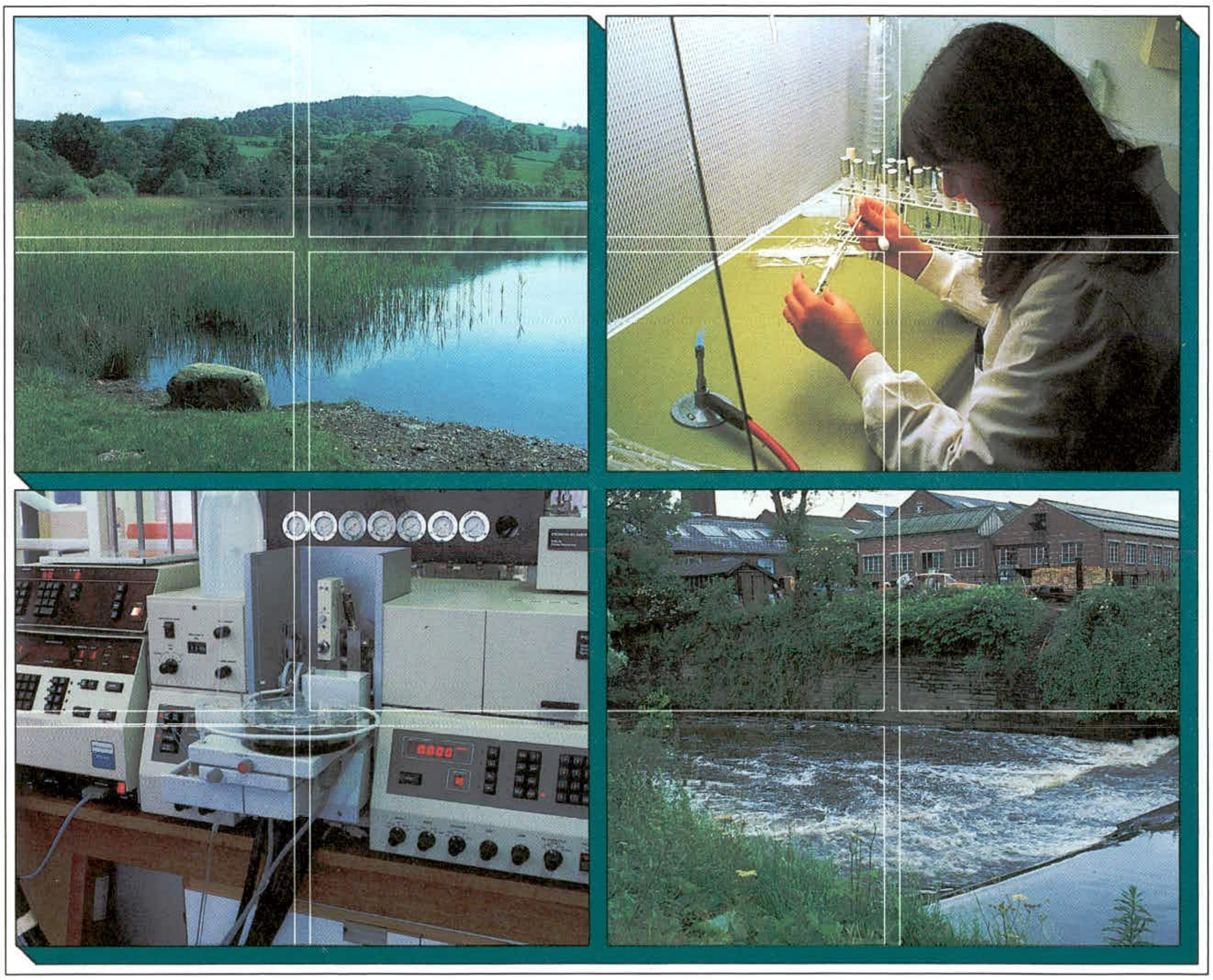
Institute of Freshwater Ecology

Proposed upgrading of sewage treatment works in Wales: assessment of the likely effects on the quality of stream waters receiving the effluents.

Phase I: general aspects of the study, the existing database and selection of field sites for the determination of the zones of effect of the discharges.

Project Manager: A E Bailey-Watts

Report to Welsh Water PLC



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PROPOSED UPGRADING OF SEWAGE TREATMENT WORKS IN WALES: ASSESSMENT OF THE LIKELY EFFECTS ON THE QUALITY OF STREAM WATERS RECEIVING THE EFFLUENTS. Phase I: General aspects of the study, the existing database and selection of field sites for the determination of the zones of effect of the discharges

Project Manager: A E Bailey-Watts

Report to Welsh Water plc
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PROPOSED UPGRADING OF SEWAGE TREATMENT WORKS IN WALES: ASSESSMENT OF THE LIKELY EFFECTS ON THE QUALITY OF STREAM WATERS RECEIVING THE EFFLUENTS: Phase I:
General aspects of the study, the existing database and selection of field sites for the determination of the zones of effect of the discharges

CONTENTS

Abstract

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The study examines the necessity to upgrade sewage treatment works (STWs) in Wales, to meet with improved BOD consents (BOD_c) in line with the recommendations of the Kinnersley Report. The structure of benthic macro-invertebrate assemblages in streams receiving sewage effluent is used as an indicator of water quality, and the programme explores the relationship between biological quality and BOD. The work comprises 3 phases, of which the first (described here) analyses existing Welsh Water data on sewage effluent quality from *ca* 200 works with BOD_c values of ≥ 100 mg l^{-1}. Data on BOD, suspended solid and ammonia levels in the effluents (BOD_e, SS_e and NH_{4e}) and on the receiving stream concentrations (ie at the point of entry of the waste) assuming theoretical, but likely minimum dilution situations (BOD_r etc), are critically assessed and analysed; the derivation of these data is also examined. On the basis of primarily, the theoretical mean level calculated for the sites at the point of entry of effluent to each stream, *ca* 60 sites were selected to be visited during Phase II of the work, to measure the zone of effect of the discharges. Levels of soluble reactive phosphorus (SRP) will be used as a 'tracer' for this purpose, although at a number of sites phosphate samples will be paired with collections of water for BOD analysis. In addition to establishing the area of influence of the discharge under the flow conditions prevailing at the time of sampling, this phase of the work will determine which 30-35 sites are likely to be suitable/appropriate for the biological analysis planned for Phase III of the study.

The present desk study revealed that many of the summary statistics on effluent content for each of *ca* 200 sites were misleading, because normal or log-normal frequency distributions had been mistakenly assumed. In most cases, however, as mean values exceeded the medians, the averages were chosen as the most suitable statistic on which to select sites for subsequent study, in that they would invariably over-estimate effluent BOD levels, for example. The arrays of the approximately 200 values for mean effluent concentrations of BOD and solids etc., described log-normal distributions. Effluent BOD averages ranged over 100-fold, while the corresponding in-stream values that were calculated, exhibited a range of 5 orders of magnitude. Neither the effluent BOD values, nor the dilution-adjusted figures appear to relate to size of population served, but ammonia and solids do parallel reasonably closely the BOD levels.

Mean effluent concentrations rarely approached the consent figures; thus, the BOD content of many effluents with consents of ≥ 100 mg l^{-1} would already satisfy considerably lower consents. Indeed, the ranges of theoretical BOD_r values were somewhat similar regardless of BOD_c between 50 mg l^{-1} and at least 300 mg l^{-1}. For this reason, the choice of sites for the zone of effect studies was biased to include the theoretically most polluted situations, ie with

all 22 of the sites with mean in-stream values of > 10 mg l^{-1}, one in every 2 of those with levels of > 1.0 to 10 mg BOD l^{-1}, one in every 3 sites with values of > 0.1 to 1.0 mg l^{-1} and one in every 4 of the locations with ≤ 0.1 mg l^{-1}. This resulted in a pool of 78 sites, of which 61 were eventually visited, and 46 were actually sampled for SRP and/or BOD analysis. The envisaged scope of the investigations to assess the zone of effect of the discharges, is outlined.

1. INTRODUCTION

1.1 Background to the study and the aim of the work

At least 200 small sewage treatment works (STWs) in Wales have high consents for biochemical oxygen demand (BOD_c) ie > 50 mg l^{-1} and ranging up to 150 mg l^{-1} and many hundreds of mg l^{-1}. This situation has prevailed for a long time - not least, because many works discharge into rivers which bring about high dilution of the waste and have relatively short passages to the sea. However, following the recent publication of the Kinnersley Report which drew attention to large numbers of discharges in this category, the National Rivers Authority produced proposals requiring all plants to be upgraded, such that effluent BOD levels (BOD_e) would be consistent with a BOD_c of 50 mg l^{-1}.

The custodians of the STWs in Wales (Welsh Water plc), have estimated that the programme of upgrading would cost *ca* £12 M. The company wishes to be convinced that spending money of this order, would result in real benefits as regards the freshwater environment. This report concerns the investigations undertaken by the Institute of Freshwater Ecology (IFE), on behalf of Welsh Water, to establish whether the estimated expenditure would be justified.

The overall aim of the work is to establish whether the quality of water receiving waste from works with effluent consents greater than 50 mg BOD l^{-1} would be measurably improved if the consents were lowered to 50 mg l^{-1}. It thus explores the relationship between stream invertebrate characteristics and BOD.

1.2 Approaches adopted

The composition of the benthic macro-invertebrate assemblages is to be used as a main indicator of 'quality' in the subsample of *ca* 35 sites to be visited during Phase III of the study. However, in selecting these sites (under Phase I) the Welsh Water records of the concentrations of BOD itself, suspended solids and ammonia in the effluents (i.e. BOD_e, SS_e and NH_{4e}) are examined in combination with estimates of minimum dilution (to give in-stream concentrations - BOD_r etc.). During Phase II the dispersion of effluent is to be tracked by measuring soluble reactive phosphorus and BOD concentrations (SRP_r and BOD_r) - hopefully in the receiving waters at *ca* 60 sites.

Plainly, the relationships between BOD_c, BOD_e and the chemical and biological quality of the receiving waters had to be considered, but BOD_e on its own, may have little effect on stream quality; the degree of dilution of the effluent by the receiving water is the key factor. An early step was to examine the relationship, in the existing databases between BOD_c and the statistics on BOD_e and BOD_r. This would establish the following:

- the nature of BOD_e and BOD_r values associated with different BOD consents, and

- to what extent the consents are met.

Initial discussions with Welsh Water suggested that BOD_e (and BOD_r) for many of the situations where consents are even considerably higher than 50 mg l^{-1}, are similar to those found for works with a consent of 50 mg l^{-1}. The investigators felt it was important to check this, because legislation relates to the actual consent, rather than the characteristics of the effluents or the receiving waters, even though these latter determine stream water quality. **Figure 1a** confirms that while log values for mean BOD_e are linearly related to log values for the consents, there is a considerable overlap in the ranges of the effluent values associated with consents varying between *ca* 50 mg l^{-1} and at least 300 mg l^{-1}. Moreover, when the dilution by the receiving waters is taken into account (**Figure 1b**) to give BOD_r, there is little difference between these concentrations, whether the consent is 50 mg l^{-1} or any other value up to at least 4 times this level; indeed, while the number of sites sampled where consents of > 300 mg l^{-1} prevail is small, the scatter of BOD_r values corresponding to them, appears to be no different from that relating to the sites with the lowest consents included in Figure 1. On this evidence, a strong BOD-quality relationship is unlikely to be established even though ideally, it should be sufficiently clear to facilitate an assessment of the effect of the proposed lowering of BOD_c.

Attention has been given to defining 'effect'. Any discharge, however small, is likely to have some effect on the receiving water course. As a first requisite for being considered significant in this study, an effluent needs to be detectable at least where it enters a stream. Again, however, variation in dilution due to streamflow fluctuations will modify this zone of effect (ZoE). While not within the scope of the present investigation, knowledge of the incidence of low flows would be valuable; water quality problems can arise at these times, even where effluents meet the consent standards. The first phase of practical work looks into the ZoE aspect, prepatory to choosing the 30 sites for the invertebrate work.

Because many of the discharges are into fast-flowing, high-volume waters, the authors were instructed by Welsh Water to bias the choice of those sites for ZoE determinations (including those for eventual biological evaluation) towards minimum dilution situations, i.e. where contrasts with conditions upstream of works were most likely to be detected.

The first discussions about the work were held with Welsh Water in December 1990. Phase I started in mid-January and comprised the data analysis described in this report. It establishes the nature of the parent data set and describes the derivation and significance of the determinands, and the inter-relationships between different factors. The frequency distributions of factors such as dilution and BOD levels over the Welsh Water region, provide the basis for selecting the sites for the later fieldwork. Because the invertebrate sampling programme had to be under way by April, but depending primarily on water temperatures leading up to that time, the ZoE work (Phase II) needed to be started by mid-February. As a consequence, the work for the desk study described here needed to be (and was) completed by early February. Work relating to Phases II and III of the contract are described in separate reports.

1.3 Scope and structure of the report

The database on sewage effluent quality, factors affecting this quality (eg size of population served by the works) and related information on the receiving water courses, is discussed in Section 2 with details of the analyses leading to the selection of sites for the field investigations. Section 3 describes the way the sites for ZoE work were selected, and illustrates how the frequency distributions of a number of effluent quality determinands in the subset compare with those of the parent array. The approaches planned for this fieldwork are outlined in Section 4, and an Appendix lists the sites chosen for this part of the study.

2. THE WELSH WATER DATABASE ON SEWAGE TREATMENT WORKS (STWs): EXAMINATION AND ANALYSIS TOWARDS THE SELECTION OF SITES FOR CHEMICAL AND BIOLOGICAL INVESTIGATION

2.1 The data files and the origin and derivation of the determinands

Data in two types of file were put at our disposal. One of these consisted of a spreadsheet with the following information:

- location of the STW by region, i.e. N/SE/SW
- name of works and the receiving water course
- hydrometric reference
- map references to the works and the sewage outfall
- the size of the population served by the works
- dilution factor calculated from the maximum discharge of the effluent and the 5-percentile values of the annual flows of the receiving water, i.e. an indication of near-minimum dilutions achieved
- the BOD consent value; this file was restricted to values > 100 mg l^{-1}
- but see Section 1.2
- the mean BOD concentrations in the effluent (these being the averages of a value obtained from however many samples had been taken from a particular works).

The second file contained details on the quality of each effluent as regards suspended solids (SS) and ammonia (NH_4), and BOD_e which had been measured at each site **either** in the traditional way, or by the method involving suppression of ammonia effects by addition of allyl thiourea (ATU). This file was limited to information gathered over the last 10 years, i.e. 1981 to 1990 inclusive (see below); sites affected by tides, those consisting of soakaways and those referring to information based on less than 10 samplings were discarded. This resulted in a list of 177 works. The items of information that were added to the first file, are as follows:

- the date and time of day of individual samplings, and the arithmetic mean values for BOD_e (ATU version), NH_{4e} and SS_e. As an index of the concentrations of BOD, for example, prevailing once the effluent enters the stream (i.e. BOD_r), BOD_e was multiplied by the reciprocal of the minimum dilution plus 1.

