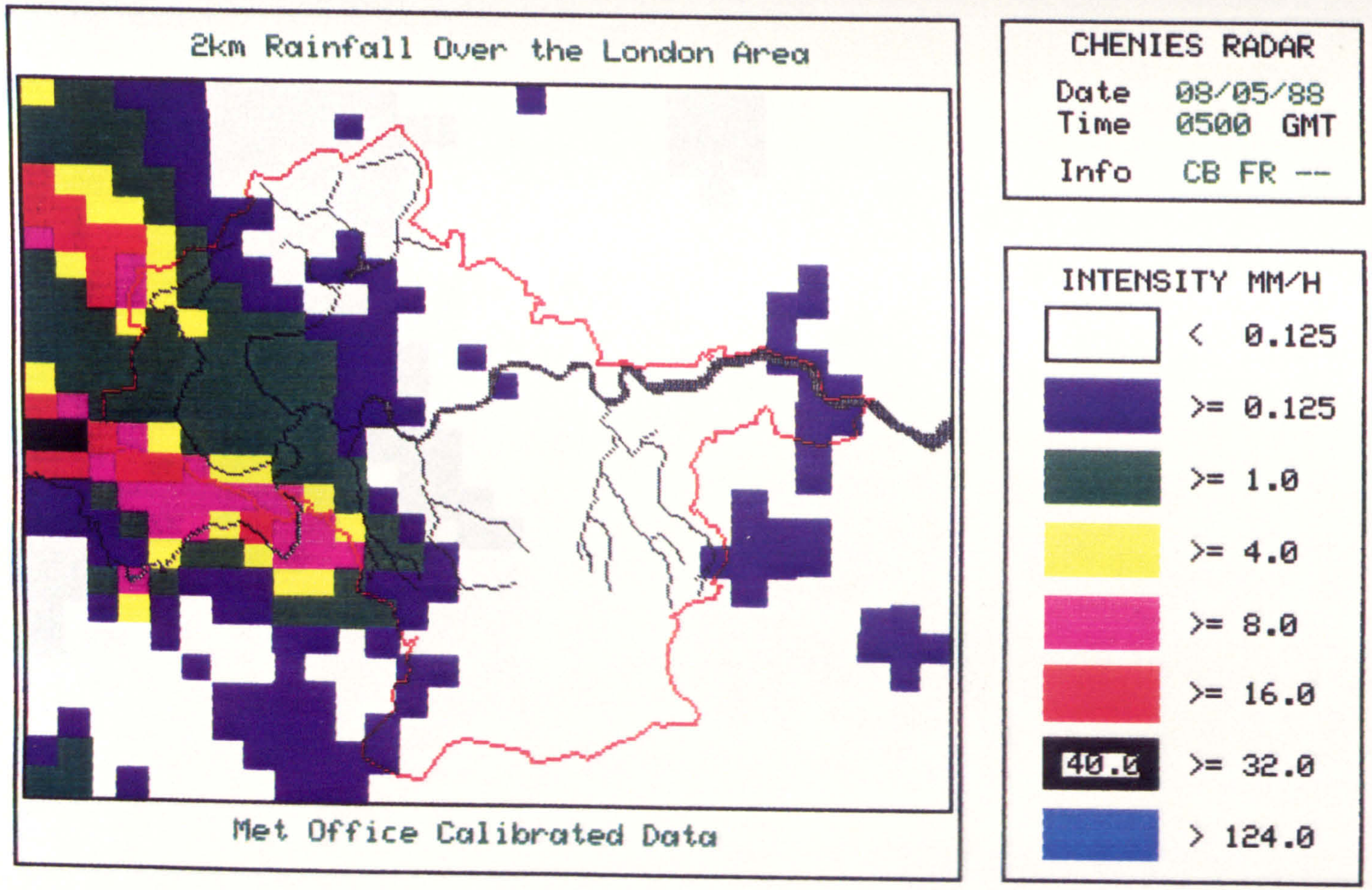
App 10. Fig 20. Rain radar sequence.



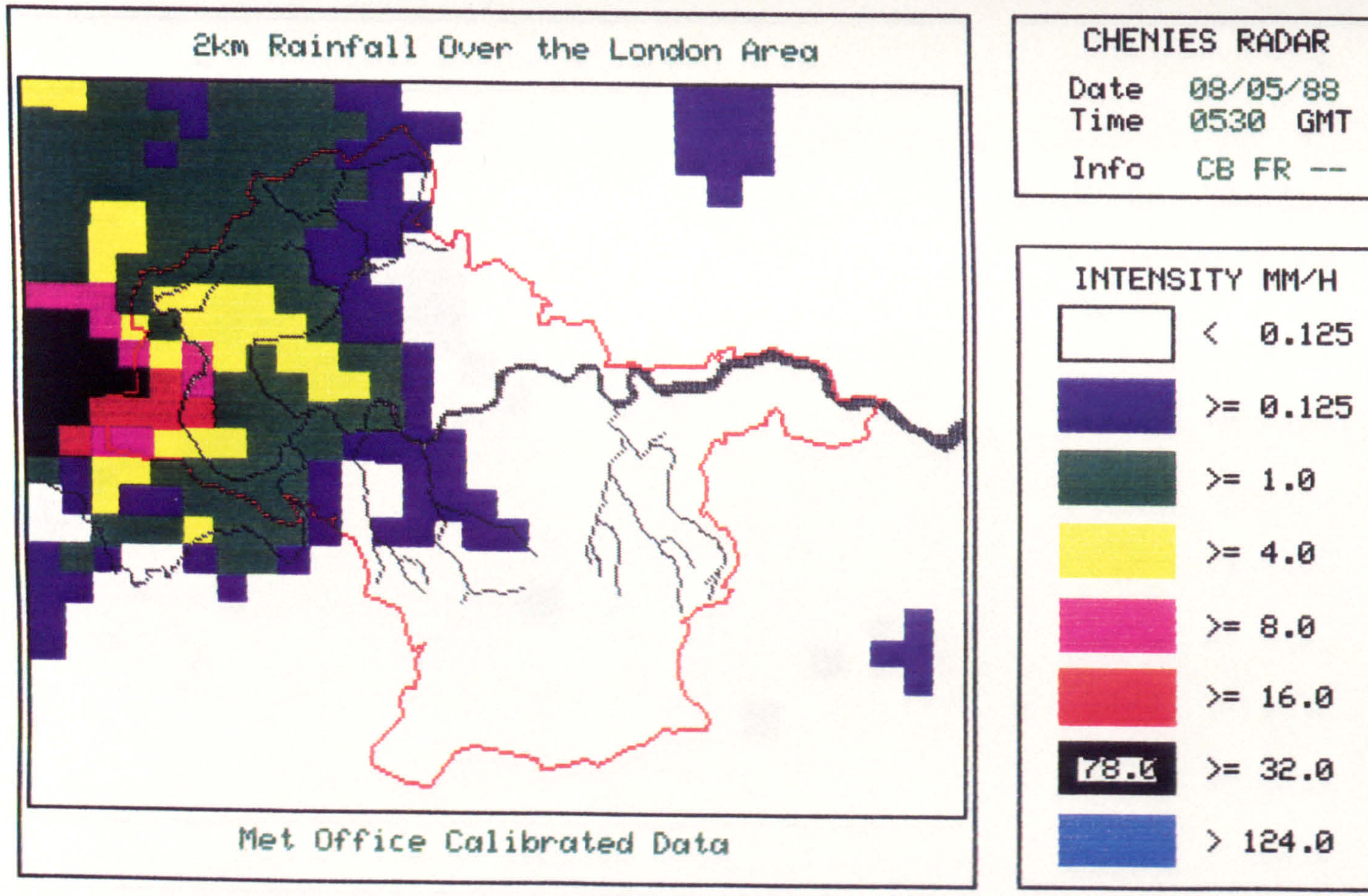
App 10. Fig 21. Rain radar sequence.



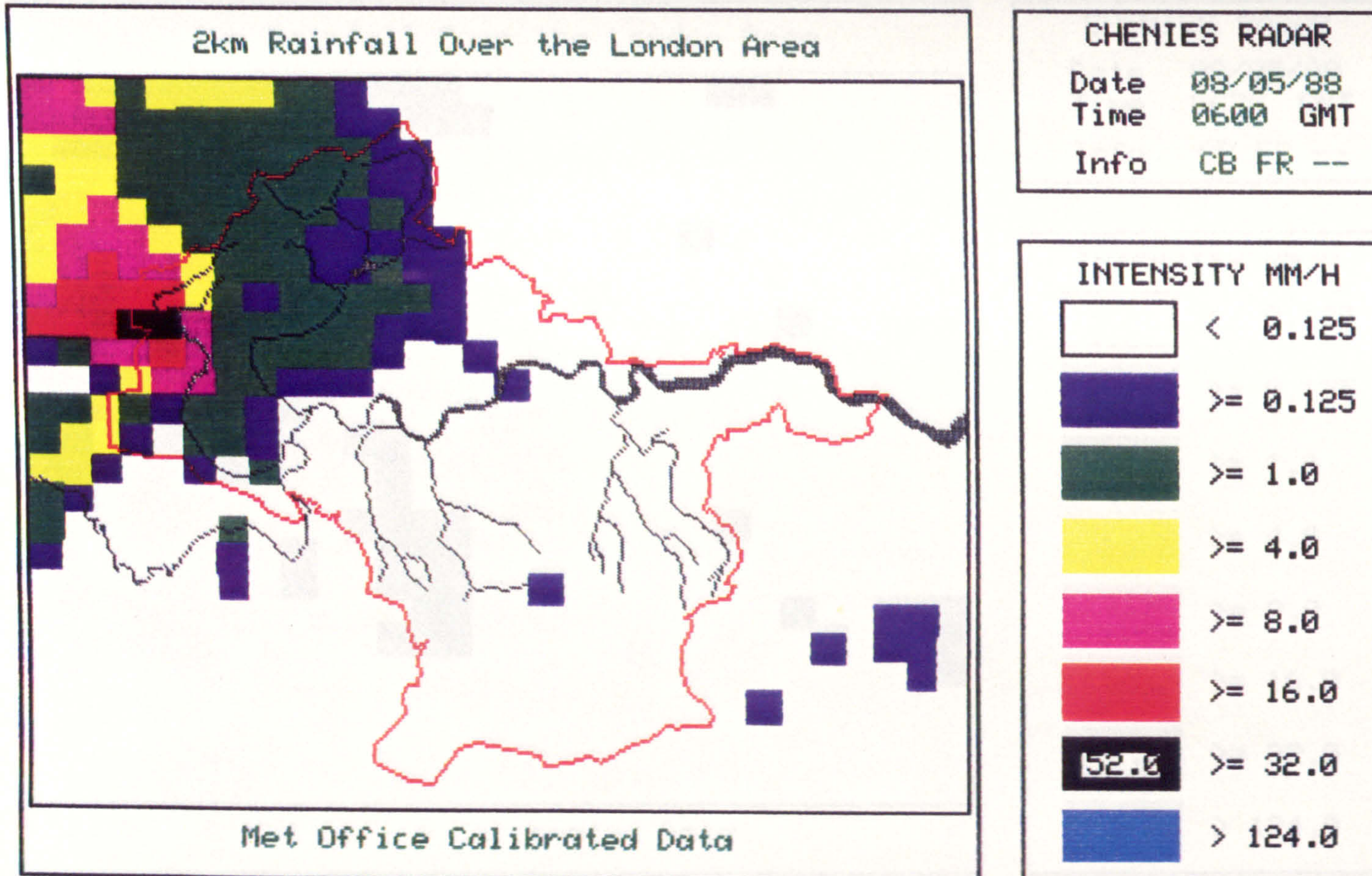
App 10. Fig 22. Rain radar sequence.



