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NRA

The River Thames Phosphate Model

- Improvements on the River Colne model
- Investigation of high decay rates
- Effects of phosphate stripping at STWs

Gerrie Veldsink

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ACKNOWLEDGEMENT

With great pleasure I fulfilled a three month practical period at the NRA Thames Region in Reading. I would like to thank Betty and Jane for supervising me and giving me interesting jobs to do.
Further more I would like to thank Andrzej, Louise, Simon and Derek. They always had time to discuss difficulties with me, to help me with a problem or to have a nice chat. It has been a pleasure working here.

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INTRODUCTION

A practical period for the Wageningen Agricultural University in Holland was fulfilled by working with The Water Quality Planning (WQP) Section in The National Rivers Authority (NRA) Thames Region. During the three months period from January '96 to March '96 a phosphate model for the River Thames has been used by WQP to determine whether phosphorus removal at sewage treatment works would have an effect on eutrophication, and to identity works where it would have the most impact. However, there appeared to be difficulties in calibrating and validating this model against data collected in the catchment of the River Colne, which is part of the Thames catchment. A more complex description of the catchment of the River Colne than being represented in the model could be an improvement.
The objective of this practical period is to improve the calibration and validation of the River Thames Phosphate model for the River Colne. Also will be tried to improve the model by checking the order of Sewage Treatment Works and to try to bring high decay rates down in a number of sub-catchments.

First, a brief description of the NRA will be given in chapter 2 of this report. In chapter 3 the phosphate circle and the model TOMCAT will be worked out, after which in chapter 4 the changes made to the River Colne model will be explained. Other work done on the River Thames Model will be told in chapter 5. Chapter 6 will contain the conclusions of this study and some recommendations will be made in chapter 7.

The graphs of the phosphate output of the TOMCAT model in this report have 'Ammonia (mg N/l)' written at the y-ax of the graph. This stands for phosphate (mg P/l).

2 THE NATIONAL RIVERS AUTHORITY AND THE WATER QUALITY PLANNING SECTION IN THE THAMES REGION

2.1 The National Rivers Authority

The National Rivers Authority (NRA) was established by the 1989 Water Act (replaced by the 1991 Water Resources Act) to safeguard the water environment of England and Wales. The NRA consists of a head quarters, largely responsible for the formulation of water management and pollution control policy and eight operational regions (figure 1), each responsible for implementing this policy on a day to day basis.

Figure 1.1 The eight regions of the NRA

The NRA Thames Region is one of the eight 'operational regions which comprise the NRA. The Thames Region with its resident population of over 11 million, covers about 5,000 square miles from Cirencester in the west to Dartford in the east and from Luton in the north to the Surrey Downs in the south. It is an area of great diversity, ranging from rural Oxfordshire and Wiltshire trough the high-tech industry of the Thames Valley to the urban spread of London. The head quarters of the Thames Region is situated in Reading.

The region is managed by a Regional Management Team led by the Regional General Manager.

Three committees assist with the Thames Region activities and provide direct channels of communication for interested parties. They are a Regional Flood Defence Committee, a Regional Fisheries Advisory Committee and a Regional Rivers Advisory Committee to cover the remaining functions. The committee chairmen, the regional board member and the regional general manager form the Regional Management Board which advises across the whole range of the

Region's responsibilities. The activities are financed from a combination of local government levies, direct charges and Government grant aid.

The aim of the NRA Thames Region is to safeguard the total river environment: the rivers and the Thames Estuary, streams and lakes in the area and the quantity and quality of underground water. The Thames Region is also responsible for flood defence, for protecting and improving fish stocks and for promoting water based recreation of all types. In carrying out these responsibilities they are committed to improving wildlife habitats and conserving the natural environment. All of these activities are carried out following an integrated river management approach.

2.2 THE WATER QUALITY PLANNING SECTION IN THE THAMES REGION

The Water Quality Planning Section in The Thames Region is part of The Scientific Department (figure 2). They are responsible for setting the river ecosystem objectives for each river within the Thames region. This is undertaken on a reach by reach basis for each watercourse in a catchment. The river quality objectives are use related and specify the concentrations of certain chemical determinants which the reach will achieve and is intended to protect the watercourse from pollution, as well as allowing for improvements in quality following investment at sewage treatment works (STWs), by other dischargers, or other beneficial activities (e.g. NRA pollution prevention initiatives). Also watercourses are being considered under the fish directives.
Water Quality Planning also derive the necessary consent conditions for discharges so as to ensure that compliance with River Quality Objectives is contained.

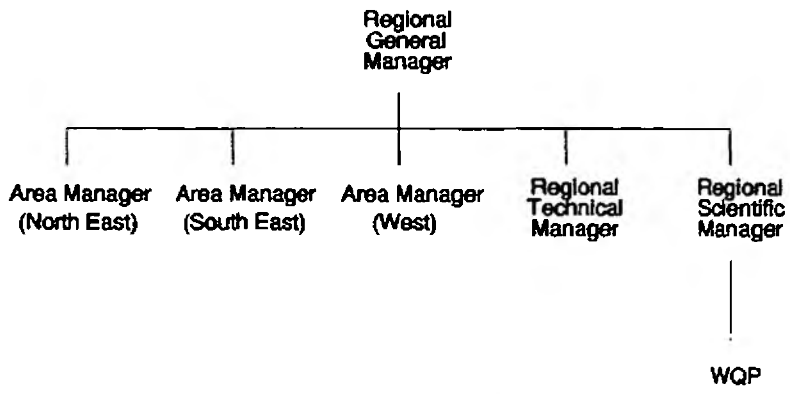


Figure 2.2 The Structure of the NRA

For a lot of these working area's water quality models are being developed and/or used. Dye studies are also carried out to provide Time Of Travel data for the calibration of these models.

On April 1st 1996 the NRA will become part of The Environment Agency. Other organisation which will be part of The Agency are Her Majesty's Inspectorate of Pollution, the Waste Regulation Authorities and several smaller units from the Department of the Environment. The Environment Agency will provide a more comprehensive approach to the protection and management of the environment by combining the regulation of land, air and water.

3 THE RIVER THAMES PHOSPHATE MODEL

3.1 Introduction

In 1994 the River Thames between Day's Lock and Teddington Lock was designated a Sensitive Area under the Urban Waste Water Treatment Directive (UWWTD). Article 5 of the Directive requires phosphorus limits to be set on qualifying discharges (sewage treatment works with a population equivalent (PE) exceeding 10,000) unless it can be shown that phosphorus removal will have no effect on eutrophication. In May 1994 the DoE requested the NRA to carry out a catchment study of the Thames to determine whether phosphorus removal would have an effect on eutrophication, and to identify works where it would have the most impact.

To predict river phosphate concentrations, a river quality model, TOMCAT, was set up for the entire Thames catchment (reference 1). TOMCAT is a river quality model that was created in 1982 by the Thames Water Authority to model the impact of the discharge sewage treatment works on water quality, and to guide investment. TOMCAT is usually used to model carbon, nitrogen and oxygen chemistry in small to medium sized catchments, but can be adapted for other purposes. It was used in this study, without modification, to model phosphate.
Using the model, there appeared to be difficulties calibrating the catchment of the River Colne which is part of the River Thames catchment.

The phosphorus cycle in rivers is a complex process, involving plant growth and water - sediment interactions. In spring and summer, orthophosphate is lost by conversion to organic phosphate in fixed plants and floating phytoplankton. Some of this phosphate will be removed altogether from the river system by grazing of plants by land animals or when the phytoplankton are carried into the estuary. However, much of the organic phosphate will stay in the river, sinking to the bed when the plants and phytoplankton die. This organic material will decay and the phosphate will become available again when the sediments are stirred up by high flows. Thus, in spring and summer there will be removal of orthophosphate from the water, but in winter there may well be an addition of orthophosphate. The model does not describe these processes in detail, it just describes one of the phosphorus species, orthophosphate. The assumption is made that it decays exponentially with distance in the river. The actual rate of decay will vary from river to river depending on, for example, the amount of shading and type of plants present. One consequence of only including orthophosphate decay but ignoring recharge from the bed, will be that the model will underestimate winter phosphate concentrations. However, in the Thames, the high phosphates tend to occur in summer, and the low phosphates in winter. Therefore this simple model will still be useful for examining high orthophosphate concentrations.
The advantage of this simple approach is that TOMCAT already uses exponential decay to model carbon and nitrogen chemistry in rivers, and that the model is easier to calibrate than a more sophisticated approach (reference 1).

3.2 TOMCAT

TOMCAT (Temporal/Overall Model for Catchments)is a steady state stochastic catchment water quality simulation model. It uses a limited set of features or events to represent a catchment. These are:

- Start of Principal Watercourse;
- Start of Tributary;
- Start of Reach;
- Confluence;
- Effluent Discharge;
- Weir;
- Bifurcation;
- Abstraction;
- River Sampling Site.

Most catchments are represented by a principal watercourse with tributaries and bifurcations into separate channels as appropriate. It can be divided up into any number of reaches with different physical characteristics, decay constants and accretions of water quality determinants. Events are arranged in geographical sequence working downstream from the upstream boundary of the principal watercourse.
Figure 3.1 shows the path which TOMCAT would follow for a hypothetical catchment.

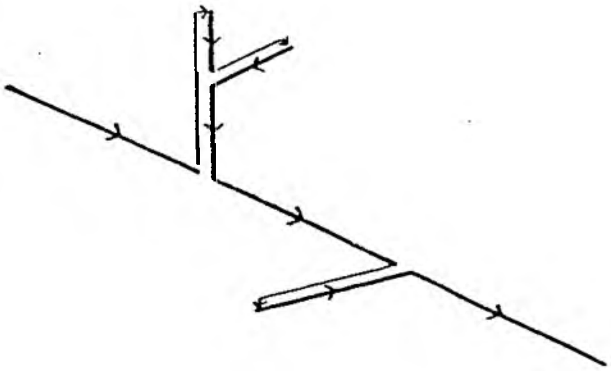


Figure 3.1 The path which TOMCAT would follow for a hypothetical catchment.

The simulation can be compared with observed data at the river sampling sites. TOMCAT performs statistical comparisons between these two: a t-test on the means, a Mann-Witney test on the medians, and a Kolmogorov-Smirnov test on the shape of the distributions.

In England and Wales, the NRA samples many STWs and river sites only 12 times a year. This does not provide enough data to run a time-series model, since there will be considerable variation in quality between samples. However, several years of data can be grouped together to give a good picture of the distributions of quality in the effluent and the river. TOMCAT uses these distributions to generate its own data set. This has monthly and hourly components, allowing for seasonal and daily variation. A separate program, MARIGOLD, converts raw data into distributions for TOMCAT. It uses analyses of variance (ANOVA) to determine the seasonal and hourly components of the data, leaving cumulative frequency distributions of the residuals. If there is very little raw data, or perhaps none at all, TOMCAT can use standard distributions, such as a normal or lognormal distribution with a user specified mean and standard deviation.

TOMCAT uses a Monte-Carlo process to generate its data. For example, it calculates the flow and concentration at the top of a river, by adding the seasonal and hourly components to random values selected from the residual distributions. It does this for a number of 'shots' each representing a different combination of season and hour. The time of travel to the next downstream event is calculated from the flow equations for each shot. Biochemical decay is incorporated in the model by reducing the river concentrations between events by appropriate amounts depending on the time of travel and decay rates fixed by the user.

4 COLNE MODEL IMPROVEMENTS

4.1 River Colne

The River Colne is part of the River Thames catchment and covers an area of 1016 km^2. The source is at London Colney in Hertfordshire.

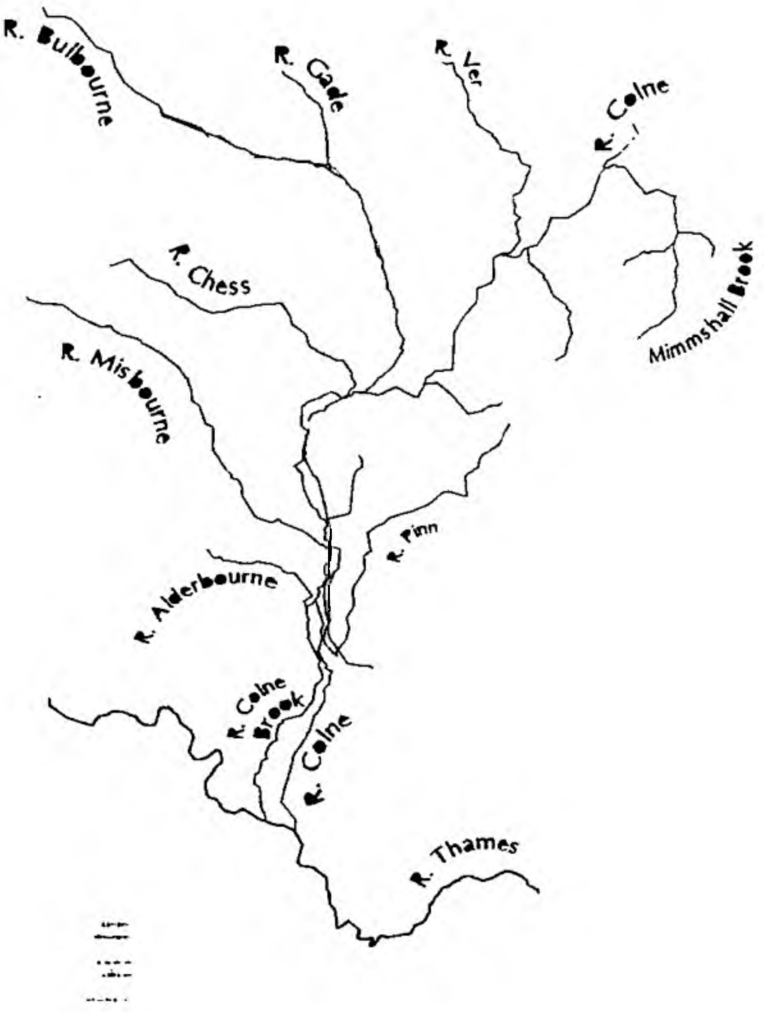


Figure 4.1. The River Colne catchment

Going downstream it flows through the Watford/Rickmansworth area, and is among others joined by the River Ver, the River Gade, the River Chess and the River Misbourne. Downstream the River Colne bifurcates into the River Colne and the River Colne Brook. The Grand Union Canal (GUC) runs through the catchment. The Colne catchment is shown in figure 4.1.

A number of STWs discharge into the Colne catchment. The main ones are owned and operated by Thames Water Utilities Plc. They are reproduced in table 4.1.

Besides these effluents, the other main influences on the water quality in the R. Colne are:
- surface run-off from urban areas e.g. St. Albans, Watford, Rickmansworth, Pinner, Ruislip and Hillingdon;
- surface run-off from commercial and industrial development, together with

highways including parts of the M1, M4, M25 and M40 motorways;
- trade effluent discharges, include cooling waters and fish farm effluents.

Table 4.1 The main STWs discharging in the catchment of the River Colne.

Sewage treatment works	Discharge into:
Markyate	via R. Ver
Berkhamsted	via R. Bulbourne and R. Gade / GUC
Blackbirds	to R. Colne direct
Maple Lodge	to GUC
Chesham	via R. Chess
Gerrards Cross	via R. Misbourne
Iver North	to Colne Brook
Iver South	to Colne Brook

Although there are no public water supply abstractions from the Colne itself, there are major abstractions from the Thames immediately downstream of the Colne confluence.

4.2 Modelling the River Colne

4.2.1 Introduction

In 1995 the whole River Thames catchment, including the River Colne, was modelled in TOMCAT (reference 1).

In that model the catchment of the R. Colne was strongly simplified. Only the main water course was modelled, the tributaries were not included. The STWs discharging into the tributaries of the R. colne were modelled as discharging directly into the Colne. This way, sewage treatment works that are far apart and on different tributaries end up close together if they are a similar distance above the Thames. Figure 4.2 shows the way the River Colne was modelled in TOMCAT.

As shown in figure 4.3, TOMCAT follows the river model in a certain way. TOMCAT goes up to the start of the Colne, walks down taking the left leg first. After this it starts at the top of the right leg and walks down. For this reason the stream upstream of Denham GS is called Colne (Brook) tributary instead of Colne tributary. .

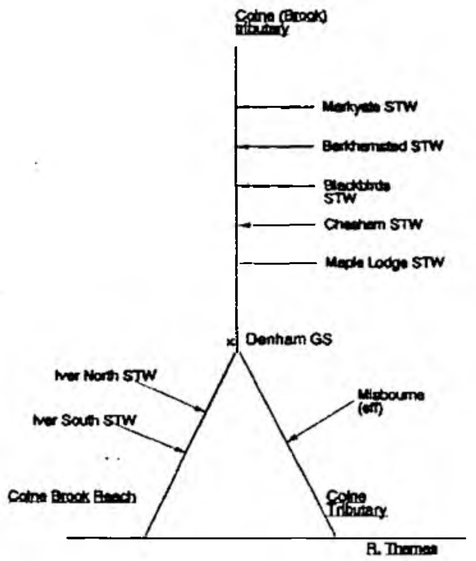


Figure 4.2 The way the River Colne was modelled in TOMCAT

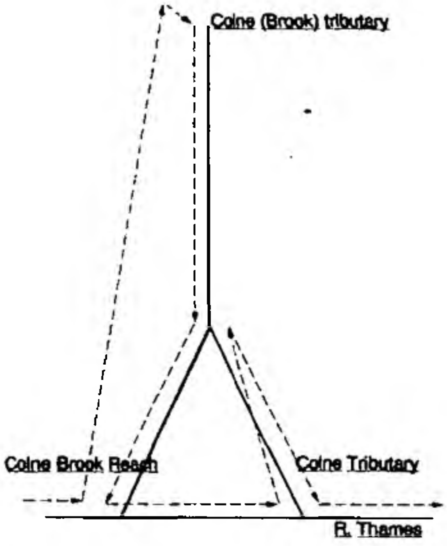


Figure 4.3 The way TOMCAT walks through the model scheme

Using TOMCAT normally a time dependent decay constant is used. For the phosphate modelling of the River Thames (which includes the River Colne) a distant dependent decay was used. Appendix A explains how to use TOMCAT with a distant dependent decay.

To run the TOMCAT Colne model 1440 shots were used.

4.2.2 Data input

For the input of the Colne model measured data were used when available. If there was no measured data, an estimate was made.

4.2.2.1 Flow upstream of the STWs

The flow and the quality of the River Ver are used as the flow and quality of the River Colne upstream of the STWs. The reason to do so is that the Colne u/s its confluence with the R. Ver often runs dry and therefor the Ver is the main water source for the River Colne. Because the measurements of the R. Ver include the flow of Markyate STW, which was modelled explicitly, this STW contribution had to be removed from the original model.

4.2.2.2 Flow downstream of the bifurcation

The flows of the River Colne and the River Colne Brook have been modelled by the hydrologic section of the NRA Thames Region. It appeared that at the point of the bifurcation 77% of the flow goes into the Colne and 23% goes into the Colne Brook. The calculation of the flow downstream of the bifurcation is explained in appendix B.

4.2.2.3 The accretional flow

The accretional flow in the catchment of the R. Colne was estimated a number of times during the last 25 years. The average accretional flow is estimated as 5400 m^3/km/day. The estimations are shown in appendix C. These estimations were made for the area upstream of Denham GS and used in the model. The same accretional flow was used for the area downstream of Denham GS.

4.2.2.4 The concentration of phosphate in the accretional flow

The concentration of phosphate in the accretional flow was calculated from the agricultural load values used for the whole of the Thames catchment, and the load in the flow upstream of the STW discharging into the River Colne. The calculation can also be found in appendix C.

4.2.2.5 Flow and quality of discharge from STWs

For the input of flow from the STWs measured data were used, when available. If there were not any flow data, the consent was used or the annual average flow from '88-'89. For the quality of the discharge from the STWs measured data were used.

4.2.2.6 Flow and quality of the River Misbourne

The River Misbourne has been modelled as an effluent discharged into the Colne Brook. For the flow and quality of this river, measured data collected just upstream of the confluence of the River Misbourne with the Colne Brook were used.

4.2.2.7 Sources of data and important files

Table 4.2 and 4.3 show the flow and quality data used for the different STWs and tributaries, from what source they came from and the name of the file where they can be found. Table 4.4 gives the names of other important files that have been used. All the files can be found in the directory I:\GERRIE\MARK\C28. The URN numbers that have been used can be found in appendix D.

Table 4.2 Flow data sources

Event	Data source	Kind of data	File name
Colne (Brook) tributary	ARCHIVE	daily	F_VER_DS.ARC
Berkhamsted STW	Thames Water	daily	F_BERK.DAT
Blackbirds STW	ARCHIVE	daily	F_BL_B.ARC
Chesham STW	Thames Water	2 year average of '88-'89	
Maple Lodge STW	Thames Water	daily	F_MAPLE.DAT
Iver North STW	consent		
Iver South STW	consent		
Misbourne	ARCHIVE	daily	F_MISB.DAT

Table 4.3 Quality data sources

Event	Source	Kind of data	name file
Colne (Brook) tributary	ARCHIVE	daily	Q_VER_DS.ARC
Berkahmsted STW	ARCHIVE	daily	Q_POINTS.ARC
Blackbirds STW	ARCHIVE	daily	Q_POINTS.ARC
Chesham STW	ARCHIVE	daily	Q_POINTS.ARC
Maple Lodge STW	ARCHIVE	daily	Q_POINTS.ARC
Iver North STW	ARCHIVE	daily	Q_POINT2.ARC
Iver South STW	ARCHIVE	daily	Q_POINT2.ARC
Misbourne	ARCHIVE	daily	Q_POINTS.ARC

Table 4.4 Important files

Content	Source	File name
Accretional flow	Hydrologists	ACC_FLOW.WK4
Calibration file flow	ARCHIVE	FLOW28.CAL
Calibration file quality	ARCHIVE	DS28ALL.CAL
Final TOMCAT file		XCOLNE57.TOM

4.2.2.8 Differences between the original model and the model in this study

There are a number of differences in the way the River Colne was originally modelled (reference 1) and the way it has been modelled in this study. Table 4.5 shows the main differences.

Table 4.5 Main differences between the original model input and the input in this study

Model input	Original Model	This study
Flow u/s of STWs	Flow at Denham GS scaled down	Flow in River Ver (§ 4.2.2.1)
P in flow u/s of STWs	Zero	Quality River Ver (§ 4.2.2.2)
Quality of STW discharge	Same normal distribution used for all STWs, mean scaled to right value	Non-parametric distribution of measured data (§ 4.2.2.5)
Flow from		
Markyate STW	'87-'88, 2 year average	removed (§ 4.2.2.1)
Berkhamsted STW	'87-'88, 2 year average	measured data (§ 4.2.2.5)
Chesham STW	'87-'88, 2 year average	measured data (§ 4.2.2.5)
Blackbirds STW	?	measured data (§ 4.2.2.5)
Maple Lodge STW	monthly means	measured data (§ 4.2.2.5)
Accretional flow	No	Yes (§ 4.2.2.3)
Accretional phosphate	Includes the phosphate in the Colne u/s of Denham GS	Does not include the phosphate in the Colne u/s of Denham GS (§ 4.2.2.3)
Misbourne effluent	Flow distribution from Denham Gs scaled down Quality: ?	measured data (flow and quality) (§ 4.2.2.6)

4.2.3 Calibration (October 1992 to October 1994)

The model was calibrated against three points, see table 4.6. The flow was calibrated against Denham GS and on Colne Brook u/s Thames. The flow could not be calibrated against Colne u/s Thames because there is not a gauging station present. The quality was calibrated against all three points.

Table 4.6 Calibration points in the Colne catchment

Calibration point	Flow	Quality
Denham GS	+	+
Colne u/s Thames	-	+
Colne Brook u/s Thames	+	+

\- = no calibration against this point;
\+ = calibration against this point

First the flow at Denham GS was calibrated and then the quality at Denham GS. After this the flow at Colne Brook above Thames was calibrated and then the quality at Colne Brook above Thames and Colne above Thames.

The flow at Denham GS was calibrated by reducing the accretional flow a little bit. The flow at Colne Brook above Thames was calibrated by using the accretional flow estimated by hydrologists.

The quality at Denham GS was calibrated by putting in a decay rate. The best fit is obtained by using a decay rate of 0.7 (1/km).

During the calibration of the quality at Colne and Colne Brook above Thames it appeared to be that the best fit was obtained by using a decay rate of 0. For Colne Brook above Thames there was even then less phosphate than observed. Therefore the accretional load was increased to 0.3 mg P/km/day. The final file is called XCOLNE57.TOM.

The graphs for calibration are shown in the figures 4.4 up to 4.8. The figures 4.4 and 4.5 show the graphs of the output for the flow calibration for Denham GS and Colne Brook u/s Thames. At Denham GS the z-test and Mann-Whitley-test are passed and at Colne Brook u/s Thames the z-test is passed. Figure 4.6 shows the graph of the phosphate calibration at Denham GS which passes all statistical tests. The phosphate calibration output at Colne Brook u/s Thames (figure 4.7) passes the z-test, and the phosphate calibration output at Colne u/s Thames (figure 4.8) passes all statistical tests also.

The figures 4.9 and 4.9[a] show the output for the flow calibration against Denham GS and Colne Brook u/s Thames, respectively, of the original model. The figure 4.10 up to 4.12 show the phosphate calibration against Denham GS, Colne Brook u/s Thames, and Colne u/s Thames, respectively, of the original model. Comparing these graphs with the graphs of the calibration of this study show that the output of the flow and phosphate of the model in this study give a better fit than the output of the original model.

4.2.4 Validation (January 1982 to January 1984)

For the validation the same type of data were used as used during calibration, but then for the validation period.
The flow from Maple Lodge STW however was not available in daily data, but weekly data.

The model was validated against the same three points used for calibration. Because there were no data available at Colne Brook u/s Thames, or Colne u/s Thames for the validation period the flow was only validated against Denham GS. The quality was validated against all three points, see table 4.7.

Table 4.7 Validation points in the Colne catchment

Calibration point	Flow	Quality
Denham GS	+	+
Colne u/s Thames	-	+
Colne Brook u/s Thames	-	+

\- = no calibration against this point;
\+ = calibration against this point

The flow at Denham GS was validated by changing the accretional flow. The accretional flow appeared to be 4000 m3\km\day. The same accretional flow was used for the Colne Brook reach and the Colne tributary.
The same phosphate concentration in the accretional flow as used in the calibration was used for validation. Also the same decay rates as used the calibration were put in. The results are shown in the figures 4.13 up to 4.16. Figure 4.13 shows the graph of the validation of the flow against Denham GS, which passes only the z-test. The graph of the validation of the phosphate against Denham GS is shown in figure 4.14 and fails all statistical tests. Also all tests are failed at the phosphate validation against Colne Brook u/s Thames (figure 4.15) and at Colne u/s Thames the phosphate validation graph passes the z-test and the Kolmogorov-Smirnov-test (figure 4.16).
To pass all the statistical tests for the phosphate validation against Denham GS a decay rate of 1.5 (1/km) has to be used. . The difference in output by using a decay rate of 0.7 or 1.5 (1/km) are shown in figure 4.17.

The final TOMCAT file is called VCOLNE67.TOM and can be found in the directory I:\GERRIE\MARK\C28\VAL28.

4.2.5 Sensitivity of the model

It is important to know to which input data the model is sensitive. When a model is sensitive to a certain input it means that with little change in that certain input the output changes a lot. The TOMCAT model for the R. Colne was examined for it's sensitivity to STWs flow, the order of the STWs in a catchment, the phosphate distribution from STWs, and the phosphate concentration in the accretional flow.