A number of other statistics on the 3 quality indicators were available, e.g. minima, maxima and medians, and 95-percentiles on the raw values, and 50 percentiles and 95- percentiles on log-transformed values. However, these appear to be of somewhat limited use, because they were calculated on the assumption that the distribution of the data from each site was normal or log-normal; a preliminary inspection of these summary statistics, and graphical examination of a few of the original data sets, suggested that the assumption was not always justified (see **Figure 2** for an example). In most cases, however, mean values exceeded the medians, so by choosing the means as the most suitable statistic, values for BOD_e etc. are likely to be over-estimates.

Another major concern over these data, is that the summary statistics for the different sites are derived from different numbers of samples. One set of analyses might relate to a site that has been sampled every month for 10 years, while another might refer to a works sampled at the same intensity for a different length of time, or for the same period but at different intervals. Indeed, the working file was restricted to the last 10 years' of data in an attempt to minimise this effect. While the intensity of work was initially thought to have been more standardised in recent years, this is not the case. However, to illustrate the likely effect of different sampling regimes on the results, variation in the different determinands have been examined for Bethesda STW - one of the most intensively sampled - sites and **Figure 3** shows BOD_e values as an example.

As noted above, in the vast majority of cases, BOD_e at any given site has been measured by one or the other of two procedures. Investigations of relationships between BOD_e and the other measures of effluent quality, are thus somewhat hampered by the fact that while the number of BOD_e measurements may equal that of SS_e and of NH_{4e}, the number of BOD values measured by one or other of the two methods would be less than the numbers of the other determinands. Their mean values are thus not comparable - and time has not allowed us to punch in all the data to calculate the 'comparable' means, and eliminate this effect. Nevertheless, the degree to which BOD_e, SS_e and NH_{4e} inter-relate, has also been examined for the Bethesda site and for the array of 177 works as a whole. On the basis of the log-log plots, the Bethesda data (**Figure 4a**) indicate a positive, approximately linear, relationship between BOD and solids, but little association between BOD and ammonia-N, while the data for all sites (**Figure 4b**) show evidence of curvi-linear relationships between BOD and both solids and ammonia. Plainly, it would be profitable, at a later date, to re-examine in detail the whole database on effluent quality.

2.2 Data analytical results

The data have been examined with the view to selecting sites for chemical and biological sampling, as it was not feasible to carry out the type of fieldwork planned, at all 177 sites.

The major criterion for selection is BOD_r (rather than BOD_e), and sites could be chosen on the basis of the frequency distribution of this factor alone. It seemed advisable, however, to examine whether other factors differed, even within a group of sites of similar BOD_r. Then, such differences could also be taken into account at the selection stage. In the absence of this type of information, interpretation of the biological results in relation to BOD_r, could be rendered more difficult; for instance, a range of invertebrate responses might be found at sites where BOD_r is elevated to similar degrees, because particulate matter or ammonia is the major influencing factor - not BOD itself. By the same token, similar animal responses might be found at sites varying in the shift in BOD_r, but experiencing relatively consistent, increased levels of solids, for example.

Figures 5-10 use the graphical method of rankits (normalised scores - see Sokal & Rohlf, 1963) to display primarily the ranges and frequency distributions of BOD_e or BOD_r. The rankit procedure is preferred to the convention of histograms, as it displays all data points and eliminates the effects of choice of class interval on the structure of the frequency histogram. Each of the sets of 177 values exhibit a log-normal distribution, i.e. the plots of normalised scores on the ranked values, describe more or less straight lines. However, gaps in the lines indicate discontinuities in the arrays of these values. While the mean effluent levels vary over 100-fold, these numbers corrected as described above, for dilution by the receiving water course, range over more than 5 orders of magnitude.

Figure 5 includes information on the consent BOD values for each of the sites. On the basis of the mean BOD_e figures, it would appear that the consent concentrations are rarely approached; there is little consistent relationship between BOD_e and BOD_c, however, even though the generally lower values for the effluents correspond to the low consents and the high BOD_e figures are associated with works with high consents.

The range and nature of the distribution of BOD_r values as derived here, are plainly dominated by the dilution terms in the calculations rather than the BOD_e values (**Figure 6**); there is little relationship between BOD_e and ('minimum') dilution but a more consistent one between BOD_r and dilution. **Figure 7** indicates that BOD_e concentrations, and the dilution-adjusted levels, vary independently of the size of the population served by a works. As examples, effluent

BOD figures range over an order of magnitude for works serving e.g. *ca* 10 000 people, and for sites dealing with the waste from *ca* 10 persons.

While features such as population size and dilution might have been considered important determinants of effluent BOD, but are apparently not on the basis of the data available so far, the concentrations of the other constituents of the waste water analysed, parallel the BOD_e levels reasonably closely. **Figures 8** and **9** illustrate the point for suspended solids and ammonia respectively.

3. SELECTION OF SITES FOR CHEMICAL 'ZONE OF EFFECT' WORK

The selection was made with the following considerations in mind. One relates to the results of the exploration of the database described in the previous Section. This suggests that from a list of sites ranked according to BOD_e, or even better, BOD_r for example, a choice of every say, third site would suffice. Such a strategy would plainly cover the range found in terms of BOD_e, or of BOD_r, and, by association, in respect of e.g. solids and ammonia, but also BOD_c and dilution. Only with regard to population values, might the 'representativeness' of the sample be in question. It is plain, however, that many of the sites are unlikely to exhibit major alterations in invertebrate population structure, that could be attributable to the sewage outfalls indicated here. This view is based on (i) the assumption that the greater the resultant concentration of effluent in the receiving water, the greater the effect on the invertebrate assemblage, and (ii) the observed preponderence of 'mean stream BOD' concentrations of < 1.0 mg l^{-1} (themselves probably over-estimates of the actual levels). From this point of view, a selection with a bias towards the most polluted sites, would appear more appropriate, although the bias should not lead to a complete discarding of the 'dilute' waters.

Another consideration takes account of the customer's wish that the selection biases towards 'minimum dilution' sites; only by including an appropriately high proportion of these locations, will it be possible to demonstrate to NRA whether upgrading of a works is necessary. In contrast to sites that it is felt should be included in the field programme in any event, there are situations that were considered best avoided on logistic grounds.

Taking each of these issues into account, a total of 78 sites was selected and, these are listed in Appendix I; this resulted from choosing all of the sites with BOD_r values of > 10 mg l^{-1}, every second of the sites with values of > 1 up to 10 mg l^{-1}, every third of the sites with values of > 0.1 up to 1.0 mg l^{-1} and every fourth in the list of sites with values of < 0.1 mg l^{-1}. Figure 10 uses SS and NH_4 data to compare the ranges and frequency distributions of the various determinands in the selected sites with those in the original arrays of 177. While the 78 plainly exceeded the maximum of 65 that it was felt possible to visit for ZoE assessment, discussions with Welsh Water led to the discarding of a number of sites due to e.g. closure or the presence of another effluent nearby. This left the 61 sites which were actually visited, and these are indicated in Appendix I.

4. THE MAIN ELEMENTS OF THE FIELDWORK TO ASSESS THE ZONE OF EFFECT OF STW OUTFALLS ON RECEIVING STREAMS

Details of the work aimed at establishing the extent of the effect of outfalls on the receiving water courses will be covered in the report on Phase II of the study. To maintain continuity in the reporting of the different phases of the programme, however, it is appropriate to conclude the present report, with an outline of the aims and scope of the second Phase.

The subset of locations selected for the fieldwork outlined below is representative of the situation in Wales generally as regards STW effluent quality, but especially includes works where the discharges are least diluted by stream waters. Sites are to be visited with a view to assessing the zone of effect of discharges, using SRP concentration as the main 'tracer'. This will indicate where best to collect samples for invertebrate analysis under Phase III of the programme (i.e. at what distances above and below the outfalls). Indeed, Phase II will also establish which sites are appropriate/suitable for the biological work, and, on this basis, 30 to 35 sites are to be selected for that work.

At each of the sites visited under Phase II, the following information will be gathered:

- an estimate of effluent discharge rate
- an estimate of flow in the receiving water course
- the concentration of SRP at 3 points across the stream at a distance of 4-5 m above the point of sewage outfall, and at distances of 1 m, 10 m, 20 m and 50 m below this outfall; except where the widths of the receiving streams were less than 1 m, samples were taken at the mid-point and at points half-way between this and each shore
- the concentration of SRP in the effluent before it enters the stream water
- BOD will be determined on a subset of samples to establish a BOD-SRP relationship with the view to expressing the zones of effect of the discharges in terms of oxygen demand.
- pH, conductivity and temperature will also be measured.

5. REFERENCES

Sokal, R.R. & Rohlf, F.J. 1969. *Biometry: the principles and practice of statistics in biological research.* Freeman. San Francisco.

6. ACKNOWLEDGEMENTS

We thank Dr Norman Lowe and Mr Clive Hingley (Welsh Water plc, Brecon) for helping with the acquisition of their company's data relevant to the present study; numerous regional staff organised our access to the works visited. Mrs Elma Lawrie typed the report.

Appendix 1. 78 sites initially selected for 'zone of effect' studies, including the 61 sites actually visited (v).

WWA no.	region	STW name	receiving water
230 v	SE	ABBEYDORE	DORE RIVER TRIB.
234	SE	ORCOP-COPWELL EST	GARREN BROOK TRIB.
235 v	N	BARTON-CODDINGTON LANE	PLOWLEY BROOK TRIB.
239 v	SE	GLEWSTONE-WILSON BROOK	LUKE BROOK
240 v	SW	LLANWNEN LOWER	GRANNELL AFON
242 v	N	FRIOG	MAWDDACH RIVER TRIB.
246 v	N	PENRHOS SMALL	PENRHOS AFON TRIB.
247 v	SE	LLANGYBI	USK RIVER
248 v	N	SAIGHTON	POWSEY BROOK TRIB.
250 v	SE	RUARDEAN-WOODSIDE	GREATHOUGH BROOK
251	SE	ST OWENS CROSS	GARREN BROOK TRIB.
252	SE	WESTON-U-PENYARD DAIRY COTTAGES	RUDHALL BROOK TRIB.
255	N	CAPEL GARMON	EYARTH AFON TRIB.
260 v	SE	NEWLAND	VALLEY BROOK
262 v	N	PISTYLL	PENISAR LON
264 v	SW	CAPEL BANGOR	MELINDWR AFON TRIB. DITCH
267 v	SW	CASTLEMORRIS	WESTERN CLEDDAU TRIB.
268 v	N	TYDDYN HYWEL	UNNAMED STREAM
269	SE	ACTON BEAUCHAMP [GREEN]	FROME RIVER TRIB.
275 v	N	HUGMORE LANE	DEVON BROOK
276 v	SE	BUILTH ROAD	DULAS BROOK
280	N	CORNIST HALL	NANT-Y-FFLINT TRIB.
289	N	EYTON	DEE RIVER TRIB.
297 v	SE	LLANWRTHWL	WYE RIVER TRIB.
302 v	N	CLOCAENOG	CLWYD RIVER TRIB.
303 v	N	CLUTTON-TATTENHALL	CARDEN BROOK
304	N	CLYNNOG FAWR	UNNAMED STREAM
305 v	N	CROESOR 3	CROESOR
310 v	N	GAERWEN	CEFNI RIVER
312 v	N	GRAIANRHYD	TERRIG RIVER TRIB.
317 v	N	KINNERTON LOWER	PULFORD BROOK TRIB.
319 v	N	LLANBRYNMAIR	LAEN
327 v	N	PENTREFELIN (GLAN CONWY)	NANT Y GARREG DDU
329 v	N	RHYDUCHAF	ABERDULDOG NANT
330 v	N	SEION 1 NEW	NANT Y GARTH TRIB.
331 v	N	TRAWSFYNYDD	PRYSOR AFON
333 v	SE	ABERBAIDEN	USK RIVER
336	SE	BWLCH [NORTH]	LLYNFI RIVER
342 v	SE	DEVAUDEN	PILL BROOK TRIB.
348 v	SE	LLANDEGLEY	MITHIL BROOK
353 v	SE	LLANSOY	PILL BROOK
363	SE	PONTSTICILL [VILLAGE]	TAFF FECHAN
366 v	SE	ST FAGANS	ELY RIVER
380 v	SW	GLOGUE	TAF AFON
381	SW	HUNDLETON	PEMBROKE RIVER
386	SW	UZMASTON	WESTERN CLEDDAU TRIB.
388 v	N	GWYDDELWERN	CAMDDWR
390 v	N	LLANGEFNI	CEFNI
392 v	SE	FELINDRE	FELINDRE BROOK
393 v	SE	LLANGARRON (HERBERTS HILL)	LLANERCH BROOK TRIB.
398 v	SW	CARWAY	GWENDRAETH FAWR TRIB.
399 v	N	BRONABER	EDEN RIVER
403 v	N	LLANFOR	DEE RIVER
404 v	N	MELIN-Y-COED	NANT Y GORON
405 v	SE	RUARDEAN	LODGEGROVE BROOK TRIB.
410	N	CAER ESTYN	PULFORD BROOK TRIB.
411 v	N	DOBSHILL	BROUGHTON BROOK TRIB.
412 v	N	DOLWYDDELAN	LLEDR AFON

413	v	N	LLANEFYDD	FFYNNON NEFYDD
414	v	SE	MUCH DEWCHURCH	WORM BROOK
415	v	SE	OLD DROPE	NANT Y DROPE
418	v	N	BETHESDA	OGWEN RIVER
421		N	CEFN MAWR	DEE RIVER
425	v	N	TILSTON	CARDEN BROOK TRIB.
426	v	N	TREGARTH	OGWEN
428		SE	CEFN COED	TAFF FAWR
429	v	SE	LIBANUS	TARELL
430	v	SE	LITTLE DEWCHURCH	WRIGGLE BROOK TRIB.
433	v	SE	PIPE & LYDE	LUGG RIVER TRIB.
435	v	SE	WALFORD (COUGHTON PLACE)	WALFORD BROOK
438	v	SW	CILYCWM	GWENLAS AFON
439		SW	FFAIRFACH	TYWI AFON
441	v	SW	LLANFARIAN	YSTWYTH AFON
442	v	SW	LLANYBYTHER	TEIFI AFON
443	v	SW	PENPARC	RHYD Y FUWCH NANT
444	v	SW	PONTRHYDYCEIRT	MORGENAU AFON
445		SW	RHOSCROWTHER	ANGLE BAY-TRIB.
447	v	SW	TREGARON	TEIFI AFON

FIGURES (1 - 10)

Figure 1a. The relationship between mean effluent BOD levels and the consent values, for STWs ranging from 50 to *ca* 700 mg BOD l^{-1} consents