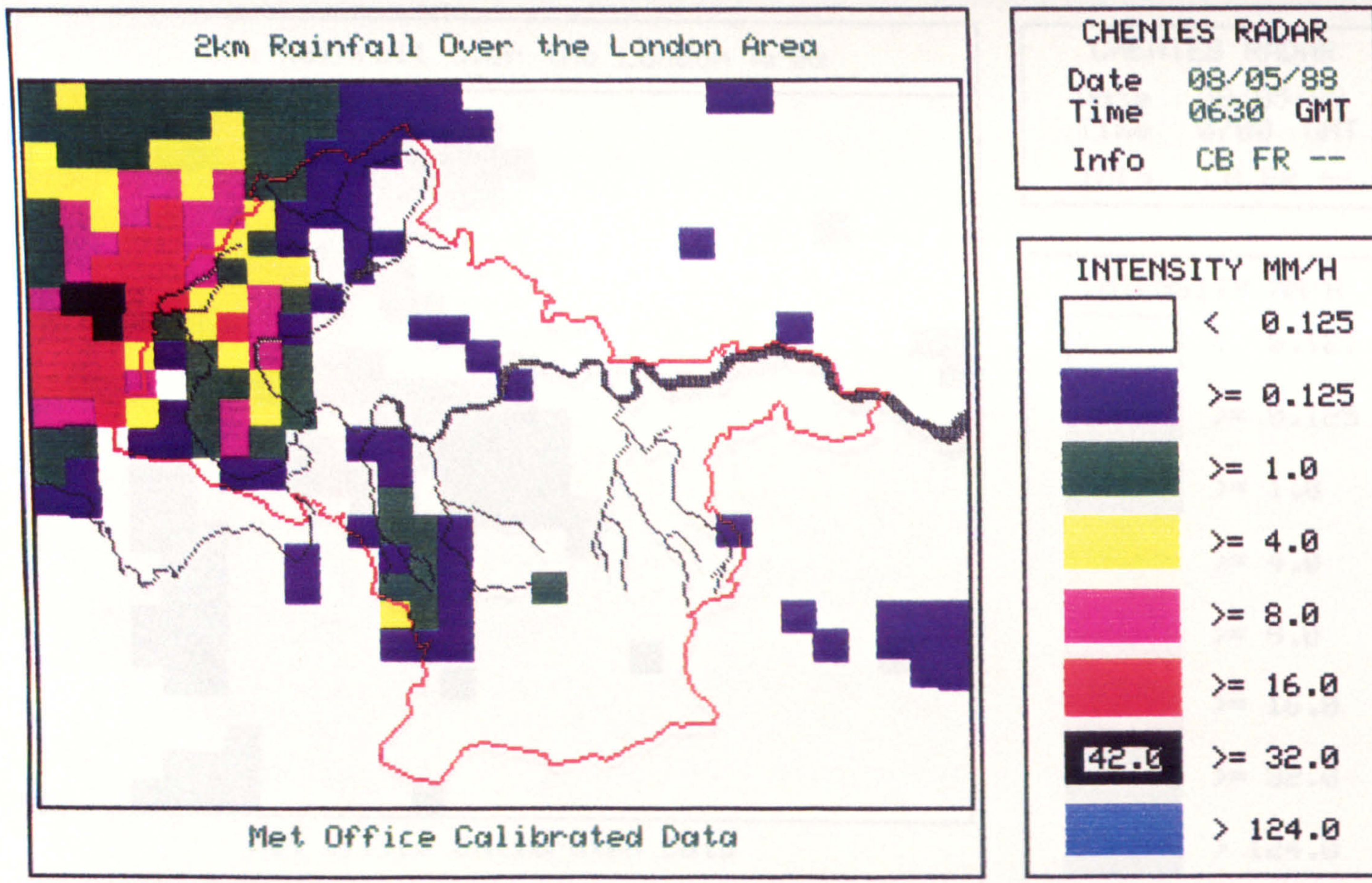
App 10. Fig 23. Rain radar sequence.



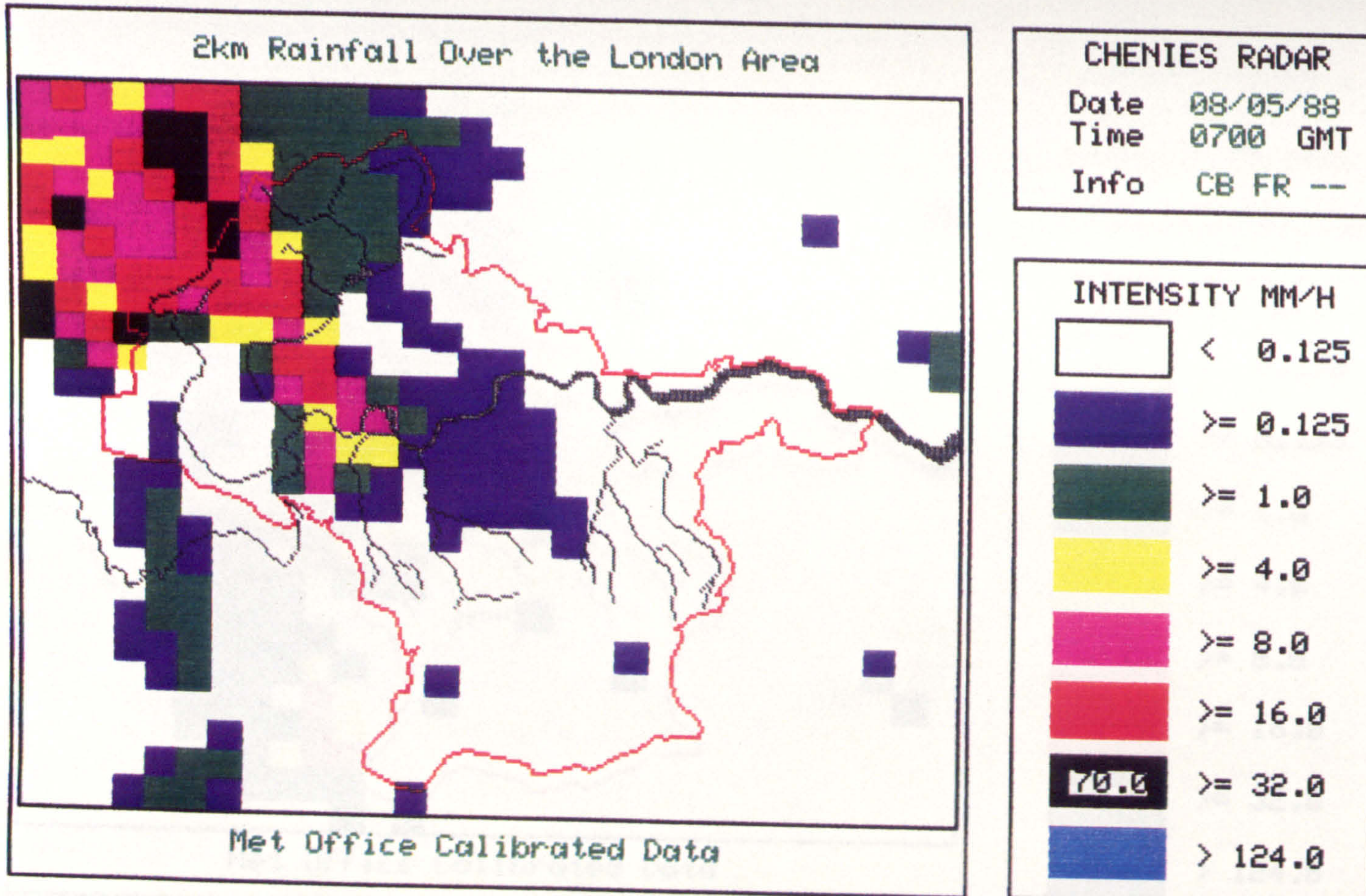
App 10. Fig 24. Rain radar sequence.



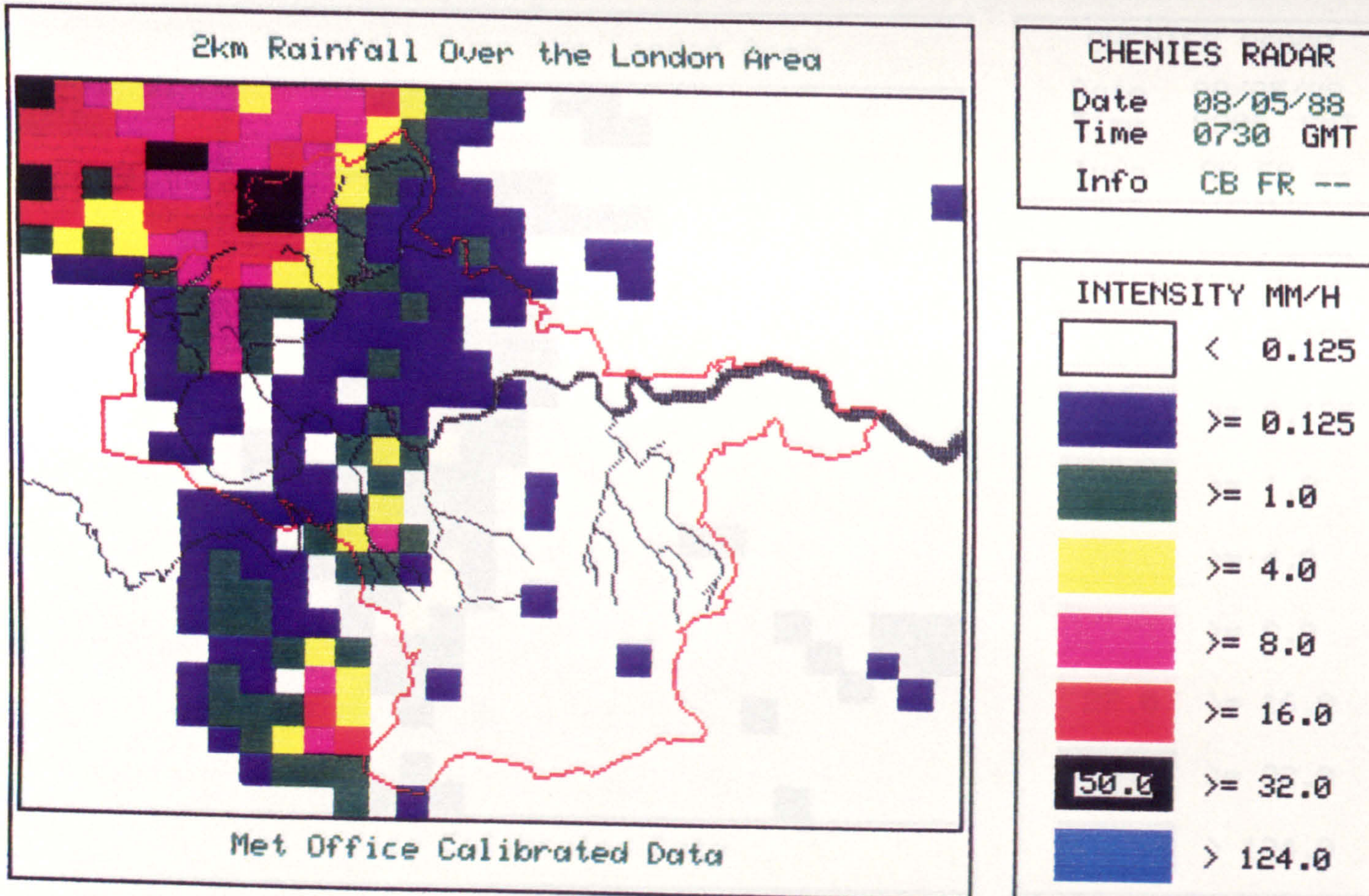
App 10. Fig 25. Rain radar sequence.



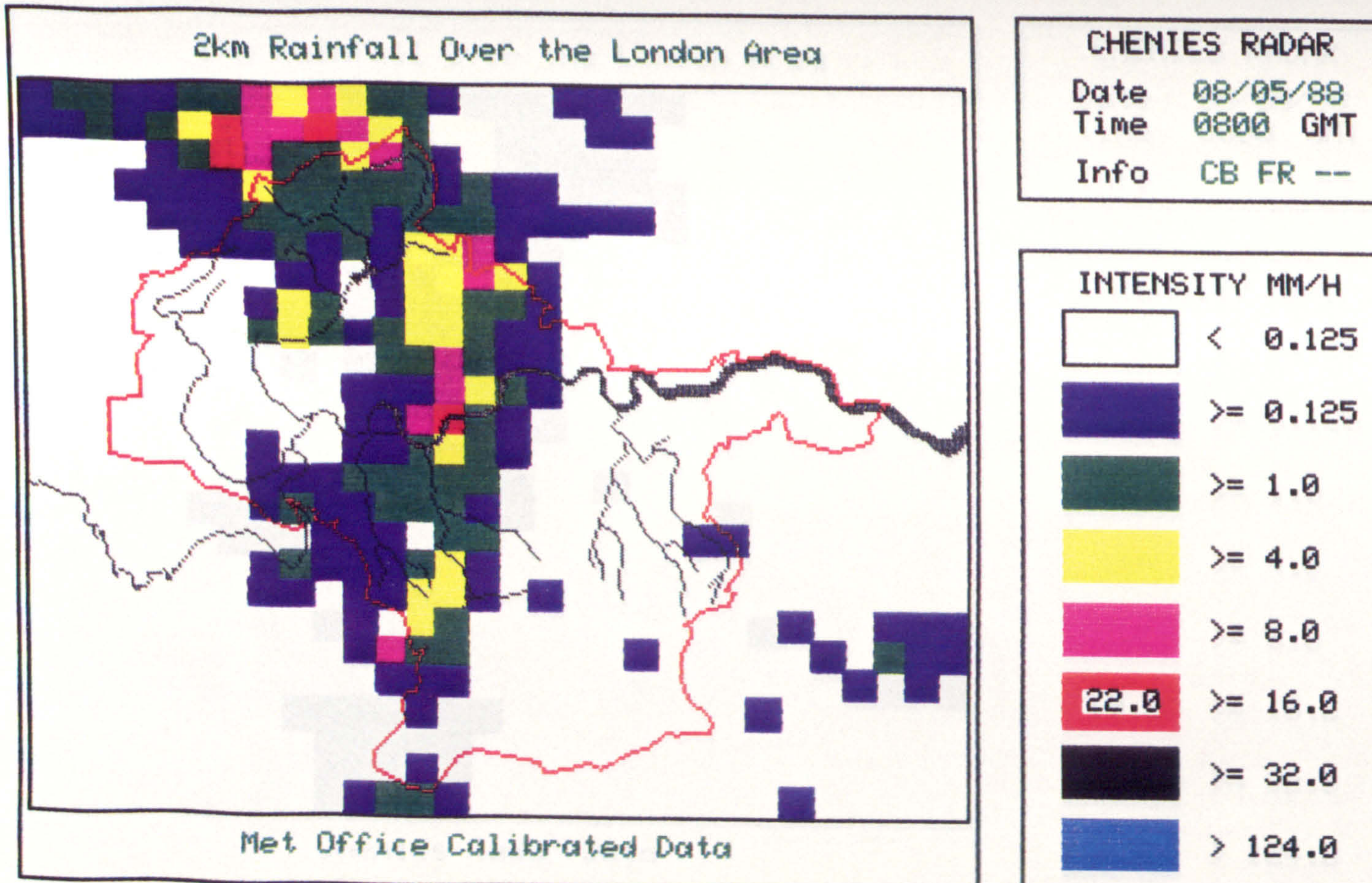
App 10. Fig 26. Rain radar sequence.