STWs flow
During the validation, the flow of the STWs turned out to be very important. To be able to use a decay rate of 0.7 (the same as in the calibration model) the flow of Blackbirds STW and Maple Lodge STW in the validation model needed to be reduced by only 4% (see figure 4.18). Without these flow reduction a decay rate of 1.7 had to be used to achieve the same simulation results as achieved in calibration (see figure 4.19). This shows that the flows of STWs are very important and need to be put in into the model as accurate as possible.

Phosphate distribution at STWs
To check the sensitivity of the model to the shape of the distribution of the phosphate coming from the STWs the phosphate distribution of Maple Lodge STW in the calibration model was changed and the output at Denham GS was examined. Maple Lodge STW was used because it is the largest STW in the Colne catchment. Table 4.8 shows the input used in the sensitivity test.

Table 4.8 Input used to test the model sensitivity to different shape of the distribution of the phosphate concentration in the Maple Lodge STW discharge

File	Distribution	Mean	S.D.
VCOLNE23.TOM	non-parametric	4.380	1.464
VCOLNE31.TOM	log normal	1.424	0.325
VCOLNE32.TOM	normal	4.380	1.464

The results are shown in the figures 4.20 and 4.21. These figures show that the distribution of phosphate concentration in the STW discharge used in the model is important, because of its influence on the simulation. The normal distribution gives a better estimation than the lognormal distribution. The graph belonging to the non-parametric distribution is most similar to the graph of the observed data.

Phosphate concentration in the accretional flow
The sensitivity of the model to the phosphate concentration in the accretional flow was examined by doubling it. The results are shown in figure 4.22. XCOLNE23.TOM has an accretional phosphate of 1.08 mg/l and XCOLNE40.TOM has an accretional flow of 2.0 mg/l. The graph of XCOLNE40.TOM lies reasonable higher than the graph of XCOLNE23.TOM. So the phosphate concentration in the accretional flow is of interest for the outcome of the simulation. Using a phosphate concentration of 1.08 mg/l in the accretional flow gives the best result.

4.3 Conclusion

The validation of the River Colne model is still not very satisfying, the decay rate used for validation against Denham GS differs from the one used against that same point during calibration. This is probably due to a lack of data for the validation period. For example there are no daily flow for Maple Lodge STW, and no accretional flow estimates. Besides this there are no data available for the phosphate concentration in the accretional flow. The sensitivity study showed that these input have influence on the output of the model. The flow of the STWs appeared to be very important. Also the distribution of the phosphate concentration in the STW discharge is important, the non-parametric distribution is the best. If there are no data available the normal distribution gives a better estimate than the lognormal distribution. Also the phosphate concentration in the accretional flow have influence on the output of the model.

However, the results of the calibration in this study are better than the results of the calibration of the original model.

5 WORK ON THE THAMES PHOSPHATE MODEL

5.1 Introduction

Besides improving the Colne catchment model other work could be done to improve the Thames Phosphate Model. In one catchment the order of the STWs appeared to be wrong. The impact of this on the model output was investigated. Most of the decay rates used in the Thames Phosphate model are below 1 (1/km), but in some catchments they are higher. These high decay rates were tried to bring down.

5.2 Order of STW

It was discovered that in the schematisation of the Loddon catchment (catchment number 24) the order of the STW, and the distances of the STW to the Thames, were wrong. After the correction of the STW order the Loddon catchment model was run again. The difference is shown in figure 5.1. LOD4.07 (name of TOMCAT output file) gives the simulation result with the wrong STWs order and LOD5.07 gives the simulation result with the right STWs order. There is a change in model output.

The order of other catchments with a lot of STWs have been checked. These catchments are:

- Cherwell catchment (catchment number 14);
- Kennet catchment (catchment number 22);
- Wey catchment (catchment number 30);
- Mole catchment (catchment number 32).

All the orders were correct.

5.3 High decay rates

5.3.1 Introduction

Some of the sub-catchments of the River Thames are being modelled with a high phosphate decay rate. These are mostly small streams with high STW flows. Changes in the input of the model were made to try to bring the decay rate down. This has been done for the following catchments:

- Great Brook (decay 2.5 1/km);
- Ginge Brook (decay 2.7 1/km);
- Sulham Brook (decay 5 1/km);
- Cholsey Brook (decay 1.8 1/km);
- Chertsey Bourne (decay 2.1 1/km).

In the Thames model also a high decay rate (8.5 1/km) occurred in the confluence of Cerney Wick Brook with the River Thames. This decay rate was also tried to reduce.

5.3.2 Reducing high decay rates

Great Brook (catchment number 9)
Three STWs discharge into the Great Brook: Brize Norton STW, Carterton STW, and Bampton STW. In the original model consents were used to model these STW flow and the quality of the STW flow was estimated by using a normal distribution.
To try to bring the decay down measured data were used in the 'new' model to model the quality of the STW flows. There are no measured data for the flow of the STWs in the catchment of the Great Brook, therefore the consents were used again.
There are no gauging stations and sampling points in the catchment of the Great Brook. Therefore no measured data for the flow and quality u/s of the STWs was available, and the estimation made in the original model for the u/s flow was used in the 'new' model. Another consequence of the lack of a gauging station is that the flow can not be calibrated.

The results of the modelling are shown in the figures 5.2 and 5.3. With the 'new' input a decay rate of 2.5 1/km had to be used again to pass all the statistical tests and the graph of the output is almost the same as the graph of the output from the original model (see figure 5.2). Using a lower decay rate in the 'new' model makes the fit of the modelled graph to the observed one worse (see figure 5.3).

Because the decay rate could not be brought down in the calibration, no validation was carried out.

Ginge Brook (catchment number 18)
Abingdon STW and Drayton STW both discharge into Ginge Brook. Abingdon STW also discharge directly into the River Thames. Two thirds of the effluent are discharged into the River Thames and one third into Ginge Brook.
In the original model consents were used to model the flow of the STWs and a normal distribution to estimate the quality of the STWs flows. The flow u/s of the STW was also estimated using a normal distribution. The quality of the flow u/s of the STWs was not modelled.
In the 'new' model the flow of Drayton STW is modelled using a normal distribution. To calculate the mean and the standard deviation of the flow measured data for 1993 and 1994 were used. There were no data available for 1992. The quality of the flow of Drayton STW was modelled using measured dat. For the flow of Abingdon STW 1/3 * the consent was used and the quality was estimated by using the mean and standard deviation of the observed data for the period 1980-1990 and using a normal distribution. No quality data was available for the calibration period, October 1992 - October 1994. To model the quality u/s of the STWs measured data from sampling point PTHR.0032 was used. The u/s flow

used in the original model was again used in the 'new' model, because no gauging station is present in this catchment.
The accretional quality was recalculated (see appendix E) and a decay rate of 2.7 1/km (same as in the original model) was used.

With this new input a higher phosphate was modelled as when using the original input as is shown in figure 5.4 and therefore the decay rate could not be brought down. For this reason no validation was carried out.

Cholsey Brook (catchment 20)
Cholsey STW discharges into Cholsey Brook. In the original model the flow of this STW was modelled using the consent and the quality was estimated using a normal distribution. The flow u/s of the STW was also estimated using a normal distribution, the quality of this flow was not modelled.

In the 'new' model the flow of the STW again the consent was used and for the quality measured data from sampling point PTHE.0043. Because there are no gauging stations in this catchment the u/s flow was modelled using the estimation from the original model. The data from sampling point PTHR.0015 was used to model the quality u/s of the STW. The accretional phosphate was recalculated as being 191 (mg/l) (see appendix E), in the original model an accretional phosphate of 284 (mg/l) was used.
It appeared that a decay rate of 1.8 or 0.5 (1/km) can both be used to make the output pass all tests. Figure 5.5 shows that there is not much difference in the output graph of the original model and the 'new' model using a decay rate of 0.5 (1/km) in both models. Figure 5.6 shows that using the original model a decay rate of 1.8 or 0.1 (1/km) can both be used to create outputs that pass all statistical tests.

During the validation the same type of data were used, but then for the validation period. When a decay rate of 1.8 (1/km) is used, all the tests are failed. Using the original input and a decay of 1.8 (1/km), all tests are passed (see figure 5.7). Using the original model again a decay rate of 1.8 or 0.1 (1/km) can both be used to pass all the statistical tests (see figure 5.8).

Sulham Brook (catchment number 21)
Pangbourne STW discharges into Sulham Brook. In the original model the flow of the STW was modelled using the consent and the quality of the STW was modelled using a normal distribution. The flow u/s of the STW was estimated using a normal distribution, the quality of that flow was not modelled.

In the 'new' model the flow u/s of the STW was modelled using data measured at a gauging (2195) u/s of the STW, and also measured data were used for the quality of this flow using measured data from a sampling point (PPSR.0006). For the flow of the STW again the consent was used and for the quality of the discharge measured data were used. The accretional phosphate was recalculated

(see appendix E) and appeared to be 0.
Figure 5.9 shows that the shape of the output graph of the 'new' is much better than the original model, using the same decay rate (5 1/km) in both models. A decay rate from 0.1 up to 5 (1/km) could be used in the 'new' model to make the output pass all the statistical tests. But the graphs (figure 5.10) show that the output with a decay rate of 5 (1/km) gives the best fit.

The same thing happened during validation, a decay rate from 0.1 to 5 (1/km) could be used to make the output pass all the statistical tests, but the output with decay rate 5 (1/km) gives the best fit (see figure 5.11). For the validation again the consent flow and measured data were used for the flow and quality of the STW. For the quality u/s of the STW measured data were used. No flow data u/s of the STW were available so the flow data from the period 1992-1993 were used.

Chertsey Bourne (catchment 29)
Three STWs discharge into Chertsey Bourne: Lichtwater STW, Chobham STW and Chertsey STW. In the original model consents were used to model the flow of the STWs and the quality of the discharge was estimated by using a normal distribution. Also the flow u/s of the STW was estimated by using a normal distribution and the quality of this flow was not modelled.

In the 'new' model again the consent was used to model the STW flows and measured data were used to model the quality of the discharges (PBNE.0024, PBNE.0020 PBNE.0009 respectively). Using this input and a decay rate of 2.1 (1/km) all the statistical tests are passed. When the decay rate decreases to 0.7 all the tests are failed (see figure 5.12). In figure 5.13 the output of the original model and the 'new' model with both a decay rate of 2.1 (1/km) are shown. Although the difference in output is little, the output of the 'new' model has a shape more similar to the observed data than the original model. The decay rate could not be brought down.

During the validation the same sort of data were used, only then for the validation period. Again a decay rate of 2.1 (1/km) had to be used. The results are shown in figure 5.14. The original model passes only the z-test and the 'new' model fails all tests. But the shape of the output graph of the 'new' model looks more like the shape of the observed graph than the output graph of the original model does.

Confluence of Cerney Wick Brook with River Thames
To try to reduce the high decay rate in the confluence of Cerney Wick Brook and the River Thames a few changes in the input of the model for the calibration period (October 1992 - October 1994) were made. The flow and quality u/s of Ashton Keynes STW were modelled by putting in the flow measured at gauging station River Thames at Ewen (GS 0130) and the quality measured at Thames Somer Ford Deynes Bridge (PUTR.0104). For Ashton Keynes STW the consented flow was used and for the quality measured data were used. The same was done for Cirencester STW which discharges into Cerney Wick Brook.

Down stream of Ashton Keynes STW Swill Brook flows into the River Thames. This is being modelled as an effluent, using the flow data of gauging station Swill Brook at Oaksey Lane (GS 0155) and the quality measured at sampling point (PUTR.0086). This tributary was not modelled in the original model.

The flow was calibrated at Cricklade (GS 0190). With this input the high percentiles flows were much too high and could not be brought down by for example deleting Swill Brook effluent.

In order to reduce the high percentile flows the seasonality components were removed from the flow at River Thames at Ewen. This was done by turning the 'monthly effects' off using ANOVA on the raw flow data in a statistical package called MARIGOLD. Another way to try to reduce the high percentile flows was to turn off the 'log option' using ANOVA on the raw flow data in MARIGOLD. The TOMCAT output files were called XTHAMES1.TOM and XTHAMES2.TOM, respectively. The TOMCAT output file XTHAMES3.TOM shows the output when the non-parametric distribution of the raw date was used, without any changes in MARIGOLD (see table 5.1).

Table 5.1 The different options used in MARIGOLD

TOMCAT output file	Log option turned off	Seasonality components removed
XTHAMES1.TOM	-	√
XTHAMES2.TOM	√	-
XTHAMES3.TOM	-	-

The effects of the two options were looked at by putting in a sampling point (called 'Input control') 10 meters d/s of the start of the reach. The graph of XTHAMES1.TOM (name of the TOMCAT output file) in figure 5.15 shows the flow 10 meters down stream of the start of the reach. XTHAMES3.TOM in figure 5.16 shows the flow at that same point with a non-parametric distribution of the raw u/s flow input. The 99%ile of XTHAMES1.TOM is about a 100 times smaller than the 99%ile of XTHAMES3.TOM.

In figure 5.17 the graph of XTHAMES2.TOM shows the flow 10 metres d/s of the u/s flow input with the 'log option' turned off. XTHAMES1.TOM again shows the flow at that same point with the seasonality removed from the u/s flow input. The graphs show that taking seasonality out of the raw flow data gives the best result. The shape of the flow is very similar to the observed one. Turning off the 'log option' in MARIGOLD does nog give as good results as taking out seasonality, but much better than putting in the non-parametric distribution of the raw data.

At Cricklade (GS 0190) the difference between taking out seasonality and turning off the log option has decreased (figure 5.18). Besides, a problem with removing seasonality from the flow data is that the phosphate concentration in the river changes with the changing of the seasons (see part two of this report). Therefore it would be better to turn off the log option and leave the seasonality in.

With both options (taking out seasonality and turning off the log option in MARIGOLD) the model was further worked out. The flow was calibrated by putting in an accretional flow of 3000 m^3/km/day for both options. No change was made for the flow in Cerney Wick Brook. The results for the flow are shown in figure 5.19.

The quality input has been described above and is the same for both options. The accretional phosphate concentration was recalculated and appeared to be 0 (see appendix F). To achieve a good fit a decay of 8.5 (1/km) had to be used, which was used in the original model. The results for the output of phosphate are shown in figure 5.20.

No improvement was made with the new input.

5.4 Effects of phosphate stripping

During work on the original model, the Thames Phosphate Model was run to see what would happen to phosphate levels in the Thames if all UWWTD works discharge at 2 mgP/l (reference 1). In this study the model was also run with all UWWTD works discharge at 0.1 mgP/l, 0.0 mgP/l and with no STW flow at all from UWWTD works[1]. If the model of a sub-catchment can be improved (see paragraph 5.3), this improvement is used in the Thames Phosphate Model. This has been done for the catchments of the River Colne, Sulham Brook, Chertsey Bourne and Cholsey Brook.

The results are shown in figure 5.21 compared with the actual phosphate concentration. The model predicts mean concentrations around 0.3 mgP/l for STW discharge of 2 mgP/l and 0.1-0.2 mgP/l for discharge of 0.1 and 0.0 mgP/l and no STW flow. The actual level lies around 0.6 mgP/l.

This study shows that phosphorus removal up to 0.1 mgP/l at all STWs would bring river phosphate levels down to around 0.1 mgP/l. Bringing the STWs output down to 0.0 mgP/l or remove all STWs discharge have almost the same effects on the phosphate concentration in the River Thames. This could mean that, due to for example agriculture, 0.1 (mgP/l) is the background phosphate concentration in the river.

1 UWWTD works, are works discharging into an area that has been designated as a Sensitive Area under the Urban Waste Water Treatment Directive.

5.5 Conclusion

It is important to make sure that the order of the STWs in the catchments is right, because the order has an influence on the output of the model.

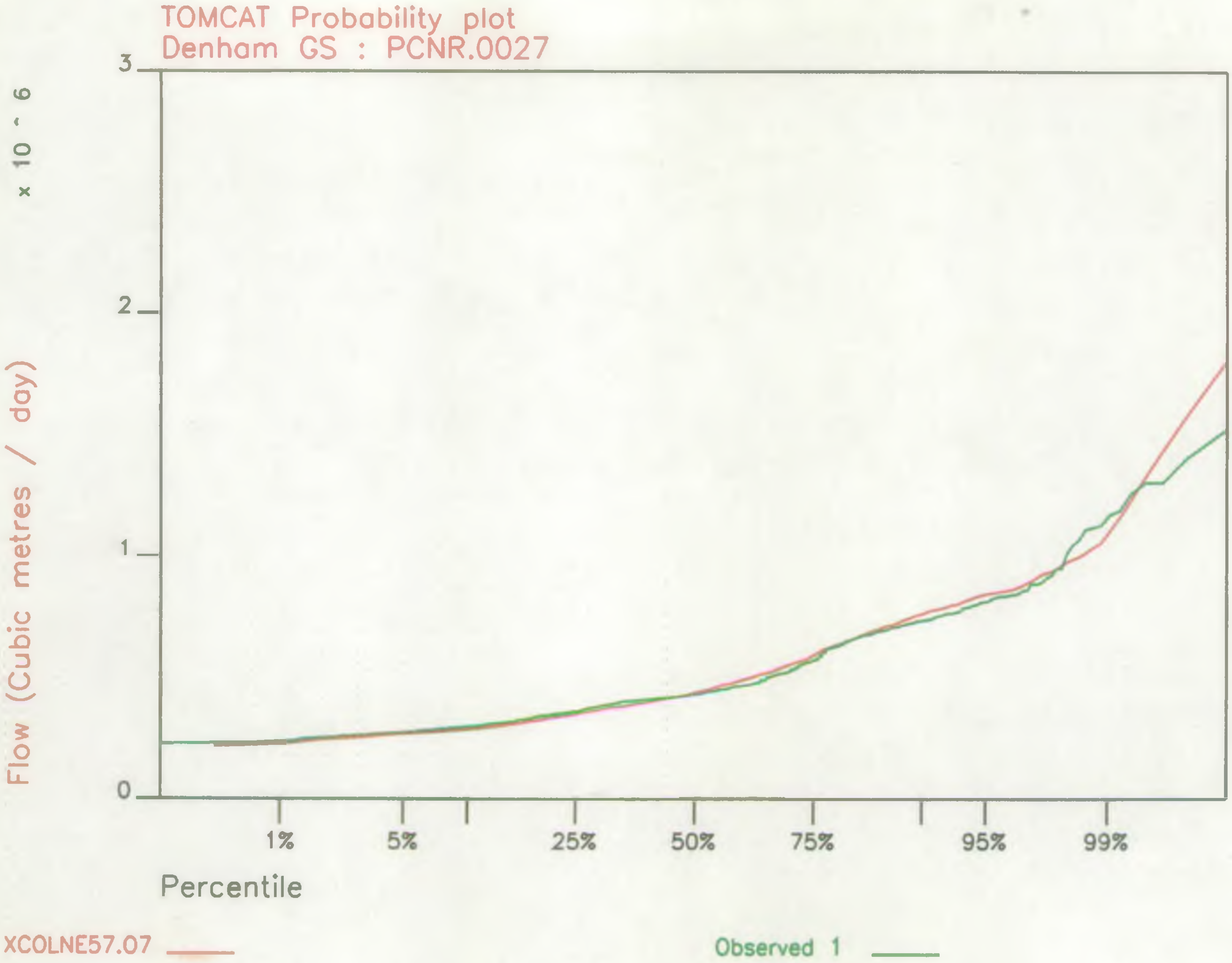
The model for the catchments of the Great Brook and the Ginge Brook could not be improved by putting in available measured data. Neither could the high decay rate in the confluence Cerney Wick Brook with River Thames be brought down. Therefore the models of these sub-catchments were not changed in the Thames Phosphate Model.

The 'new' models for the Sulham Brook and the Chertsey Bourne do not have a lower decay rate, but the output graphs have a shape more similar to the observed output graph than the original models. The 'new' model for the Cholsey Brook did not improve the output, but the original model can be run with a lower decay rate (0.1 1/km) and still pass all the statistical tests. These changes have been put in into the Thames Phosphate Model.

Using the improved Thames Phosphate Model, it appears that the phosphate concentration in the River Thames can be brought down by reducing the output of phosphate by STWs to 0.1 mgP/l.

REFERENCE

1 Tinsley, M. and Bennett, J. (1995) Phosphorus in the Thames Catchment. National Rivers Authority. Thames Region.



TOMCAT Probability plot
Denham GS : PCNR.0027
x 10 ^ 6
Flow (Cubic metres / day)
3
2
1
0
1%
5%
25%
50%
75%
95%
99%
Percentile
XCOLNE57.07
Observed 1

Figure 4.4

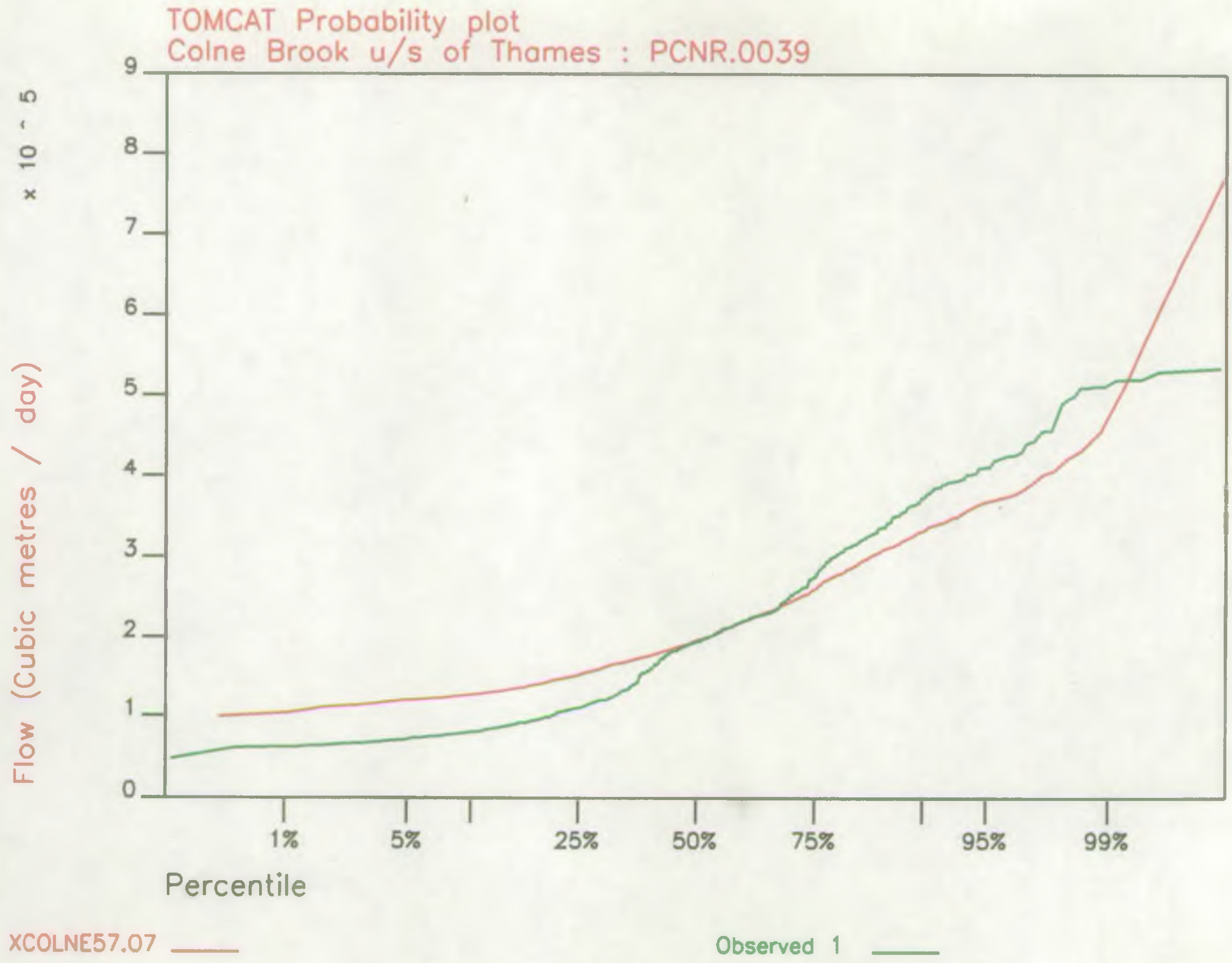
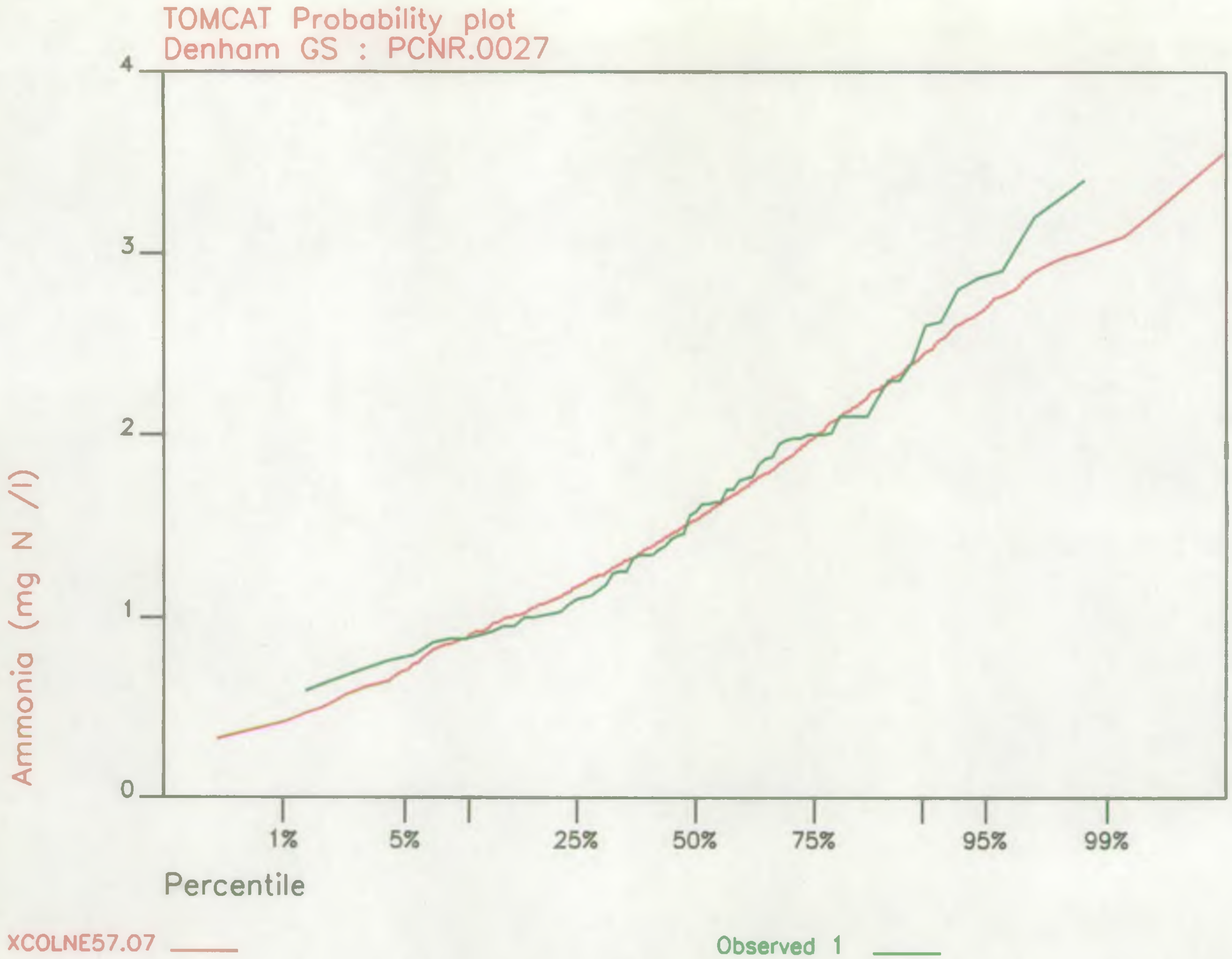