Welsh Water STWs – consent >49 mg BOD/l: mean BOD in effluent related to consent

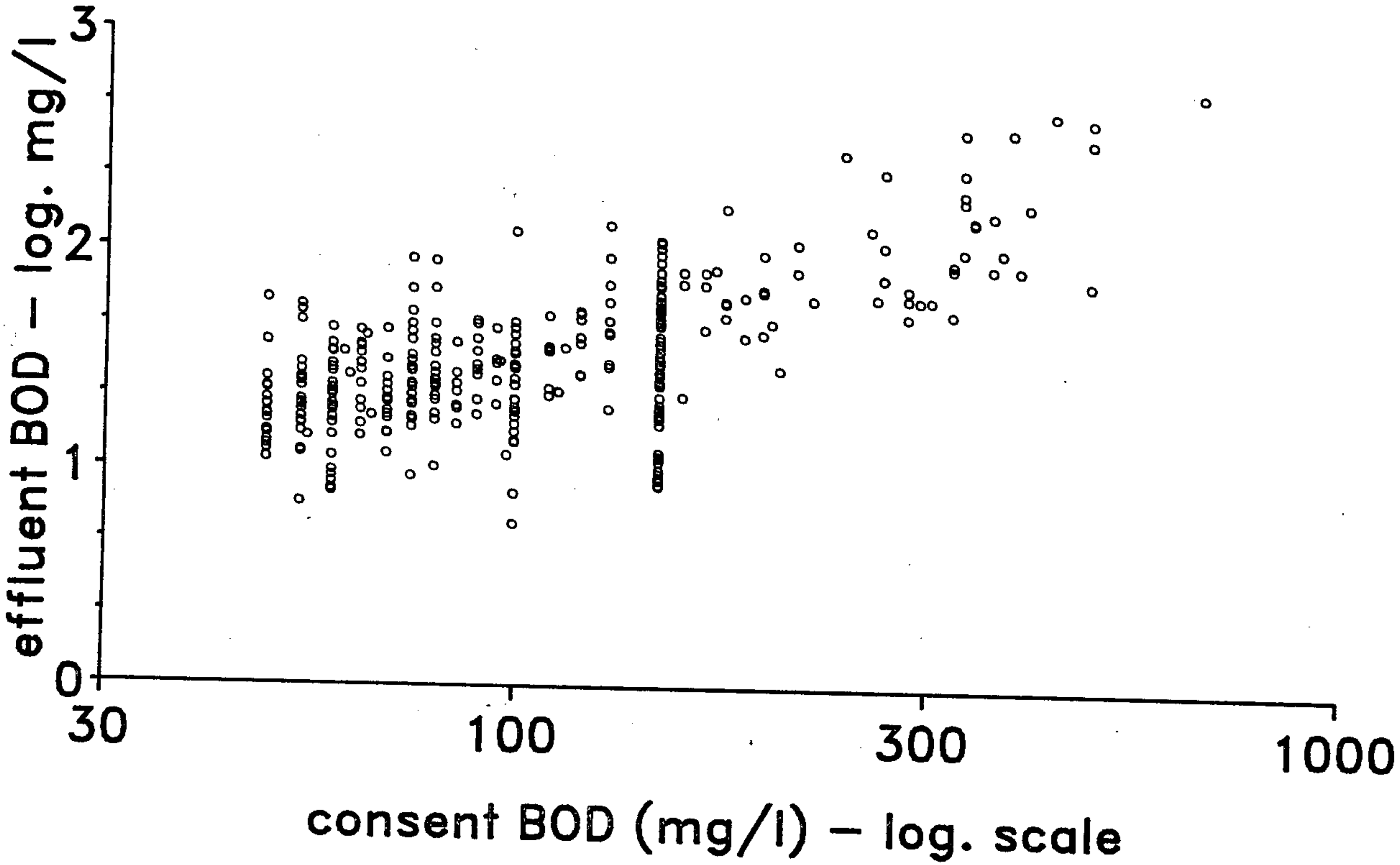


Figure 1b An investigation of the relationship between in-stream BOD levels (BOD_r in the text) and the consent concentrations (BOD_c in the text) for Welsh Water sewage treatment works with consents ≥ 50 mg BOD l^{-1}; BOD_r values have been calculated from:

$$BOD_r = (BOD_e)/D+1$$

where BOD_e is the mean concentration of all samples of effluent analysed for each works, and D represents the value indicating the minimum degree to which the effluent is diluted by the water in the receiving stream, i.e. a value based on the theoretically lowest stream flow and the maximum effluent discharge.

Welsh Water STWs – consent >49 mg BOD/l: in–stream BOD levels related to consent

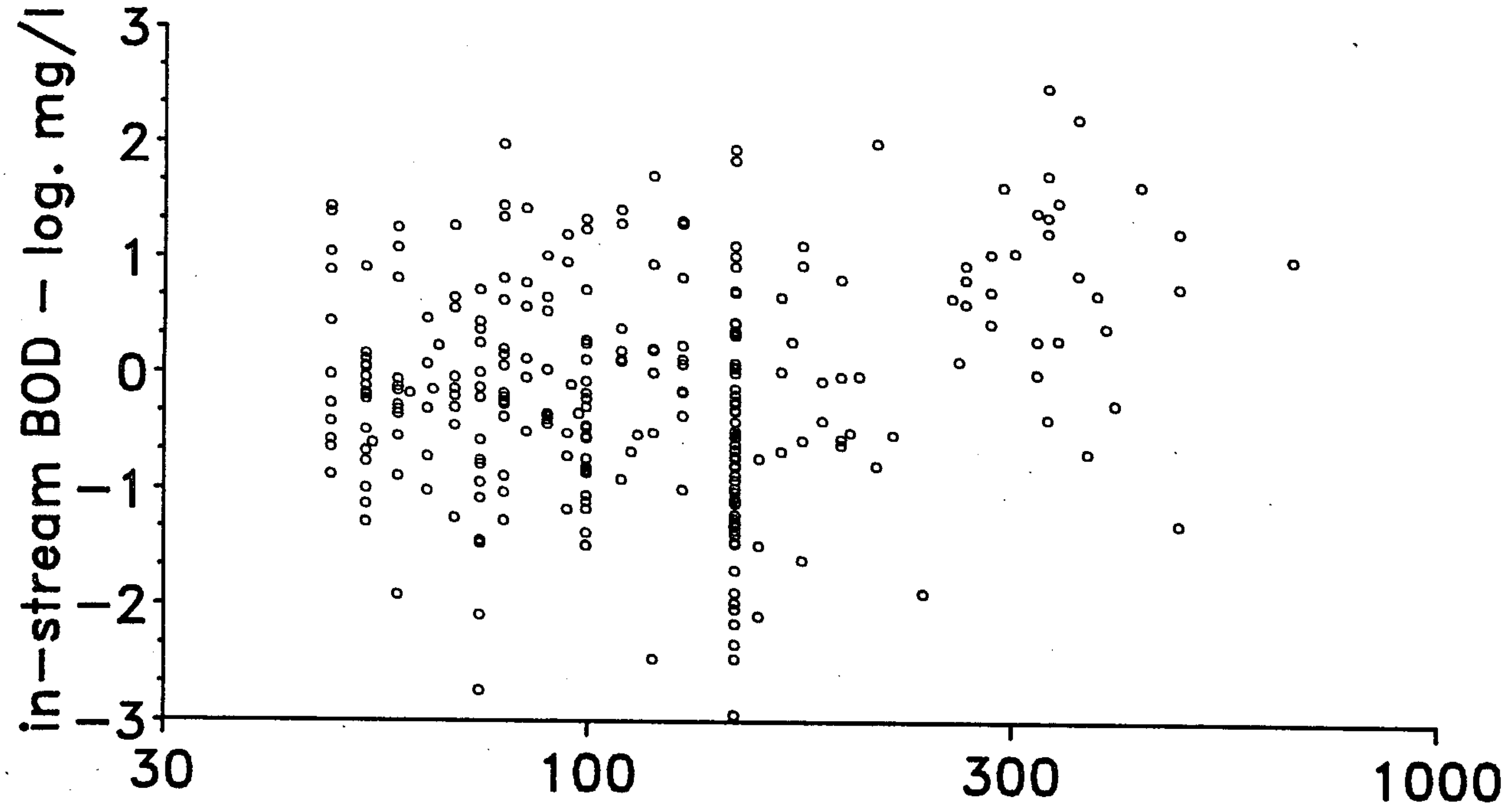
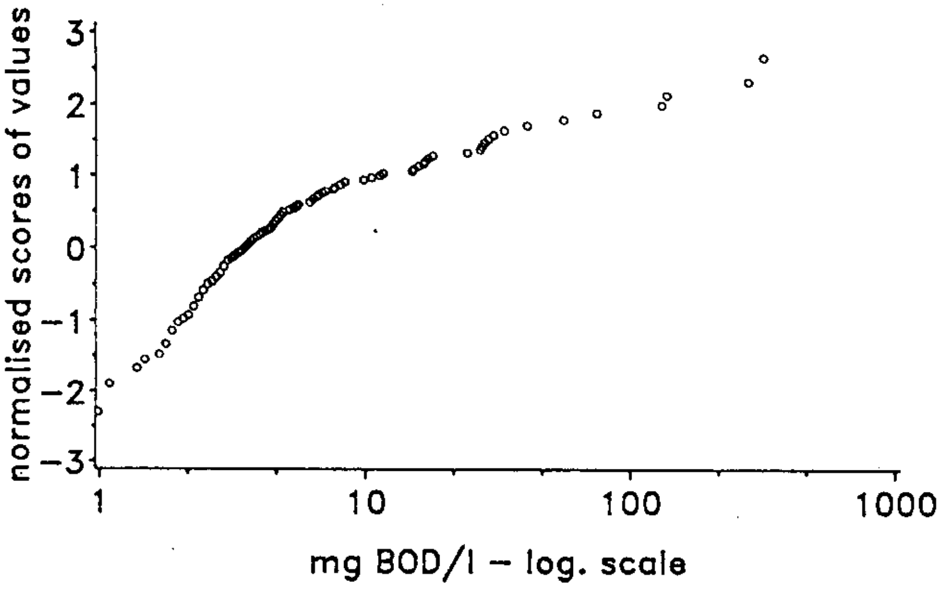
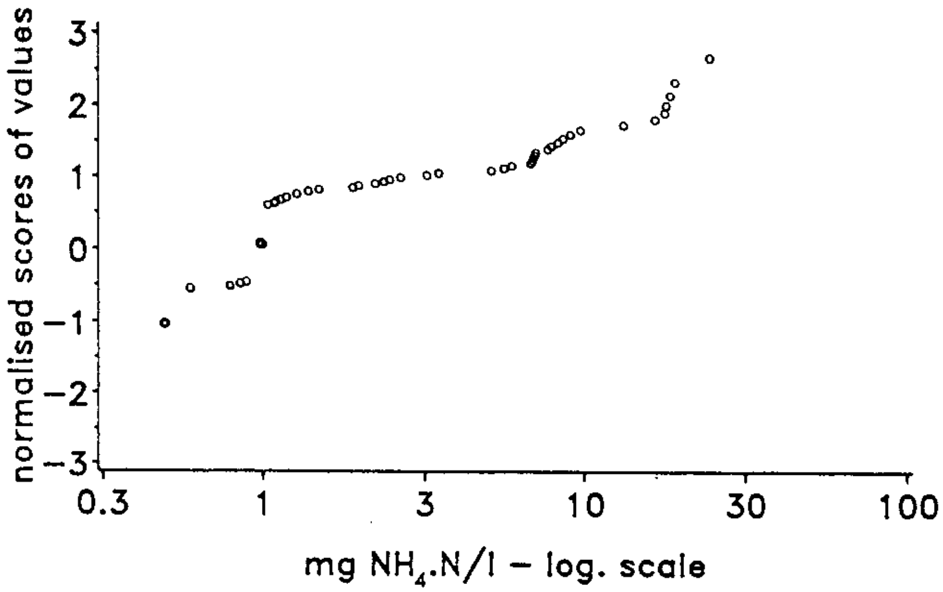


Figure 2. Frequency distributions of the concentrations of BOD (ATU), suspended solids and ammonia in effluent from Bethesda STW - a works sampled approximately 150 times over 1986 to 1990 inclusive.

Bethesda STW effluent (Wales) – 1986–1990: frequency distribution of BOD levels



Bethesda STW effluent (Wales) – 1986–1990: frequency distribution of NH_4.N levels



Bethesda STW effluent (Wales) – 1986–1990: frequency distribution of solids levels

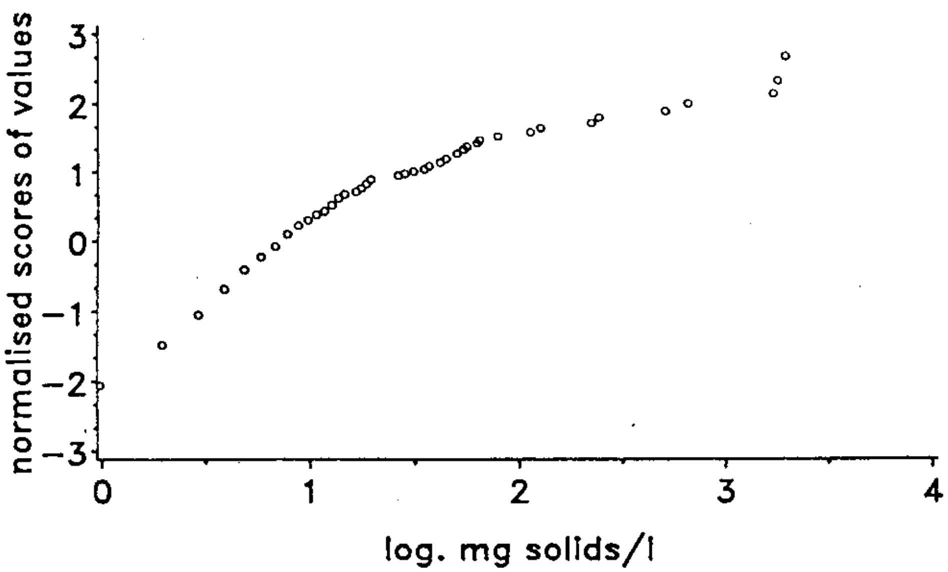


Figure 3. Bethesda STW: temporal variation in effluent BOD concentrations, to illustrate the likely strong effect on mean values calculated from sampling runs differing in intensity and/or duration; the graph excludes 4 values exceeding 100 mg l^{-1}.