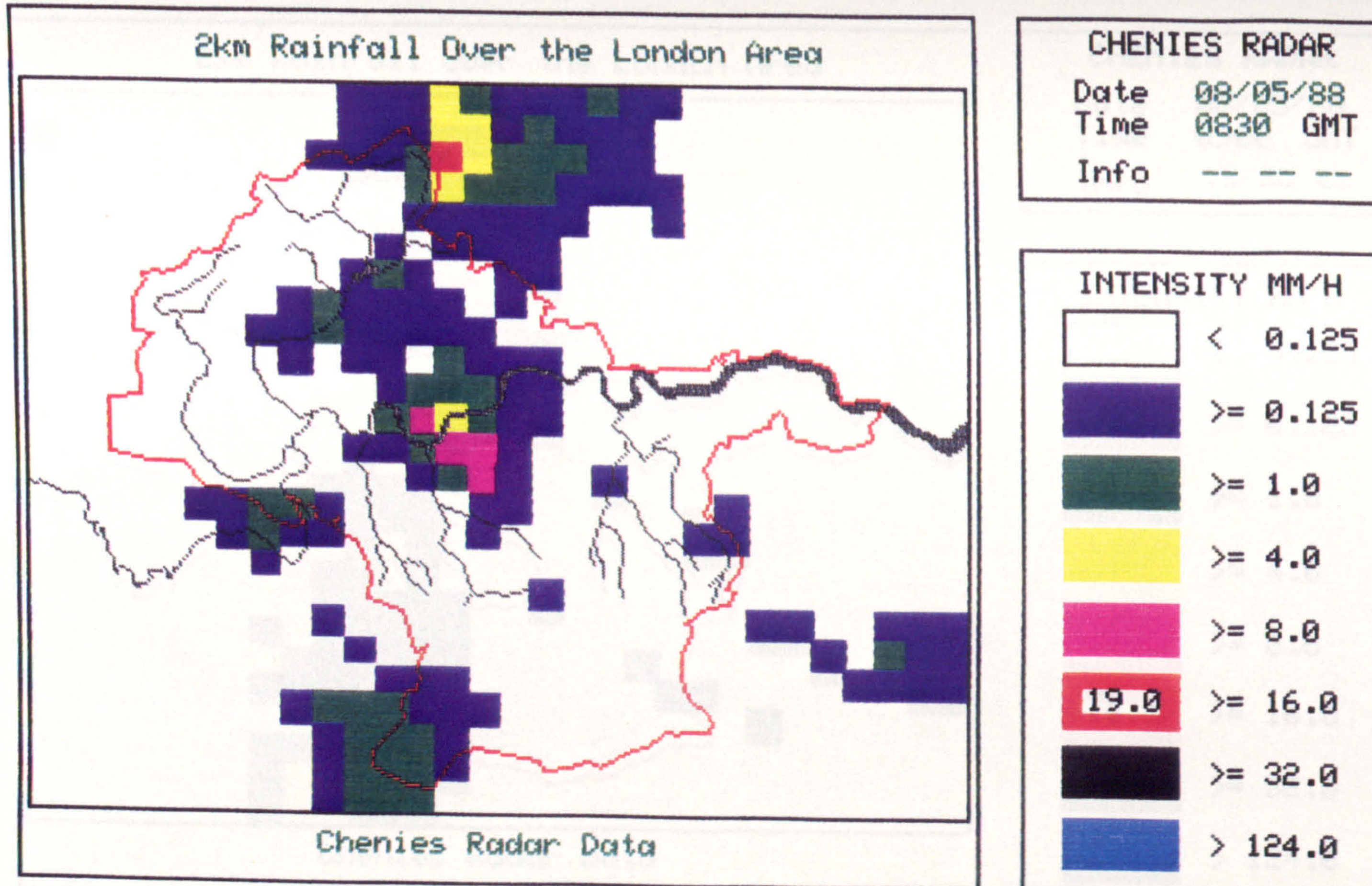
App 10. Fig 27. Rain radar sequence.



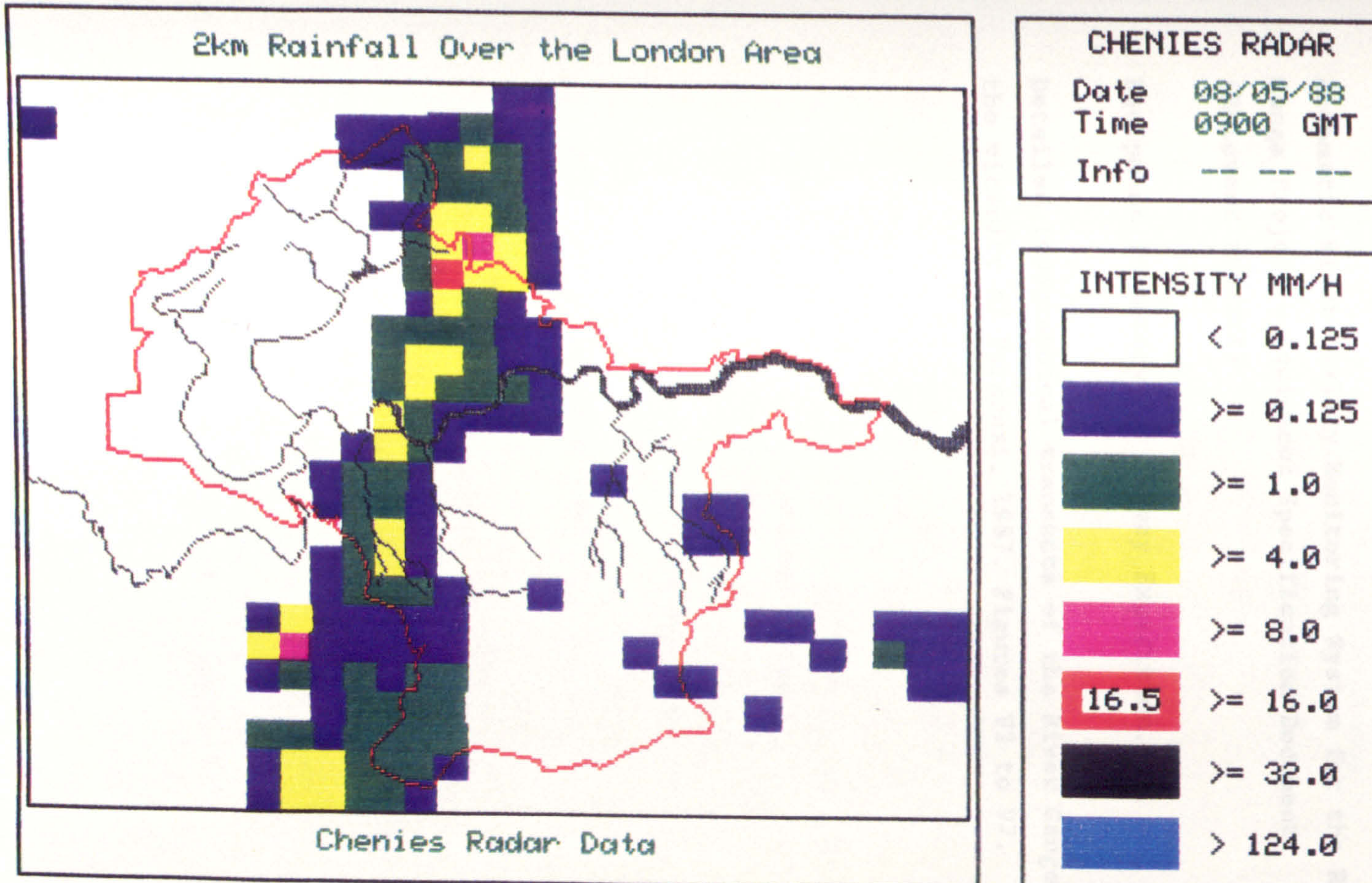
App 10. Fig 28. Rain radar sequence.



App 10. Fig 29. Rain radar sequence.



App 10. Fig 30. Rain radar sequence.



App 10. Fig 31. Rain radar sequence.

APPENDIX 12

Automatic River Quality Monitoring System for the River Ganga Project - Equipment Specification Document (Relevent extract).

Equipment Inventory for Survey Expedition.

Detailed topographical transects of the River Ganges in the vicinity of Varanasi, 1987. Figures V2 to V7.

Draft Equipment Specification Document

Contents

PAGES MISSING

SECTION 1. GENERAL

SECTION 2

Detailed Specification

1 Parameter

The parameters measured will be as follows:-

Parameter	Range	Sensitivity
Dissolved Oxygen	0 - 20 mg/l	- 0.1 mg/l
Temperature	$0^{o}C - 40^{o}C$	- $0.1^{o}C$
pH	4 - 10	- 0.1 pH unit
Conductivity*	0 - 1000 micro siemens	- 10 micro siemens
Turbidity**	0 - 500 FTU 0 - 2000 FTU	- 10 FTU - 20 FTU

Three spare channels should be included to allow addition of further sensors at a later date. (Velocity, depth and ammonium are proposed).

* NB. Some units may be specified for estuarine use and will require measurement in the range 0 - 3000 micro siemens. Dual range capability may be advantageous in this case.

** Dual range facility may be advantageous.

2 Power

2.1 No mains power supply will be available.

2.2 Battery power will therefore be required with sufficient storage to allow operation of equipment for a minimum of one month (see sampling interval 5.3).

2.3 Solar Power options would be considered. Battery back up supply for one week would be required.

2.4 Input points for mains power should be provided.

2.5 Input sockets for alternative 12v/24v power sources should be made available to allow solar cells or additional battery power to increase site longevity.

2.6 As an exchange battery system is envisaged batteries should be easily removable during servicing.

2.7 Batteries should be adequately secured within housing.

2.8 Batteries should be rechargeable and designed for ease of manhandling in and out of small boats and vehicles. Thus weight, robustness, provision of carrying handles and, if lead acid type, preferably sealed to avoid spillage of acid.

2.9 Adequate recharging facilities and instructions must be made available at each operational base.

2.10 A battery life meter, or other means of estimating battery life, should be included.

3 Housing

3.1 It is envisaged that all equipment will be modular in construction and each unit environmentally housed. However an outer protective housing to be mounted on the floating platform will be necessary.

3.2 Housing should be lockable, as vandal proof as practicably possible and should provide protection against environmental hazards eg heavy rain, spray and sunshine.

3.3 Absorption of solar radiation, combined with high ambient temperature ($>45^{\circ}C$) must be considered. Excessive temperatures could occur within such a housing and options such as ventilation, and insulation may be necessary.

3.4 Housing should have doors which give easy access to equipment for routine service and repairs. Doors should be permanently attached to the housing to prevent loss into the river during servicing.

3.5 Design should prevent water from pooling in the bottom of housing and possibly flooding equipment.

3.6 Housing should be of a neutral colour which will blend into the surroundings. It should be resilient to tropical sunlight and temperatures.

3.7 Birds roosting on the structure may be a problem and some thought should be given to this.

3.8 It should be designed so that it can be removed from the floating pontoon with the monitoring equipment inside.

3.9 Excessive weight and size should be avoided in view of limited availability of large boats and vehicles.

4 Mounting of Sensors

4.1 Sensors will be placed directly into the river.

4.2 Sensors should be mounted on a robust "lance" assembly to allow a sampling depth of 0.5 - 1 metre below the surface.

4.3 Sensors should be protected from damage by impacts from floating debris.

4.4 Sensors should be easily removed for servicing and cleaning.

4.5 Biological fouling may be a problem and some anti-fouling provision would be advantageous. Design should minimise clogging with filamentous weed and reduce colonisation by crustaceans and leeches.

4.6 Design to allow probe assembly to swing up and back down if in collision with a submerged object may be advantageous.

5 Sampling Interval

5.1 Sampling interval will be eventually decided upon after experience of running the stations and will be dependent upon the variability of the river.

5.2 A range of sampling intervals should be provided but must include intervals of:

24 per day
12 per day
6 per day
4 per day
1 per day

5.3 This may be accommodated by switching the equipment off and on using a timeclock at the above intervals, thus saving power, or by running equipment continuously and programming the data logger to these intervals

6 Routine Servicing

6.1 Service interval will eventually be decided upon after experience of running the stations, however the minimum service interval must be two weeks.

6.2 It is likely that biological fouling, sensor stablility and battery life will be the most limiting factors.

6.3 It is envisaged that a routine service schedule will be developed requiring a boat party to visit the site, at each service interval and perform the following functions:

1. Check moorings and platform
2. Clean sensors) a complete exchange system with
3. Calibrate sensors) laboratory calibration may be
4. Change logger) advantageous.
5. Change battery
6. Exchange any broken equipment

Bidders must advise on the details of routine servicing.

6.4 All routine servicing will take place from a small boat. Most boats are of local design and none exceed 6 metres in length. All service operations must be accomplished from this sort of craft.