TOMCAT Probability plot
Colne Brook u/s of Thames : PCNR.0039
x 10 ^ 5
Flow (Cubic metres / day)
9
8
7
6
5
4
3
2
1
0
1%
5%
25%
50%
75%
95%
99%
Percentile
XCOLNE57.07
Observed 1

Figure 4.5



TOMCAT Probability plot
Denham GS : PCNR.0027
Ammonia (mg N /l)
0
1
2
3
4
1%
5%
25%
50%
75%
95%
99%
Percentile
XCOLNE57.07
Observed 1

Figure 4.6

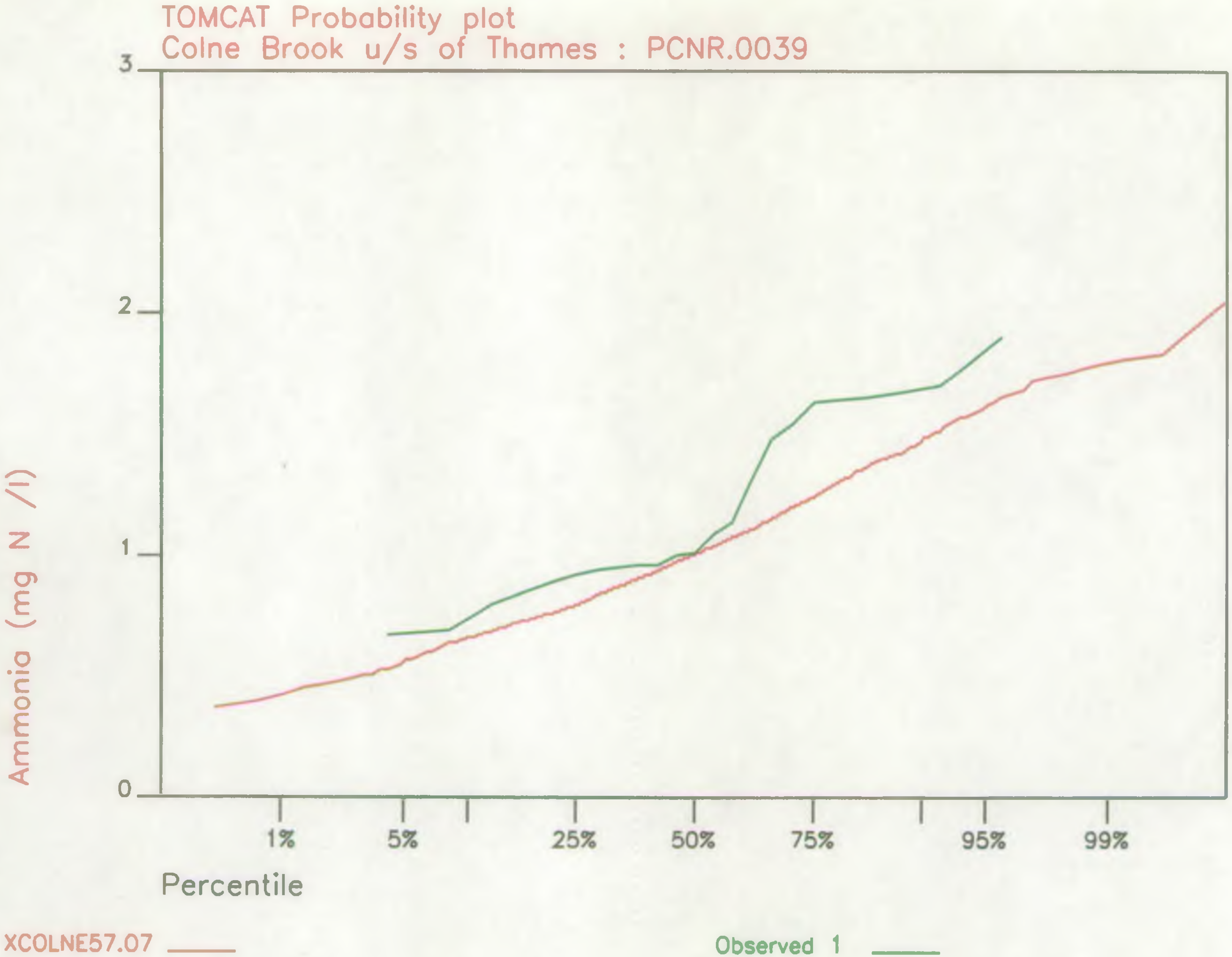
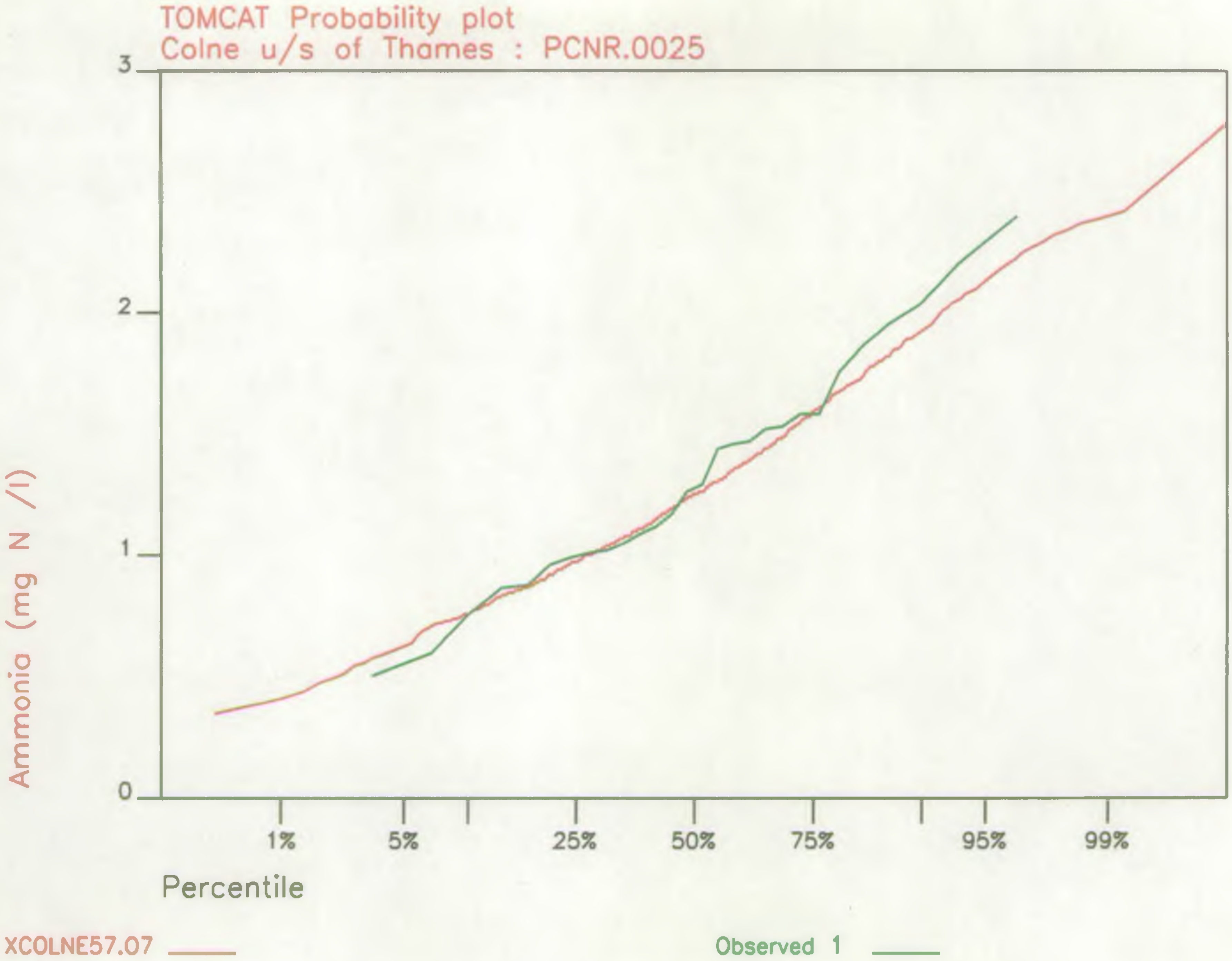
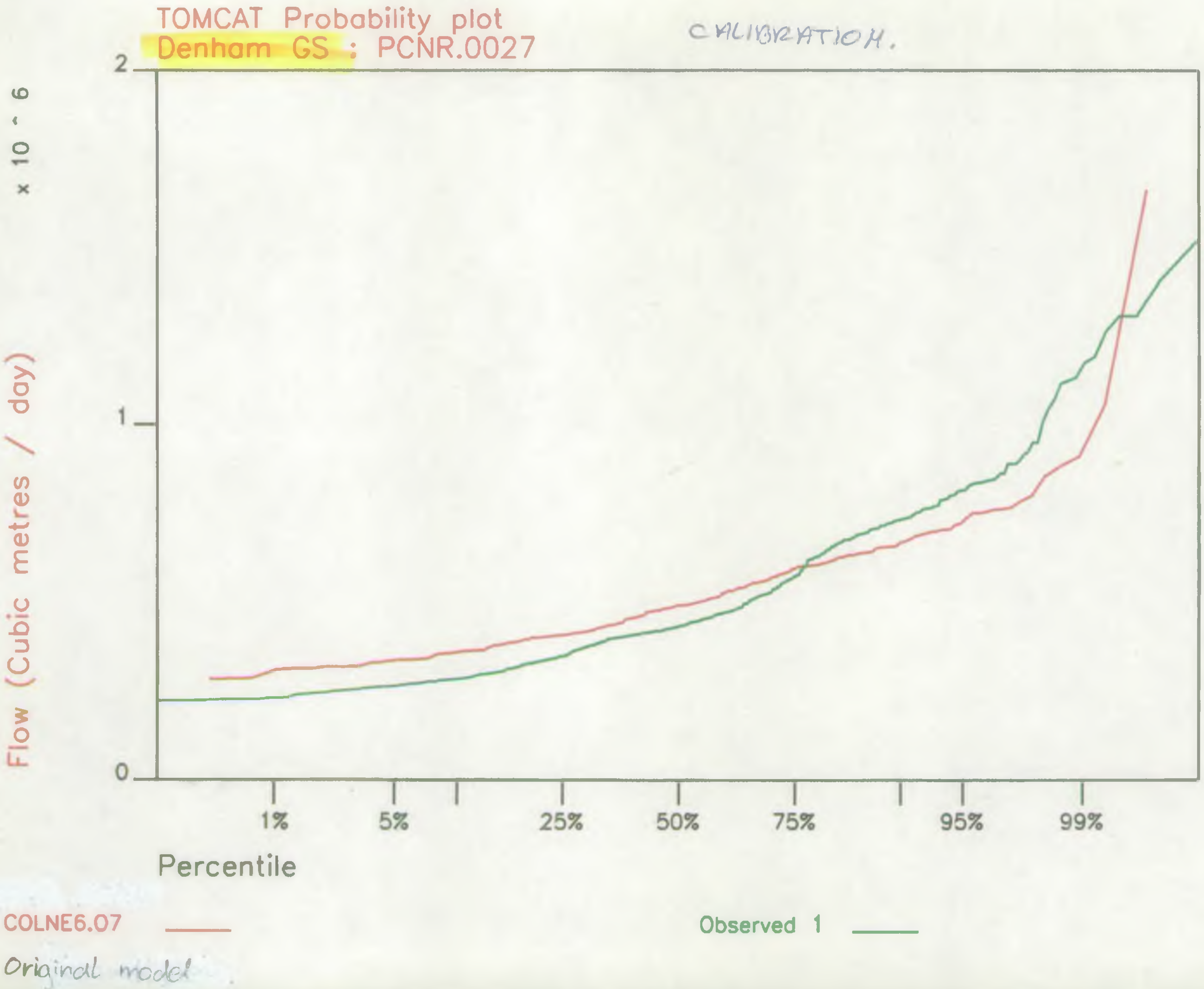

TOMCAT Probability plot
Colne Brook u/s of Thames : PCNR.0039
3
2
1
0
Ammonia (mg N /l)
1%
5%
25%
50%
75%
95%
99%
Percentile
XCOLNE57.07
Observed 1

Figure 4.7



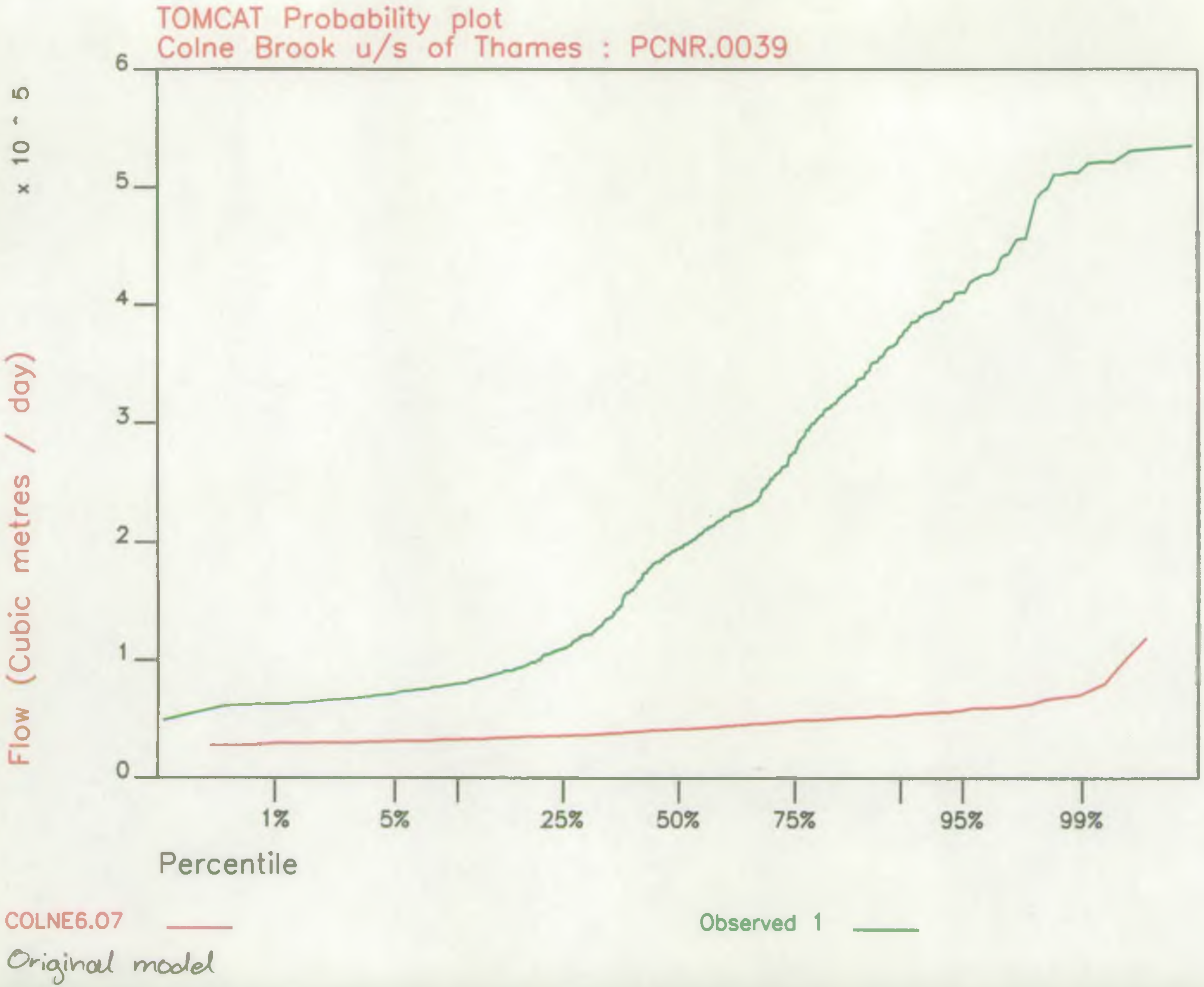
TOMCAT Probability plot
Colne u/s of Thames : PCNR.0025
3
2
1
0
Ammonia (mg N /l)
1%
5%
25%
50%
75%
95%
99%
Percentile
XCOLNE57.07
Observed 1

Figure 4.8



TOMCAT Probability plot
Denham GS : PCNR.0027
CALIBRATION.
2
1
0
x 10 ^ 6
Flow (Cubic metres / day)
1%
5%
25%
50%
75%
95%
99%
Percentile
COLNE6.07
Observed 1
Original model

Figure 4.9



TOMCAT Probability plot
Colne Brook u/s of Thames : PCNR.0039
Flow (Cubic metres / day)
x 10 ^ 5
0
1
2
3
4
5
6
1%
5%
25%
50%
75%
95%
99%
Percentile
COLNE6.07
Original model
Observed 1

Figure 4.9a

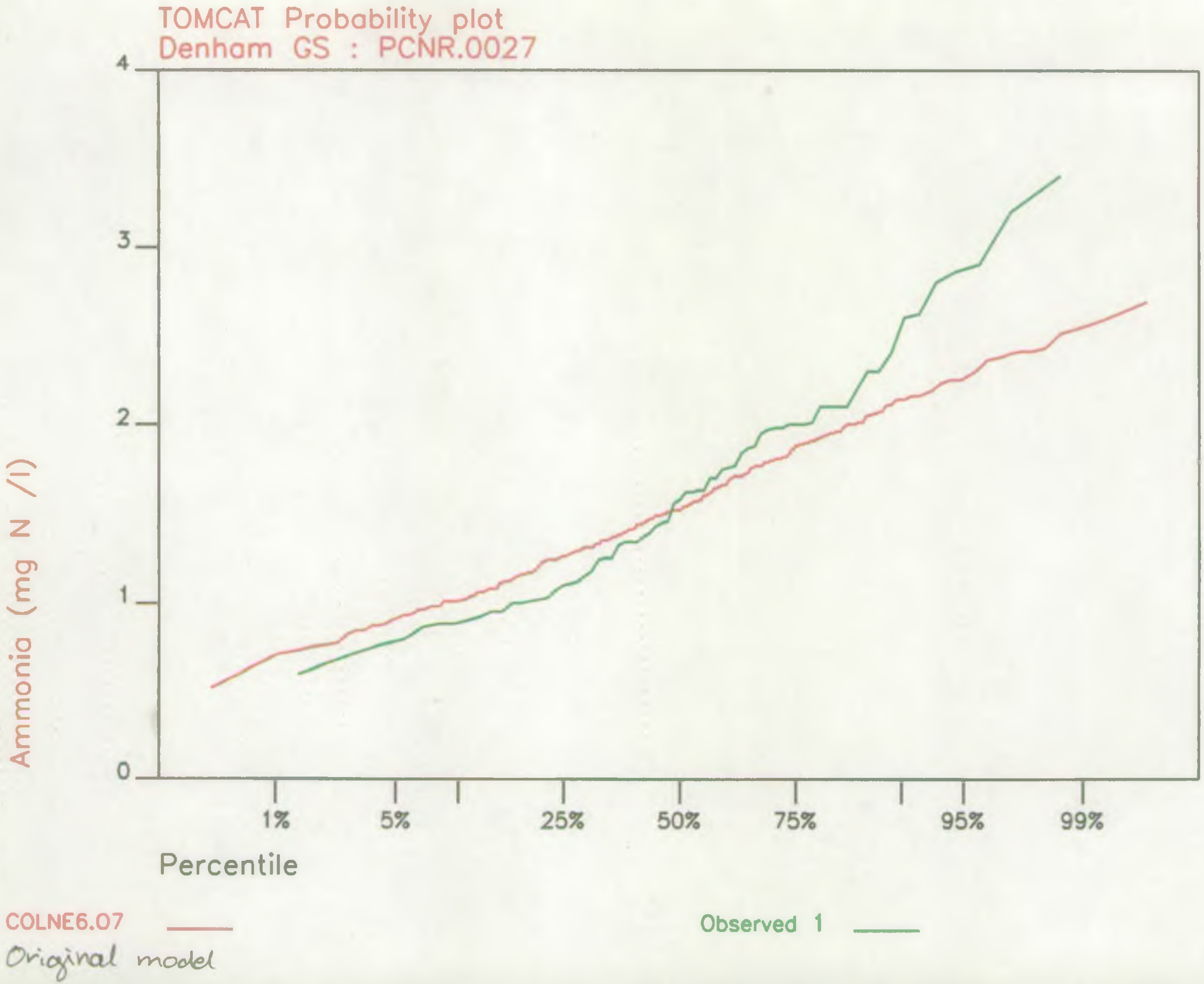
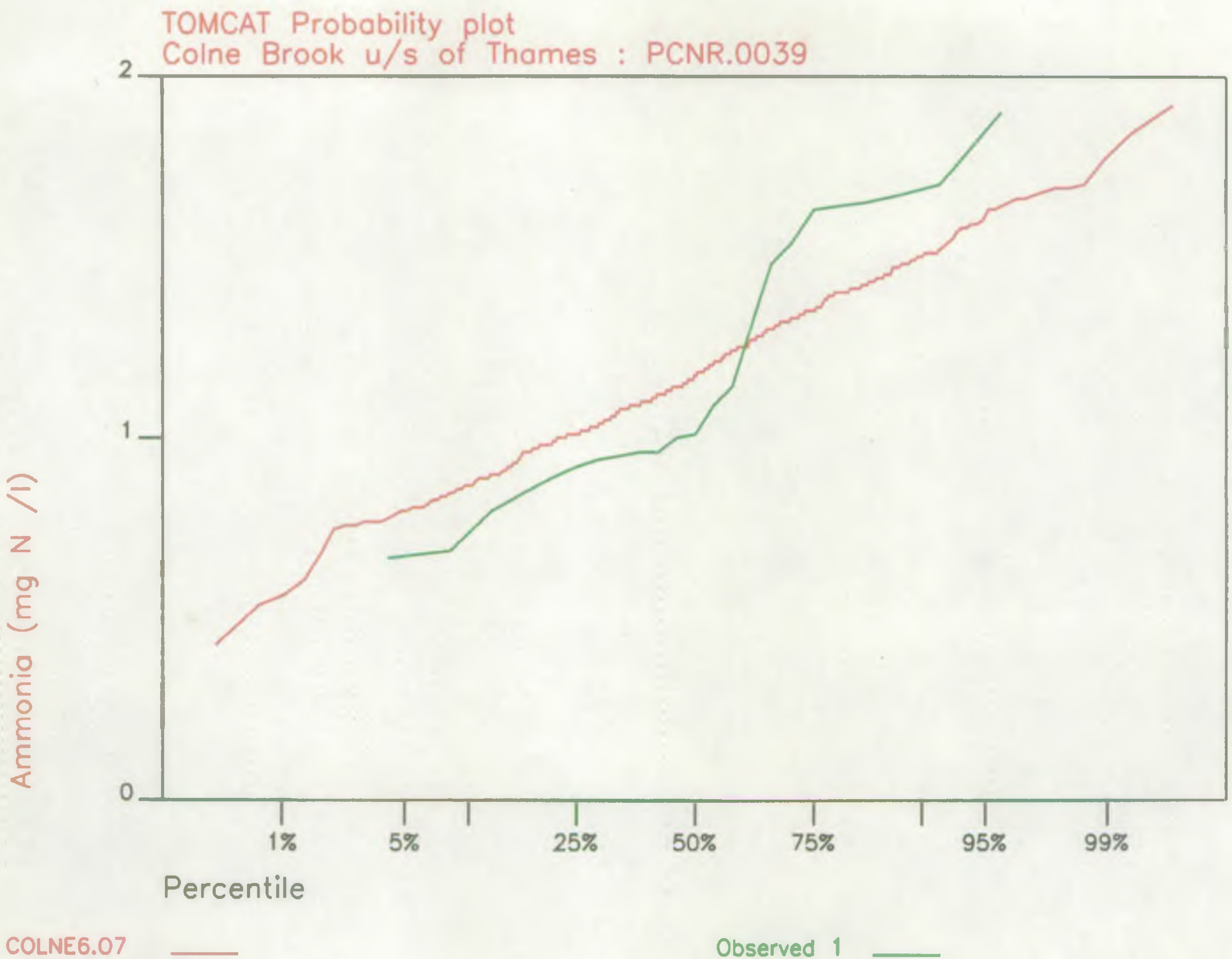

TOMCAT Probability plot
Denham GS : PCNR.0027
4
3
2
1
0
Ammonia (mg N /l)
1%
5%
25%
50%
75%
95%
99%
Percentile
COLNE6.07
Original model
Observed 1

Figure 4.10



Original model

Figure 4.11

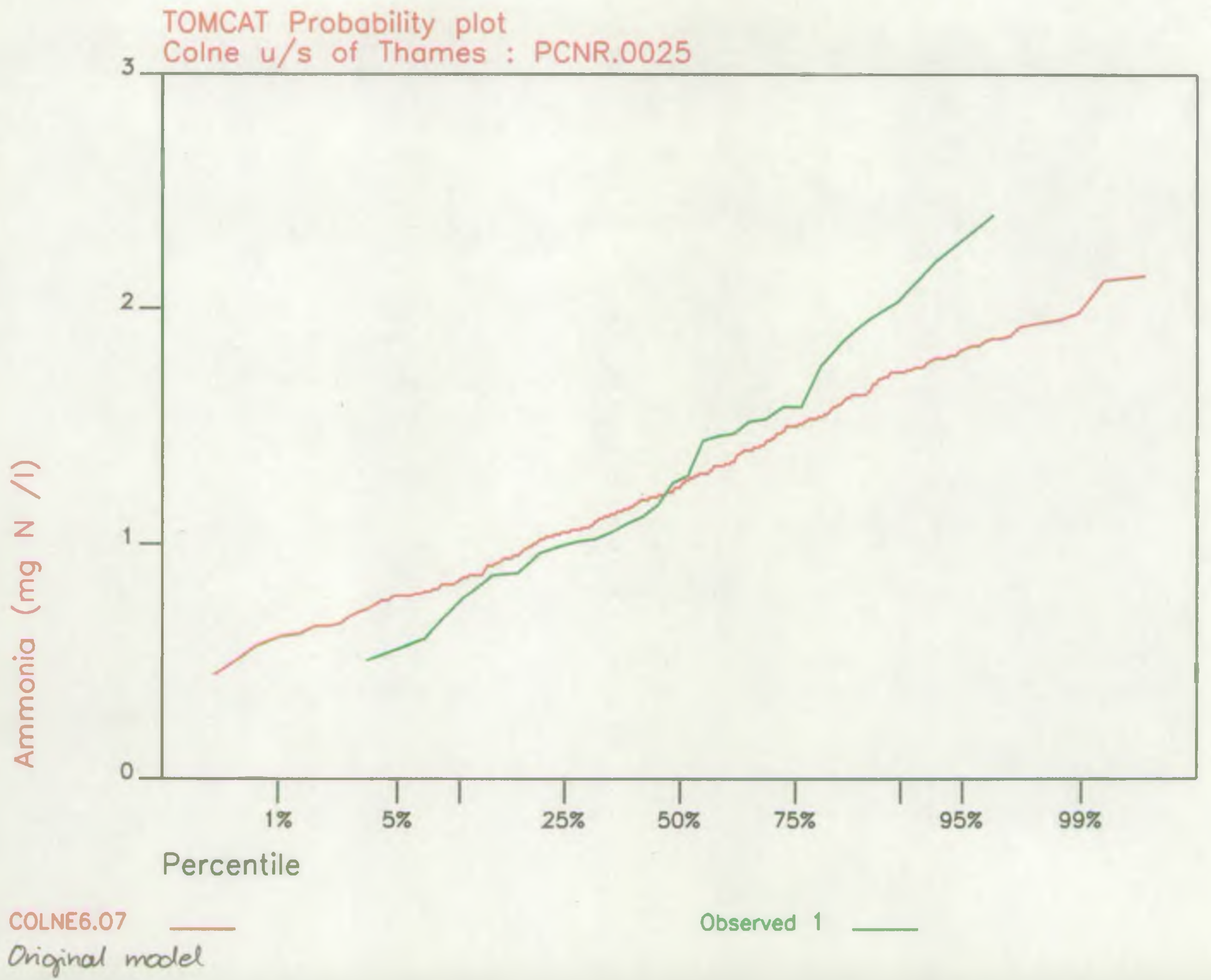

TOMCAT Probability plot
Colne u/s of Thames : PCNR.0025
3
2
1
0
Ammonia (mg N /l)
1%
5%
25%
50%
75%
95%
99%
Percentile
COLNE6.07
Original model
Observed 1