Bethesda STW effluent – Wales
Biochemical oxygen demand – (ATU)

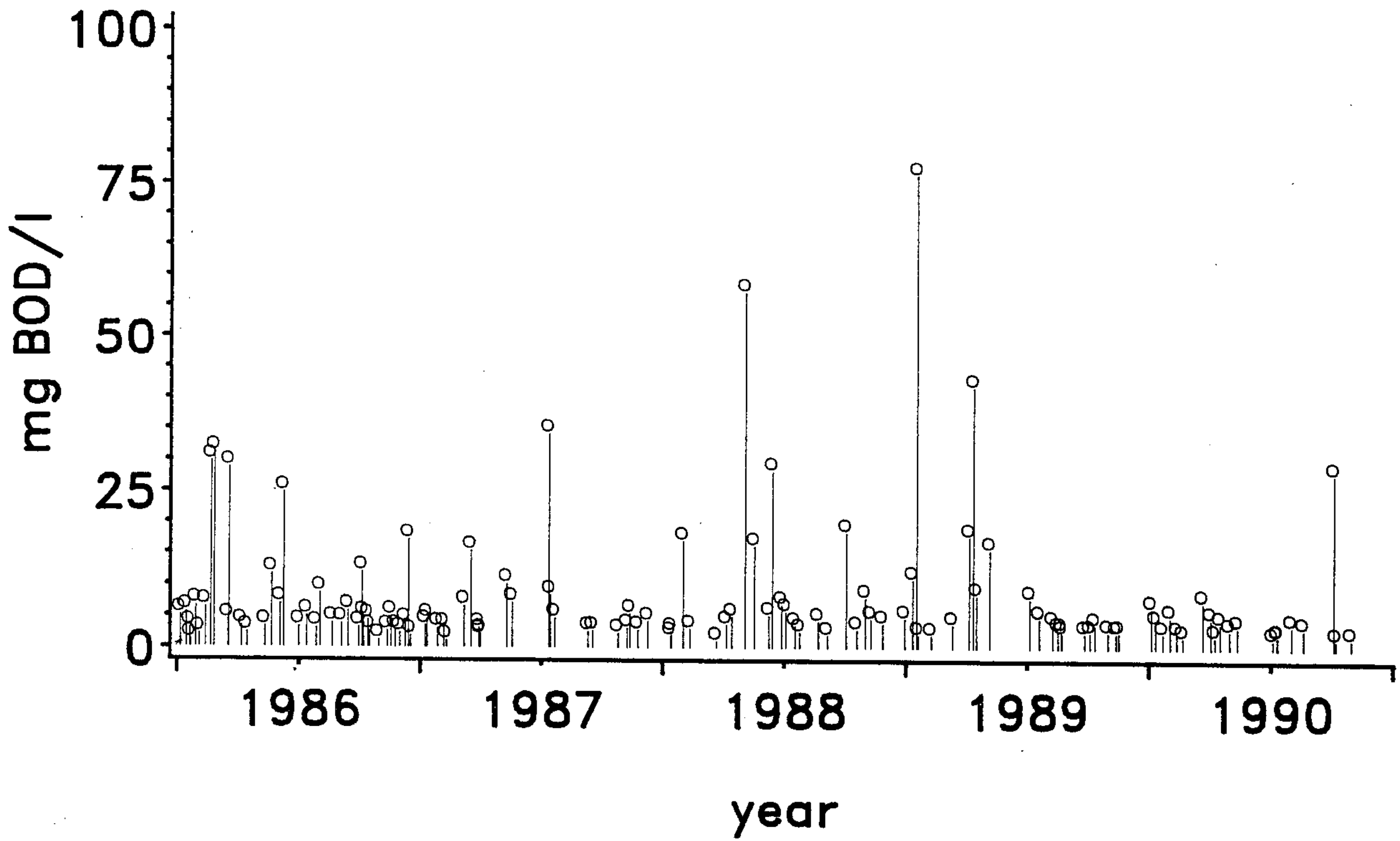
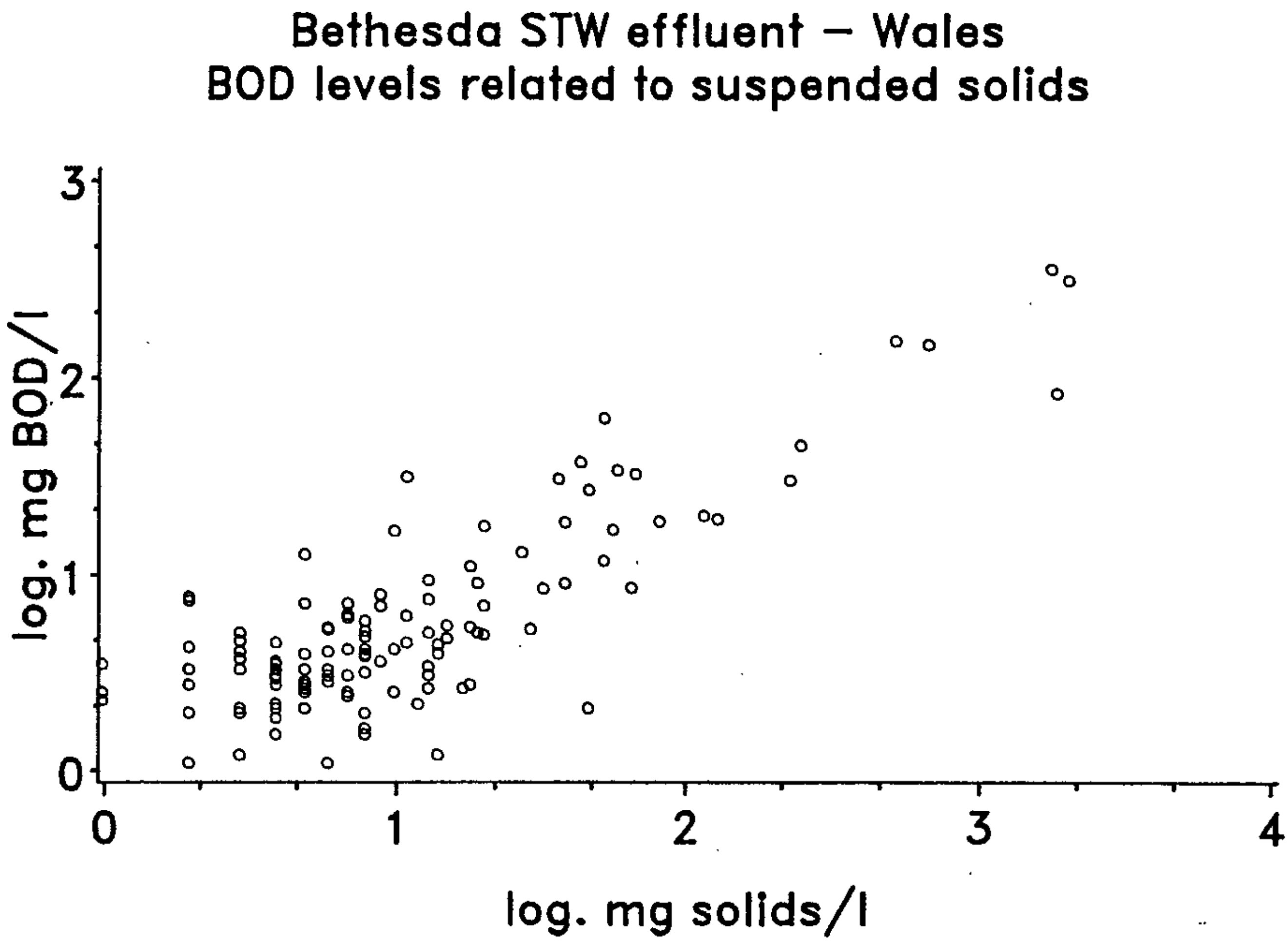
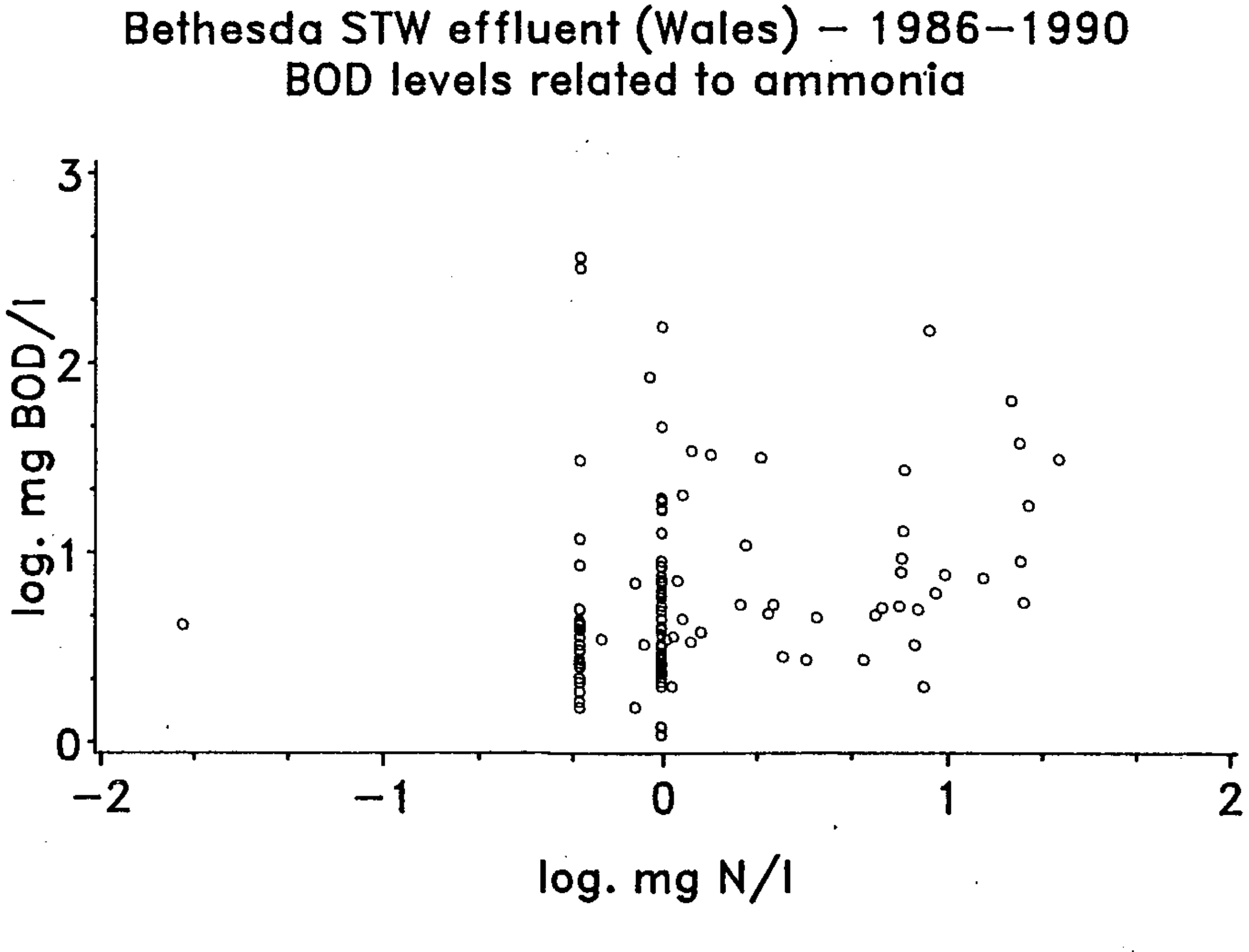


Figure 4(a). The relationship between the concentrations of BOD and solids (upper graph) and ammonia (lower graph) in the effluent of Bethesda STW; to the period and intensity intensity of sampling indicated in Figure 3.



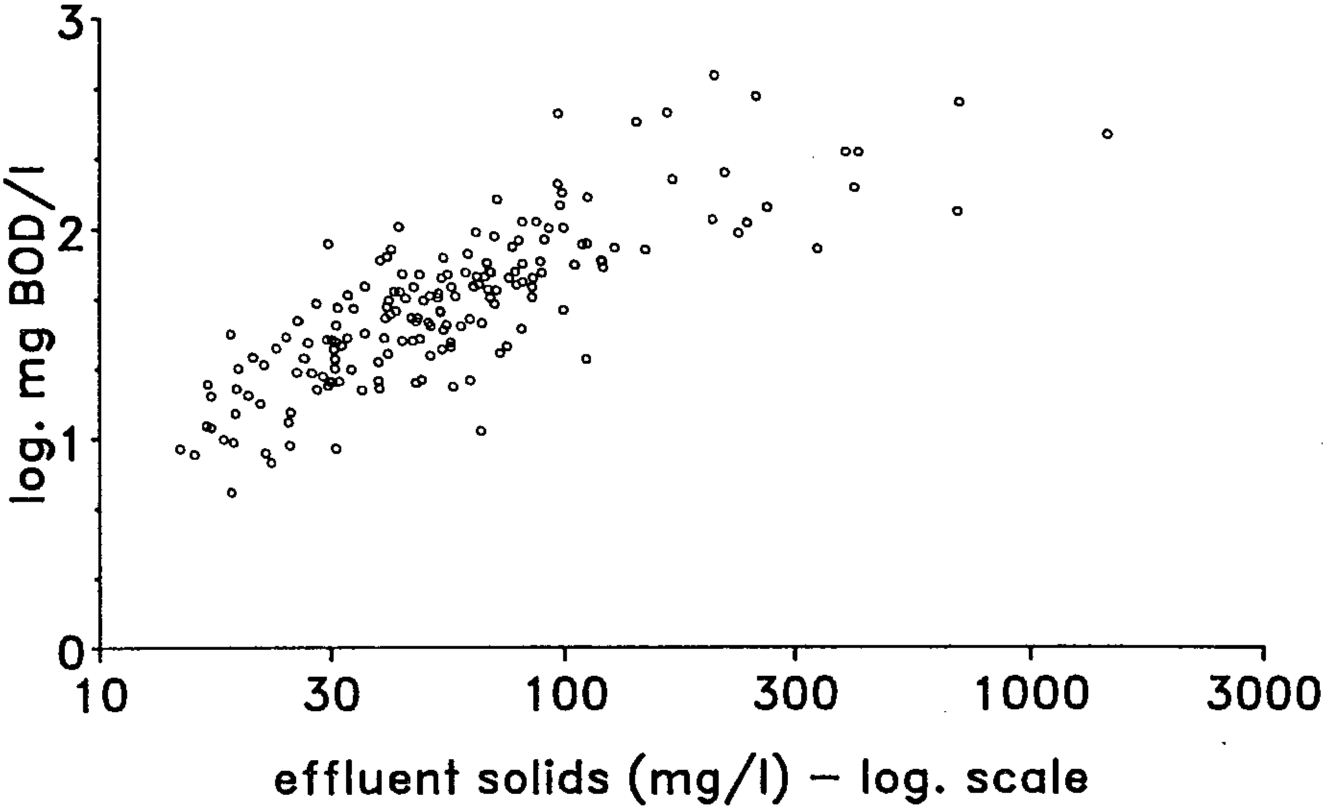
Bethesda STW effluent - Wales
BOD levels related to suspended solids
log. mg BOD/l
log. mg solids/l
0
1
2
3
4



Bethesda STW effluent (Wales) - 1986-1990
BOD levels related to ammonia
log. mg BOD/l
log. mg N/l
-2
-1
0
1
2
3

Figure 4(b). As Figure 4(a) but using the mean effluent contents of BOD, solids and ammonia-N of all 177 works with consents greater than 99 mg BOD l^{-1}.