7 Sensor Instrumentation

7.1 Should be modular in construction and housed to I.P. 65 standards

7.2 Should be easily removable for service or repair. An exchange system of maintenance is envisaged.

7.3 Facility to directly read sensors via a digital display should be provided.

7.4 Calibration controls should be easily accessible.

7.5 Instrumentation should be sufficiently rugged since Indian roads and vehicles would destroy most western instrumentation.

7.6 High operational temperatures must be accommodated.

7.7 Voltage or current outputs compatible with the data loggers must be provided.

7.8 Provision of protective carrying cases for sensitive instrumentation should be considered.

8 Data Logging

8.1 Solid state data loggers should be used to collect information.

8.2 Initially it is proposed to download data loggers into an IBM AT microcomputer at the Central Ganga Authority in Delhi. A system of exchangeable data loggers will be most compatible with this proposed method of operation.

8.3 Data loggers must have sufficient capacity to store the minimum of one month's data from all channels assuming a record rate of one hour.

8.4 Data loggers should be easily removed during exchange and should be sufficiently robust, preferably to I.P. 65 specification.

8.5 Data loggers should be capable of maintaining memory for a minimum of three months and a battery life indicator is essential

8.6 The ability to trickle charge logger batteries from the main power supply would be advantageous.

8.7 Data loggers must have an RS 232 output socket.

9 Data Downloading

9.1 Any cables or adaptors necessary to download data into an RS 232 interface on the IBM AT must be supplied.

9.2 A data downloading programme to produce a data file compatible with IBM "Lotus" or "Symphony" software must be provided with appropriate documentation.

10 Data Transmission

Data transmission systems should be made available. Satellite data transmission systems are probably most suitable for this application.

11 Interconnection Sockets and Cables

All sockets and cables must be waterproof, lockable and robust.

12 Floating Platform - Design Only

12.1 Great variations in river level, lack of fixed structures, unmade banks and effluent streaming exclude fixed sites. A floating platform anchored to the riverbed will overcome the above problems and give the maximum flexibility in site positioning. In some instances fixed structures such as bridges, may be used for anchorage. A one off design should suit all sites.

12.2 Platform should be sufficently robust for the conditions of this large river.

12.3 Platform must take into account the housing, sensor mounting, and servicing requirements specified earlier.

12.4 Specialist advice from marine experts should be sought regarding the anchorage of the platform.

12.5 Availability and size of craft to position and anchor the platform must be taken into account.

12.6 Provision for anti-fouling should be made.

12.7 The need for navigation lights must be established. The Central Ganga Authority have been asked to investigate.

12.8 Design of platform should allow the system to be operational during the monsoon. If this is not possible provision to remove equipment during the monsoon should be made. It should be noted that it is important to operate the equipment during the "first flush" of the monsoon.

EQUIPMENT INVENTORY

TECHNICAL CO-OPERATION PROGRAMME
BETWEEN GOVERNMENTS OF INDIA AND THE UK
CORPORATE ADVISORY SERVICES FOR CENTRAL GANGA AUTHORITY
IN RELATION TO GANGA POLLUTION CONTROL PLAN
PROVIDED BY THE THAMES WATER AUTHORITY

SCHEDULE OF EQUIPMENT TO BE USED ON DETAILED RIVER SURVEYS
ITEMS TO BE PRESENTED AS GIFT TO GANGA PROJECT DIRECTORATE

RIVER MONITORING EQUIPMENT

ITEM	DESCRIPTION	NO. OFF	VALUE	SERIAL NO
1.1	pHox Multiparameter Water Monitor	1	2500	1240486
1.2	pHox Multiparameter Water Monitor	1	2500	910486
1.3	pHox Recording Dissolved Oxygen Meter Type 67	1	1500	480486
1.4	Spares for above	1	500	N/A
	TOTAL VALUE		£7000	

TECHNICAL CO-OPERATION PROGRAMME
BETWEEN GOVERNMENTS OF INDIA AND THE UK
CORPORATE ADVISORY SERVICES FOR CENTRAL GANGA AUTHORITY
IN RELATION TO GANGA POLLUTION CONTROL PLAN
PROVIDED BY THE THAMES WATER AUTHORITY

SCHEDULE OF EQUIPMENT TO BE USED ON DETAILED RIVER SURVEYS
ITEMS OF PROFESSIONAL TOOLS AND EQUIPMENT TO BE TEMPORARILY IMPORTED
AND RE-EXPORTED FOLLOWING COMPLETION OF SURVEY WORK (MAX 12 WEEKS)

RIVER MONITORING EQUIPMENT

ITEM	DESCRIPTION	NO. OFF	VALUE	SERIAL NO
2.1	LTH Magpie Dissolved Oxygen Meter	1	1200	77825
2.2	LTH Magpie Dissolved Oxygen Meter	1	1200	77826
2.3	Avometer 2001	1	200	FD 0053033
2.4	Labcol Water Sampler Collins Labs (Casella)	1	70	N/A
2.5	Knudsons Water Sampler	1	50	N 10 4839
2.6	Tool Kit	1	200	N/A
2.7	Calibration Standards	1	50	N/A
2.8	Battery Chargers pHox Type 12 Sonneschein	1	100	N/A
2.9	Chartpaper (Rustrak)	1	17	N/A
2.10	PAQUALAB Water Testing Kit	1	1700	N/A
2.11	Microscope	1	250	N/A
2.12	Pressure Cooker	1	30	N/A
2.13	Miscellaneous Items	1	100	N/A
2.14	Algal Sampling Bottles	1	20	N/A
2.15	Rope	1	13	N/A
2.16	Stationery	1	20	N/A
	TOTAL		£5220	

TECHNICAL CO-OPERATION PROGRAMME
BETWEEN GOVERNMENTS OF INDIA AND THE UK
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PROVIDED BY THE THAMES WATER AUTHORITY

SCHEDULE OF EQUIPMENT TO BE USED ON DETAILED RIVER SURVEYS
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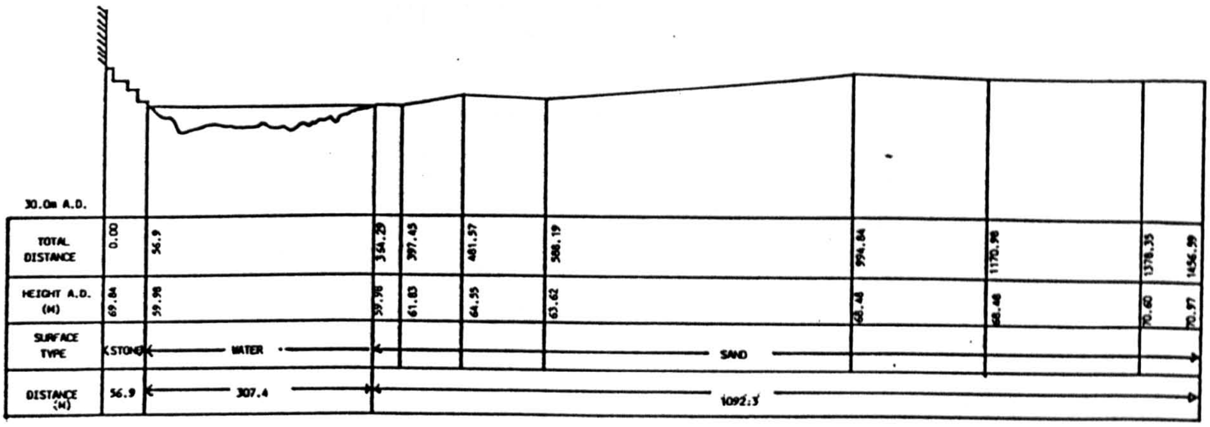
AND RE-EXPORTED FOLLOWING COMPLETION OF SURVEY WORK (MAX 12 WEEKS)

RIVER SURVEYING EQUIPMENT

ITEM	DESCRIPTION	NO. OFF	VALUE	SERIAL NO
3.1	Raytheon DE-719B Survey Acho Sounder	1	2200	R:1875
3.2	Spare Parts for above item 3.1	1	100	
3.3	Recording Paper for above item 3.1	1	100	
	Wild Heerbrugg Surveying Instruments			
3.4	T16 - Theodolite	1		298208
3.5	NA20 Automatic Level	1		559670
3.6	D15 Distomat	1		51100
3.7	GGD4 Counterwieght T1/T1	1		N/A
3.8	Keyboard for D15	1		N/A
3.9	GEB70 Battery	4		N/A
3.10	GKL Charger	2		N/A
3.11	Battery Cable Pole	1		N/A
3.12	GPR1 - Round Prism in case	3		N/A
3.13	GPH1A Tilt Prism Holder	2		N/A
3.14	GPH3 Three Prism Holder	1		N/A
3.15	Container	1		N/A
3.16	GZT1 - Target Plate	2		N/A
3.17	GZT2 - Large Target Place	2		N/A
3.18	Target Lamp - GEB72	3		N/A
3.19	Spare Halogen Bulb - GEB7	3		N/A
3.20	Battery Cable for GEB70 & GEB71 Battery	3		N/A
3.21	Wilmark G2 Tripods	7		N/A
3.22	GSL4E 4M Staff	1		N/A
3.23	GDF21 Tribrach T1/16 RD	2		N/A
3.24	GRT10 Carriers	2		N/A
	Items 3.4 - 3.24		17500	N/A
3.25	MKIICGT Zodiac Inflatable Boat (Not Automatic)	1	1300	N/A
3.26	15 HP Evinrude Outboard Motor	1	900	R1471914
3.27	Sunhood for Item 3.25	1	200	N/A
3.28	Spares for Item 3.26	1	200	N/A
3.29	Miscellaneous Items		3500	N/A
	TOTAL		£26000	

TRANSIT NO. V3.
ASI GHAT FLOOD PLAIN, VARANASI, R. GANGA
LOOKING DOWNSTREAM

APRIL 1987
D.E.B. JONES

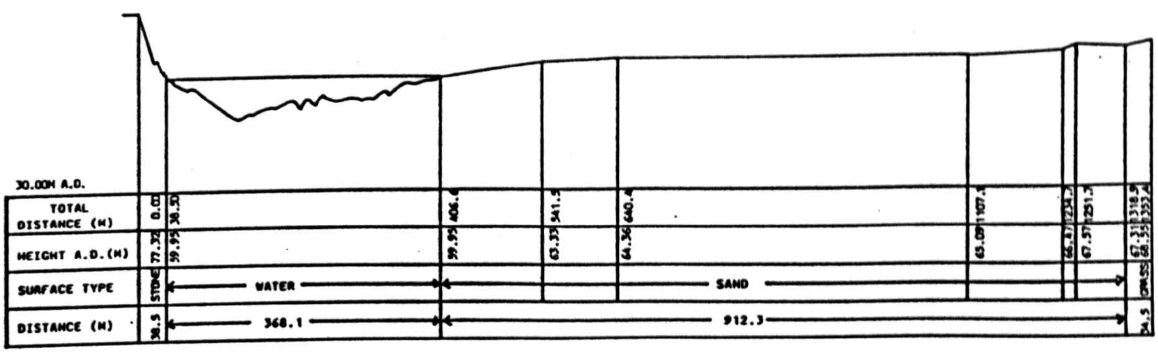


SCALES: V. 1:1000
H. 1:5000

Fig. V2

TRANSECT NO. V4.
LALI GHAT STAIRS, VARANASI, R.GANGA
LOOKING DOWNSTREAM

APRIL 1987
D.E.B. JONES
J. KANYOTRA



SCALES: V. 1:1000
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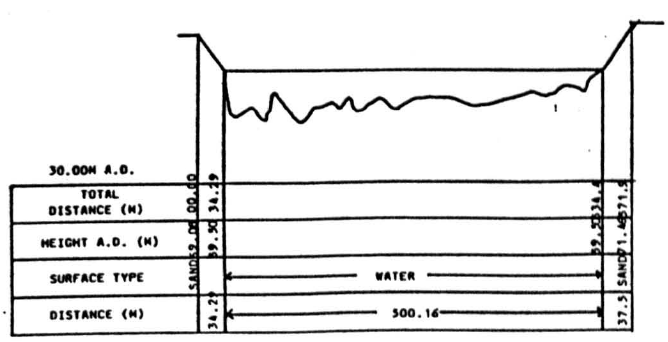
Fig. V3

TRANSECT NO. V9.
50m D/S OF MALVIYA BRIDGE, VARANASI, R. GANGA
LOOKING DOWNSTREAM

APRIL 1987
D.E.B. JONES
J. KANYOTRA



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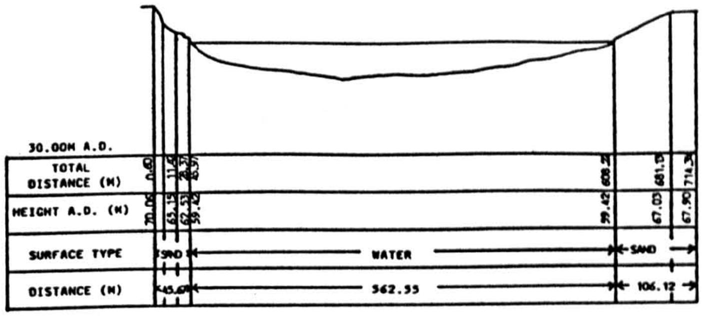
H. 1:5000