Figure 4.12

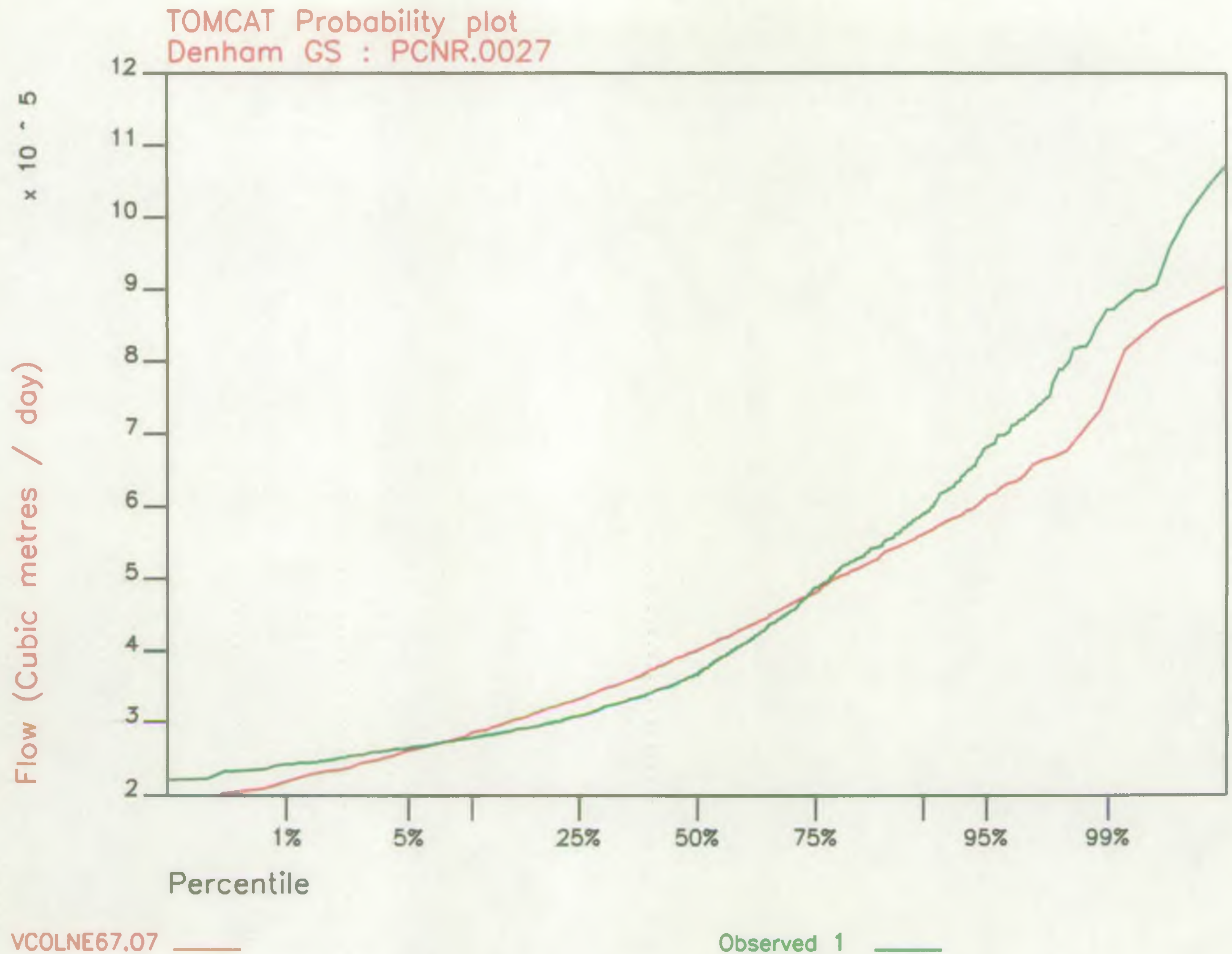
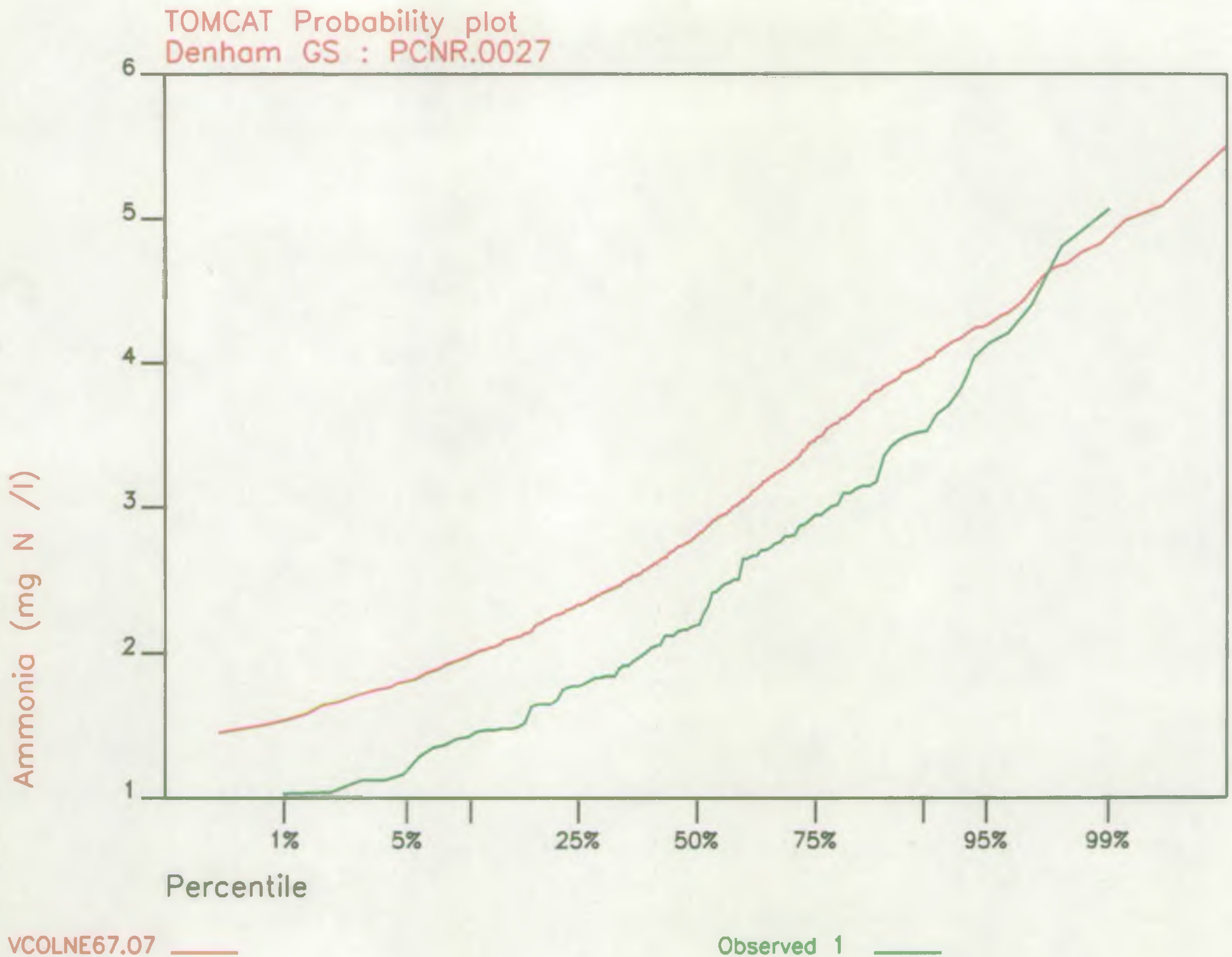

TOMCAT Probability plot
Denham GS : PCNR.0027
x 10 ^ 5
12
11
10
9
8
7
6
5
4
3
2
Flow (Cubic metres / day)
1%
5%
25%
50%
75%
95%
99%
Percentile
VCOLNE67.07
Observed 1

Figure 4.13



TOMCAT Probability plot
Denham GS : PCNR.0027
6
5
4
3
2
1
Ammonia (mg N /l)
1%
5%
25%
50%
75%
95%
99%
Percentile
VCOLNE67.07
Observed 1

Figure 4.14

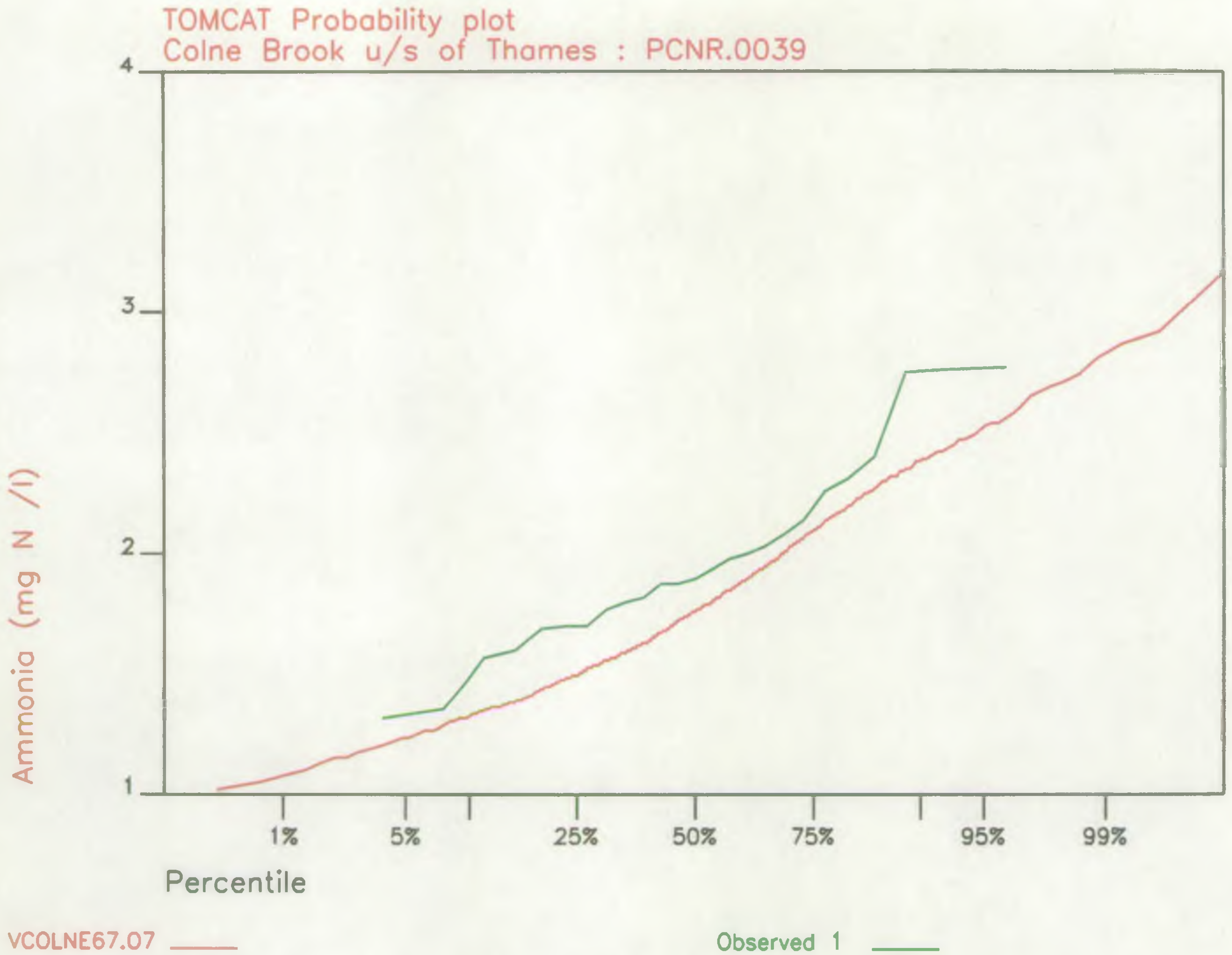

TOMCAT Probability plot
Colne Brook u/s of Thames : PCNR.0039
Ammonia (mg N /l)
4
3
2
1
1%
5%
25%
50%
75%
95%
99%
Percentile
VCOLNE67.07
Observed 1

Figure 4.15

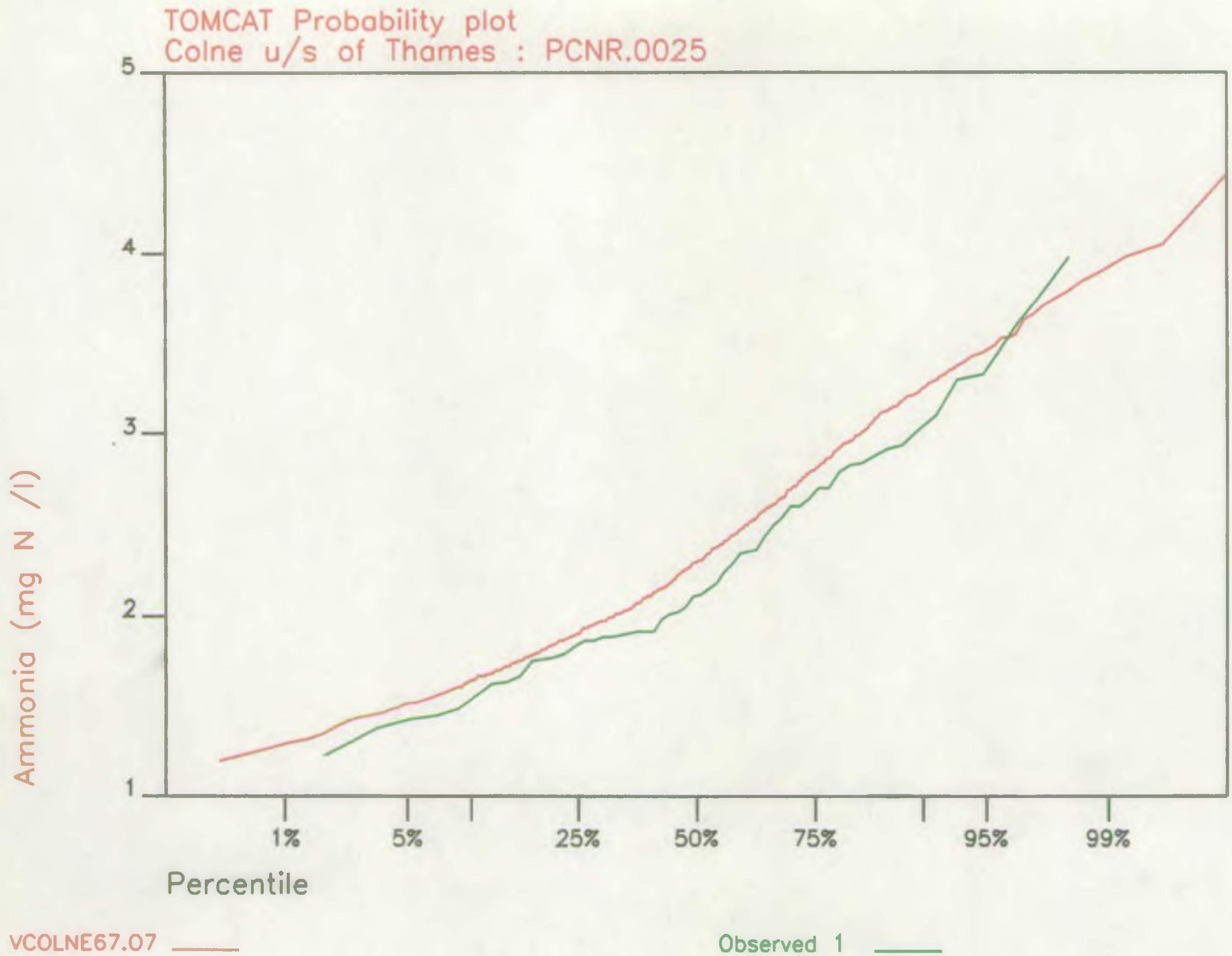

TOMCAT Probability plot
Colne u/s of Thames : PCNR.0025
5
4
3
2
1
Ammonia (mg N /l)
1%
5%
25%
50%
75%
95%
99%
Percentile
VCOLNE67.07
Observed 1

Figure 4.16

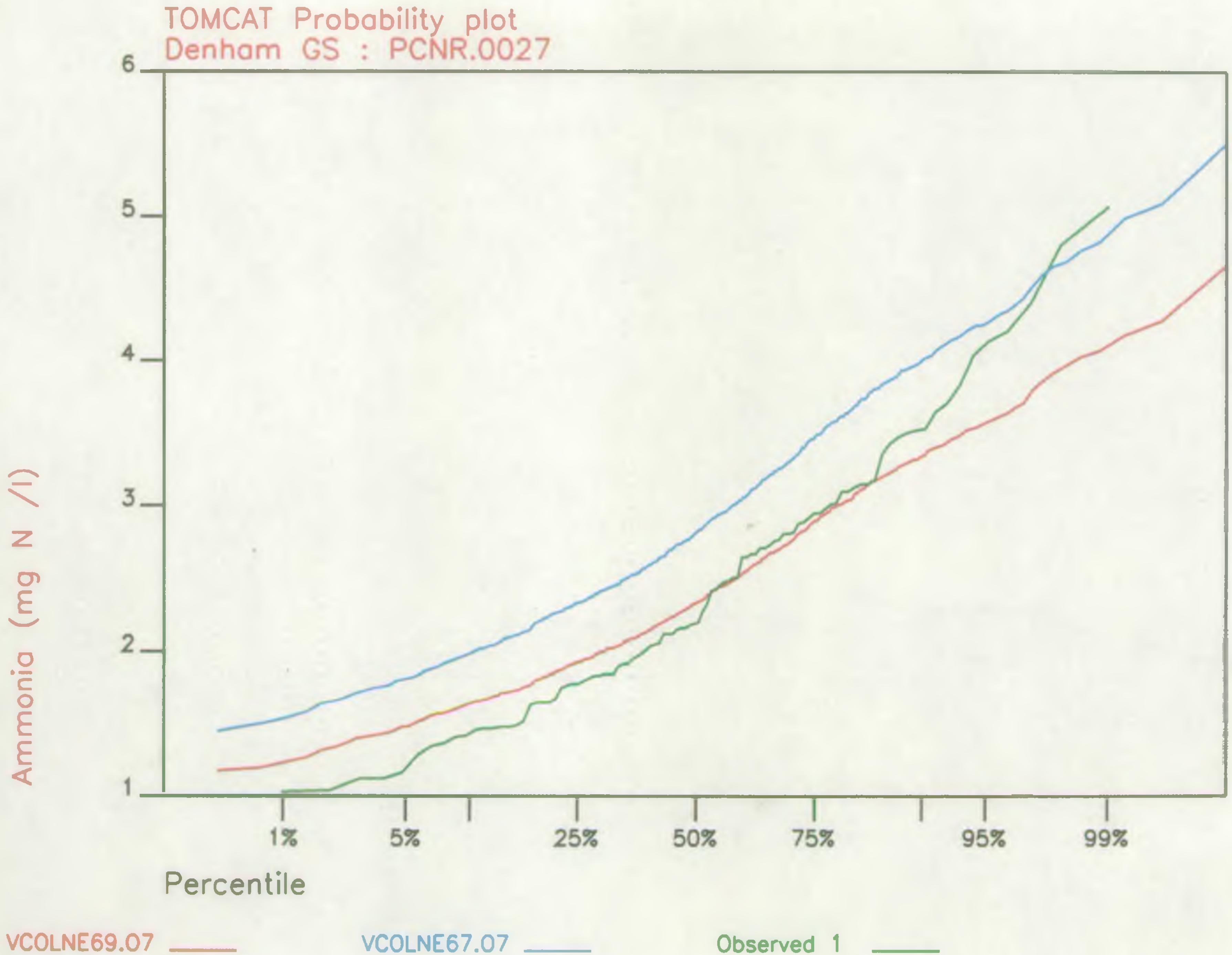

TOMCAT Probability plot
Denham GS : PCNR.0027
6
5
4
3
2
1
Ammonia (mg N /l)
1%
5%
25%
50%
75%
95%
99%
Percentile
VCOLNE69.07
VCOLNE67.07
Observed 1

Figure 4.17

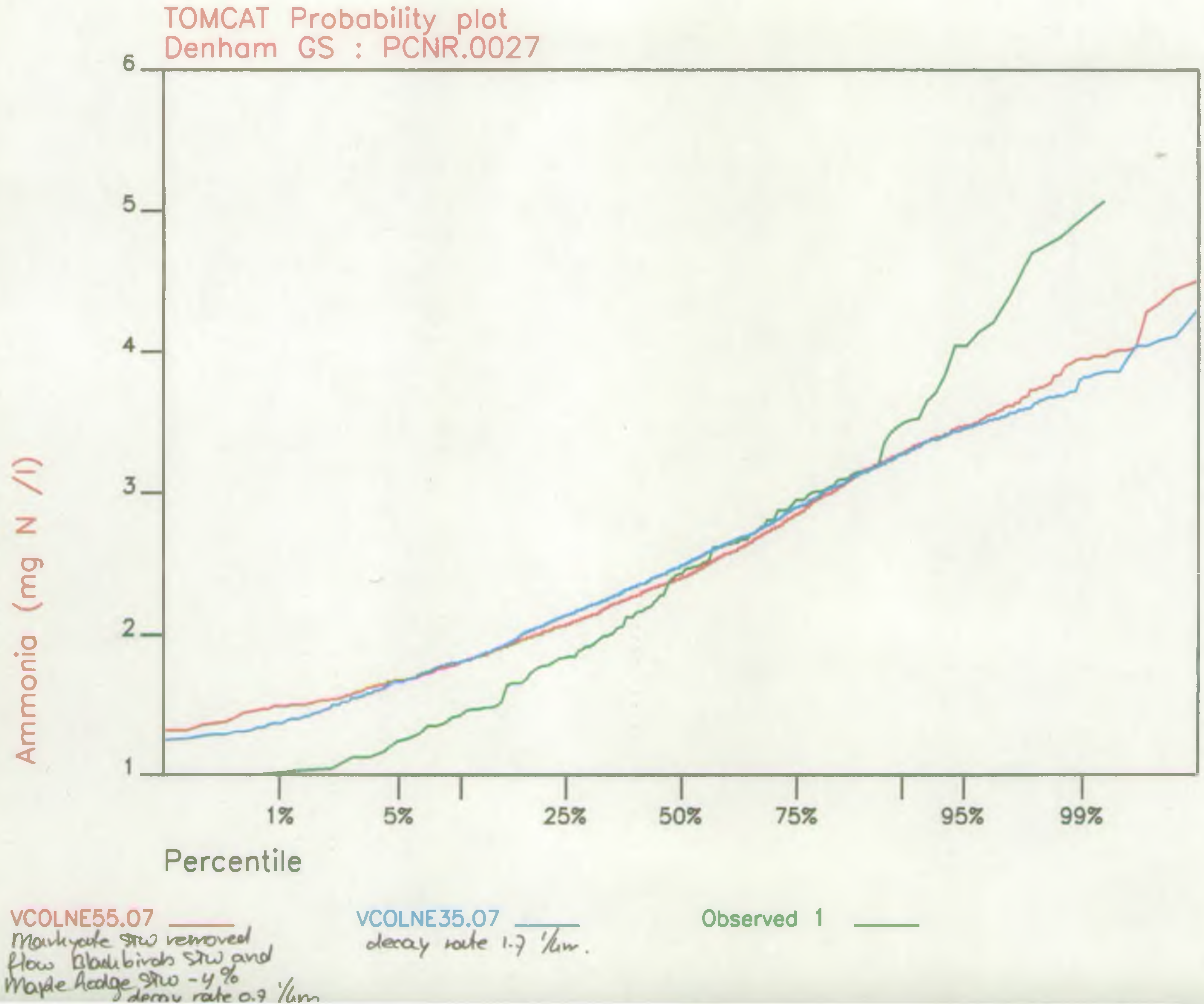
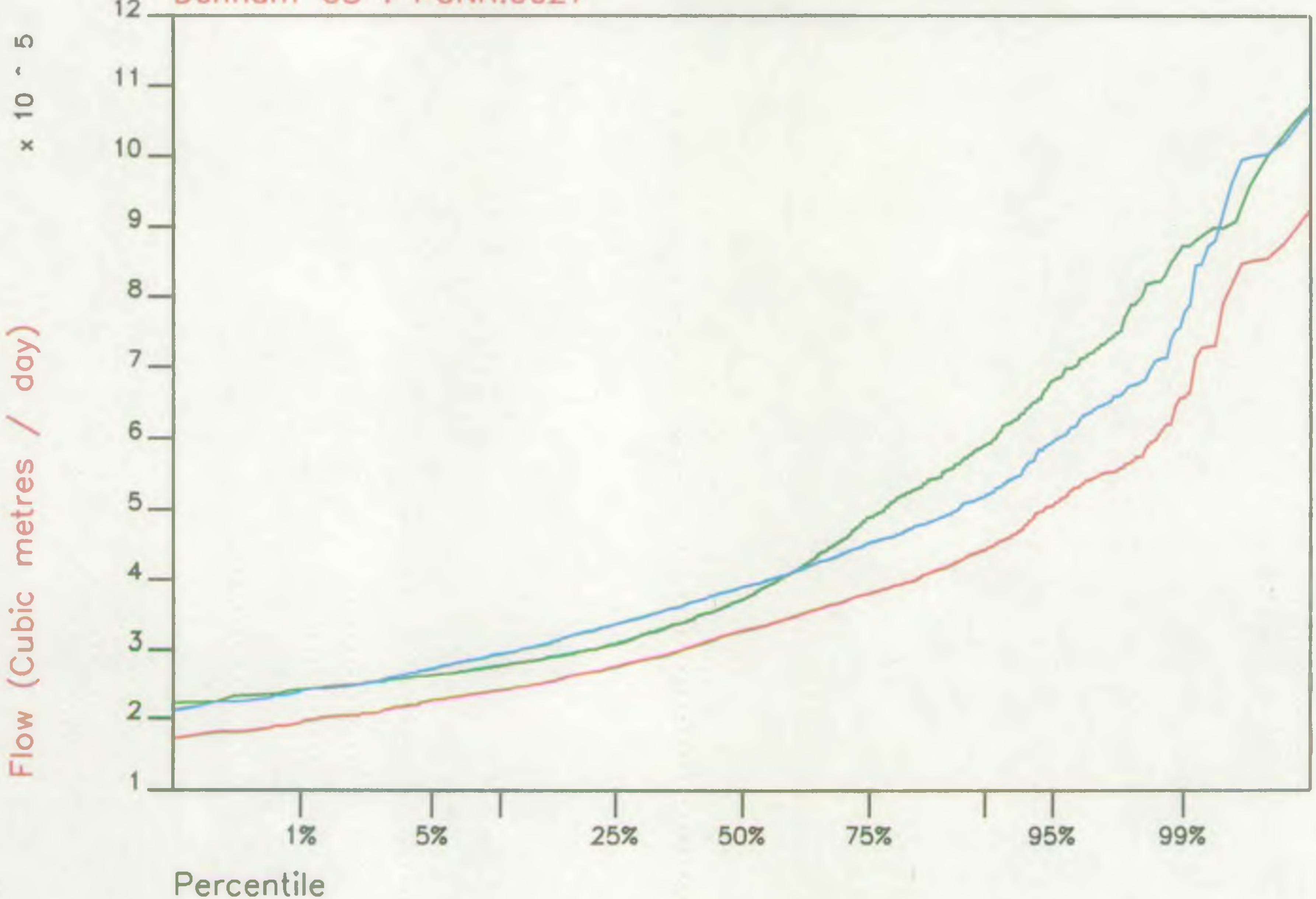