Welsh Water STWs – consent >99 mg BOD/l:
mean BOD in effluent related to solids



Welsh Water STWs – consent >99 mg BOD/l:
mean BOD in effluent related to ammonia

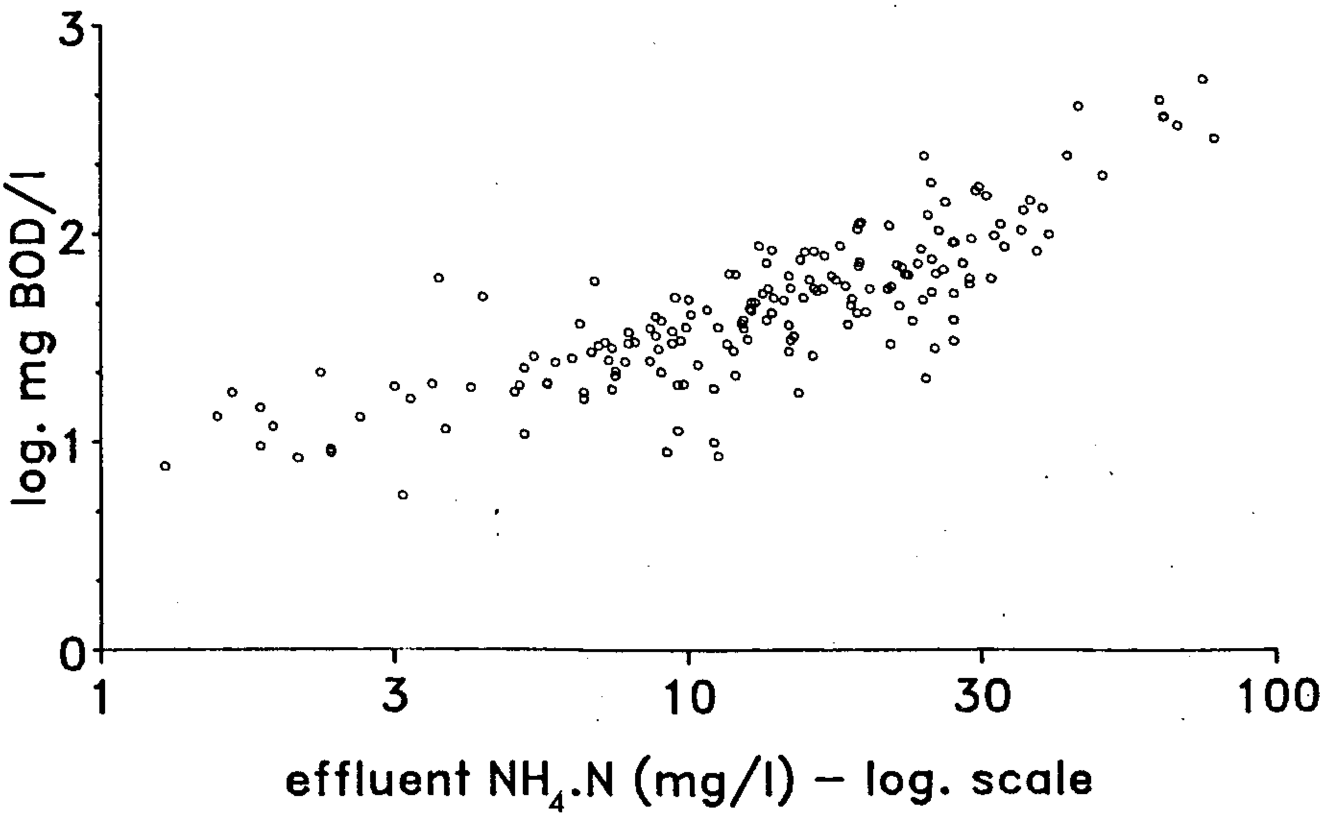
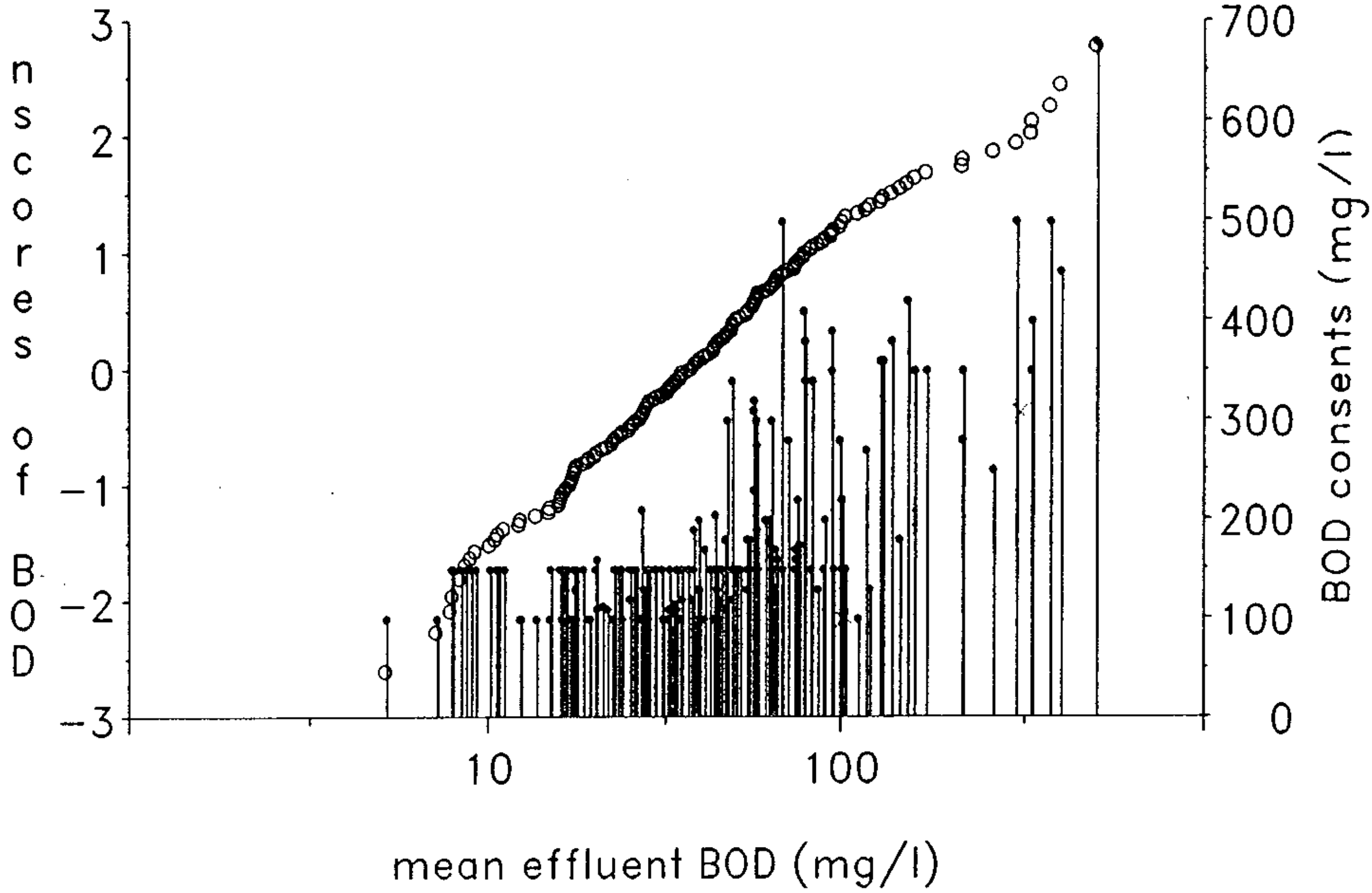


Figure 5. Upper panel: the range (horizontal axis) and frequency distribution (left-hand vertical axis, using normalised scores), of the mean effluent BOD concentrations (open circles) in the effluents of 177 Welsh Water STWs with BOD consents of ≥ 100 mg l^{-1} (indicated by the needle plots and the scale on the right-hand vertical axis).

Lower panel: as upper panel but for BOD concentrations in the streams receiving these effluents i.e. having taken account of dilution effects (see text)

STWs – consents =/> 100mg BOD/l
effluent BOD distribution (°) and the consent (•)



STWs – consents =/> 100mg BOD/l
stream BOD distribution (°) and the consent (•)

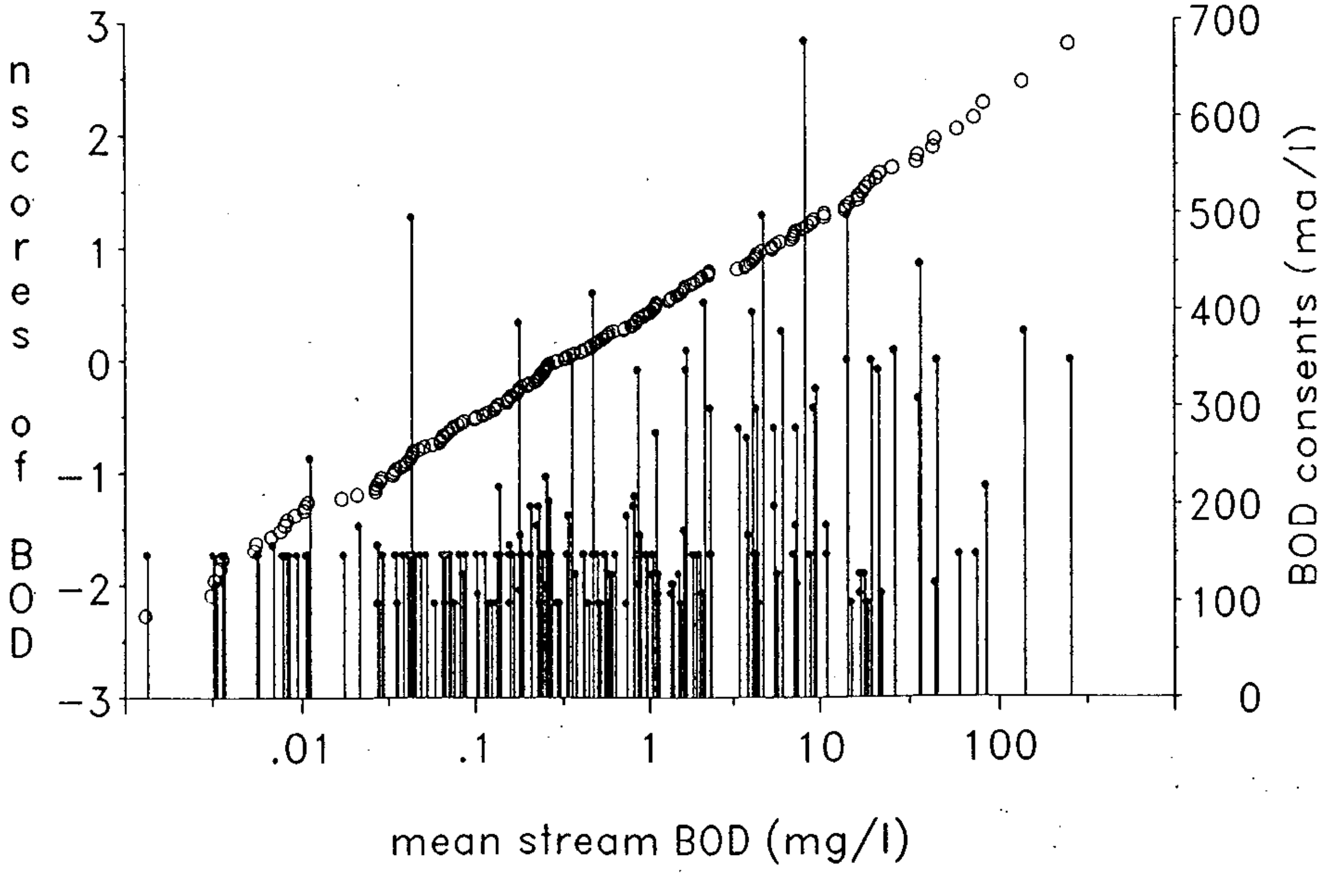
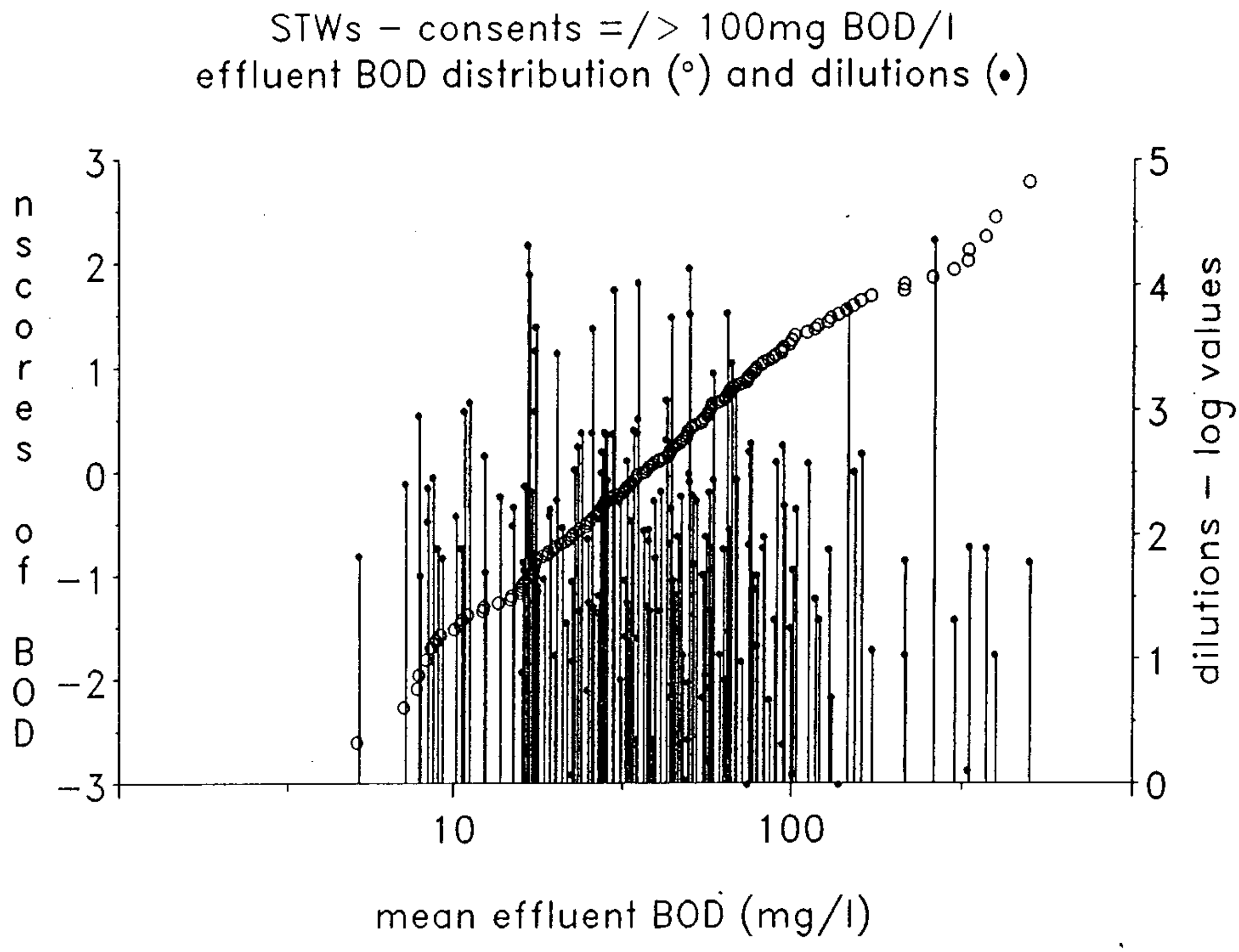


Figure 6. As Figure 5 but with needle plots of dilution values.