Fig. V4

TRANSECT NO. V10.
D/S OF MAIN SEWAGE O/F, VARANASI, R.GANGA
LOOKING DOWNSTREAM

APRIL 1987
D.E.B. JONES
J. KANYOTRA

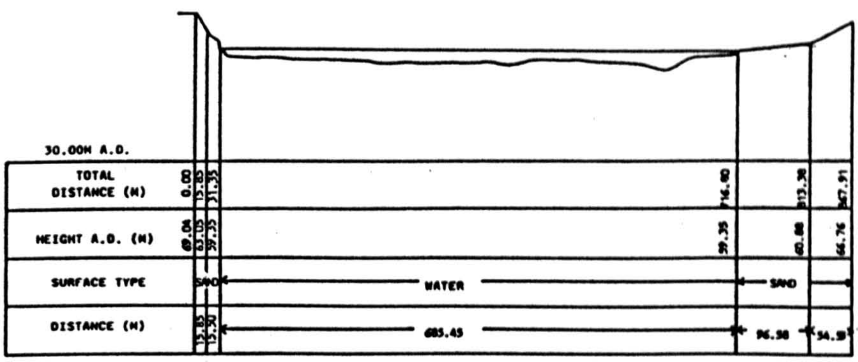


SCALES: V. 1:1000
H. 1:5000

Fig. V5

TRANSECT NO. V11.
D/S OF VARUNA RIVER CONFLUENCE, VARANASI, R. GANGA
LOOKING DOWNSTREAM

APRIL 1987
D.E.B. JONES
J. KANYOTRA

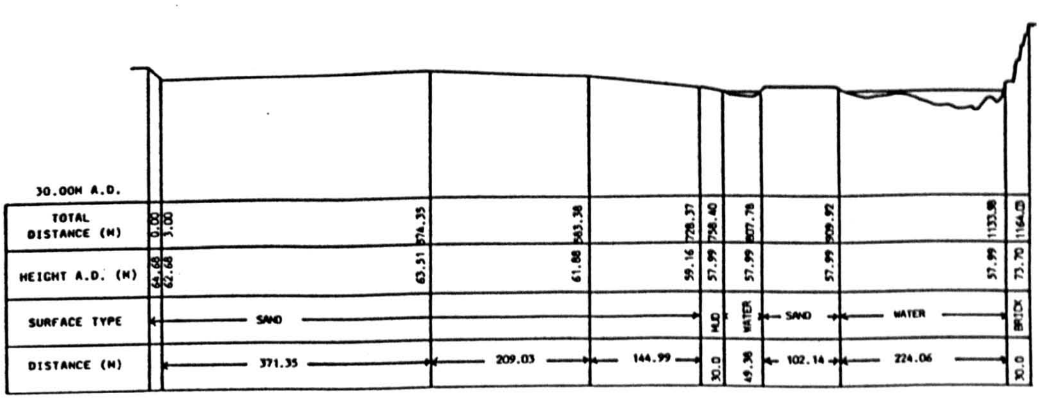


SCALES: V. 1:1000
H. 1:5000

Fig. V6

TRANSECT NO. V14.
BHOPAULI IRRIGATION INTAKE, R. GANGA
LOOKING DOWNSTREAM

APRIL 1987
D.E.B. JONES
J. KANYOTRA



SCALES: V. 1:1000
H. 1:5000

Fig. V7

APPENDIX 13

Griffiths, 1987. Automatic Water Quality Monitoring in the River Thames Catchment.

Wishart, Lumbers and Griffiths, 1990. Expert Systems for the Interpretation of River Quality Data.

AUTOMATIC WATER QUALITY MONITORING IN THE RIVER THAMES CATCHMENT — PRACTICAL ASPECTS OF SYSTEMS DESIGN AND UTILISATION

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ABSTRACT

The Thames Water Authority has developed a network of automatic river water quality monitoring stations controlled by a regional telemetry system. The operation of the stations is discussed, and the approaches taken to overcome the problems of freshwater monitoring are highlighted. Intermittent but regular sampling and remote fault monitoring are features of the freshwater system. Satellite data transmission is utilised by mobile stations. Data presentation methods are described including graphical formats for management, archive and real time usage. The role of automatic monitors in the management of river quality is considered and examples are given from within the River Thames catchment. The system is cited as a multidisciplinary approach to water quality management and future developments of the system are discussed.

KEYWORDS

River Thames, River Quality, Automatic monitoring, Telemetry, Satellite, Data Presentation, Freshwater, Tidal.

INTRODUCTION

The Thames Water Authority is one of the ten Regional Water Authorities in England and Wales responsible for river basin management. It controls the entire water cycle within the River Thames catchment, supplying water and treating sewage for 11.5 million people. Pollution control is an important part of this function, not only to benefit the environment but also to preserve the water resources of this heavily populated area.

An extensive river quality sampling programme is undertaken to monitor the quality of the rivers, to satisfy statutory requirements and provide information for planning purposes. Manual sampling and laboratory analysis form the basis of this programme but automatic water quality monitors are becoming increasingly important. The manual and automatic sampling efforts are seen as complementary. The automatic system has the advantage of offering 24 hour real time monitoring of the rivers, thus broadening the sampling window, allowing alarm systems to operate and enabling positive remedial action to be taken if water quality problems are detected. Its principal disadvantage is the limited number of determinands which can be monitored reliably.

The Authority operates a network of twelve freshwater, six tidal and two mobile monitoring stations. Figure 1 shows the Thames river network and the position of the monitoring stations.

TELEMETRY SYSTEM

Thames Water has an extensive Regional Telemetry System which was installed ten years ago, principally to control a groundwater water resource management scheme. Originally the system comprised 35 outstations but now has been expanded to 99. These 99 outstations consist of the following: 14 linksites, 21 rain gauges and 28 river gauges, 12 freshwater quality and 6 tidal water quality monitors plus 14 borehole and 4 outfall monitors.

The system is based upon a VHF radio network linked to a dual Ferranti Argus computer. In addition, microwave links are used to carry internal telephone and mobile radio circuits as well as telemetry data. Access to data is via remote terminals, direct microcomputer links or telephone modems. Historic data are stored on an ICL mainframe via magnetic tape transfer operation.

The Argus system is also used to collect weather radar information from a joint project between Thames Water and the Metereological Office. These data are used to monitor storm events (which are important in flood control) and to complement rain gauge information.

A satellite data transmission system is utilised by the two mobile water quality monitors and two remote rain gauges. The system utilises geostationary satellites, presently GOES 4 and Meteosat 2. The satellites relay information to a rooftop receiver dish (via a groundstation at Darmstadt, West Germany). Data are transmitted twice daily at precisely allocated timeslots of 0400 hours and 1600 hours to provide information at the start and finish of the working day. Alarm messages triggered by preset threshold levels will override this timeslot to provide warning of possible pollution problems, The satellite data are not currently processed by the Argus system.

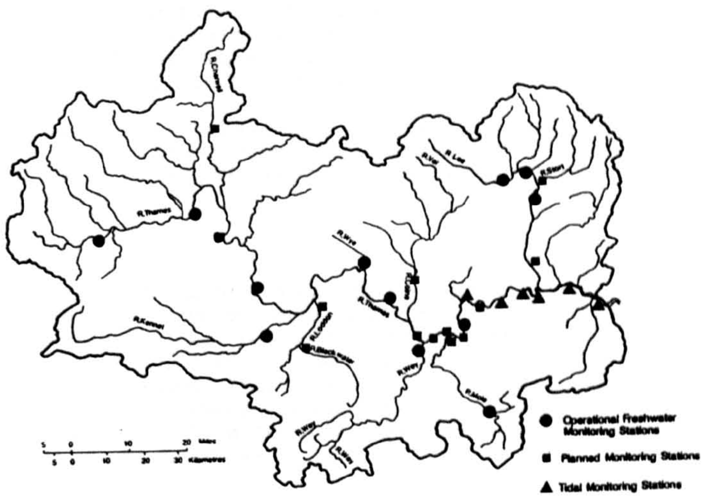

Figure 1. River Thames catchment showing position of automatic river quality monitoring stations.

AUTOMATIC WATER QUALITY OUTSTATIONS

The geographical nature of the catchment means that outstations are very remote from the operational headquarters at Reading. Therefore reliability, long service intervals and the ability to detect faults remotely are essential features for the cost effective maintenance of the stations.

Freshwater Monitoring Stations

The freshwater automatic water quality monitoring stations measure dissolved oxygen, temperature, conductivity, suspended solids, pH, ammonia and nitrate. Water is pumped from the river into flow cells containing the sensors. The design of the pumping system and flowcells is fundamental to the reliability of the system.

Telemetry control allows the monitoring equipment to be operated in an intermittent mode. The sample pump and monitoring equipment is triggered once per hour and readings taken when stable. This mode of operation reduces pump wear, reagent consumption and biological fouling. Calibration and cleaning sequences are triggered once per day.

In total, sixteen parameters are measured and transmitted at hourly intervals from the water quality outstations; seven are water quality measurements (as listed previously) and nine are river housekeeping measurements. The transmission of housekeeping information makes it possible to detect faults remotely and increases confidence in the results. False alarms are reduced by remote interrogation of the stations to check results and instrumentation operation before a pollution alert is called.

Comprehensive housekeeping information is particularly important for the ammonia and nitrate monitors. Ammonia and nitrate are measured by specially modified specific ion monitors. All calibration and sequencing is triggered by the telemetry system. The houskeeping information includes monitoring 'electrode offset potentials' which are an indication of electrode stability and allows the longevity of the electrode to be estimated. The results of the daily calibration against the standard solutions provide a further point of reference. Water bath temperatures, the stability of which are essential for reliable specific ion estimations, are also telemetered.

Dissolved oxygen, temperature, pH, conductivity and suspended solids are measured by a microprocessor controlled monitor built to 'in house' specifications. The monitor incorporates the telemetry control equipment, analogue to digital converters and the VHF radio. It also provides sufficient input channels to act as the telemetry outstation for flow gauging equipment which is often housed in the same hut.

Measurement sequences can be initiated manually and displayed locally on digital displays which allows pollution officers direct access to information when necessary. Servicing visits are generally carried out at fortnightly intervals when reagents are replenished and vigorous calibration checks are made.

Tidal Sites

The requirements of the tidal Thames have necessitated a radically different approach to that seen in the freshwater stations. The essential water quality parameters for the management of the tidal Thames are dissolved oxygen, temperature and electrical conductivity (used as an indication of salinity) (Griffiths 1985). These are measured by immersing probes directly in the river. The sensors are suspended from floating piers on steel lances which can be raised for maintenance. The equipment produces a signal which is pre-amplified under water to produce a strong signal output which is directly compatible with the telemetry equipment. Readings are taken at 15 minute intervals.

Mobile Monitors

The monitoring equipment in the mobile stations is similar in format to that in the freshwater sites. The telemetry differs in having a satellite system which allows only five analogues to be telemetered. Intermittent operation and sequencing is controlled by an internal clock linked to the accurate satellite data equipment. The mobile monitors are used for special investigations such as sewage treatment works commissioning or ongoing pollution investigations. The five parameters that are telemetered are chosen according to the nature of the investigation.

DATA HANDLING

Clearly the automatic water quality monitoring system operated by Thames Water Authority produces a considerable volume of data. It is essential that clear objectives are defined and that efficient data presentation and reduction techniques are utilised. Figure 2 summarises the principal data pathways utilised by the Thames system.

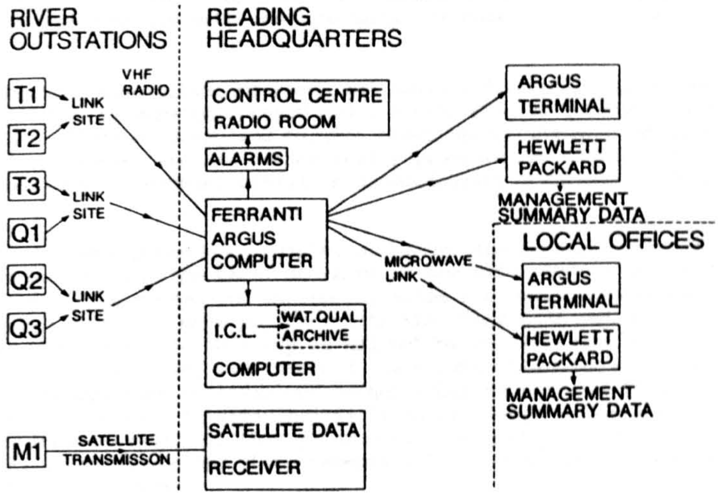

Figure 2. Data flow diagrams.

Data usage can be split into three main categories.

Real time usage. Use of unprocessed data for alarm enunciation, management of pollution incidents and resource management. Real time data are collected by the Ferranti Argus computer and converted into engineering units. Alarm thresholds are set for important parameters and the control room notifies the relevant pollution control personnel. Remote access to these data is available via telephone modem or microwave linked terminals.

Management Summary Information. Data are produced in graphical format for management use and take the form of daily or weekly summaries dependent upon environmental and management needs. These summaries can be updated with real time information if required.

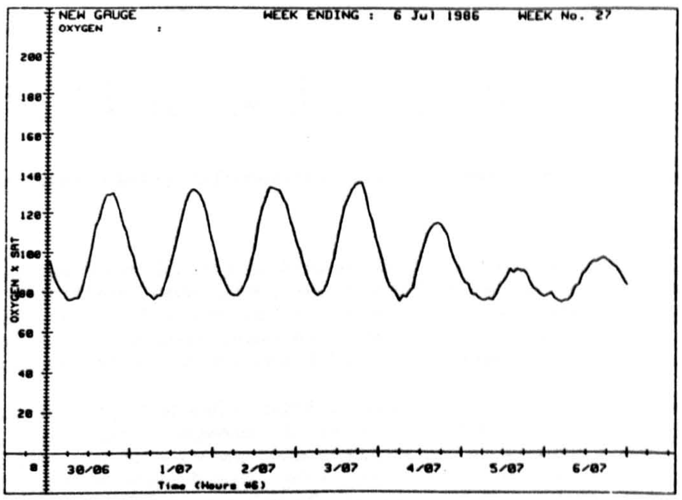

Figure 3. Example of management summary information. Freshwater site.