TOMCAT Probability plot
Denham GS : PCNR.0027
Ammonia (mg N /l)
6
5
4
3
2
1
1%
5%
25%
50%
75%
95%
99%
Percentile
VCOLNE55.07
Markyate STW removed
flow Blackbirds STW and
Maple Lodge STW -4%
decay rate 0.9 /km
VCOLNE35.07
decay rate 1.7 /km.
Observed 1

Figure 4.18

TOMCAT Probability plot
Denham GS : PCNR.0027



VCOLNE55.07
Markyate STW removed
flow Blackbirds STW and
Maple Lodge STW - 4% decay
rate 0.7 1/km

VCOLNE35.07
decay rate 1.7 1/km

Observed 1

Figure 4.19

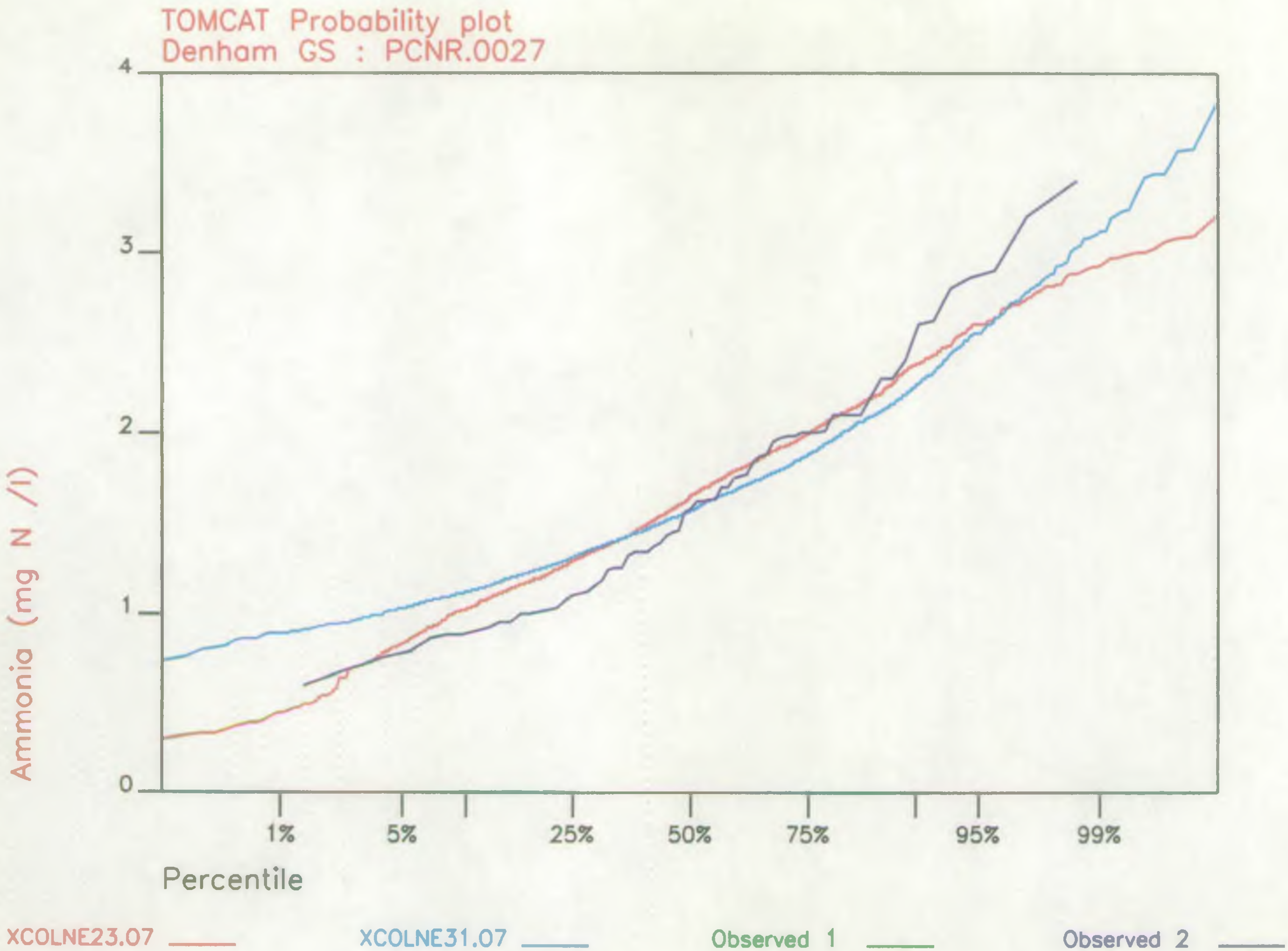
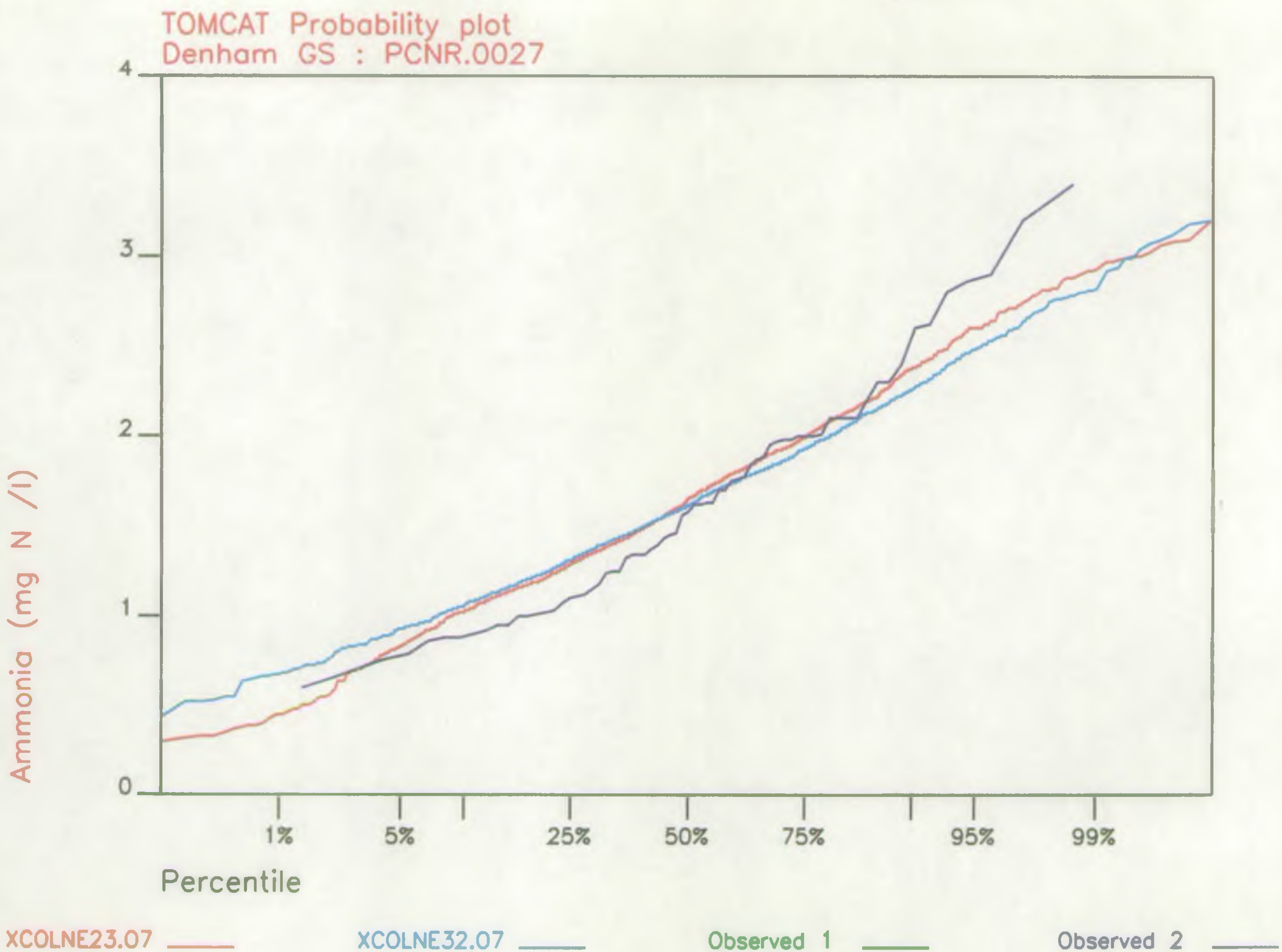

TOMCAT Probability plot
Denham GS : PCNR.0027
Ammonia (mg N /l)
0
1
2
3
4
1%
5%
25%
50%
75%
95%
99%
Percentile
XCOLNE23.07
XCOLNE31.07
Observed 1
Observed 2

Figure 4.20


TOMCAT Probability plot
Denham GS : PCNR.0027
4
3
2
1
0
Ammonia (mg N /l)
1%
5%
25%
50%
75%
95%
99%
Percentile
XCOLNE23.07
XCOLNE32.07
Observed 1
Observed 2
Figure 4.21

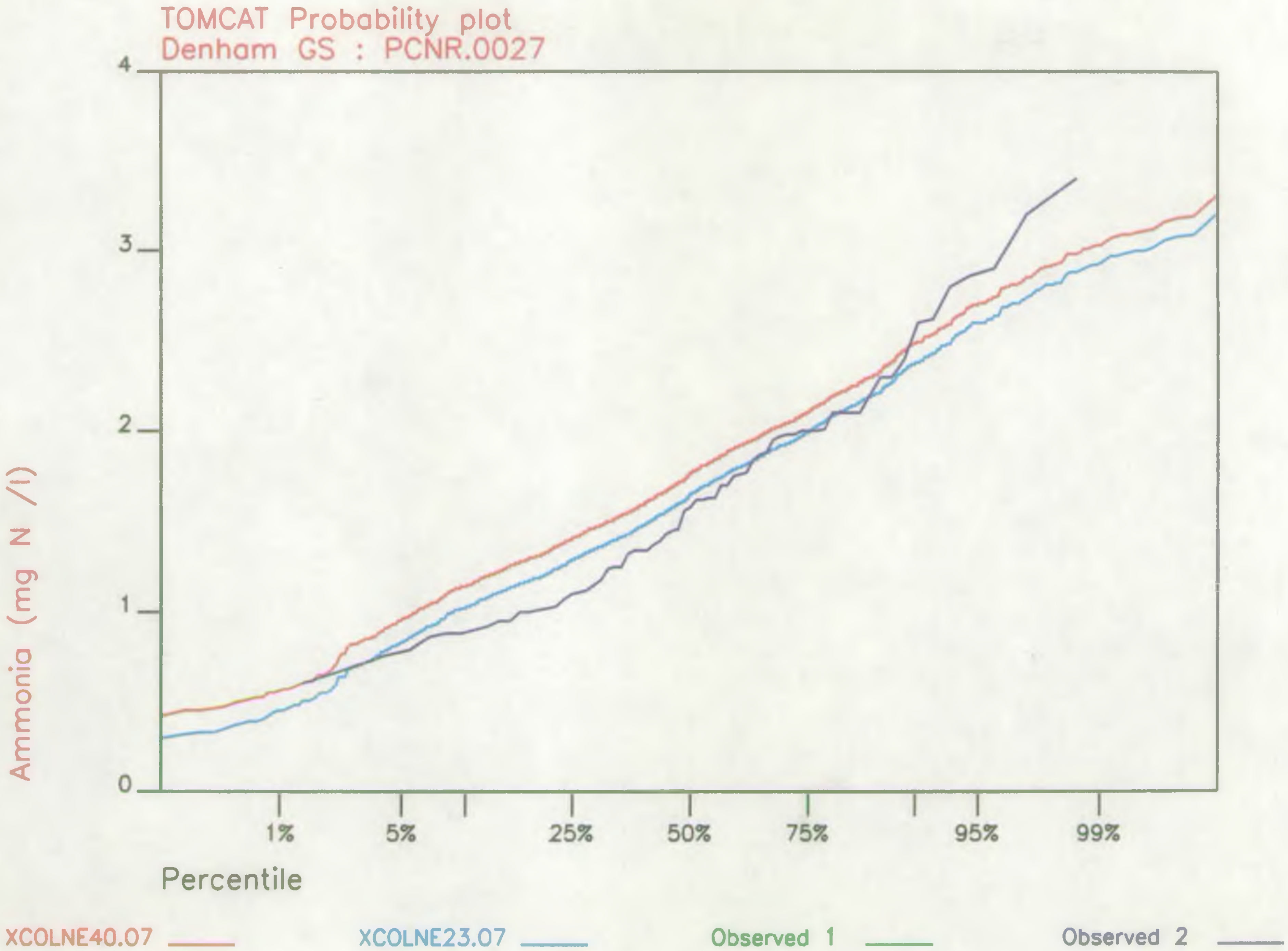

TOMCAT Probability plot
Denham GS : PCNR.0027
Ammonia (mg N /l)
0
1
2
3
4
1%
5%
25%
50%
75%
95%
99%
Percentile
XCOLNE40.07
XCOLNE23.07
Observed 1
Observed 2

Figure 4.22

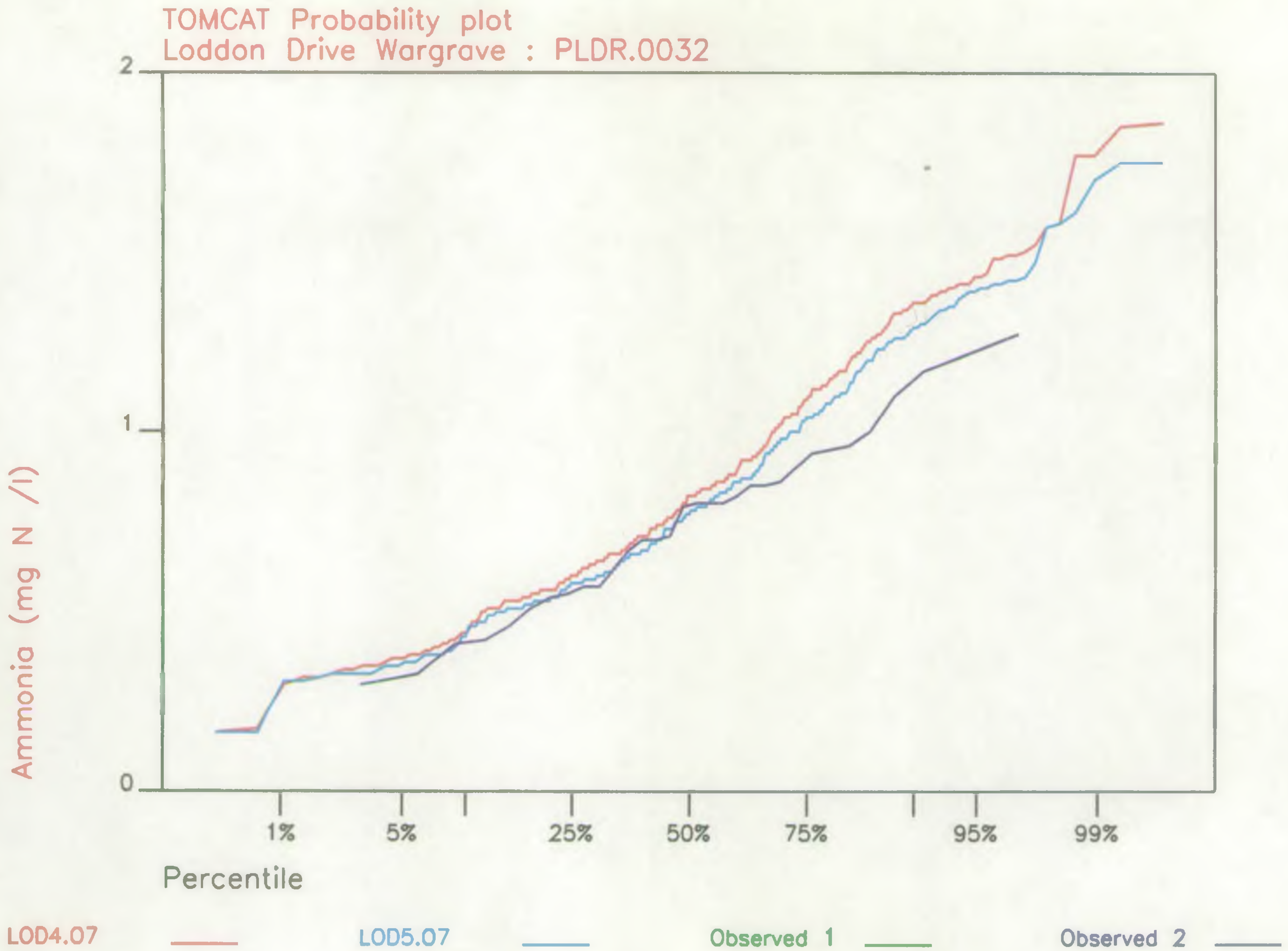
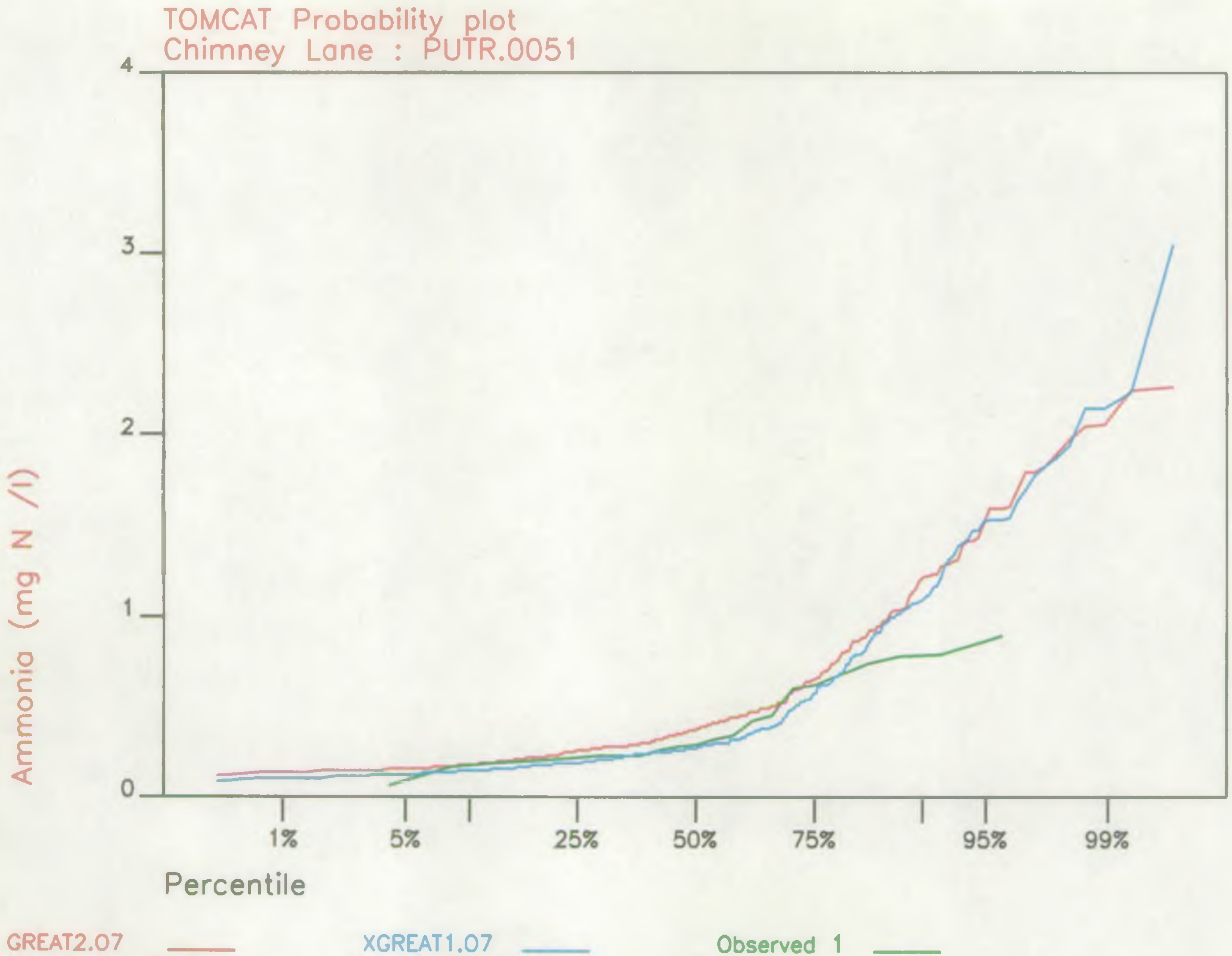

TOMCAT Probability plot
Loddon Drive Wargrave : PLDR.0032
Ammonia (mg N /l)
2
1
0
1%
5%
25%
50%
75%
95%
99%
Percentile
LOD4.07
LOD5.07
Observed 1
Observed 2