STWs - consents =/> 100mg BOD/l
effluent BOD distribution (°) and dilutions (•)
nscores of BOD
dilutions - log values
mean effluent BOD (mg/l)
3
2
1
0
−1
−2
−3
5
4
3
2
1
0
10
100

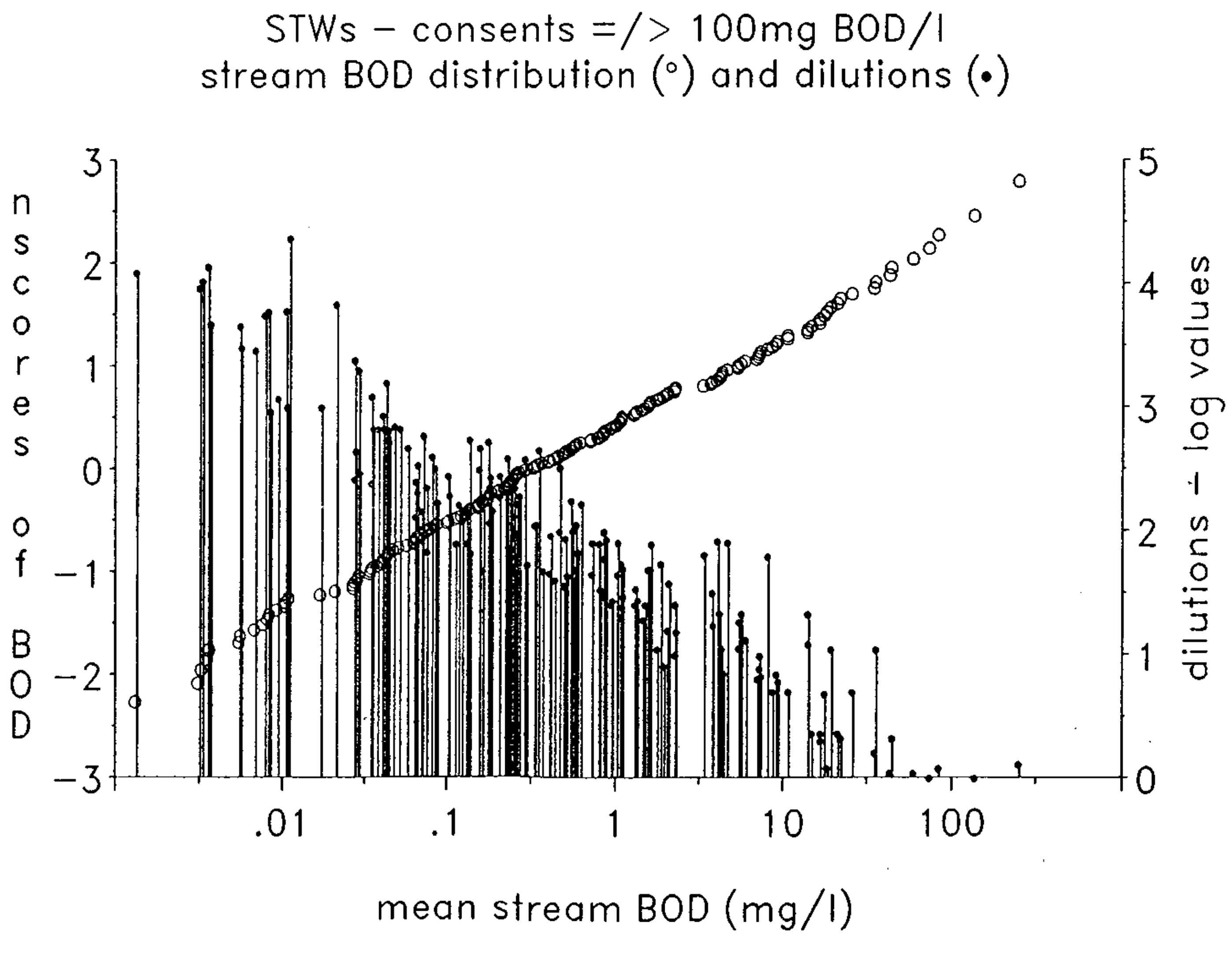
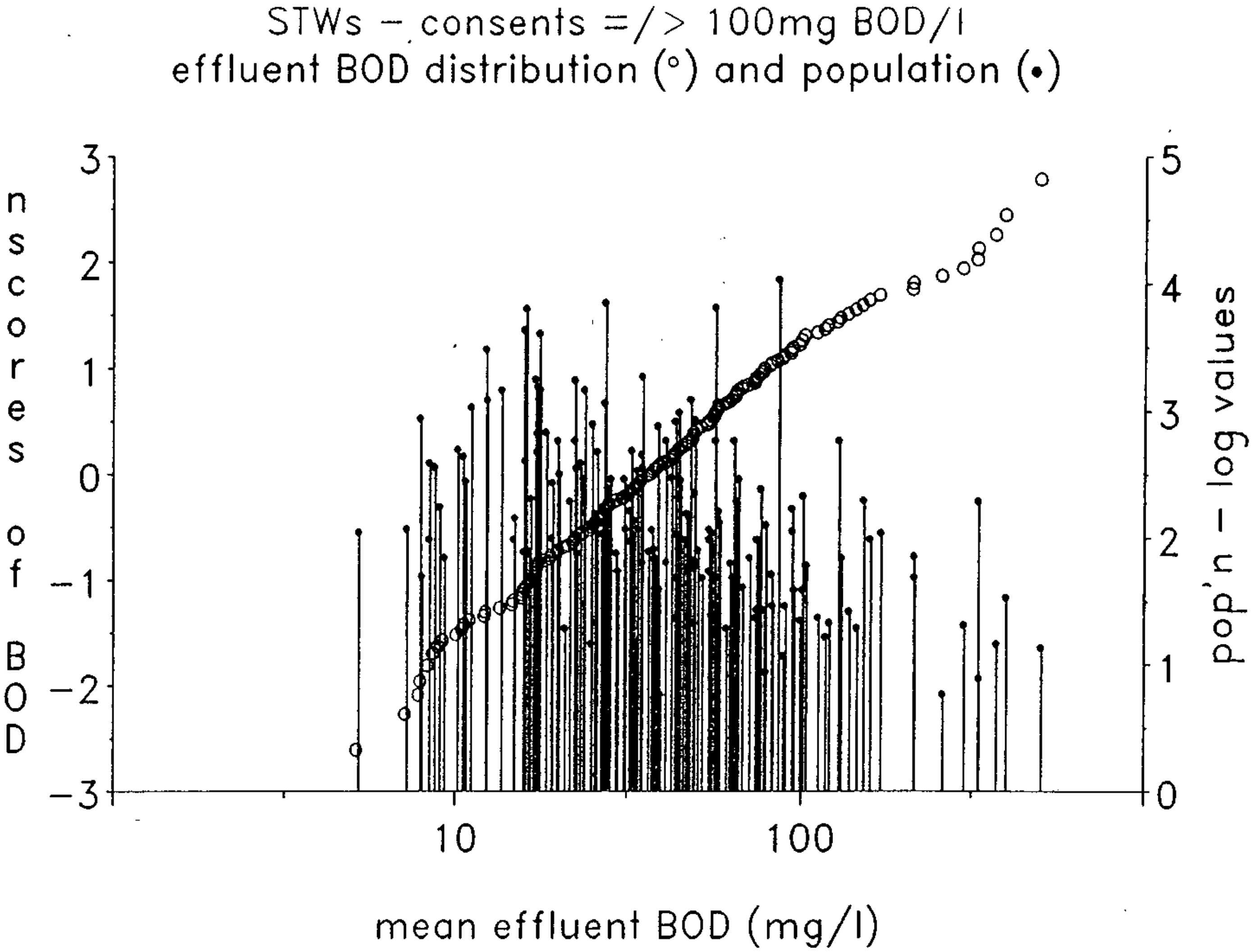
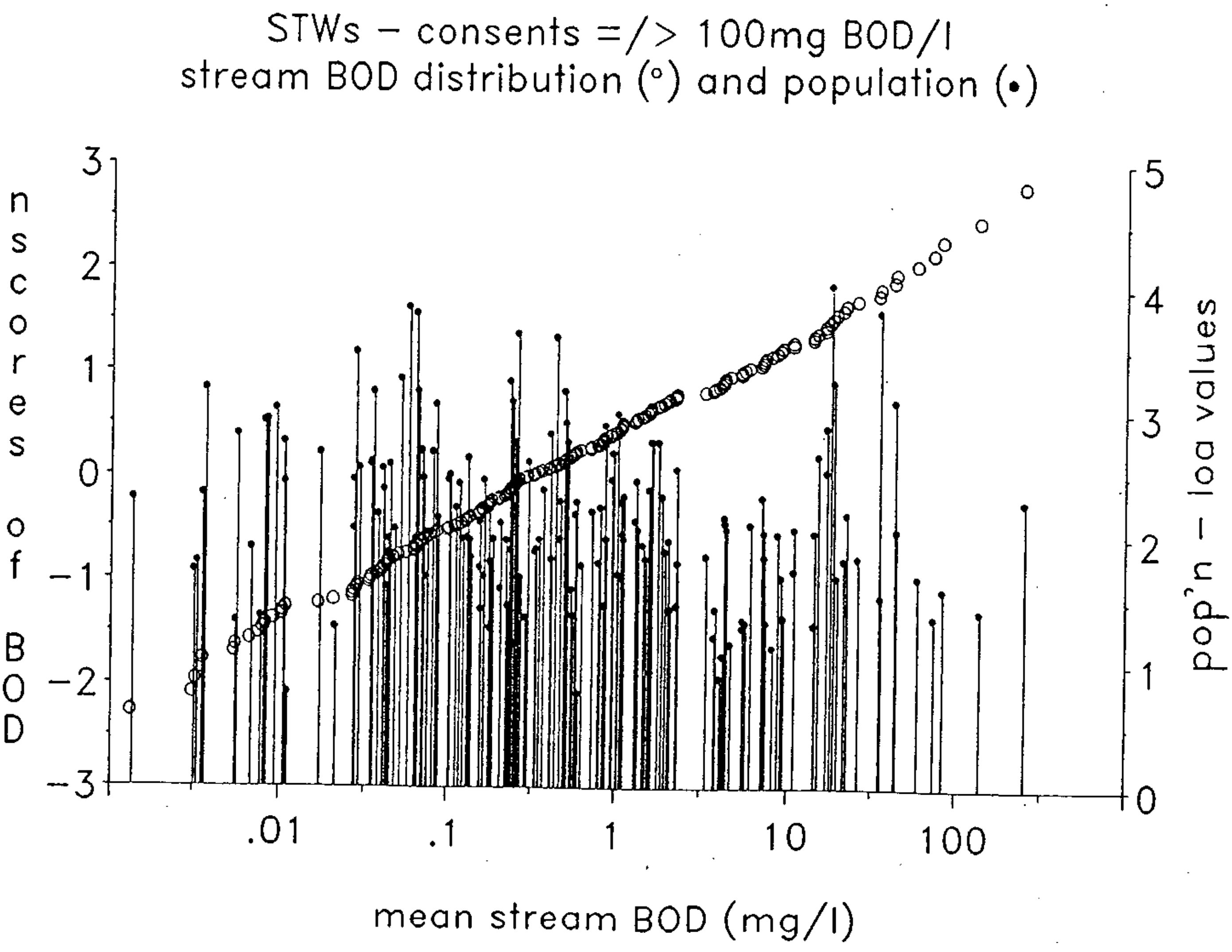

STWs - consents =/> 100mg BOD/l
stream BOD distribution (°) and dilutions (•)
nscores of BOD
dilutions - log values
mean stream BOD (mg/l)
3
2
1
0
−1
−2
−3
5
4
3
2
1
0
.01
.1
1
10
100

Figure 7. As Figure 5 but with needle plots of the sizes of the population served by the works.



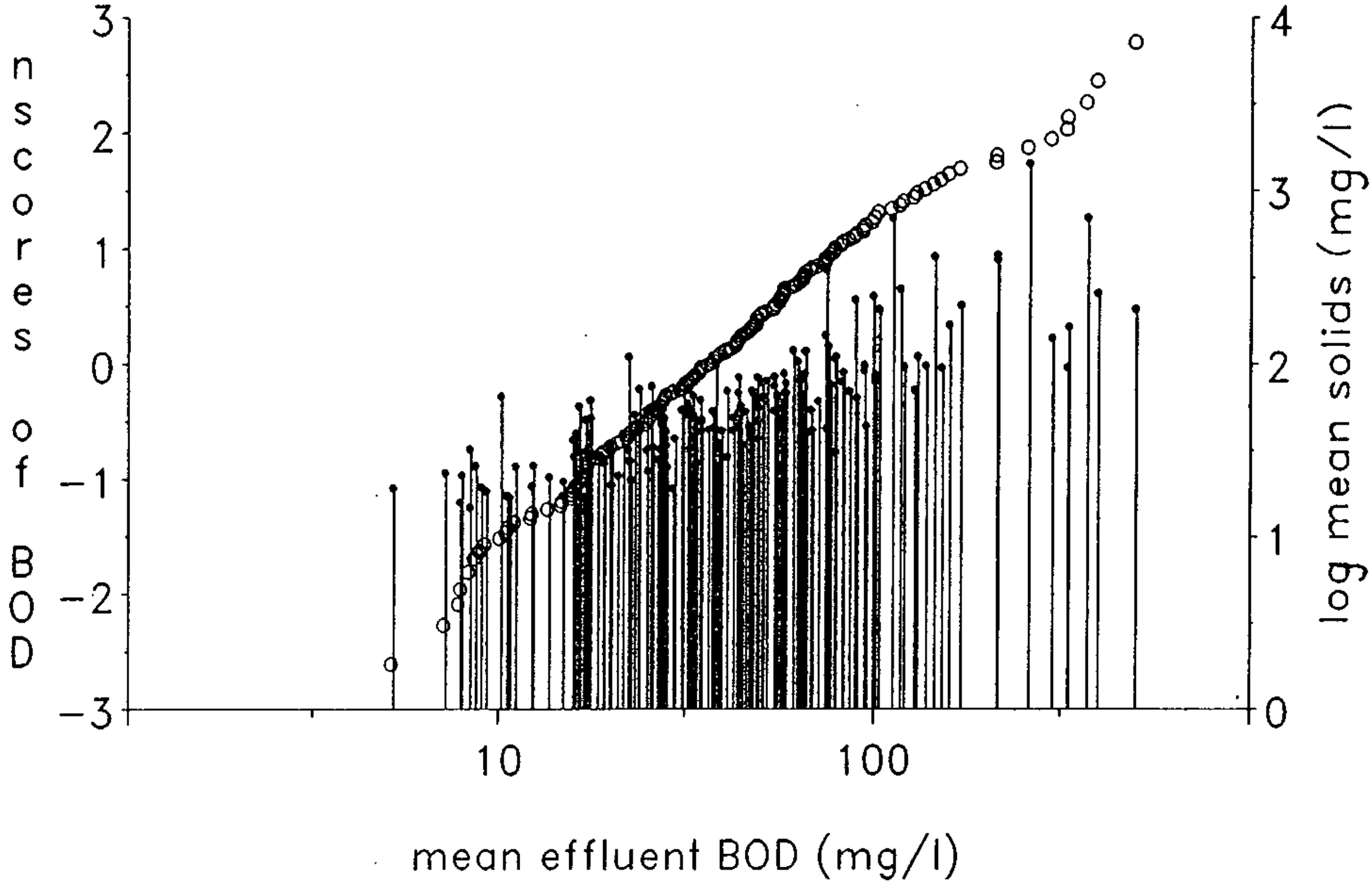
STWs - consents =/> 100mg BOD/l
effluent BOD distribution (°) and population (•)
nscores of BOD
pop'n - log values
3
2
1
0
-1
-2
-3
5
4
3
2
1
0
10
100
mean effluent BOD (mg/l)



STWs - consents =/> 100mg BOD/l
stream BOD distribution (°) and population (•)
nscores of BOD
pop'n - log values
3
2
1
0
-1
-2
-3
5
4
3
2
1
0
.01
.1
1
10
100
mean stream BOD (mg/l)

Figure 8. As Figure 5 for suspended solids in the effluent (upper panel), and the concentrations in the receiving streams, adjusted for the dilution by this water (lower panel).