The management summaries are produced by automatically downloading data via a microcomputer interface onto a Hewlett Packard 9836. Some automatic verification and error checking is incorporated into the program. Set formats for data presentation have been developed so that information can be compared easily with previous data and trends can be visually and rapidly identified.

Freshwater and tidal management have differing needs and require different approaches. The presentation of freshwater data is straightforward and a weekly plot of parameter against time is produced (see figure 3). Plots of dissolved oxygen, temperature, ammonia and nitrate are sufficient for most routine purposes and are automatically produced and distributed on a weekly basis. Telefax machines are proving useful in disseminating graphical information to remote offices.

The management of the tidal Thames poses more complex problems, and sophisticated data processing is required to correct for the tidal movement of the water body. This tidal movement has been exploited by the system and monitoring sites are positioned so that water monitored at one site at low tide will move up river with the flood tide and be monitored again at the next site at high tide. In this way 60 kilometres of river can be monitored by six sites. A composite oxygen sag curve, see figure 4, is constructed four times per day on each ebb and flood tide. Fluctuations in dissolved oxygen occur rapidly and this level of cover is necessary at times of storm. An experimental 'rate of change' alarm system for dissolved oxygen has been incorporated into this programme. Calculations that extrapolate salinity from conductivity measurements and that compensate for the effect of salinity on dissolved oxygen values are undertaken.

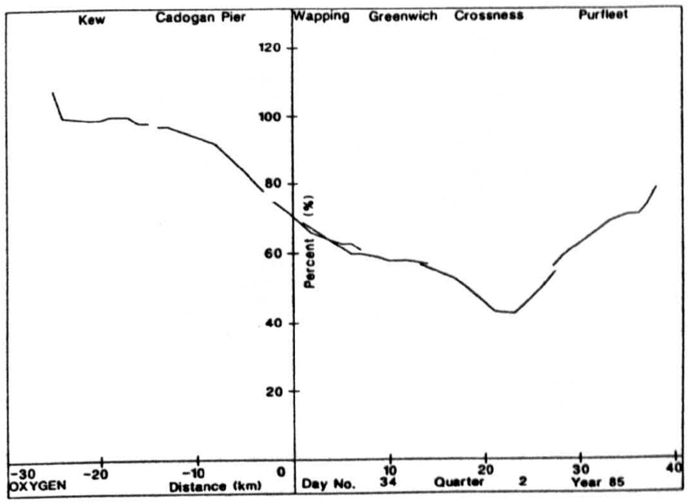

Figure 4. Example of Management summary information. Tidal Thames oxygen sag curve.

Archived Data

The Authority maintains a large Water Quality Archive on an ICL mainframe computer. This is used to satisfy statutory objectives, undertake planning studies and to test the compliance of rivers and sewage treatment works with river quality objectives. Most data are derived from manual sampling programmes which have been undertaken over the past fifteen years. It is proposed to incorporate automatically derived data into this database.

The frequency and volume of data and the wide sampling 'window' offer significant advantages in statistical and planning exercises. However, it is not feasible to archive all the data. It has been decided to utilise raw data rather than averages and to archive a complete 24 hour picture of hourly readings once in every 8 days, plus the midday value on the remaining days. The 24 hour picture will not be biased to one day of the week and the midday value acts as an indicator of variation in the intervening period and should be most compatible with any manual sampling. All data will be flagged as automatic to distinguish them from the manual data.

DISCUSSION

The Thames Water Authority monitoring system is now reaching its full potential and provides added protection to our watercourses and potable intakes. In addition, data are available for management and planning exercises in a readily usable format compared with earlier systems. Reliability has improved markedly and considerable less manpower is needed to service and run the outstations. The telemetry control and remote 'housekeeping' data have been significant in improving reliability and increasing confidence in the results.

The Ferranti Argus telemetry computer is very dated and its inflexible nature has necessitated the data pathways described. Communications between computers have been a major problem. Specifications are being drawn up to replace this computer and it is hoped that the increased flexibility and graphics capability of a modern telemetry computer will enable much of the above work to be undertaken on single machine. The principles of outstation design, station management and data presentation will be of great assistance in specifying this system.

The automatically derived data have great potential for mathematical modelling which has largely been unexploited by the British water industry. Whitehead (1980) has undertaken some work on the Great Ouse system and is currently undertaking preliminary work on the River Thames. River flow, rainfall and quality data are all collected by the same telemetry system and could be integrated into valuable predictive models which could run in real time, in the future.

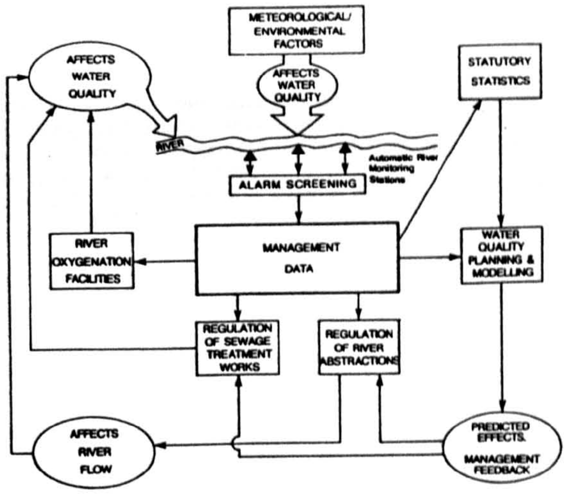

Figure 5. The role of automatic monitoring stations in river management.

Management data are most effective when positive action can be taken in response to water quality fluctuations and pollution events. Figure 5 summarises the role of automatic river quality monitoring in river management, enabling feedback control mechanisms to be applied to river quality.

The tidal Thames is one example of how the automatic system forms an important key to the feedback and control mechanism necessary to monitor and manage the estuary. Dissolved oxygen is the most critical ecological factor in the estuary. It is influenced by seasonal and environmental factors combined with discharges from three major sewage treatment works. Major metereological events and accidental pollution incidents can give rise to acute deoxygenation problems, especially in the upper tideway. Such problems are usually associated with storm sewage discharges and industrial accidents (fires, etc). In response to the more acute deoxygenation problems, the Thames Water Authority can mobilise an oxygen injection barge capable of injecting ten tonnes of oxygen per day into the river. The automatic monitoring system is important in the call out and deployment of the barge.

A water resource management project is presently being implemented in the lower reaches of the freshwater River Thames. Flow monitoring, potable abstraction and water quality monitoring data will be automatically collected in order to maximise water abstraction whilst minimising environmental impact. Automatic monitoring will form a fundamental part of this management scheme.

CONCLUSIONS

Automatic monitors can be a valuable tool in water quality management especially when positive action can be taken in response to water quality problems. Outstation design is crucial to the reliability of the monitors and adequate 'housekeeping' data increase confidence in the analytical data and reduce the number of false alarms. Appropriate data presentation is essential for management purposes and must be adapted to the characteristics of the river. Automatic data have considerable potential for predictive modelling. The processing power of modern computers and their graphics capability should allow the water quality monitoring exercise to be more easily achieved and thus accelerate its development.

ACKNOWLEDGEMENTS

Robin Hooper, Senior Technician must be credited for his development of the freshwater monitoring system, especially the intermittent sampling approach. I must also thank Dr M C Dart, Director of Regulation and Monitoring, Thames Water Authority for permission to present this paper. The views expressed in this paper are those of the author and do not necessarily represent the views of the Thames Water Authority.

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Expert Systems for the Interpretation of River Quality Data

By S. J. WISHART, MSc, MA, DIC, CEng, MICE *(Member)**, J. P. LUMBERS, PhD, MSc, DIC, BSc, MICE *(Member)***, and I. M. GRIFFITHS, MSc, DWM *(Member)****

ABSTRACT

Sample data on river quality are used for a variety of management purposes. The paper considers the role of expert systems in interpreting such data. An example is given of a prototype rule-based system designed to aid in assessing compliance with European Community (EC) Directives. It is suggested that, although this type of formal characterization is a necessary part of management, it provides poor information for decision making. The development of an expert system to provide a more accurate and informative interpretation of episodic pollution events is then described. The paper concludes by discussing the practical application of these approaches.

Key words: Expert systems; river quality management; data interpretation; compliance assessment.

INTRODUCTION

Water quality samples are collected and parameters are evaluated as part of the routine monitoring of surface waters or to investigate particular problems. Parameter values may also be predicted by mathematical models of river water quality used in the planning and design of new works, the setting of consent conditions and for operational management. Such data collection and modelling activities typically produce 'time-series' of a range of physical and chemical parameters.

The proposal to introduce statutory quality objectives in 1992 has generated considerable debate within the water industry on the methods used for compliance assessment and classification of surface waters. It is therefore topical to consider the methods used to interpret physicochemical data and the relation between classifications based on these data and more general assessments of fitness for use.

This paper considers the assistance that expert systems can provide in interpreting river quality data in the light of management objectives for surface waters. The aims and methods of data interpretation are first discussed. The use of expert systems to assist in interpretation is then illustrated in two examples:

(i) A simple rule-based system for inspecting the criteria given in EC water quality Directives, and for checking compliance with the Directives; and
(ii) A program for assessing the likely effect on fish of time-varying ammonia concentrations.

The merits and limitations of these applications of expert systems are discussed, together with the practical implications of the methods.

WHAT ARE THE DATA FOR?

River quality data are collected and analysed for a wide variety of purposes, and the management framework within which the data are obtained and used is shown schematically in Fig. 1. This takes the principal, long-term objective of river quality management to be the attainment and maintenance of the environmental quality objective (EQO) for the water. In order to express this objective in measurable terms, it is usual to set a river quality standard (RQS). The difference between objectives and standards is often unclear, and this paper makes the following distinctions between them:

(a) An environmental quality objective describes the intended use or uses for a river reach. Meeting this objective entails ensuring that the water is fit for the specified use or uses;
(b) A river quality standard is an attempt to capture, usually in terms of limiting values for selected physical and chemical parameters, the conditions which must exist for the EQO to be met.

The translation of an objective into a standard is normally achieved by applying criteria which set out the permissible values of water quality determinands for a particular use. Highly specific criteria are given in EC Directives such as those for the support of freshwater fisheries[1], water for abstraction for potable supply[2] and bathing waters[3]. The proposed UK standards for List II substances also relate limits to uses. Less specific but broadly use-related criteria are given in the National Water Council (NWC) classification scheme[4]. Some individual water authorities have introduced refinements of the NWC classification[5] or have prepared their own criteria to protect particular water uses[6].

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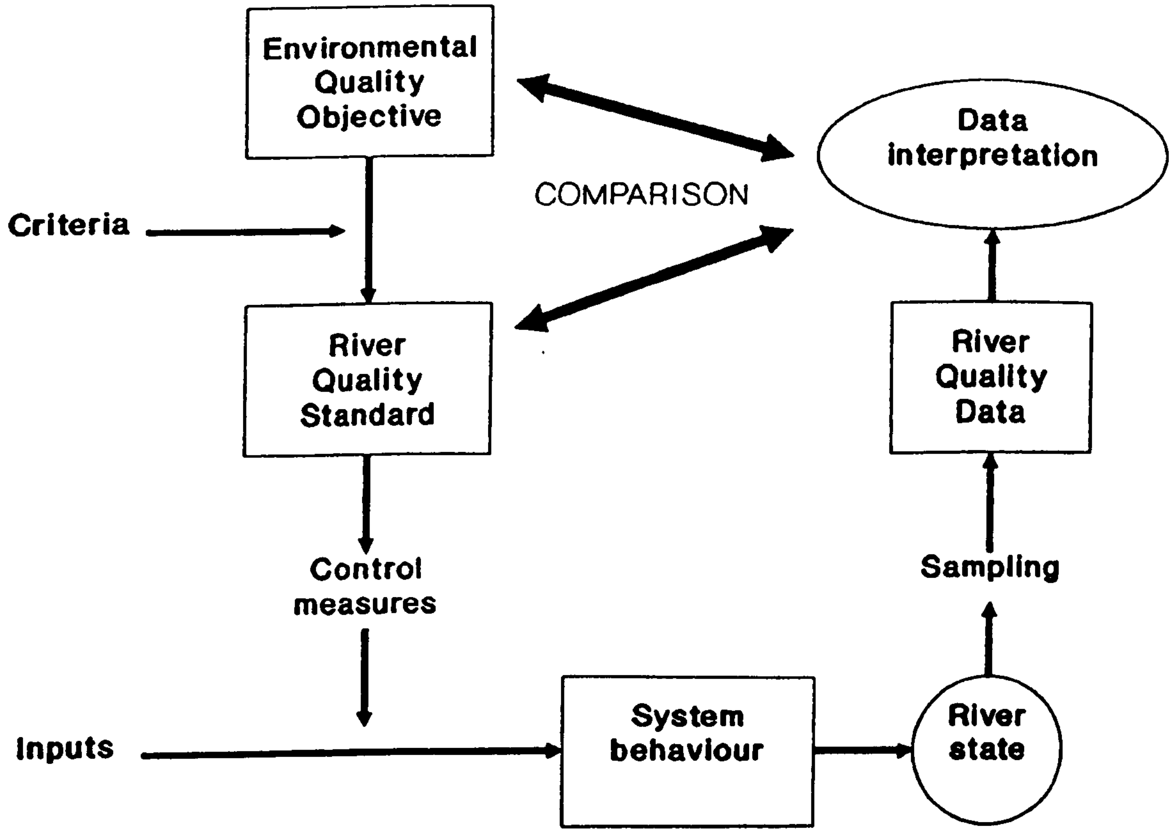

Fig. 1. Schematic diagram of river quality management

The success of pollution control measures in meeting the EQO is assessed by monitoring the quality of the river water. This normally involves taking samples which are analysed for a range of parameters. The frequency of sampling may vary from monthly (or less) to the virtually continuous traces of water quality which may be obtained from automatic water quality monitors[7]. In addition, biological monitoring of river quality may be used to supplement the physical and chemical parameters determined from the samples.