Figure 5.1



Original model
decay rate 2.5 1/km

'new' model'
decay rate 2.5 1/km

Figure 5.2

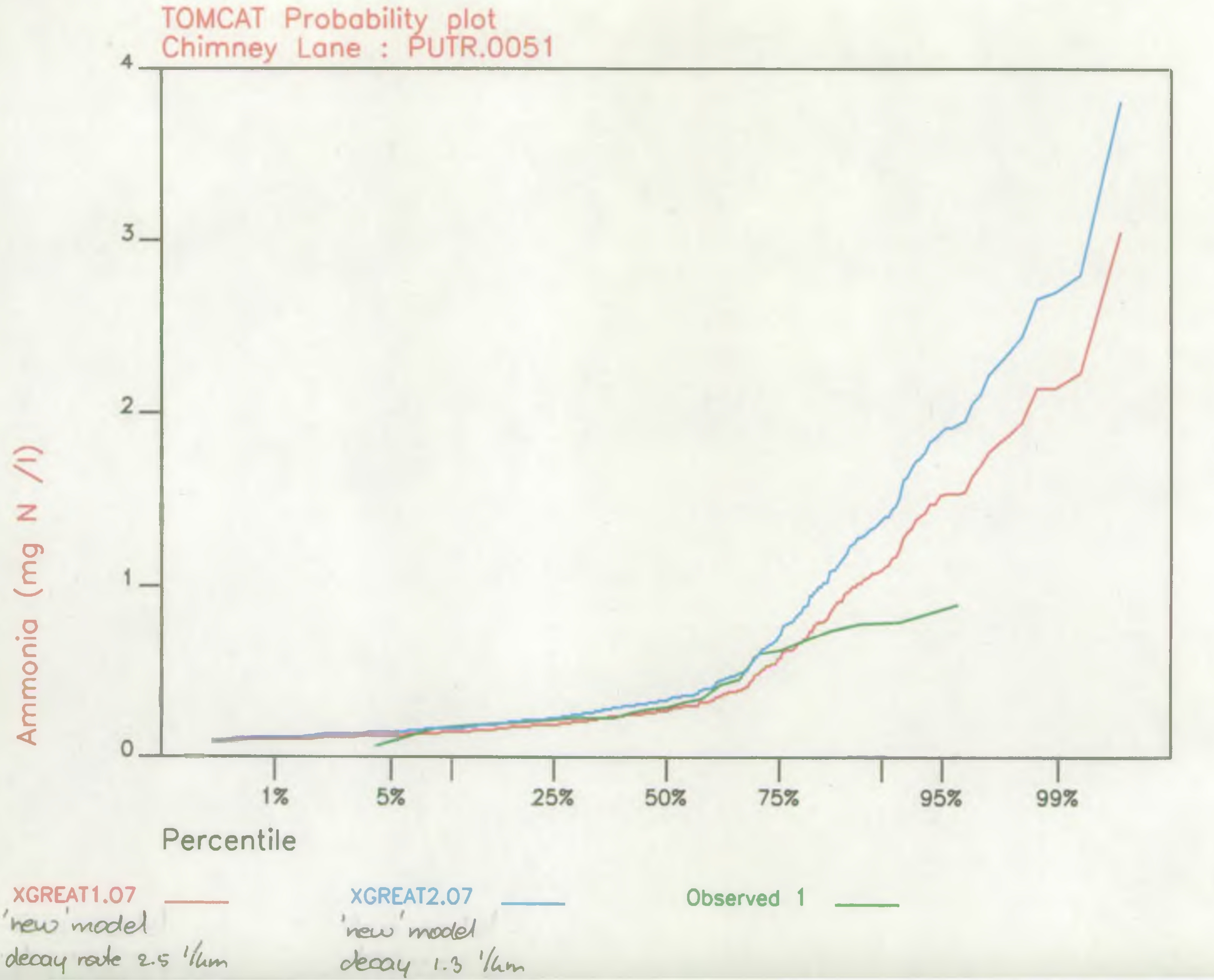
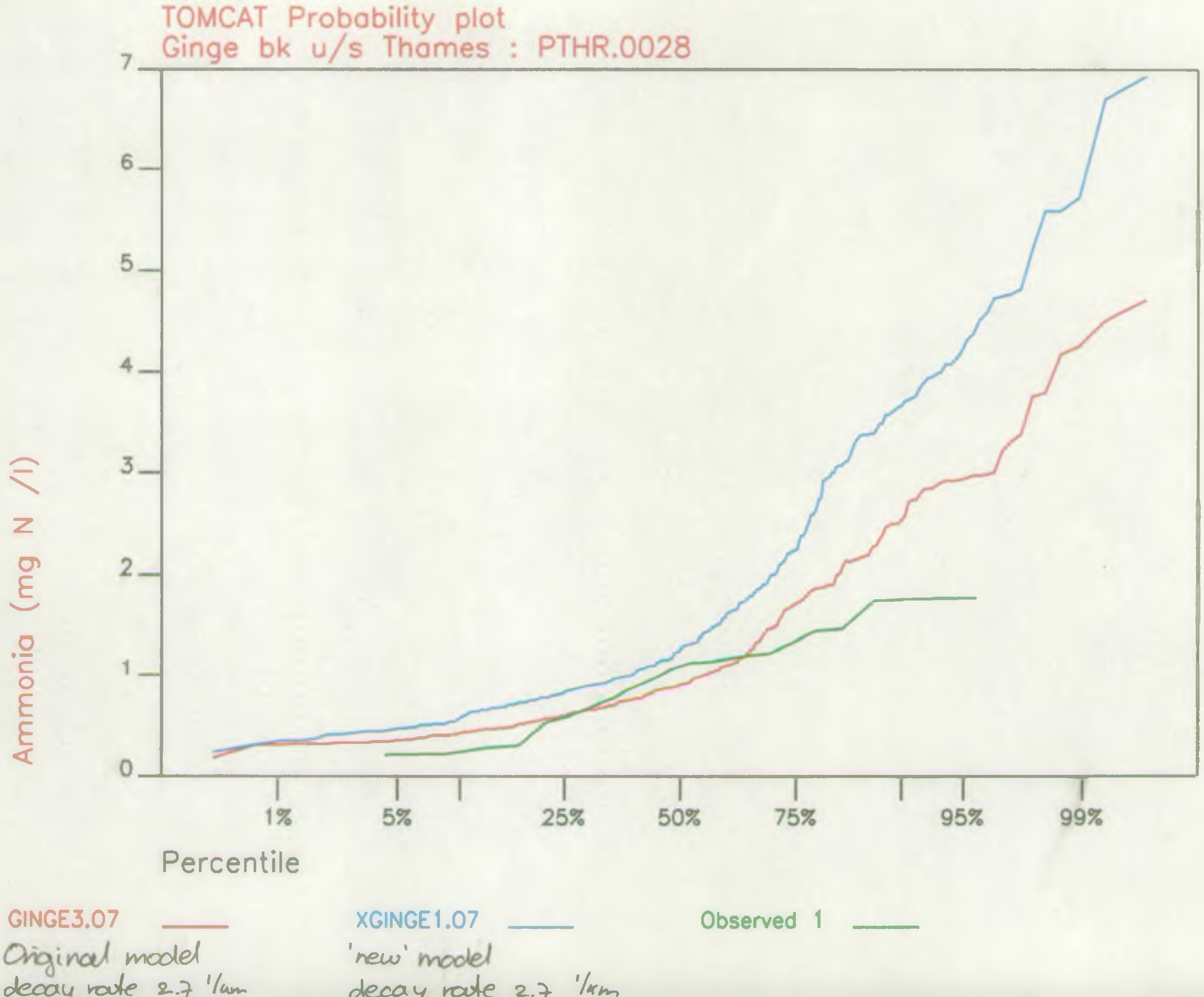
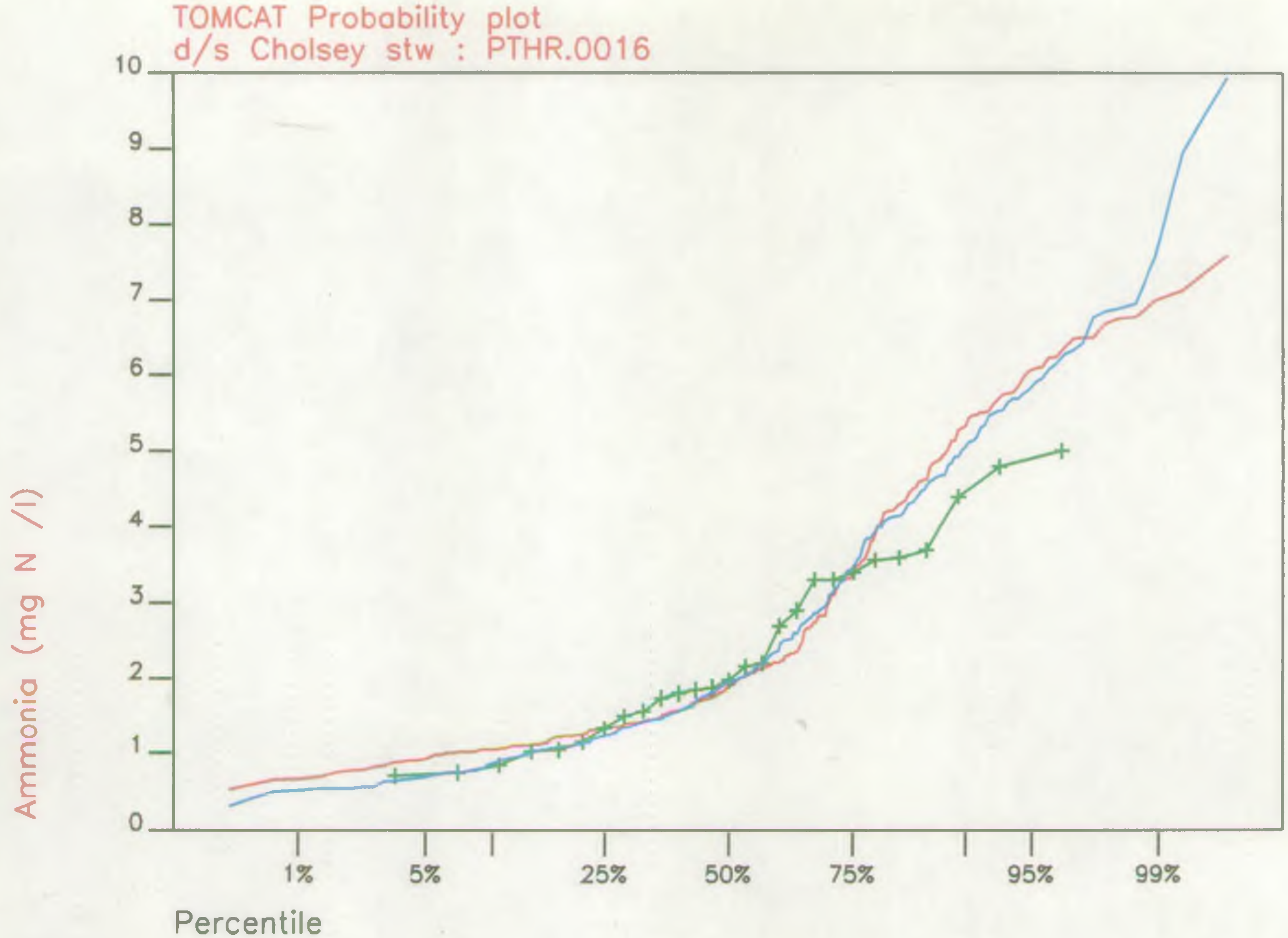

TOMCAT Probability plot
Chimney Lane : PUTR.0051
Ammonia (mg N /l)
4
3
2
1
0
1%
5%
25%
50%
75%
95%
99%
Percentile
XGREAT1.07
'new' model
decay rate 2.5 1/km
XGREAT2.07
'new' model
decay 1.3 1/km
Observed 1

Figure 5.3



TOMCAT Probability plot
Ginge bk u/s Thames : PTHR.0028
Ammonia (mg N /l)
0
1
2
3
4
5
6
7
1%
5%
25%
50%
75%
95%
99%
Percentile
GINGE3.07
Original model
decay rate 2.7 1/km
XGINGE1.07
'new' model
decay rate 2.7 1/km
Observed 1

Figure 5.4



XCHOL2.07 — 'new' model decay rate 0.5 1/km

XCHOL3.07 — Original model decay rate 0.5 1/km

Observed 1

Figure 5.5

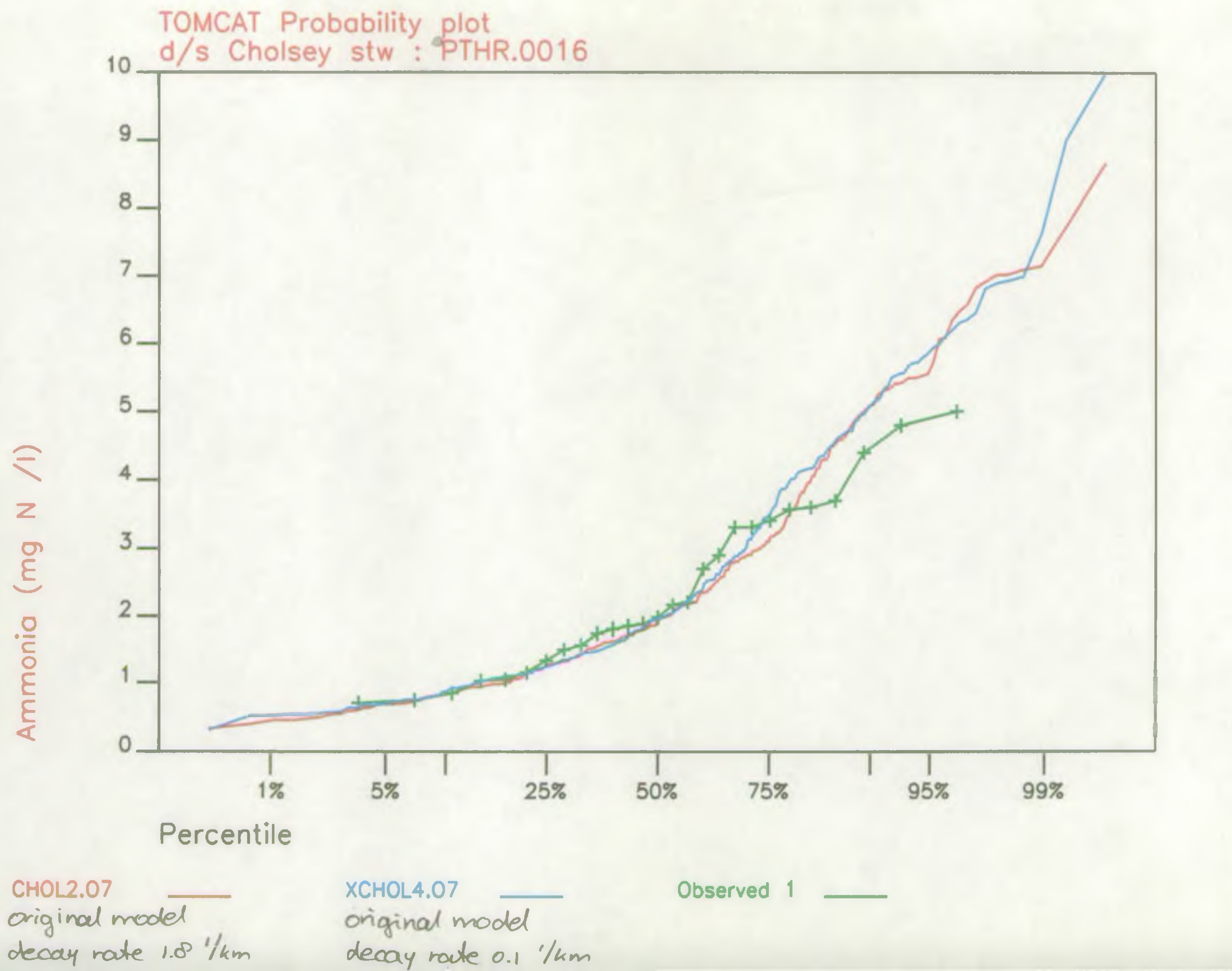
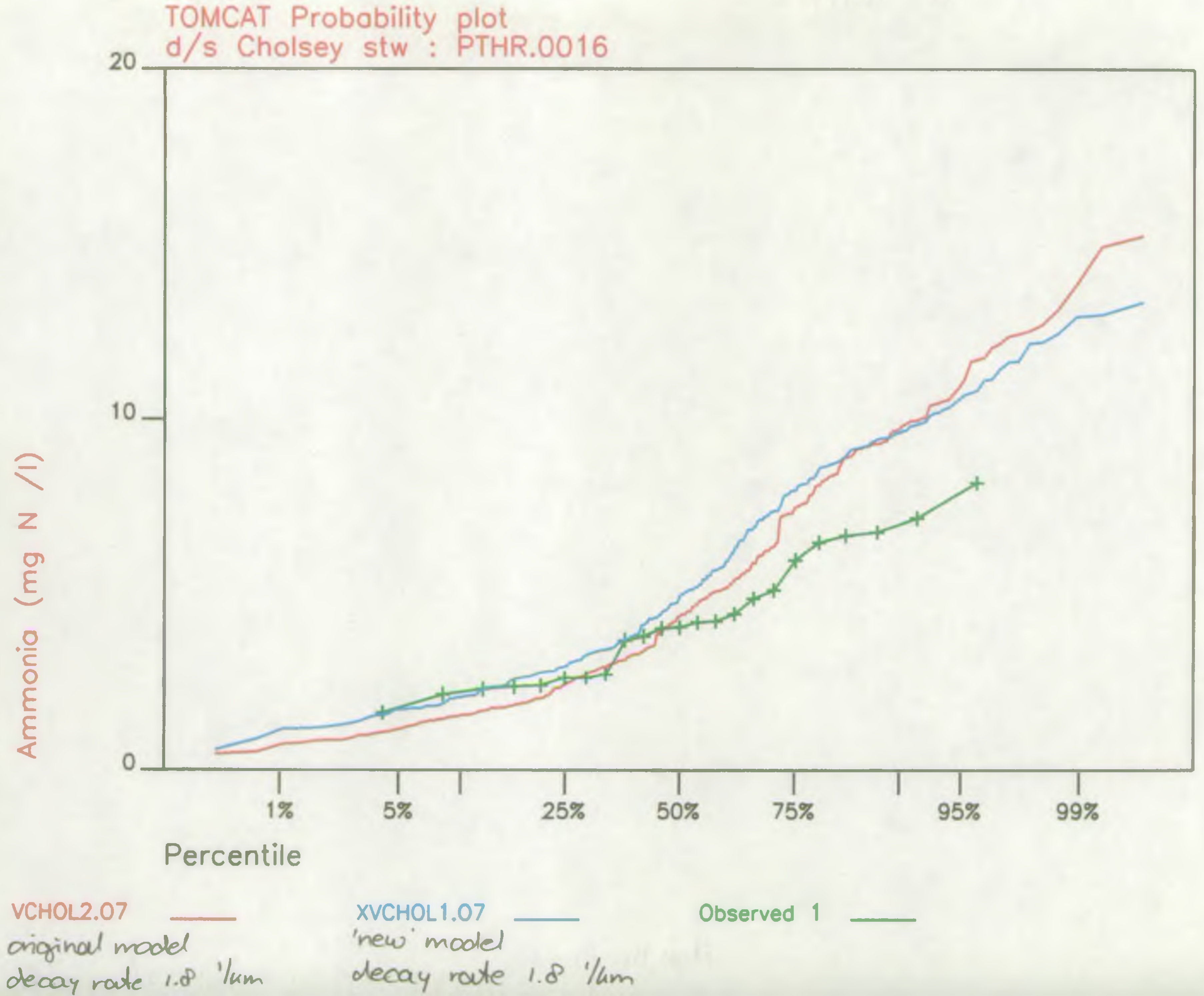
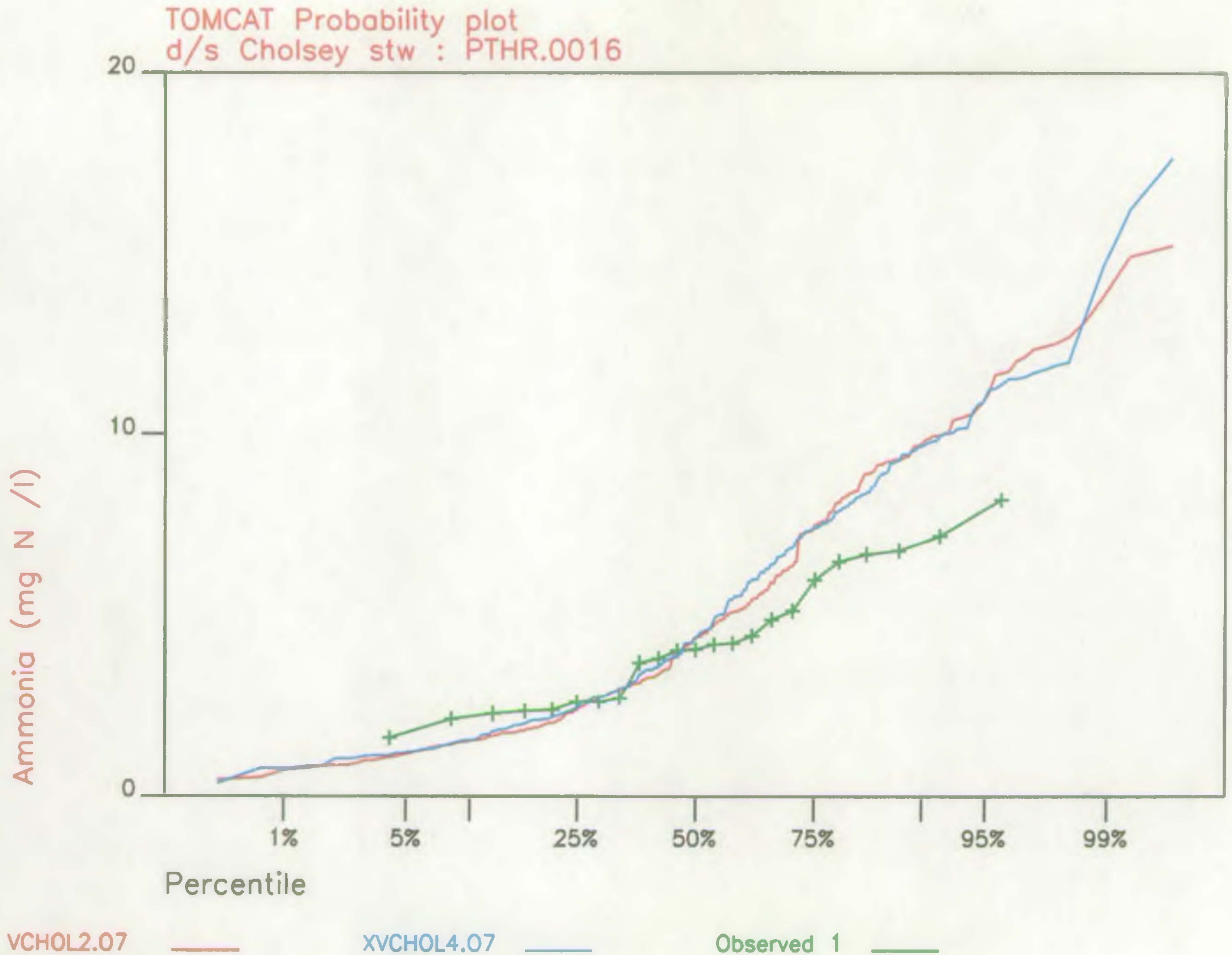

TOMCAT Probability plot
d/s Cholsey stw : PTHR.0016
Ammonia (mg N /l)
10
9
8
7
6
5
4
3
2
1
0
1%
5%
25%
50%
75%
95%
99%
Percentile
CHOL2.07
original model
decay rate 1.8 1/km
XCHOL4.07
original model
decay rate 0.1 1/km
Observed 1

Figure 5.6



TOMCAT Probability plot
d/s Cholsey stw : PTHR.0016
20
10
0
Ammonia (mg N /l)
1%
5%
25%
50%
75%
95%
99%
Percentile
VCHOL2.07
original model
decay rate 1.8 1/km
XVCHOL1.07
'new' model
decay rate 1.8 1/km
Observed 1

Figure 5.7



Original model
decay rate 1.8 '/km

original model
decay rate 0.1 '/km

Figure 5.8

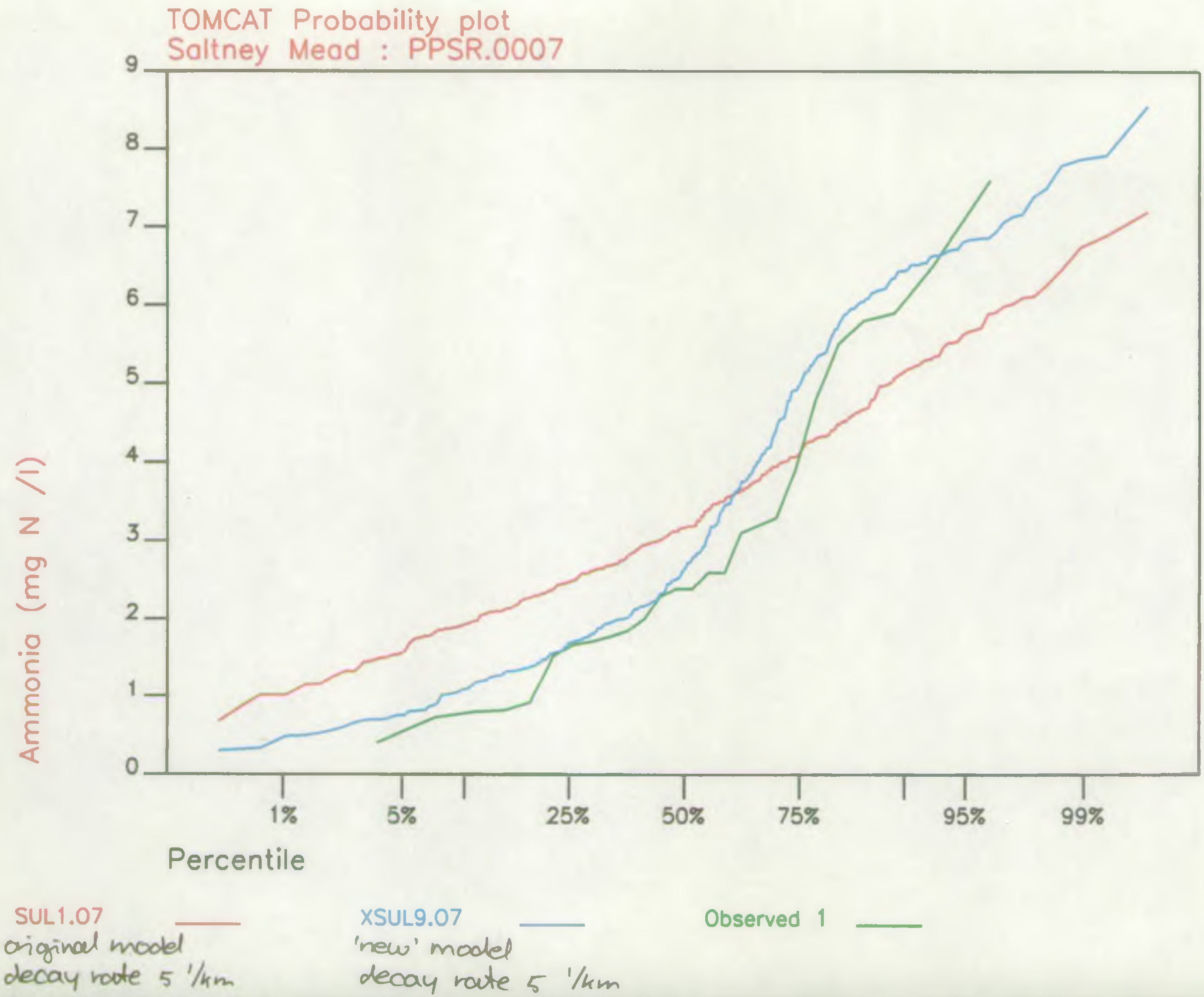

TOMCAT Probability plot
Saltney Mead : PPSR.0007
Ammonia (mg N /l)
0
1
2
3
4
5
6
7
8
9
1%
5%
25%
50%
75%
95%
99%
Percentile
SUL1.07
original model
decay rate 5 1/km
XSUL9.07
'new' model
decay rate 5 1/km
Observed 1

Figure 59

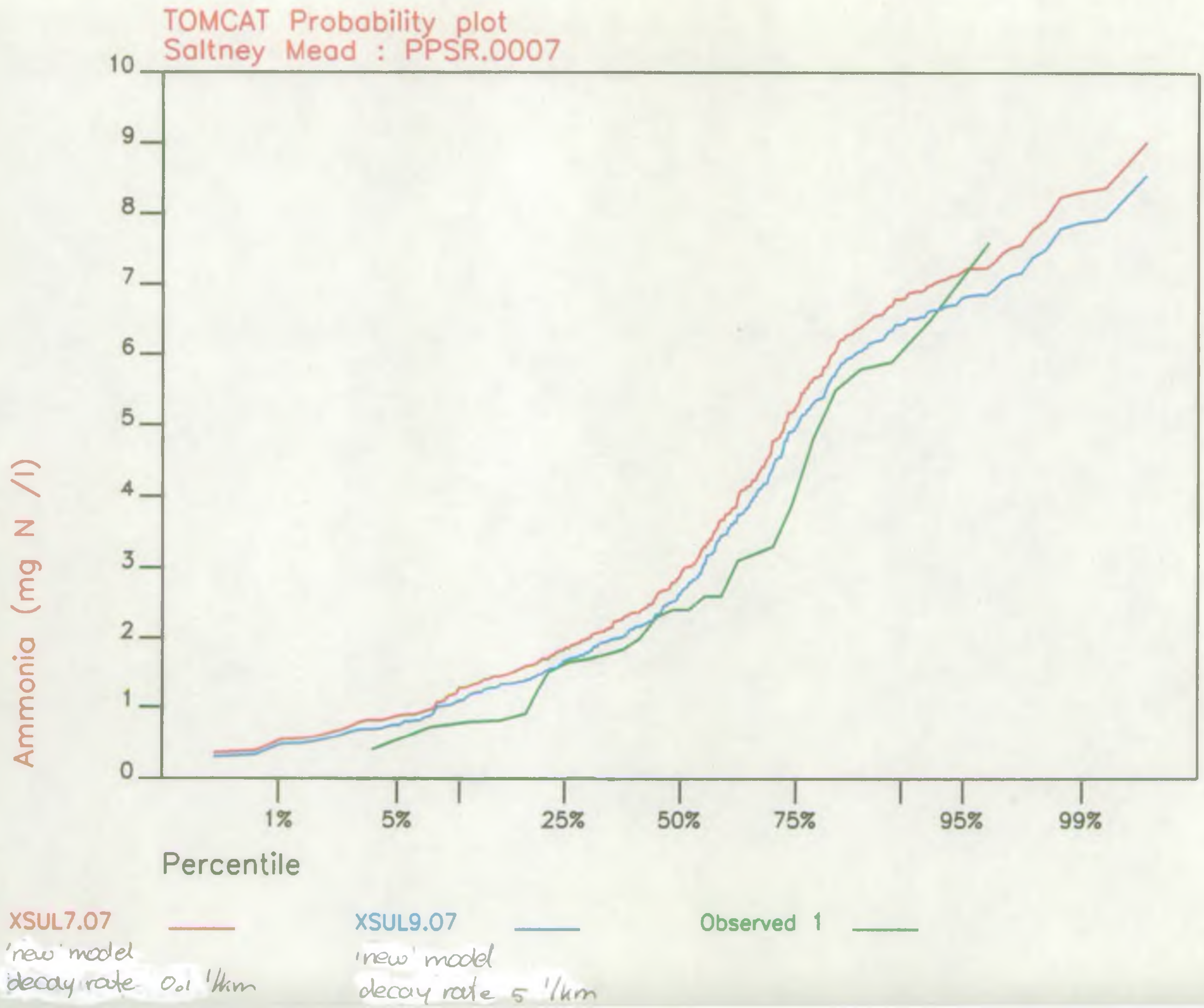

TOMCAT Probability plot
Saltney Mead : PPSR.0007
Ammonia (mg N /l)
0
1
2
3
4
5
6
7
8
9
10
1%
5%
25%
50%
75%
95%
99%
Percentile
XSUL7.07
'new' model
decay rate 0.01 1/km
XSUL9.07
'new' model
decay rate 5 1/km
Observed 1