STWs - consents =/> 100mg BOD/l
effluent BOD distribution (°) and solids (•)



STWs - consents =/> 100mg BOD/l
stream BOD distribution (°) and solids (•)

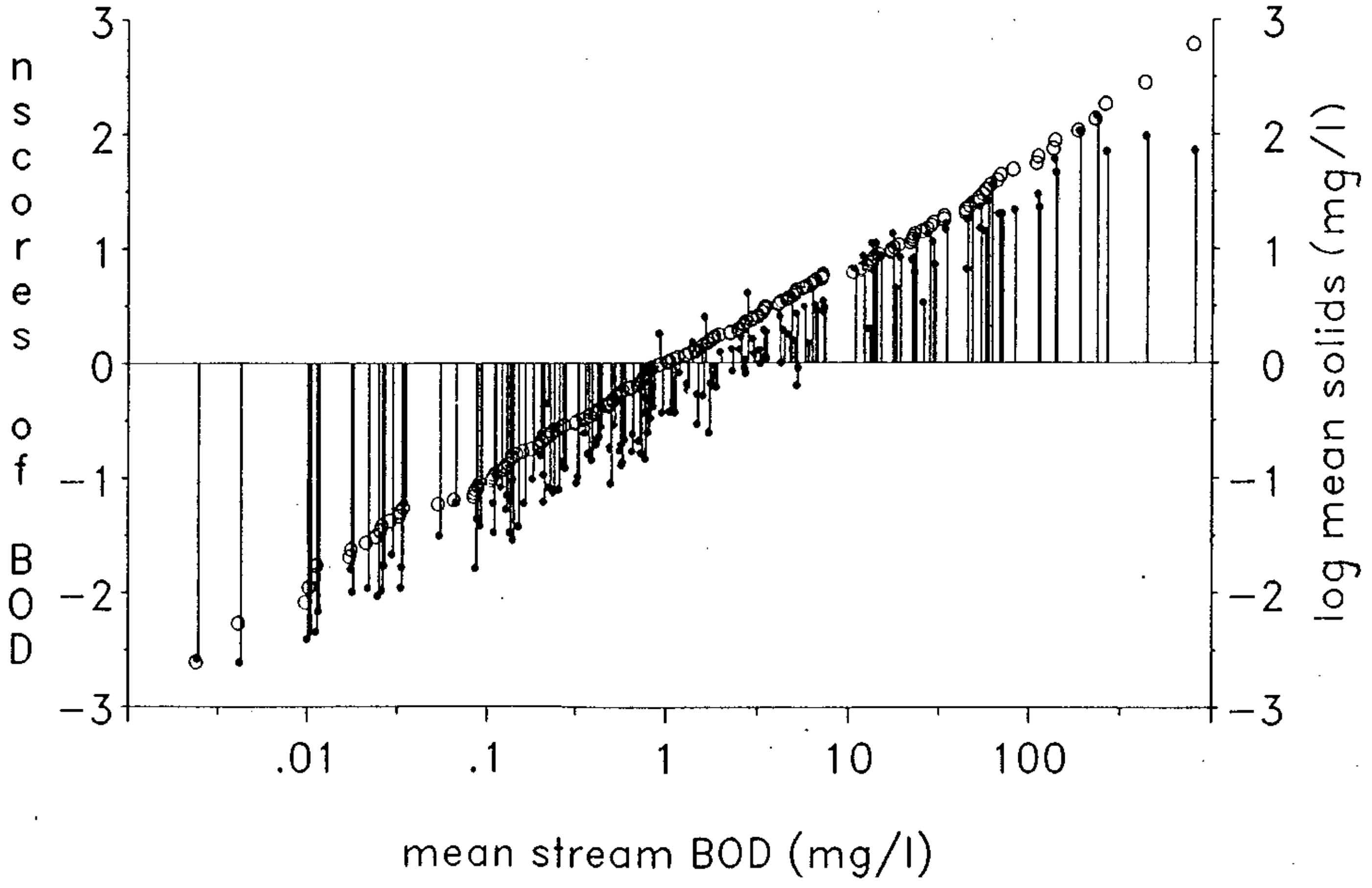
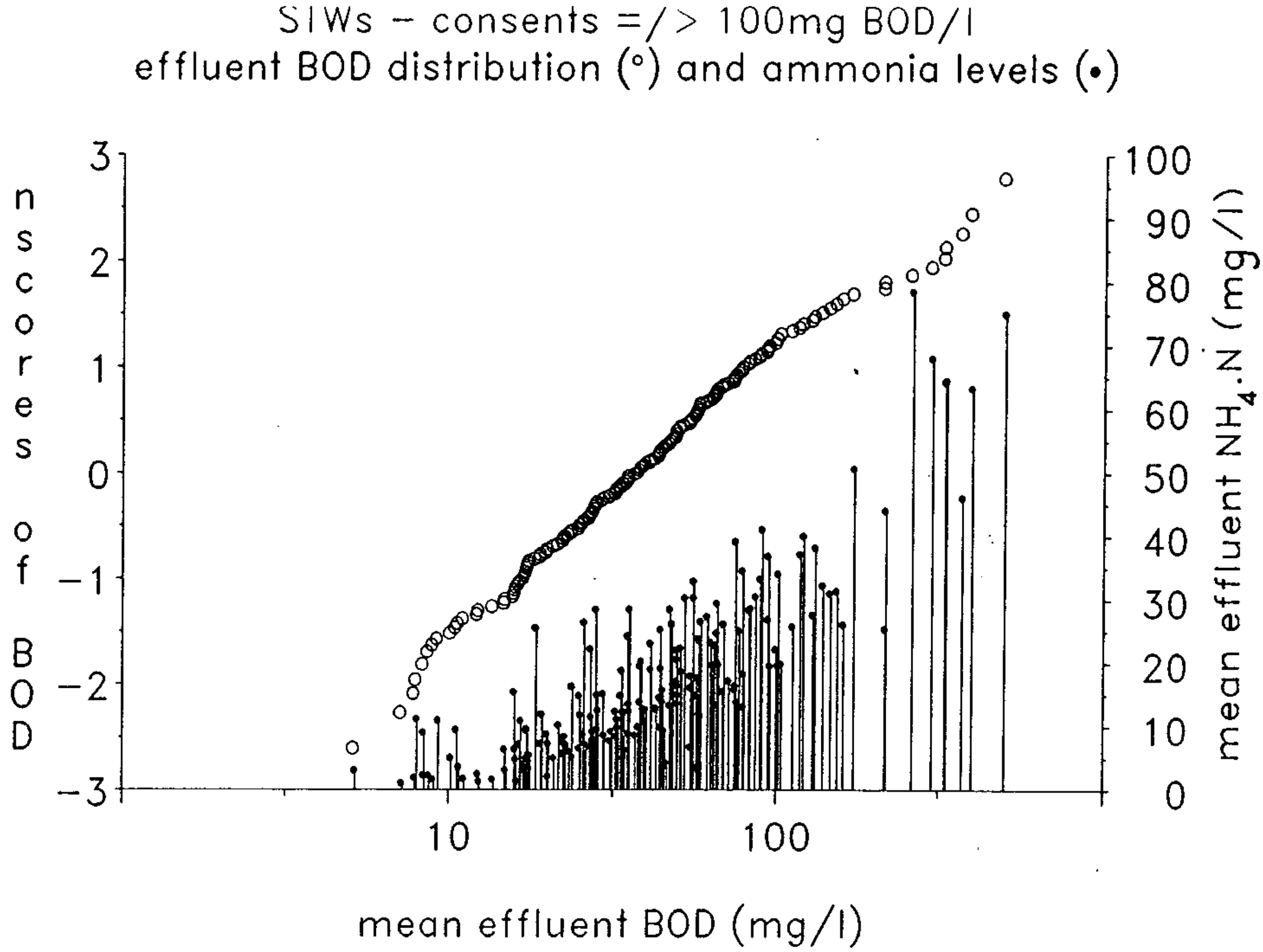


Figure 9. As Figure 5 for ammonia in the effluent (upper panel), and the concentrations in the receiving streams, adjusted for the dilution by this water (lower panel).


STWs - consents =/> 100mg BOD/l
effluent BOD distribution (°) and ammonia levels (•)
nscores of BOD
mean effluent NH_4.N (mg/l)
mean effluent BOD (mg/l)
3
2
1
0
-1
-2
-3
100
90
80
70
60
50
40
30
20
10
0
10
100

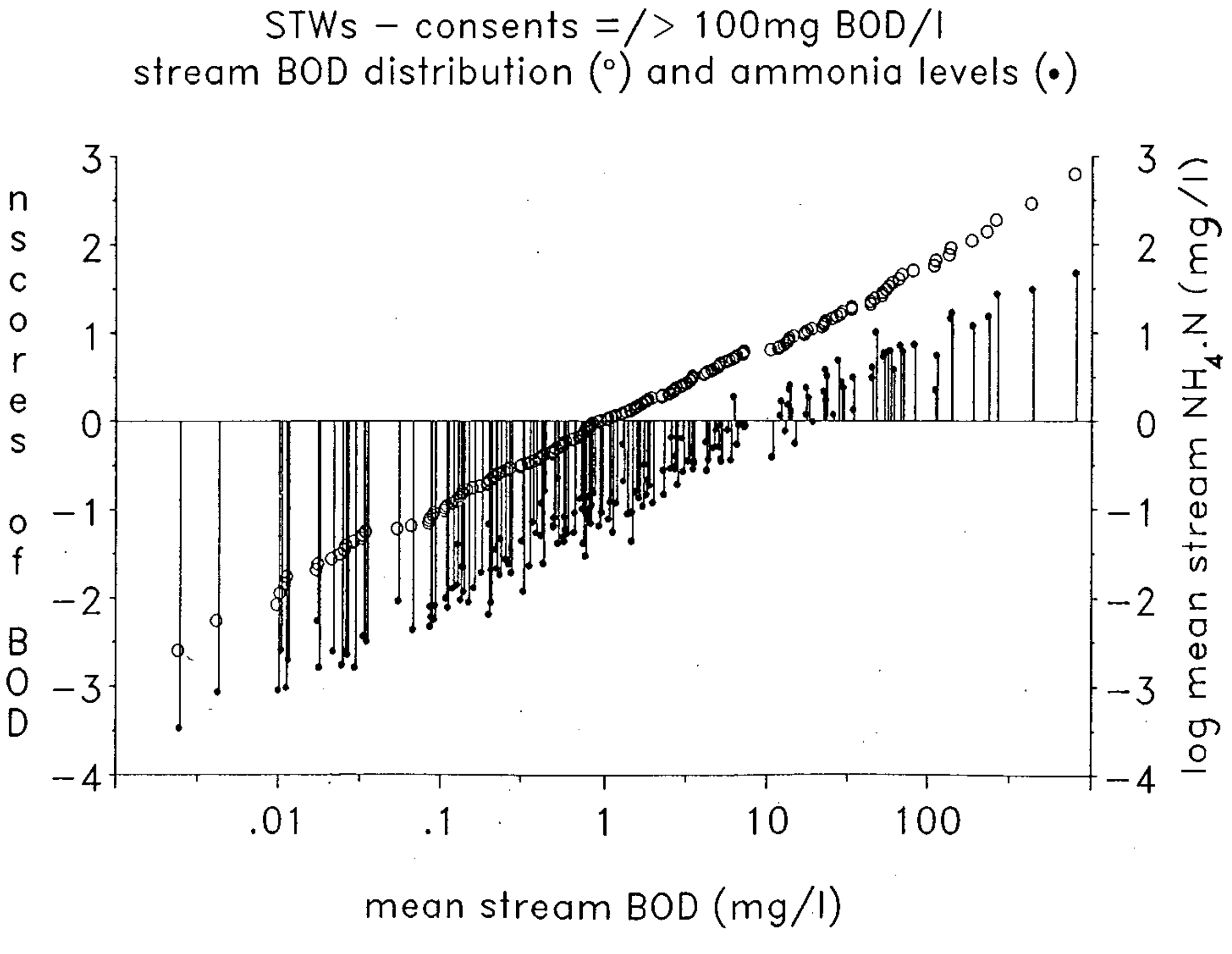
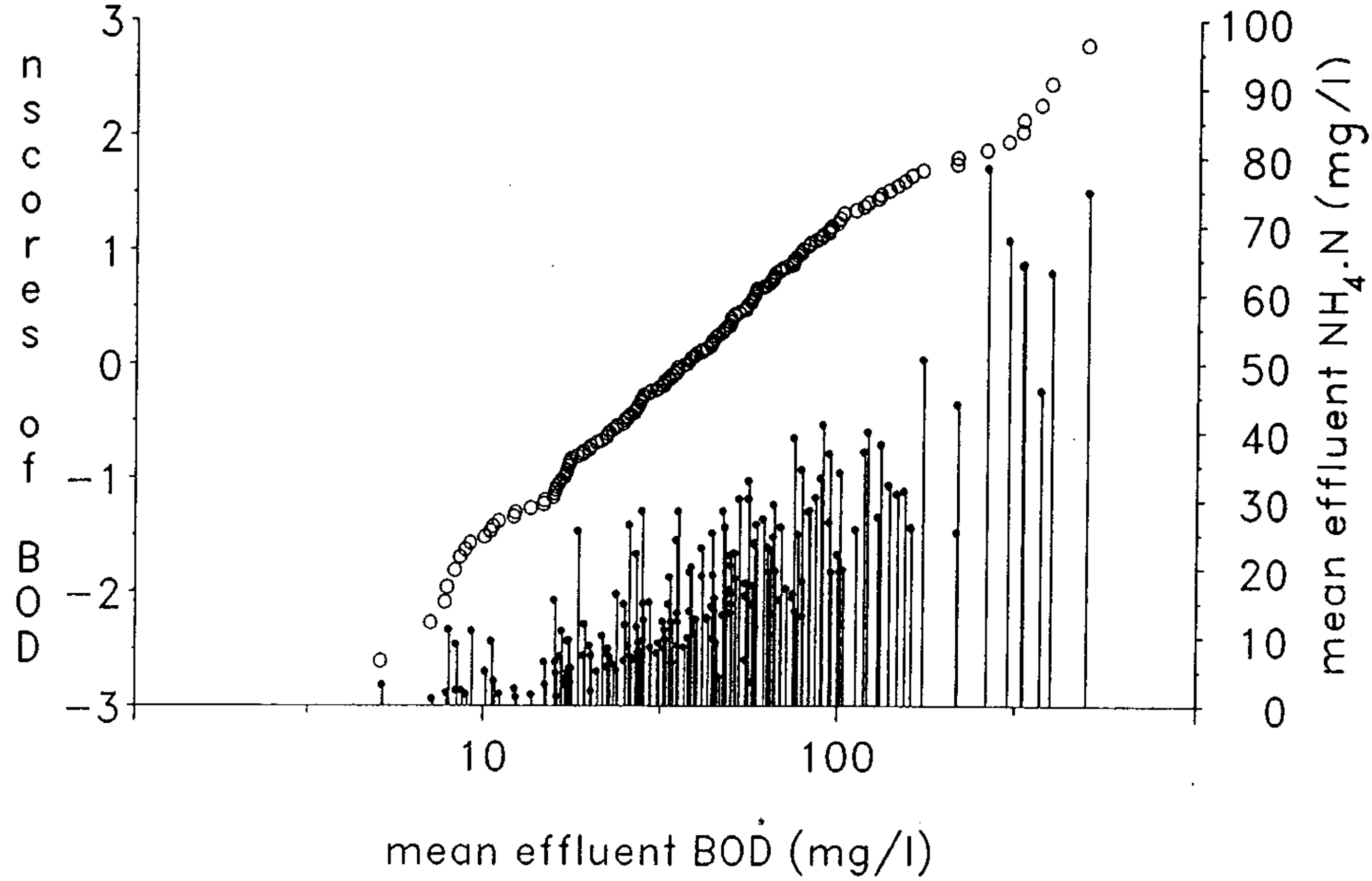