These data provide the basis for assessing the state of the river, in particular its quality relative to the EQO and RQS. They can also be used to explain the conditions observed and to help in the selection or modification of pollution control measures. Uses of the river quality data are as follows:

(a) Inclusion in public registers and returns required by the Department of the Environment (DoE) and EC;
(b) Determination of compliance with the RQS;
(c) Classification of river quality and detection of temporal and spatial trends in quality;
(d) Warning of short-term adverse changes in water quality requiring operational responses, e.g. intake closure, deployment of oxygen injection equipment;
(e) Assessment of the effect of changes in control measures on river quality, e.g. effect of commissioning new sewage-treatment works;
(f) Identification of causes of perceived pollution problems, e.g. investigation of fish kills or algal blooms; and
(g) Long-term planning and modelling needs.

WHAT DO THE NUMBERS MEAN?

Interpretation is the task of extracting from the sample data the necessary information for the above-mentioned uses. The interpretation process can conveniently be divided into two main stages, i.e. characterization and explanation.

Characterization provides an assessment of the fitness for use of the water, and explanation gives the reasons for the assessment. Interpretation is normally carried out to provide information for some management action. Thus the deduced information should be in a form which is suitable to support decision making.

The question of what the numbers mean may be addressed at two levels. Firstly there is the problem of sampling error, i.e. the statistical uncertainty in ascertaining the true determinand values from limited sample data. Secondly there is the difficulty of evaluating what the measurements signify in terms of fitness for use. For example, what effect does an annual 95 percentile value for a DO concentration of 4 mg/l have on a fish population?

The conventional method of interpreting river quality data is by comparison with river quality standards or classification schemes. The first example of the use of an expert system for interpretation concerns this type of formal characterization, employing limits set in EC Directives.

EXPERT SYSTEMS FOR INTERPRETING WATER QUALITY DATA

The following description by Rossman[8] contains the essence of what constitutes an expert system:

> '*Expert systems are computer programs that encode knowledge and reasoning used by specialists to solve difficult problems in narrowly-defined domains. They rely more on heuristic methods, rules of thumb, and pattern matching to achieve these results, rather than numerical models and algorithms. Problems involving classification, interpretation, diagnosis, prediction, instruction, planning and design are all amenable to expert system solutions.*'

The main elements of an expert system are:

(i) A knowledge base or bases which contain, in an encoded form, the knowledge derived from the domain experts;
(ii) The 'inference engine', i.e. the program which explores the knowledge bases in response to user inputs; and
(iii) The user interface which allows the user to communicate with the inference engine. (The interface prompts the user for inputs, displays outputs and provides explanations and status messages).

Several authors have reviewed the use of expert systems in environmental management[9,10,11,12] and have identified a wide range of applications. The examples below consider the use of expert systems for the interpretation of river quality data.

EC WATER QUALITY DIRECTIVES IN A RULE-BASED SYSTEM

The various EC Directives concerning the quality of surface waters provide criteria which may be used to characterize the suitability of waters for particular uses. These criteria provide a convenient source of 'prepackaged' knowledge for incorporation in an expert system. This has the advantage that the knowledge of domain experts (e.g. in aquatic toxicology, freshwater ecology and sampling theory) has already been condensed into a readily-accessible form, thus avoiding the need for a major knowledge acquisition stage.

In order to evaluate the feasibility of encoding the requirements of the Directives in a rule format and to assess its usefulness, a prototype rule-based program has been written to automate the application of the two following EC Directives:

(i) The Directive concerning the quality required of surface water intended for abstraction of drinking water[2]; and
(ii) The Directive on the quality of freshwaters needing protection or improvement to support fish life[1].

The Directive on surface waters for abstraction provides limits related to three different categories of treatment after abstraction (see Table I for treatment definitions). The fisheries Directive sets limits for two different types of fisheries: salmonid waters and cyprinid waters (coarse fisheries). The surface waters and fisheries Directives include 46 and 14 determinands respectively. In assessing the potential for encoding these Directives in a rule-based system, a subset of only 10 determinands has been used. The 10 chosen determinands were based on those selected by the Scottish Development Department for inclusion in a general water quality index[13]. The 10 determinands and 5 water-use classes form the determinand-use matrix shown in Table I.

The program has been designed to perform the following tasks on this matrix of information:

(i) To allow inspection of the appropriate criteria for any use or determinand;
(ii) To compare water quality data with the criteria to determine the uses for which the water is considered fit; and
(iii) to show why (i.e. on which determinands and to what extent) a particular set of data has passed or failed.

Encoding Knowledge

The first step in encoding the information contained in the Directives was to identify the attributes associated with each determinand-use pair. An examination of the Directives revealed the following attributes:

(a) The type of limit (mandatory or guideline value);
(b) The use;
(c) The determinand;
(d) The percentile of the sample data specified in the criterion (e.g. 95, 90 or 50 %ile value);
(e) The limit value(s) for the specified percentile; and
(f) The conditional operator used to compare the data value with the limit value (e.g. more-than, less-than).

Written as a rule, a water quality criterion containing these attributes has the form:

The (_type) limit on (_determinand) for (_use)
requires that
the (_percentile) value is (_operator) (_limit)

TABLE I. Criteria Used for Prototype Development

Determinand	Water use				
	Abstraction			Salmonid fish	Cyprinid fish
	A1	A2	A3		
DO	G	G	G	I, G	I, G
BOD	G	G	G	G	G
Total ammonia	G	I, G	I, G	I, G	I, G
pH	G	G	G	I	I
Nitrate	G	G	G	—	—
Phosphate	G	G	G	G	G
SS	G	—	—	I	I
Temperature	I, G	I, G	I, G	I	I
Conductivity	G	G	G	—	—
Faecal coliforms	G	G	G	—	—

Notes: 1. I = Mandatory limit in EC Directive, G = Guideline limit

2. Definition of standard methods for treating surface waters of categories A1, A2, and A3:

Category A1 – Simple physical treatment and disinfection;
Category A2 – Normal physical treatment, chemical treatment and disinfection;
Category A3 – Intensive physical and chemical treatment, extended treatment and disinfection.

where variables are denoted by the underlining prefix. An example of a criterion with values substituted for the variables is:

The (guideline) limit on (un-ionized ammonia) for (salmonid fish)
requires that
the (95 %ile) value is (less-than) (0.005 mg/l).

The values of _type, _determinand and _use identify the criterion, whilst the values of _percentile, _operator and _limit define the conditions that must be met for the criterion to be satisfied. Hence a water quality criterion may be represented as a list of two elements (_identifier, _condition) in which each element is itself a three-part list containing the identifying and condition-defining attributes respectively. Each determinand–use criterion is encoded in the knowledge base as a list of this form, and inspection of the criteria or assessment of data involves a manipulation of these lists.

Two complications arose in encoding the criteria. Firstly, in a few cases, there is more than one condition associated with a single identifier. For example, the guideline limits on dissolved oxygen for coarse fish specify that:

50%ile > 8 mg/l
and 100%ile > 5 mg/l

In this case each condition was made a separate rule in the knowledge base. Secondly, the temperature criteria for fisheries stipulate that, if the water contains fish species which need cold water for reproduction, a lower temperature is required during the breeding season. The program handles this conditional rule by asking the user whether the water contains cold-water species and, if so, whether it is the breeding season. The program then selects the appropriate limit values on the basis of these responses.

Program Operation

The knowledge-base rules and the program which operates on these rules have been written using LPA micro-PROLOG Professional[14]. In its present form the program prompts the user to input data values interactively. The extension of the program to operate with data files and to check the data before interpretation is considered in the last part of the paper. The data requested by the program depend on the type of criteria and the use or uses specified by the user. Therefore only data relevant to the appropriate assessment are required.

For the water to be considered fit for a particular use, every criterion associated with the use must be satisfied. The standards are framed in such a way that provided each determinand separately satisfies its criterion the water is assessed as being suitable. No account is taken of interactions between determinands. The program carries out the checking process in two steps:

(i) The condition in each relevant criterion is tested against the data using the rule:
IF (_condition) is-true
THEN (_criterion) is-satisfied; and

(ii) The success of this test is checked for all relevant determinands using the rule:
IF (_criterion) is-satisfied
FORALL (_determinand)
THEN (_use) is-suitable

At the end of this comparison the water is assessed as either passing or failing. The reasons why the water passed or failed can be elicited by the user who, for each determinand, is shown the data value and the limit value against which it was compared.

If at the start of the data comparison no type or use is specified, the program will request the data needed to check against the full range of criteria in the knowledge base, and will assess for which uses the water is suitable. In this case the program is making a general interpretation of the water quality data in the light of the knowledge incorporated in the rule base.

Limitations of Approach

Although comparison against standards is an important aspect of management, this approach does have limitations as a way of providing decision support. These limitations relate to what may be termed the empirical adequacy and explanatory power of the criteria.

Empirical Adequacy

This is indicated by a good match between the environmental assessment, made by application of the standards, and direct observations of environmental quality. For example, a water which is classed as being suitable for coarse fish should be capable of supporting a fishery, whilst a water classed as being unsuitable should not contain a healthy fish population. It is in the nature of standards that they are unlikely to give a good match in all cases. Standards are designed to give a degree of protection and may explicitly include a factor of safety[15]. They are usually based on the reaction of the most sensitive species and life stages. In addition, the need to agree a single standard which can be applied to all waters is likely to introduce a degree of caution and possibly also of economic and political compromise into the values which are adopted.

There is also a more basic difficulty in trying to capture the effects of multiple, time-varying determinand concentrations on an ecosystem or treatment process in a simple standard. These difficulties arise because, in general, there is not a simple correspondence between the magnitude of a single determinand and the effect which it produces. The effect is also likely to be influenced by:

(a) The history of exposure, e.g. the duration and frequency of peak concentrations, the rate at which changes occur and the extent of recovery between peaks; and
(b) Interactions between determinands.

Current UK standards and classification schemes, which are based on the frequency distributions of individual determinands, do not explicitly allow for these factors. Taking these points together, it may be unrealistic to expect that criteria intended primarily for regulation will provide an adequate model of behaviour.

Explanatory Power

The second limitation concerns the amount of explanation which this method of interpretation offers. For example, a water may fail to comply with the EC fisheries Directive. In itself this statement gives no indication of how close the water is to being classed as 'suitable' or which parameters were critical in determining its classification. More detailed examination of the data would show the magnitude of the sample statistic of each parameter relative to its limiting vale. Even this explanation is comparatively superficial. It is expressed in terms of the standard and gives little insight into the underlying reasons for the environmental quality. Poor information is given on points such as:

(a) What is the controlling influence on the quality of the fishery? For example, do episodic pollution events or chronic conditions determine the quality?
(b) How serious is the situation? Is the water acutely lethal to fish, or is the failure of compliance based on concern over long-term effects or damage to sensitive life stages?

Information of this type is needed to assess management priorities and select appropriate control measures. The way in which an expert system might be used to provide this sort of in-depth interpretation is considered using the example of a rule-based program for assessing the effect of ammonia on fish.

RULE-BASED SYSTEM FOR ASSESSING EFFECT OF AMMONIA ON FISH

Ammonia is a component of most effluents and may also occur in runoff, particularly from agricultural land. Ammonia is toxic to fish, the main source of toxicity being the un-ionized form (NH_3). The work described below derives from current studies to incorporate current knowledge of ammonia toxicity[16,17,18] into a rule-based system for interpreting the effect of time-varying ammonia concentrations.

The aim is to encode the knowledge of the toxic effect of ammonia in rules which relate cause (water quality conditions) and effect (the impact on the fish population). The linkages between conditions and effects can be formally represented by the use of 'fault trees'. These techniques originated in the fields of risk analysis and reliability evaluation[19]. A fault tree shows a particular failure condition and identifies the various combinations and sequences of failures which lead to the top-level (system) failure.