Figure 5.10

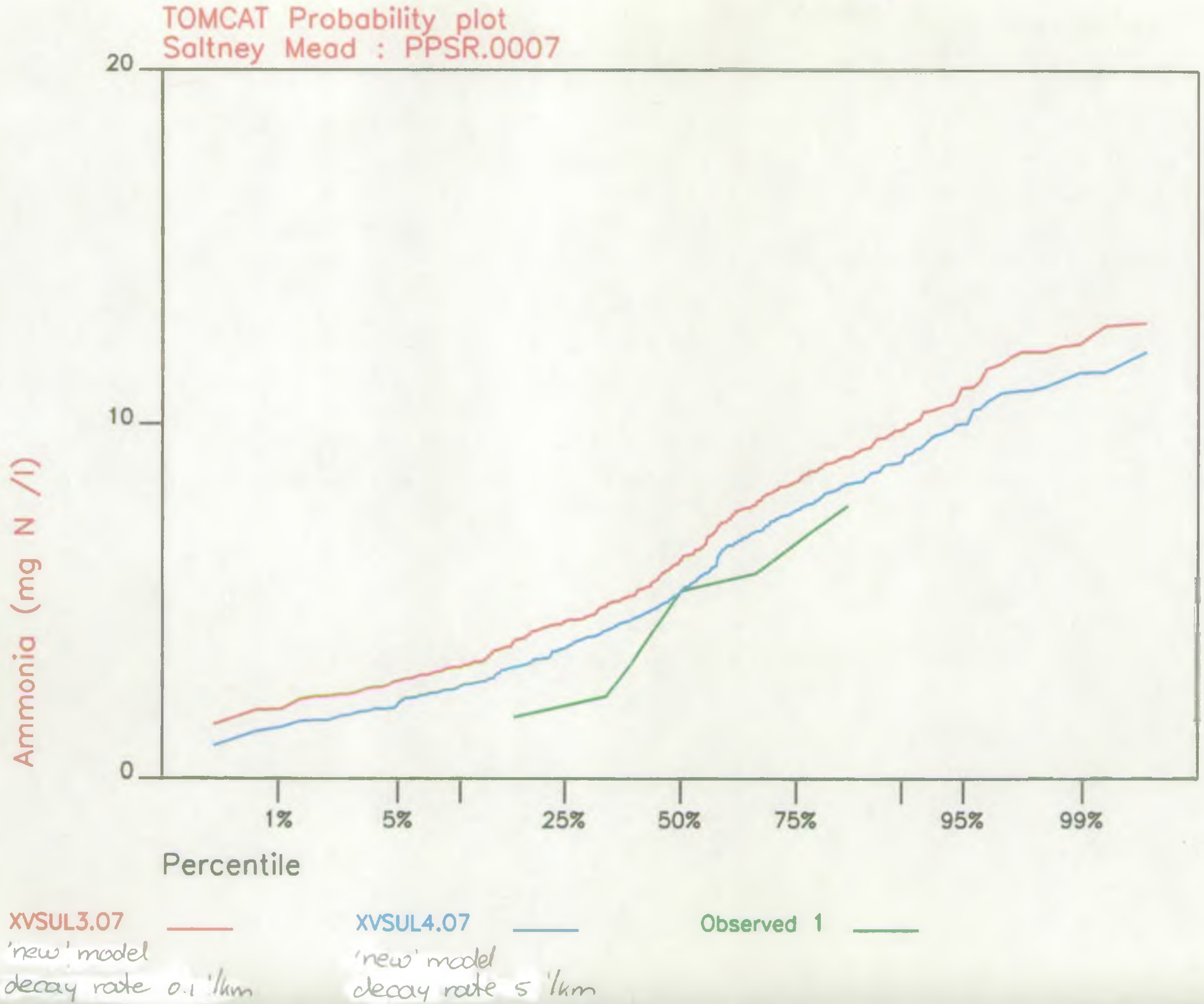
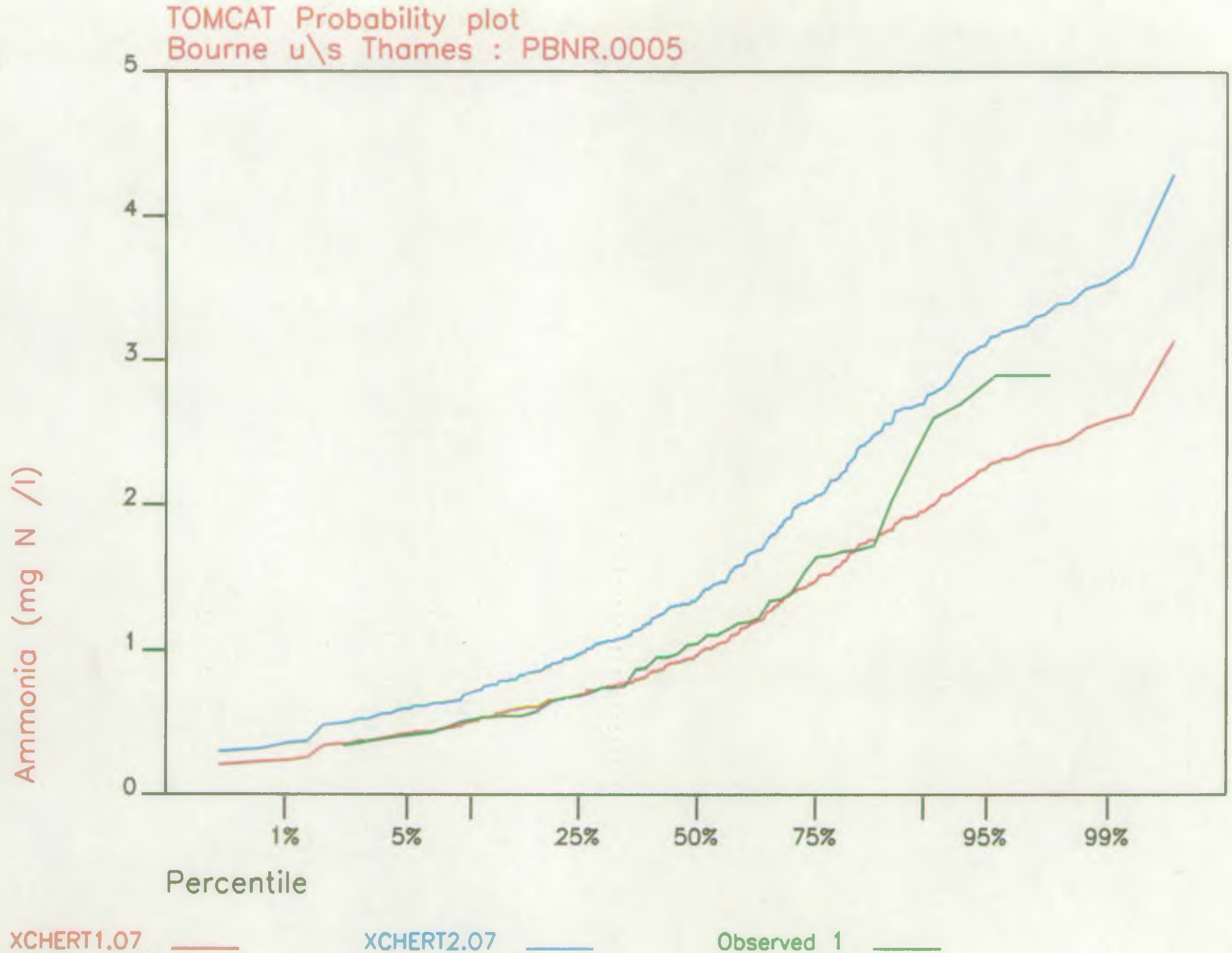

TOMCAT Probability plot
Saltney Mead : PPSR.0007
20
10
0
Ammonia (mg N /l)
1%
5%
25%
50%
75%
95%
99%
Percentile
XVSUL3.07
'new' model
decay rate 0.1 /km
XVSUL4.07
'new' model
decay rate 5 /km
Observed 1

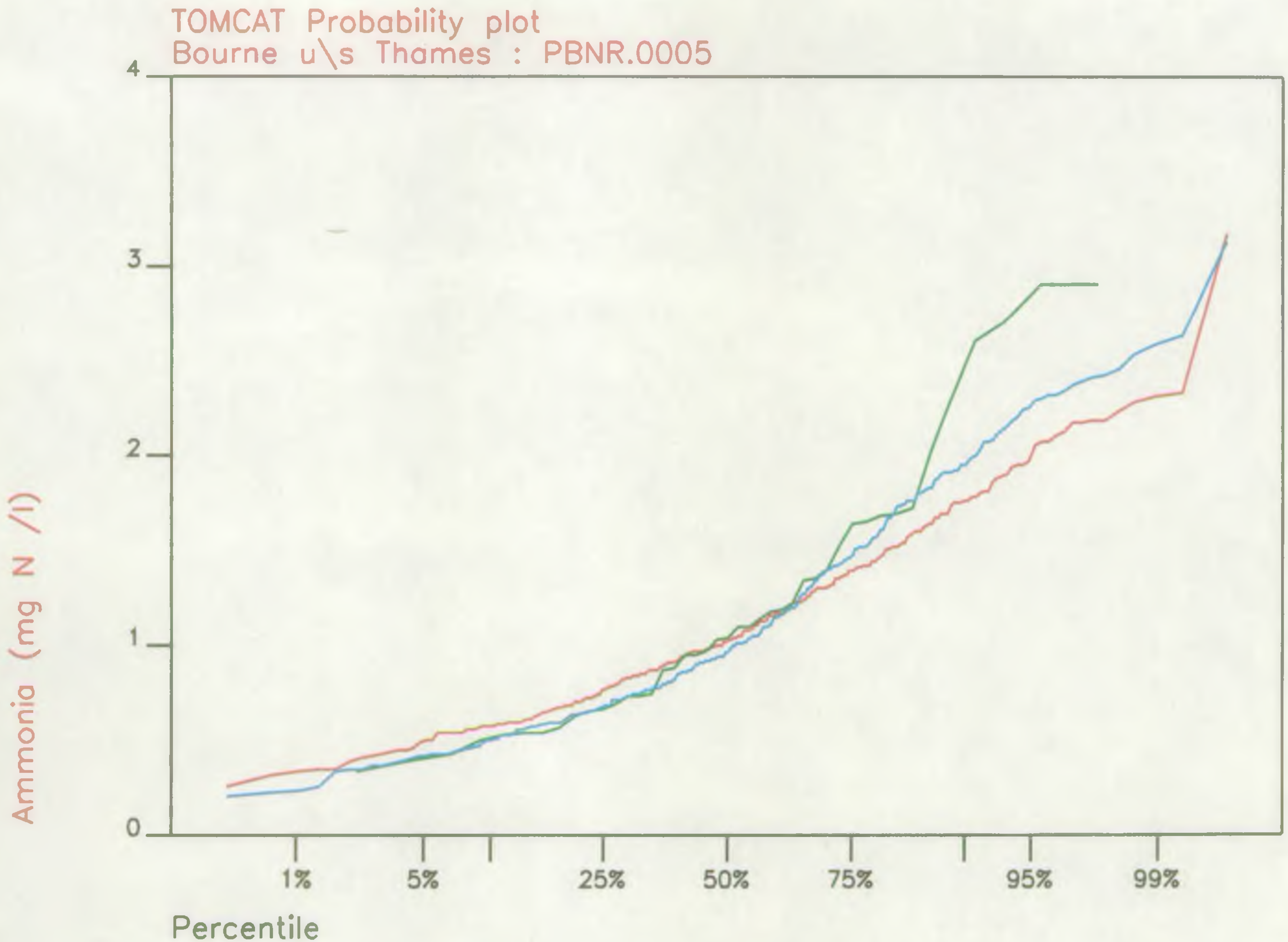
Figure 5.11



'new' model
decay rate 2.1 '/km

'new' model
decay rate 0.7 '/km

Figure 5.12



CHERT4.07 original model decay rate 2.1 1/km

XCHERT1.07 'new' model decay rate 2.1 1/km

Observed 1

Figure 5.13

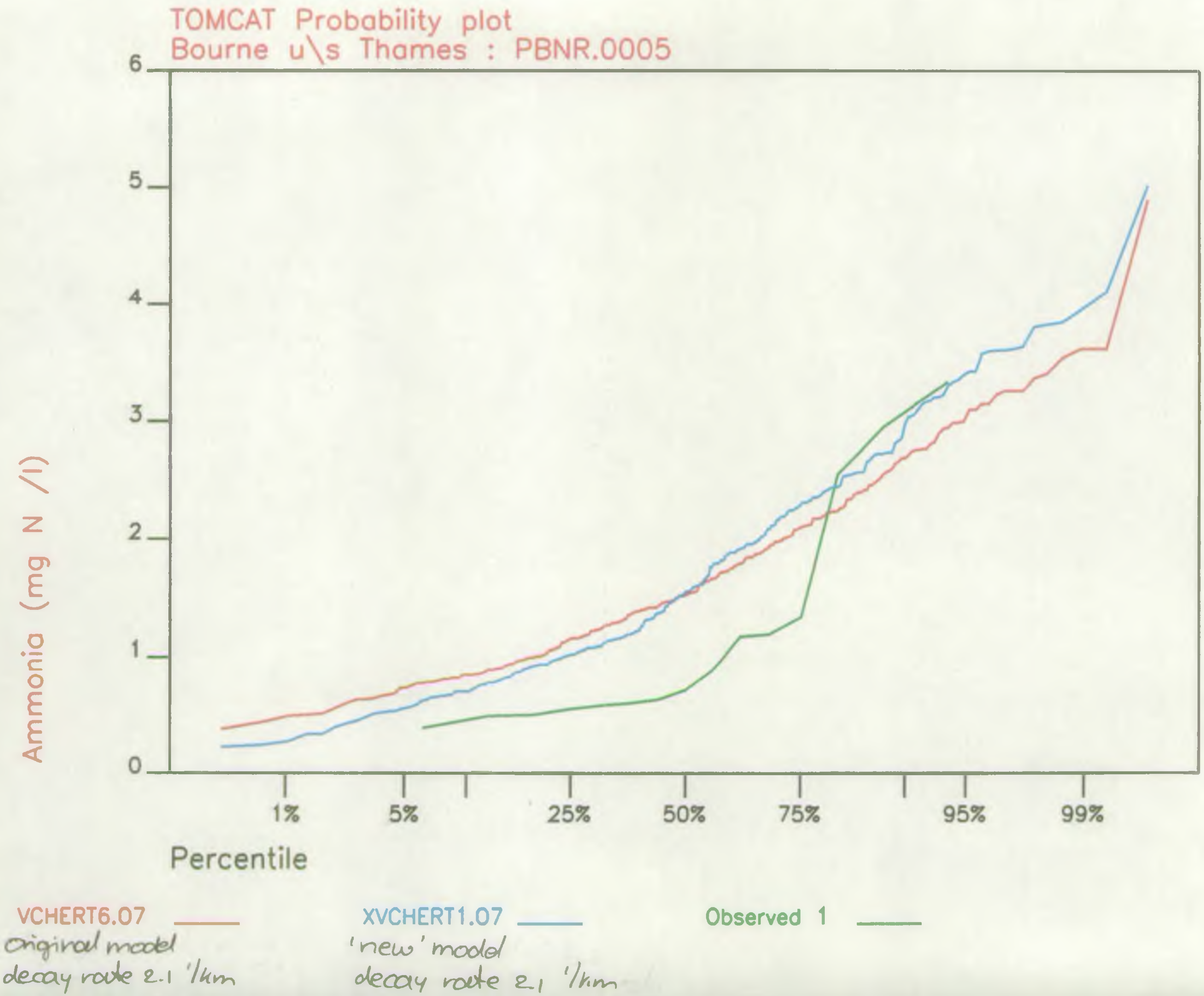
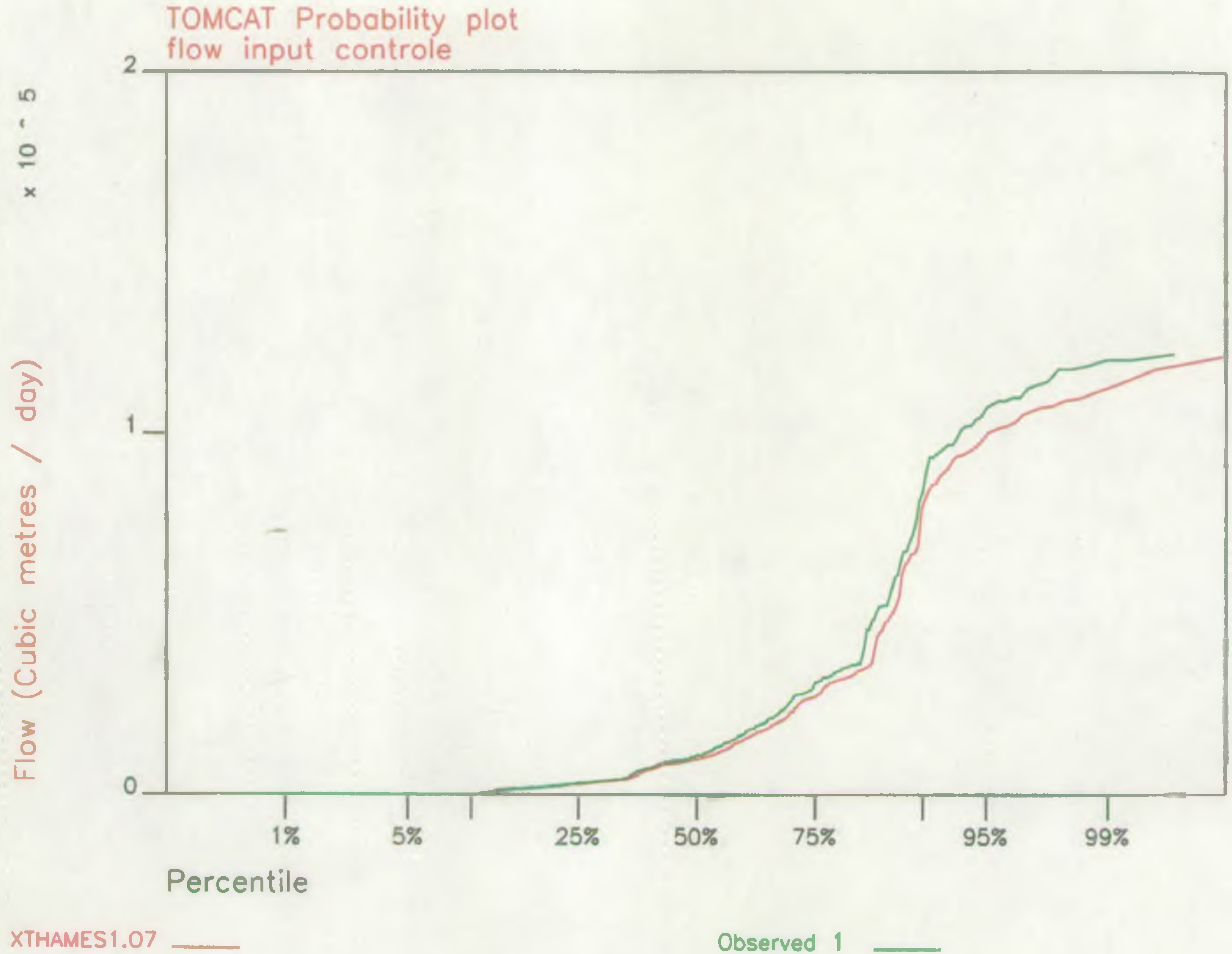

TOMCAT Probability plot
Bourne u\s Thames : PBNR.0005
Ammonia (mg N /l)
0
1
2
3
4
5
6
1%
5%
25%
50%
75%
95%
99%
Percentile
VCHERT6.07
original model
decay rate 2.1 1/km
XVCHERT1.07
'new' model
decay rate 2.1 1/km
Observed 1

Figure 5.14



TOMCAT Probability plot
flow input controle
2
1
0
x 10 ^ 5
Flow (Cubic metres / day)
1%
5%
25%
50%
75%
95%
99%
Percentile
XTHAMES1.07
Observed 1

Figure 5.15

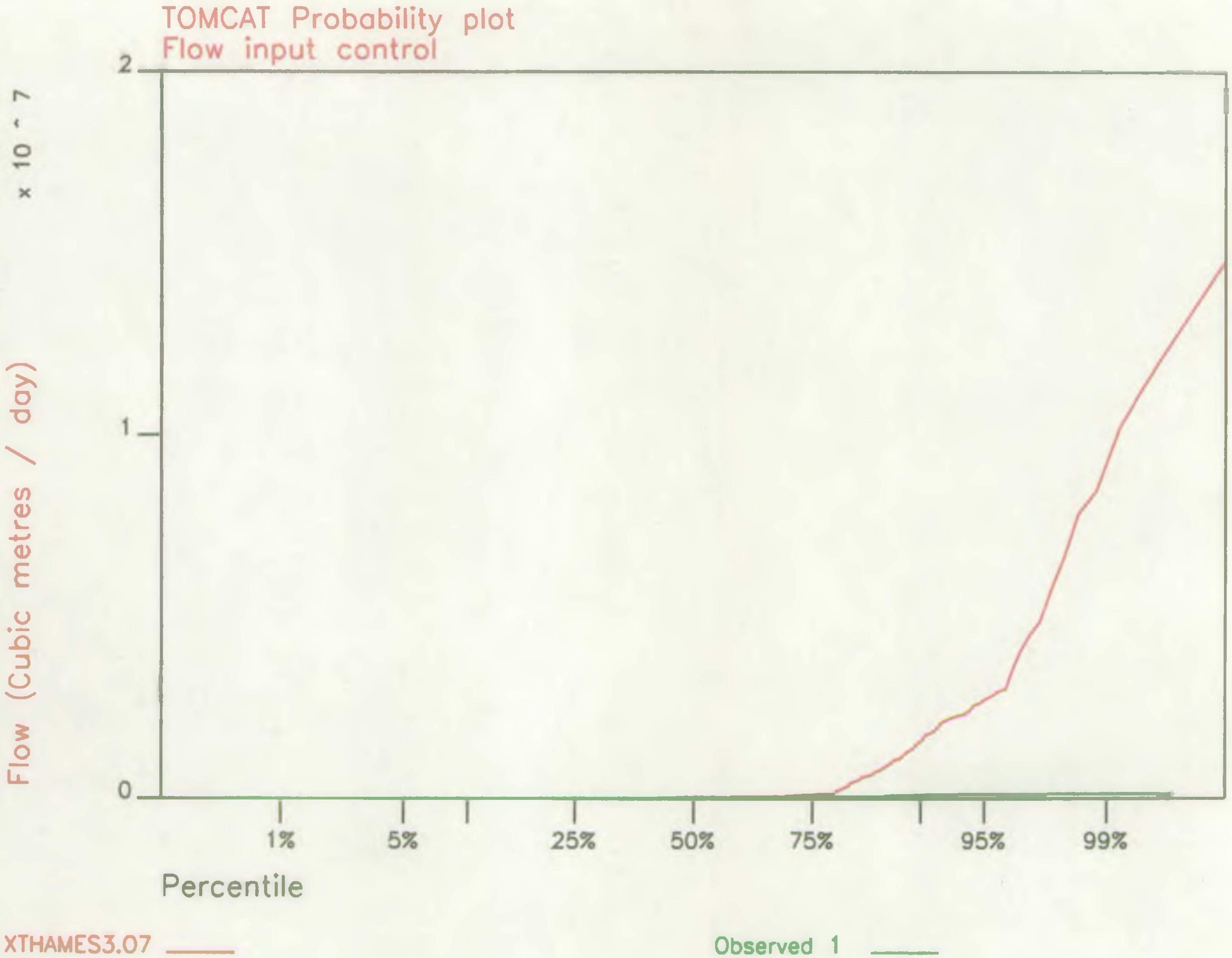

TOMCAT Probability plot
Flow input control
x 10 ^ 7
2
1
0
Flow (Cubic metres / day)
1%
5%
25%
50%
75%
95%
99%
Percentile
XTHAMES3.07
Observed 1

Figure 5.16

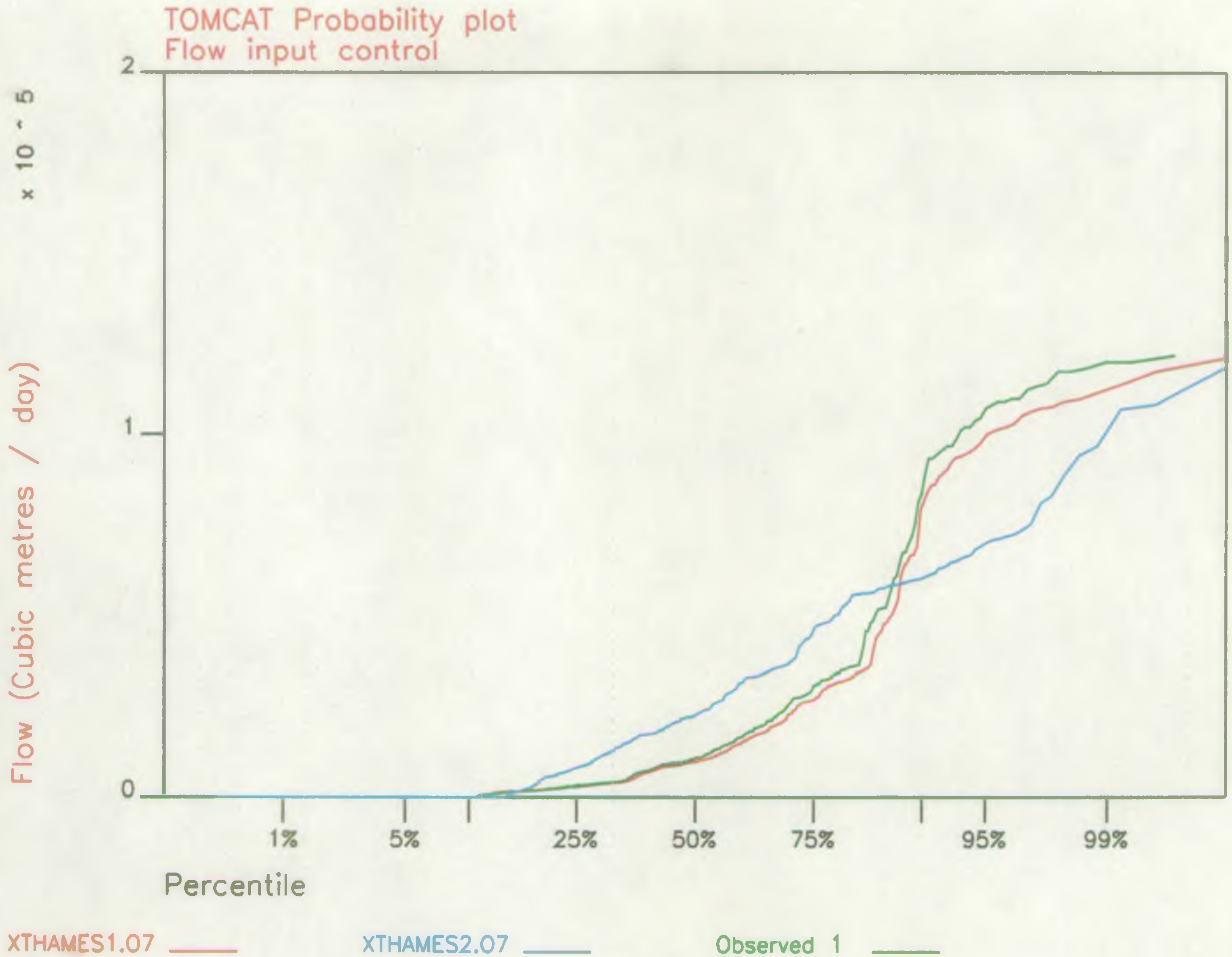

TOMCAT Probability plot
Flow input control
2
1
0
x 10 ^ 5
Flow (Cubic metres / day)
1%
5%
25%
50%
75%
95%
99%
Percentile
XTHAMES1.07
XTHAMES2.07
Observed 1