STWs - consents =/> 100mg BOD/l
stream BOD distribution (°) and ammonia levels (•)
nscores of BOD
log mean stream NH_4.N (mg/l)
mean stream BOD (mg/l)
3
2
1
0
-1
-2
-3
-4
.01
.1
1
10
100

Figure 10(a). As Figure 5, but using effluent ammonia concentrations to compare the range and frequency distribution of effluent quality values in the array of sites selected for Phase II of the study, with those in the original total array.

STWs – consents =/> 100mg BOD/l
effluent BOD distribution (°) and ammonia levels (•)



STWs Selected for Phase 2
effluent BOD distribution (°) and ammonia levels (•)

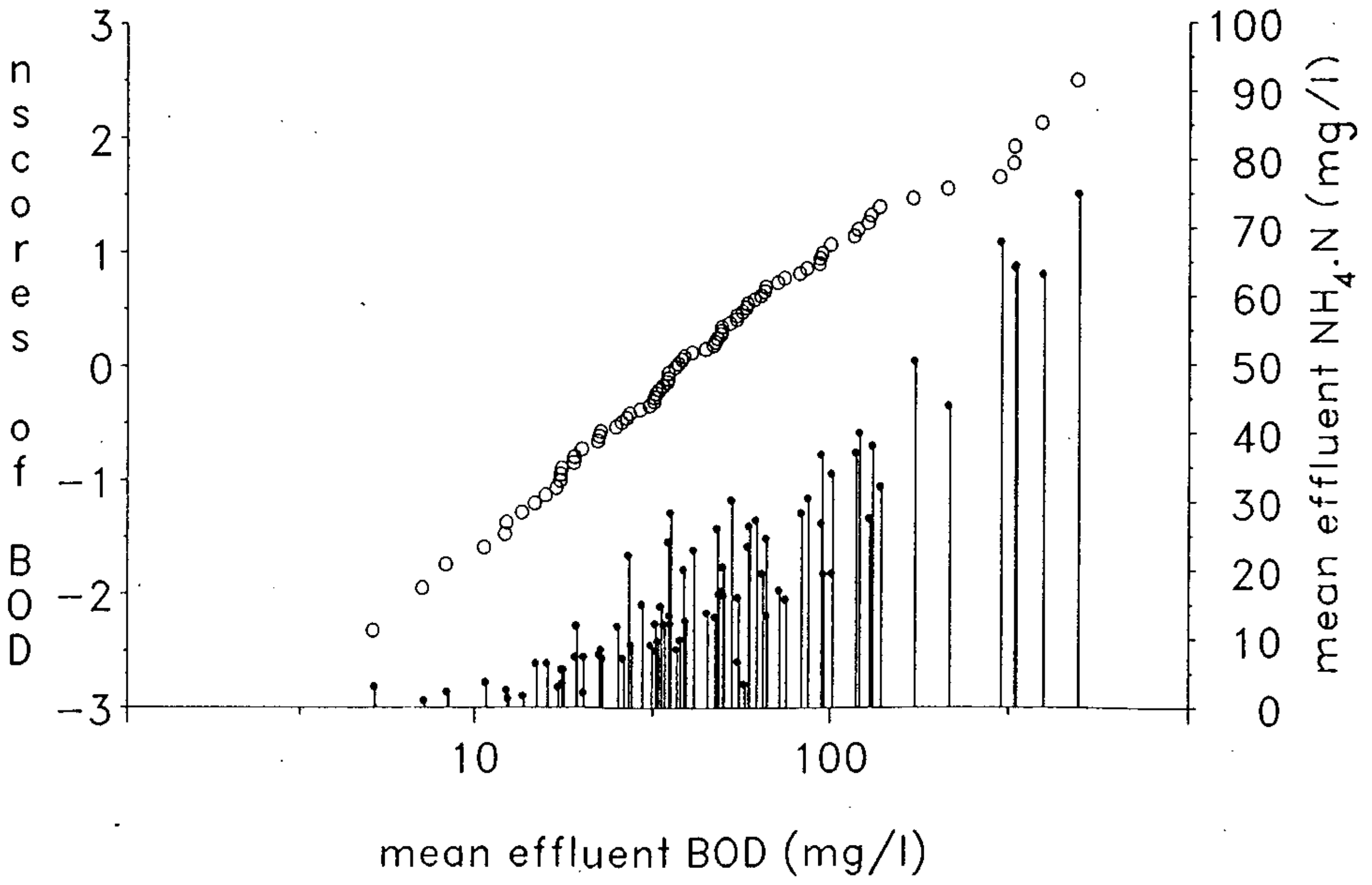
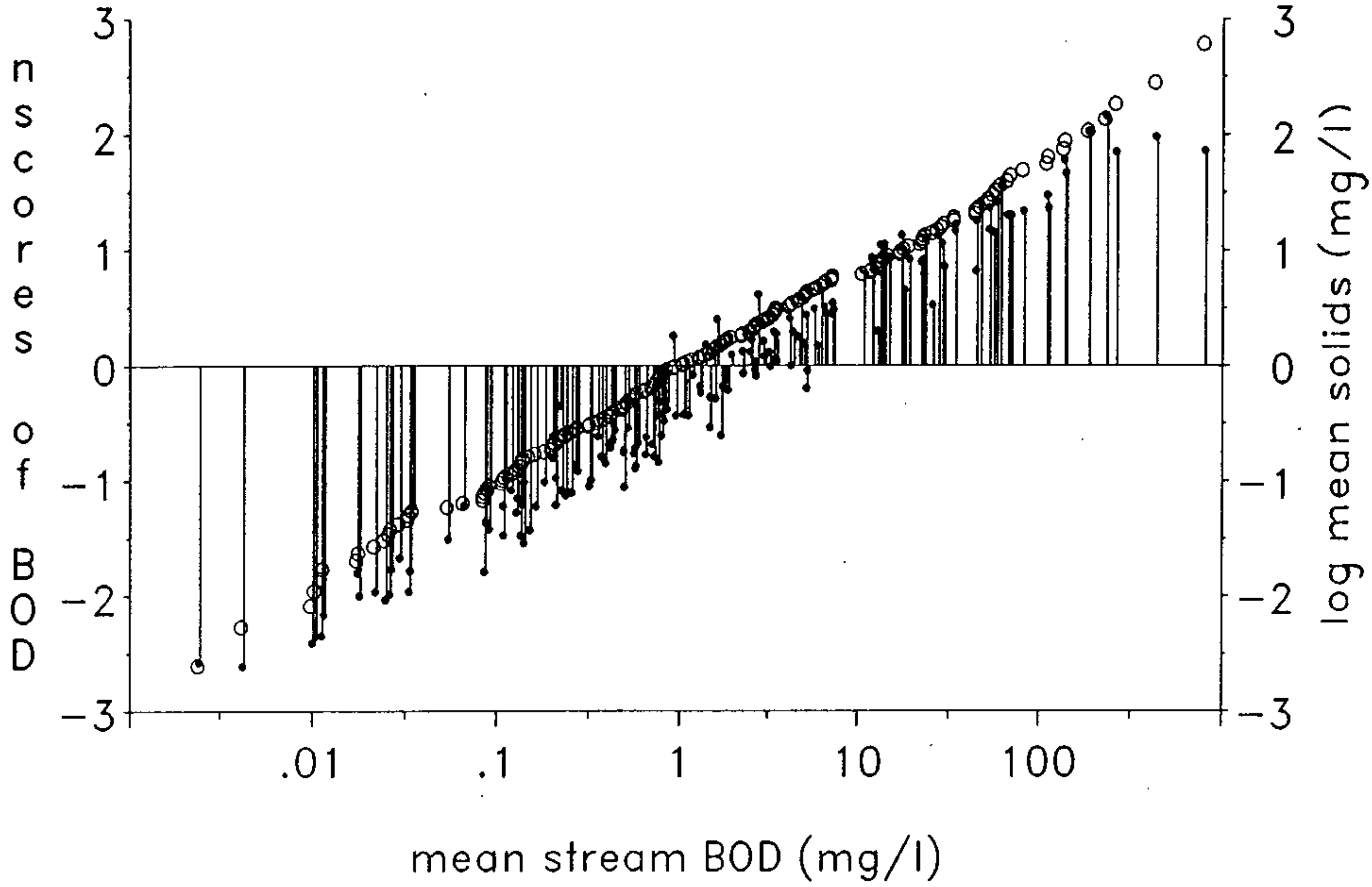
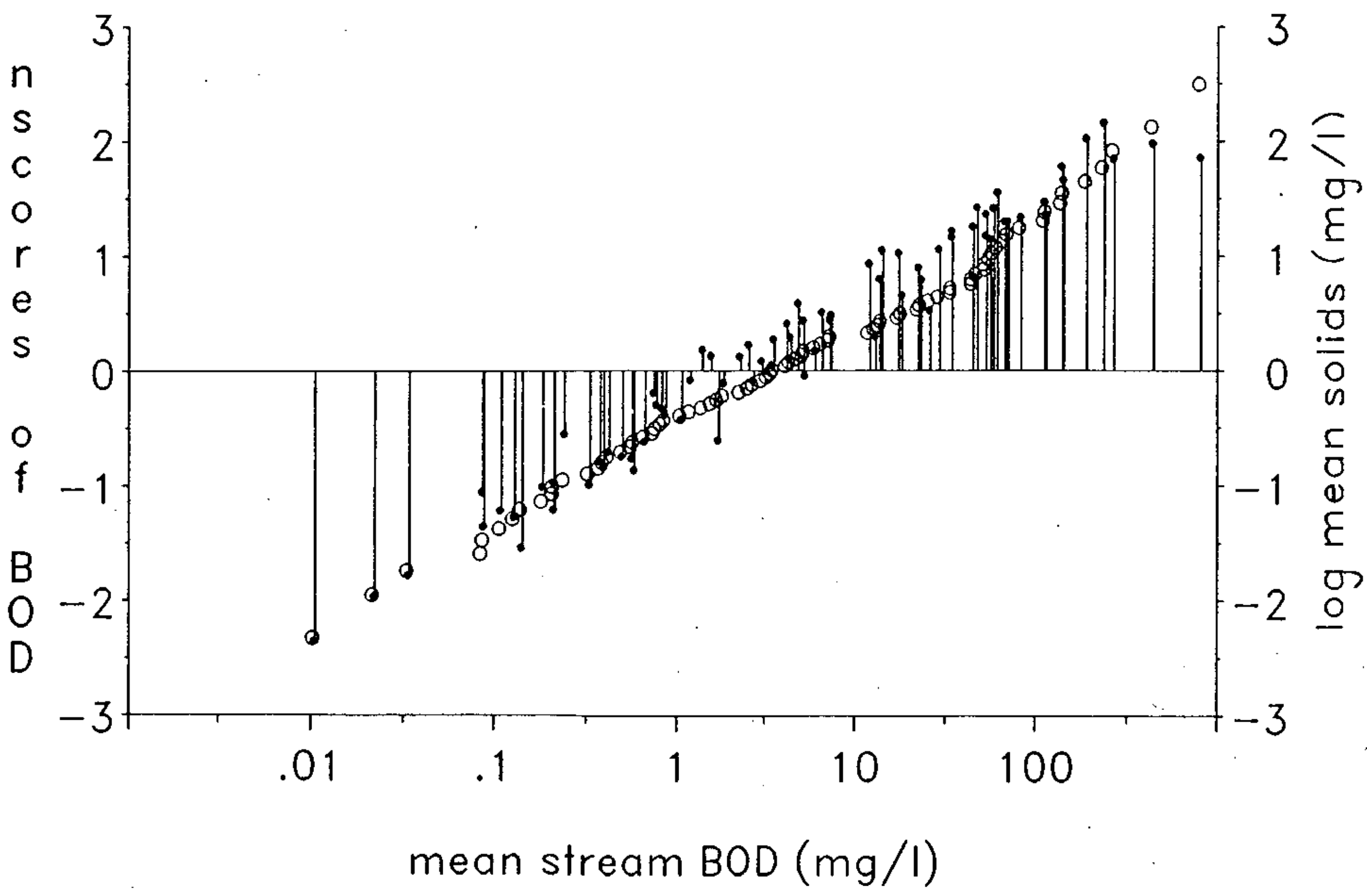


Figure 10(b). As Figure 10(a) but using calculated stream suspended solids values.

STWs – consents =/> 100mg BOD/l
stream BOD distribution (°) and solids (•)



STWs Selected for Phase 2
stream BOD distribution (°) and solids (•)



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