A fault tree showing how damage to a fish population may arise is shown in Fig. 2. The attempt to represent, in a tree diagram, the complex interactions of factors which affect the health of a fish population must be considered to be a gross simplification of reality. For this reason it may be preferable to view Fig. 2 as a classification of the knowledge concerning toxic effects. Present work is

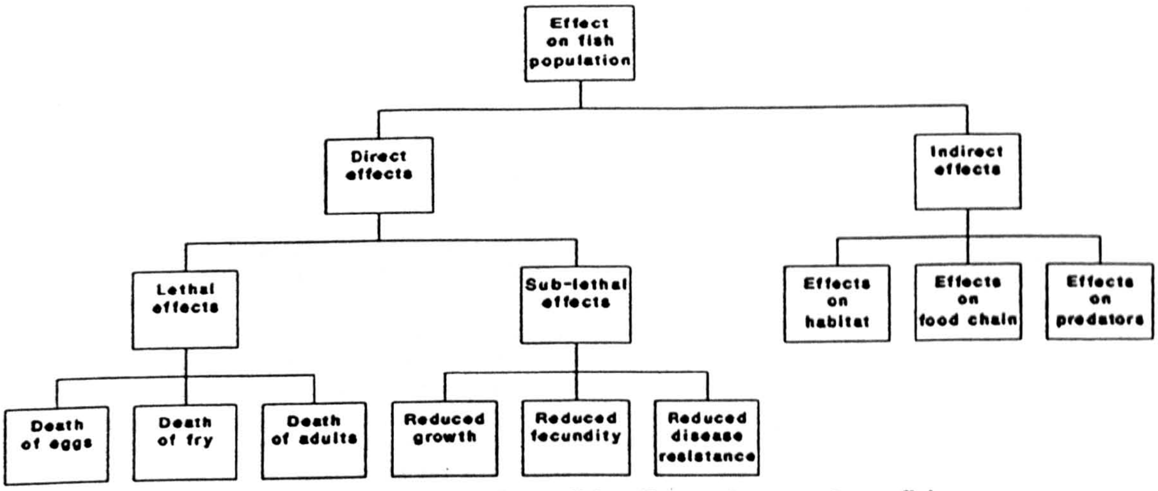

Fig. 2. Classification of possible effects of ammonia on fish

concentrating on the development of a rule base for one of the effects shown in Fig. 2, i.e. lethal effects on adult fish.

The literature shows that not only the concentration of ammonia, but also the duration of exposure and other factors including the concentration of dissolved oxygen (DO) and the prior acclimation to ammonia, can influence the response of fish. Individual laboratory tests indicate conditions which have proved to be lethal, and some generalization from these instances is necessary to provide rules covering the range of conditions which may occur in practice.

A mathematical model has been developed to describe the toxic action of ammonia on fish, taking account of exposure duration and the main modifying factors[20]. The model simulates the exchange of ammonia between a series of compartments representing the external environment and different groups of tissues within the fish. Interactions between factors are simulated by adjustments to the model parameters. For example, the effect of prior exposure on the lethal concentration can be simulated by making the rate of ammonia excretion a function of the moving average of the ammonia concentration over the preceding 24 h, a higher prior exposure leading to a faster rate of excretion. The compartmental model is being used to investigate the conditions which are lethal to fish. The results of these investigations can be used to construct fault trees, such as that shown in Fig. 3, which indicate combinations of conditions producing a lethal effect. This tree is an extension from the 'death of adults' node at the bottom of Fig. 2. Each branch of the fault tree can be expressed as a rule such as:

IF (1-h mean ammonia > X1)
AND (1-h mean ammonia < X2)
AND (1-h mean DO > Y2)
AND (Average ammonia over previous 24 h was < Z1)
THEN (Death of adult fish likely).

The complete rule base is produced by constructing diagrams for a range of different ammonia events. Rules in this form are being combined with the inference engine and user interface described by Beck *et al*[21] to provide an expert system for interpreting the effect of episodic ammonia events on adult fish.

DISCUSSION

The two examples raise some general points about the use of expert systems forthe interpretation of water quality data which are considered below.

Practical Use of an Expert System

The EC Directives or the NWC river classification system provide a convenient source of codified knowledge. The prototype program described in this paper and the studies of the NWC classification system reported by Ventilla *et al*[22] have shown the feasibility of representing this type of knowledge in a rule-based system. These exercises give insights into the structure and limitations of the criteria, but is there a practical application for this type of expert system?

The comparison of sample statistics (i.e. percentiles) with limits set in EC Directives hardly seems to be a problem of the complexity to warrant the use of an expert system. However, in reality this comparison is not the simple task represented in the prototype program, nor is it the only step in assessing compliance. The full process of compliance assessment is shown in Fig. 4.

Before sample statistics can be compared with criteria they must be derived from raw data. This involves data validation and statistical analysis. Data validation may include checking that the sampling

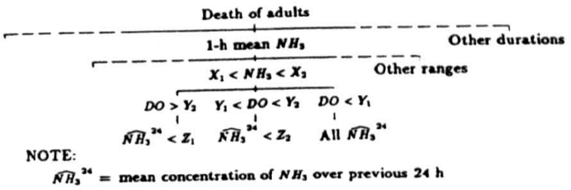

Fig. 3. Example of ammonia conditions leading to death of adult fish

frequency satisfies the requirements of the Directives, identification, and correction of measurement or transcription errors. Statistical analysis of the validated data provides the sample statistics. Additional tests may also be performed to evaluate confidence limits, discontinuities and temporal and spatial trends in the data.

The rule base incorporated in the prototype program to assess the compliance of these sample statistics is a simplification of the criteria contained in the EC Directives. The Directives include qualitative statements and areas for discretionary judgement which have been omitted from the rule base. For example, the limits of several parameters in the fisheries Directive are qualified by statements such as:

(a) 'Over-sudden variations in temperature shall be avoided';
(b) 'Values for un-ionized ammonia may be exceeded in the form of minor peaks in the daytime'; and
(c) 'Higher values of total chlorine can be accepted if the pH is higher (than 6)'.

Similarly the Directive on surface waters for abstraction contains comments concerning permissible characteristics for the samples which exceed the limit values. Both Directives allow exceedances for certain parameters in the event of exceptional meteorological or geographical conditions, and in some cases more formal derogations are permitted. Expert opinion on such matters as what constitutes an 'over-sudden variation', what is an acceptable 'minor peak', or when may exceedances be attributed to exceptional meteorological conditions, could be encoded in rule form. Inclusion of this more heuristic type of knowledge would provide a system which more truly performs the functions of an expert.

The full range of knowledge bases that would need to be employed for compliance assessment are represented by the boxes at the bottom of Fig. 4. Encoding this knowledge within a single expert system for compliance assessment would realize the advantages which are available from this approach, namely:

(a) Access to expertise in a variety of domains, including heuristic knowledge not available in the Directives;
(b) The speedy execution of a relatively complex task;
(c) Modular knowledge bases which may be updated as knowledge improves or legislation changes;
(d) A detailed explanation of the assessments; and
(e) A consistent application of the requirements of the EC Directives.

Use of Models with Expert Systems

A mathematical model was used to derive rules describing the toxic effects of ammonia on fish. This raises the question 'If a mathematical model can be constructed, why not use it directly to predict effects rather than to derive rules?' The reasons for favouring use of the model to derive rules are that:

(i) The aim is to provide an interpretation system which will characterize and explain the effects arising from water quality conditions. Explanations of conclusions reached and justifications for the lines of reasoning can more readily be provided in a rule-based system;
(ii) The model is only an approximate representation of toxic action. By presenting results in the form of rules, model behaviour is more open to examination and review. The possibility also exists of attaching a measure of certainty or probability to individual rules to reflect the degree of confidence in inferences drawn from the rule; and

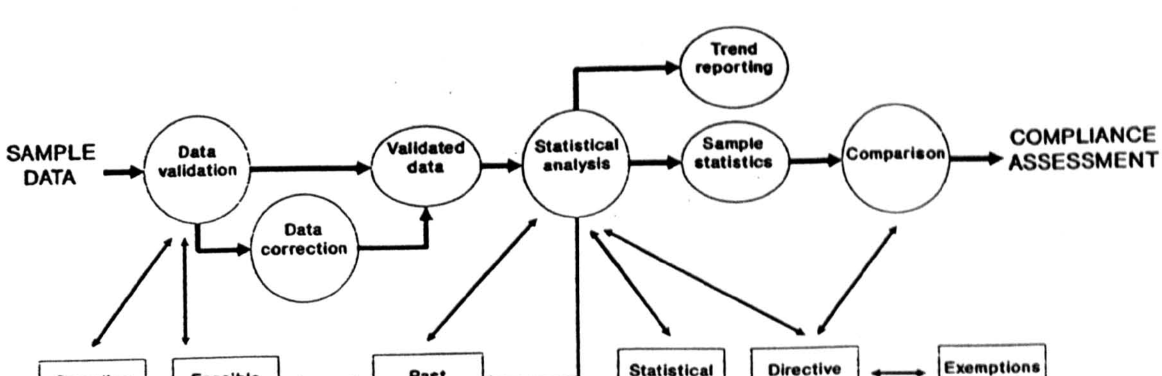

Fig. 4. Steps in assessing compliance with EC Directive

(iii) additional rules embodying knowledge outside the scope of the model can be incorporated in a rule-based system.

Thus the model is treated as an aid in structuring the available information on toxicity, rather than as a substitute for expert knowledge. If a sufficiently comprehensive mathematical model were developed, the role of the expert system might be modified to that of an expert adviser[23] or knowledge-based front-end[24] for the model. In this type of application the expert system provides an interface with the mathematical model and assists the user in selection of model types and parameter values.

Sampling Implications

The program for interpreting the effects of ammonia on fish examines time-series data for ammonia and associated parameters. This implies the need for more sampling than is necessary to estimate the frequency distributions used for compliance testing. Evaluation of the interpretation program is being carried out using high-frequency data collected by automatic water quality monitors.

Although such data are becoming increasingly available, the sampling needs of more detailed interpretation methods are still an important consideration. Any changes in the sampling regime used for compliance assessment (such as the inclusion of night-time values) may have serious implications for the operation of sewage-treatment works and other dischargers. To the river quality manager there is a trade-off between the extra costs of additional sampling and the potential benefits of more precise and informative methods of interpretation. These benefits may include greater assurance that objectives are being achieved and a better understanding of the effects observed.

The ability to realize these benefits will depend (in part) on the amount of discretion available in the application of river quality standards. The proposed introduction of statutory river quality standards seems likely to increase the emphasis placed on compliance with physical and chemical criteria. In this case, management efforts may be focused on achieving compliance with standards, irrespective of how well these standards achieve the quality objectives. If this happens there will be less scope to use the better understanding which an interpretive expert system offers.

CONCLUSIONS

1. Two areas for the application of expert systems in the interpretation of water quality data have been discussed.
2. The first of these is the automation of compliance testing and classification. A prototype program has shown the feasibility of encoding this type of information in a rule-based system. Extension of this approach to incorporate expertise in data validation, statistical analysis and heuristic knowledge of the application of standards would provide an expert system of practical value in compliance assessment.
3. The need for standards to be applied uniformly, to provide a degree of protection and to be legally enforceable and administratively simple places limits on their use for interpretation. These limits relate to the accuracy of characterization and the amount of explanation provided by the application of standards.
4. The second application is directed towards remedying these defects and uses an expert system to interpret the effect of varying ammonia levels on fish. A mathematical model has been used to derive rules describing the effect of fluctuating pollutant concentrations.
5. This type of system has the potential to provide a greater insight into the effect of episodic pollution events than conventional classification procedures. However, more data are needed for this assessment than are required to characterize water quality using conventional methods. The balance between the cost of collecting additional data and the benefit of a more detailed assessment of environmental quality has to be established according to particular circumstances.
6. The current place for expert systems in the interpretation of river quality data appears to be to support, and in some cases to extend, current methods rather than replace them. Expert systems provide opportunities to automate and standardize routine procedures and also to extract better information from sample data in support of decision making. In the long term, expert systems may aid in the formulation of standards which give a better match between interpreted and observed environmental quality.

ACKNOWLEDGEMENTS

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DISCUSSION

(Abridged)

Mr A. H. Bunch (North West Water) referred to the two examples given in the paper. He said that the first part did not seem to be a knowledge-based system, but was more a summary of EC Directives; the second part appeared to show a method of revising these Directives. Again, it was a summary of combinations of conditions which might cause fish kills, and he asked if the authors could comment on this aspect.

Mr G. Crowder (George Crowder Associates) considered that a little confusion had developed over the application presented by Mr Wishart and whether it was a 'knowledge'-based system. Mr Wishart's work appeared to have integrated 'expert knowledge', 'mathematical modelling' and 'statistical analysis' in one application of the program.

Authors' Reply

In reply, the authors said that the paper was concerned with the way in which knowledge-based systems could assist in the assessment of environmental quality for river pollution control.

The prototype system described was simple, but suggested that there would be benefit in extending the program to provide expert advice in the areas where the Directives allowed discretion in assessment. Eventually such a system might be linked to other knowledge bases, databases and statistical packages to provide data validation and analysis. This type of system could offer several advantages including (a) access to expertise in several different domains; (b) consistency and speed of interpretation, and (c) modular knowledge bases that could readily be revised to accommodate advances in understanding or changes in legislation.

Although this type of compliance assessment was an important part of water quality management, the criteria used and the way in which they were applied might not always provide an accurate and informative assessment of environmental quality. Therefore, the second part of the paper looked at how a knowledge-based system might be used to provide more information on the assessment than was available with conventional criteria. The example given was of a knowledge-based system to interpret the effects of fluctuating ammonia levels on fish. The rules used in the program had been derived from a dynamic mathematical model of ammonia toxicity.

This second type of system was not intended as a replacement for EC Directives or classification schemes, but as an additional tool to extract better information from sample data in support of decision making. In the long term this approach might assist in the formulation of standards which could give a better match between interpreted and observed environmental quality.

A copy of the full version of the proceedings of this Workshop can be obtained from the Institution's Headquarters.