Figure 5.17

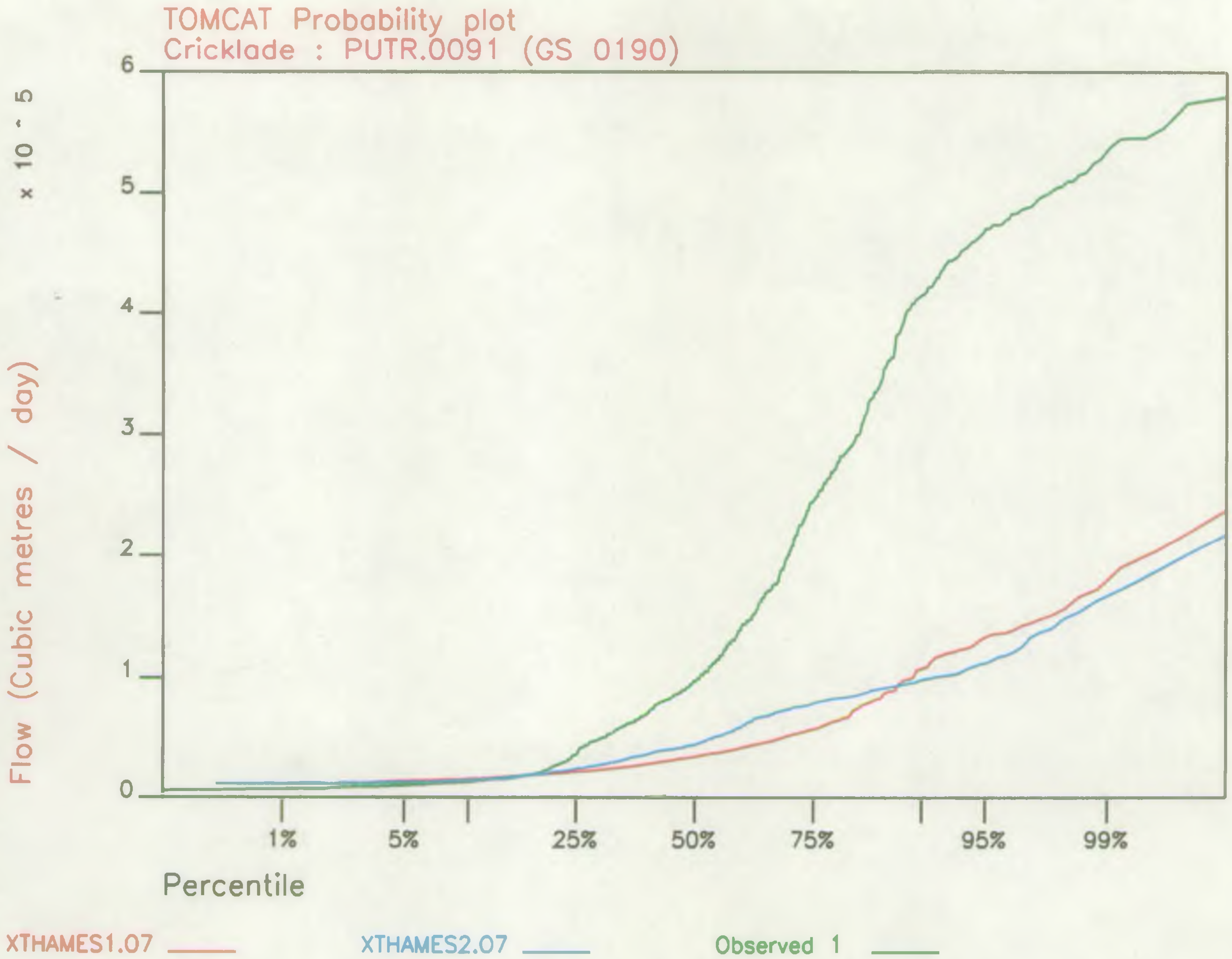

TOMCAT Probability plot
Cricklade : PUTR.0091 (GS 0190)
Flow (Cubic metres / day)
x 10 ^ 5
0
1
2
3
4
5
6
1%
5%
25%
50%
75%
95%
99%
Percentile
XTHAMES1.07
XTHAMES2.07
Observed 1

Figure 5.18

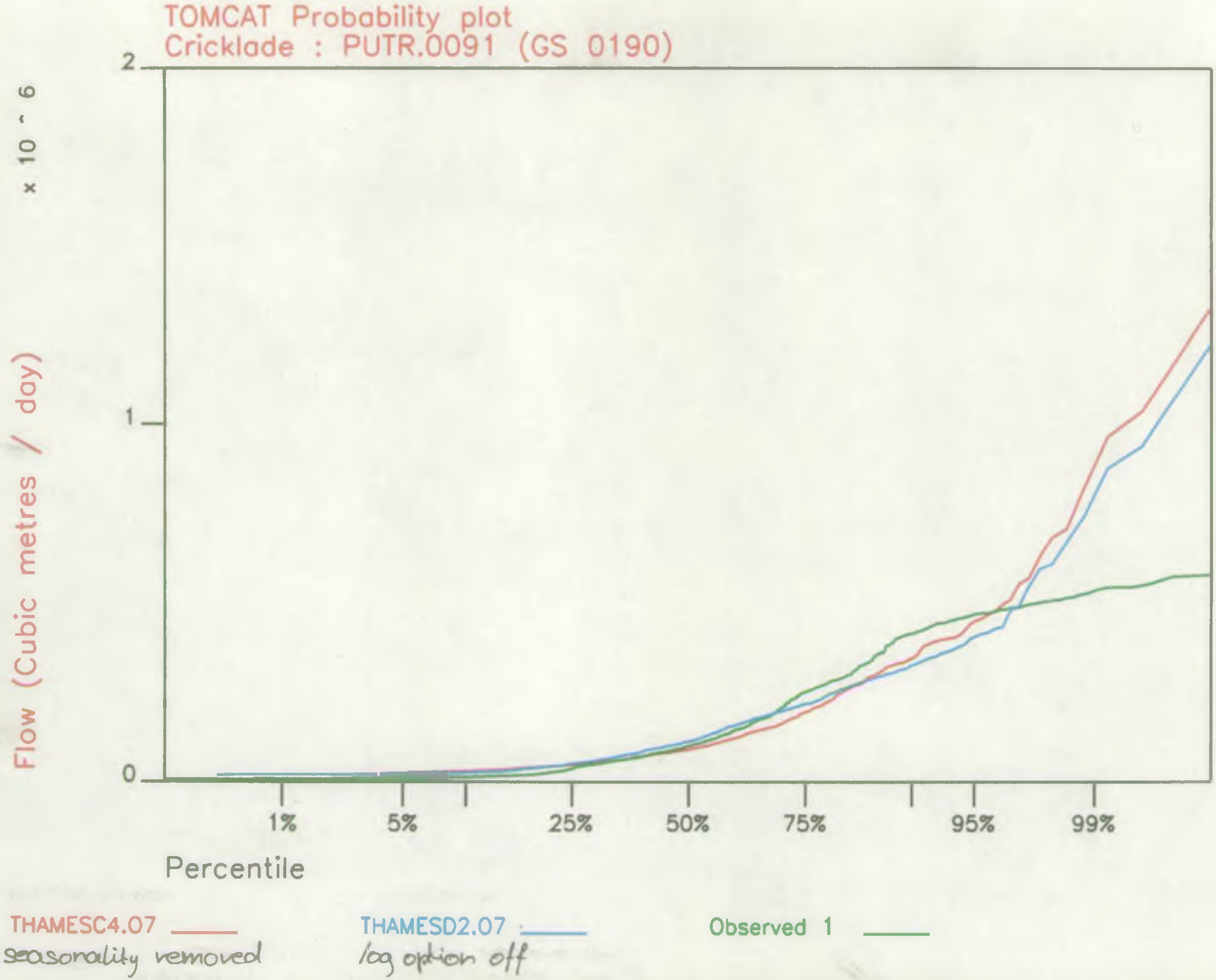

TOMCAT Probability plot
Cricklade : PUTR.0091 (GS 0190)
x 10 ^ 6
2
1
0
Flow (Cubic metres / day)
1%
5%
25%
50%
75%
95%
99%
Percentile
THAMESC4.07
seasonality removed
THAMESD2.07
log option off
Observed 1

Figure 5.19

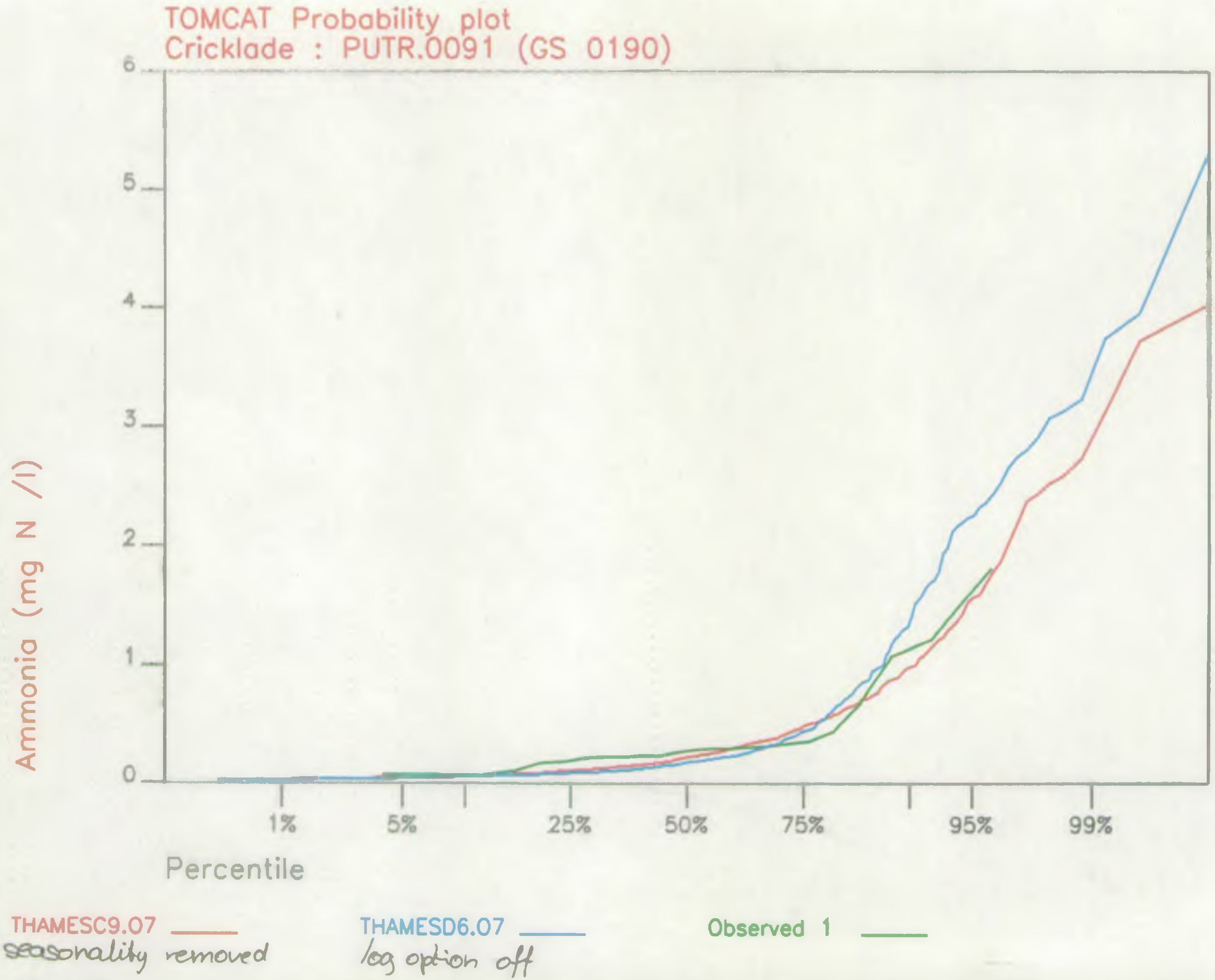

TOMCAT Probability plot
Cricklade : PUTR.0091 (GS 0190)
Ammonia (mg N /l)
0
1
2
3
4
5
6
1%
5%
25%
50%
75%
95%
99%
Percentile
THAMESC9.07
seasonality removed
THAMESD6.07
log option off
Observed 1

Figure 5.20

Orthophosphate removal at UWWTD works
TOMCAT output

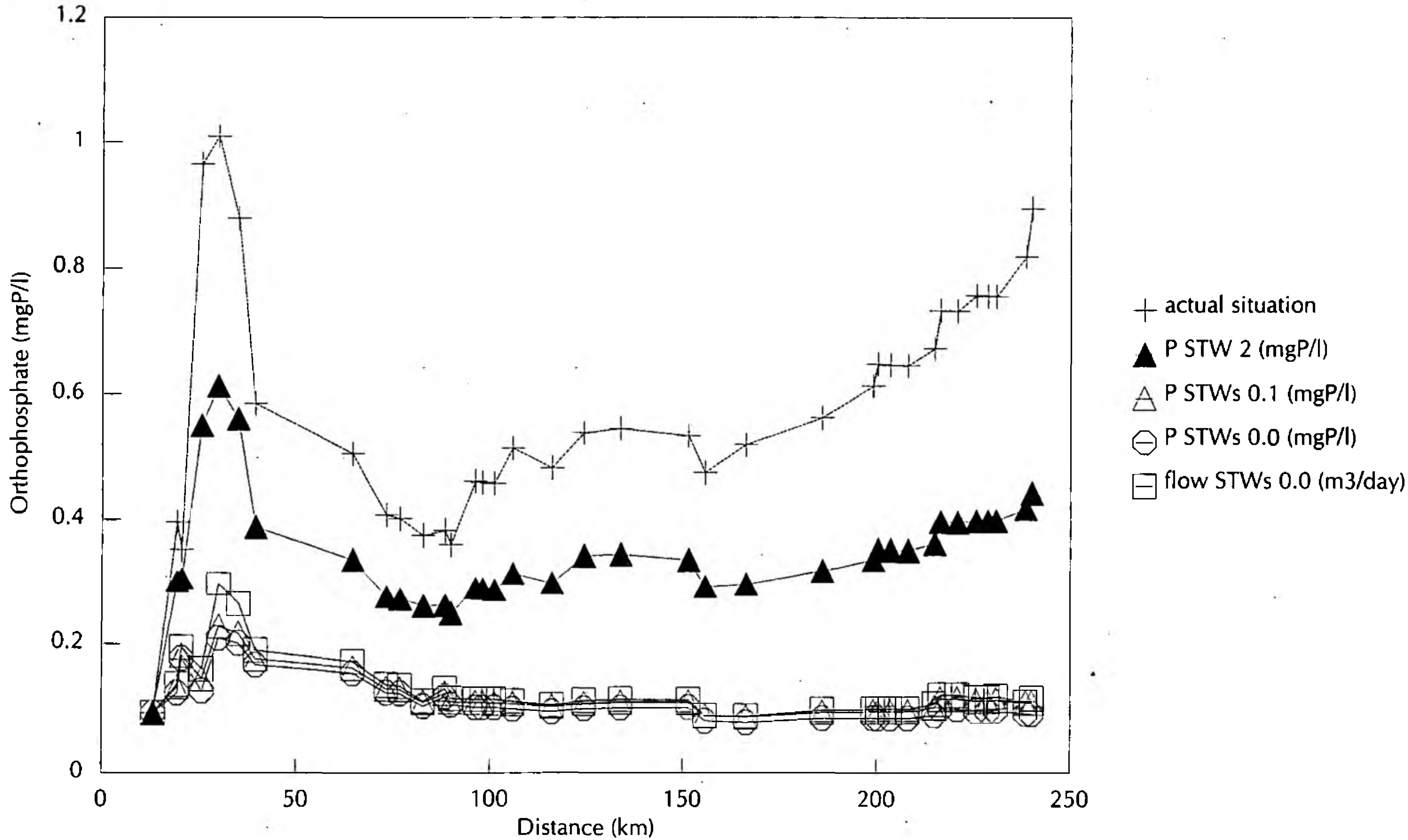


Figure 5.21

APPENDICES

A	Distant dependent decay
B	Flow after bifurcation
C	Accretional flow and its quality in the Colne catchment
D	URN numbers used in the Colne catchment
E	Accretional phosphate calculated for Ginge Brook, Sulham Brook and Cholsey Brook
F	Accretional phosphate calculated for the River Thames u/s of the confluence with Cerney Wick Brook

APPENDIX A DISTANT DEPENDENT DECAY

The local velocity U of the stream is derived from Mannings's formula

$$U=\frac{S^{\frac{1}{2}}R(h)^{\frac{3}{4}}}{n} \qquad (1)$$

where U = velocity;
S = slope of the channel bed;
R(h) = local hydraulic radius which is a function of the depth h;
n = roughness coefficient of the channel.

If Mannings n is negative in TOMCAT, TOMCAT models the flow according to the expression:

$$U=aQ^{b} \qquad (2)$$

where Q = flow;

By setting b very small the equation becomes

$$U=a \qquad (3)$$

The time of travel (tot) is then given by

$$tot=\frac{d}{a} \qquad (4)$$

where d = distance;
a = velocity.

The TOMCAT code requires 'a' to be put in m/s and then converts it into km/day (i.e *86.4).

The decay equation in TOMCAT is expressed as

$$c=c_0e^{-k_0*t} \qquad (5)$$

where c = downstream concentration;
c^0 = start concentration;
k_0 = decay at 0 temperature.

k_0 is calculated in TOMCAT for 0 temperature T as

$$k_o = k_{20} f^{-20} \qquad (6)$$

where f = 1.0717735;
k_{20} = input decay rate (/day).

Equation 5 may be written as

$$c = c_o e^{\frac{-0.25 k_{20} d}{86.4 a}} \qquad (7)$$

As

$$a = \frac{1}{8.64} \qquad (8)$$

then

$$c = c_0 e^{-0.025 k_{20} d} \qquad (9)$$

The variable $0.025k_{20}$ is thus the decay per kilometre (reference 1).

APPENDIX B FLOW AFTER BIFURCATION

The first three columns of table 1 show the data from the hydrologists. With these the total flow upstream of the bifurcation and the percentage of the flow going into the Colne and Colne Brook could be calculated. These are also shown in table 1.

Table I Flow data from which the total flow and percentage of the total flow going into the Colne and the Colne Brook is calculated.

Model data description	Flow downstream of the confluence: on the Colne	Flow downstream of the confluence: on the Colne Brook	Total flow u/s difluence	% flow into the Colne	% flow into the Colne Brook
100 year return period maximum	17.3	6.9	24.182	0.7134	0.287
100 year return period minimum	3.9	1.0	4.932	0.798	0.202
25 year return period maximum	13.1	4.7	17.762	0.736	0.264
25 year return period minimum	3.9	1.0	4.938	0.796	0.204
2 year return period maximum	7.9	2.4	10.332	0.765	0.235
2 year return period minimum	3.9	1.0	4.882	0.804	0.196
			mean	0.769	0.231

The data show that 77% of the flow upstream of the bifurcation goes into the Colne and 23% goes into the Colne Brook.

APPENDIX C ACCRETIONAL FLOW AND IT'S QUALITY IN THE COLNE CATCHMENT

The hydrologists made a number of estimates of the accretional flow in the catchment of the Colne upstream of Denham GS during the last 25 years. They are summarised in the first column of table 1 and then calculated to the dimension (m^3/km/day). The distance from the source of the Colne to Denham GS is 39.77 km. The accretional flow used in the model is the mean accretional flow calculated from the estimated accretional flows.

Table I Estimations of the accretional flow in the catchments of the Colne upstream of Denham GS.

Date	Flow m^3/sec	Flow (m^3/km/day)
Oct. 1971	2.4	5214
Sept. 1972	2.2	4779
Oct. 1975	2.7	5866
Feb. 1976	3.2	6952
July 1976	0.9	1955
Nov. 1976	1.9	4128
Oct. 1980	2.8	6083
Sept. 1981	3.9	8473
Sept. 1982	2.7	5866
mean	2.5	5480

Calculation of the phosphate concentration in the accretional flow

A phosphate concentration in the flow upstream of the STWs in the Colne catchment was not put into the original model. The contribution of the upstream phosphate concentration was put in into the accretional phosphate.

In the model developed in this study, there is an upstream phosphate concentration and therefore the accretional phosphate concentration must be calculated again.

The u/s load and the accretional load can be calculated using equation (1) and (2).

u/s load = u/s flow * u/s concentration
(1)

Accretional load = agricultural load - u/s load
(2)

The accretional phosphate concentration can be calculated using the following equation:

$$Acc.Phos. = \frac{10^5 * A * 0.32}{365 * L * F} \qquad (3)$$

where A = u/s area;
L = length of river;
F = accretional flow.

The u/s load and the accretional load can be calculated using equation (1) and (2).

u/s load = u/s flow * u/s concentration
(1)

Accretional load = agricultural load - u/s load
(2)

The accretional phosphate concentration can be calculated using the following equation:

$$Acc.Phos. = \frac{10^5 * A * 0.32}{365 * L * F} \qquad (3)$$

where A = u/s area;
L = length of river;
F = accretional flow.

For the Colne catchment:

A	= 1017.2 km^2 = 101720 ha (from original model)
L	= 55 km;
F	= 4800 m^3/km/day.
agricultural load	= 0.32 k P/ha/year (reference 1)
u/s flow	= 52.73 10^3 m^3/day (measured mean at GS 2819 in R. Ver)
	= 52.73 10^6 l/day
u/s concentration	= 0.0787 mg P/l (measured mean at PCNR.0088 in R. Ver)
u/s load	= 4149851 mg P/day
	= 4.149 k P/day
	= 1515 k P/year

= 0.01489 k P/ha/year.

Accretional load = 0.32 - 0.01489
= 0.305 k P/ha/year

The phosphate concentration in the accretional load is 0.323 mg/l.

APPENDIX D URN NUMBERS USED IN THE COLNE CATCHMENT

URN numbers and National Grid References (NGR) of the STWs, sampling points and gauging stations.

URN number and NGR of STWs

STW	URN number	NGR
Berkhamsted	PCNE.0024	TL 015 068
Blackbirds	PCNE.0011	TL 137 011
Chesham	PCNE.0031	SU 981 996
Maple Lodge	PCME.0119	TQ 042 920
Iver North	PCNE.0102	TQ 044 807
Iver South	PCNE.0103	TQ 039 778

URN number and NGR of gauging stations

Gauging station	URN number	NGR
River Colne at Denham	2870	TQ 051 863
River Ver at Colney Street (Hansteads)	2819	TL 150 021
Misbourne at Denham Lodgs	2879	TQ 047 864
Colne Brook at Hythe End	2894	TQ 019 723

URN numbers and NGR of sampling points

Sampling points	URN	NGR
River Colne at gauging station Denham	PCNR.0027	TQ 052 863
Colne u/s Thames	PCNR.0039	TQ 019 723
Colne Brook u/s Thames	PCNR.0025	TQ 033 716
Ver u/s Colne	PCNR.0088	TL 142 014
Misbourne d/s Gerrards Cross	PCNR.0072	TQ 029 876

APPENDIX E ACCRETIONAL PHOSPHATE CALCULATED FOR GINGE BROOK, SULHAM BROOK, AND CHOLSEY BROOK

A phosphate concentration in the flow upstream of the STWs in the catchments of Ginge Brook, Sulham Brook, and Cholsey Brook was not put into the original model. The contribution of the upstream phosphate concentration was put in into the accretional phosphate.

In the models developed in this study, there is an upstream phosphate concentration and therefore the accretional phosphate concentration must be calculated again. For each catchment mentioned here, it will be shown how the phosphate concentration in the accretional flow was calculated.

The u/s load and the accretional load can be calculated using equation (1) and (2).

u/s load = u/s flow * u/s concentration (1)

Accretional load = agricultural load - u/s load (2)

The accretional phosphate concentration can be calculated using the following equation:

$$Acc.Phos. = \frac{10^5 * A * 0.32}{365 * L * F} \quad (3)$$

where A = u/s area;
L = length of river;
F = accretional flow.

<u>Ginge Brook</u>

A	= 46.5 km^2 = 4650 ha (from original model);
L	= 13 km;
F	= 1 m^3/km/day.
agricultural load	= 0.32 kg P/ha/year (reference 1)
u/s flow	= 24.72 10^3 m^3/day (mean used in the original model)
	= 24.72 10^6 l/day
u/s concentration	= 0.0669 mg P/l (measured mean at PTHR.0032)
u/s load	= 1654000 mg P/day
	= 1.65 kg P/day
	= 603.7 kg P/year
	= 0.1298 kg P/ha/year.

Accretional load = 0.32 - 0.1298
= 0.190 kg P/ha/year

So the accretional phosphate concentration is 186 mg/l.

Sulham Brook

A	= 11 km^2 = 1100 ha (from original model);
L	= 30.2 km;
F	= 1 m^3/km/day.
agricultural load	= 0.32 kg P/ha/year (reference 1)
u/s flow	= 6.890 10^6 l/day (measured mean at GS 2195)
u/s concentration	= 0.181 mg P/l (measured mean at PPSR.0006)
u/s load	= 0.4138 kg P/ha/year.
Accretional load	= agricultural load - u/s load
	= 0.32 - 0.4138
	= 0.0 kg P/ha/year

So the phosphate concentration in the accretional concentration is 0.0 mg/l.

Cholsey Brook

A	= 20.8 km^2 = 2080 ha (from original model)
L	= 6.43 km;
F	= 1 m^3/km/day.
agricultural load	= 0.32 kg P/ha/year (reference 1)
u/s flow	= 8.838 10^6 l/day (mean used in original model)
u/s concentration	= 0.0671 mg P/l (measured mean at PTHR.0015)
u/s load	= 0.104 kg P/ha/year.
Accretional load	= agricultural load - u/s load
	= 0.32 - 0.104
	= 0.216 kg P/ha/year

The phosphate concentration in the accretional phosphate concentration is 191 mg/l.

APPENDIX F ACCRETIONAL PHOSPHATE CALCULATED FOR THE RIVER THAMES U/S OF THE CONFLUENCE WITH CERNEY WICK BROOK

For the equations used see appendix E.

A	= 22 km^2 = 2200 ha (assuming the same area as Cerney Wick Brook from the original model);
L	= 20.46 km;
F	= 3000 m^3/km/day.
agricultural load	= 0.32 kg P/ha/year (reference 1)
u/s flow	= 2.394 10^6 l/day (measured mean at GS 2195)
u/s concentration	= 0.073 mg P/l (measured mean at PPSR.0006)
u/s load	= 0.29 kg P/ha/year.
Accretional load	= agricultural load - u/s load
	= 0.32 - 0.29
	= 0.03 kg P/ha/year

So the phosphate concentration in the accretional phosphate concentration is 0.00295=0.0 mg/l.