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SEWAGE SLUDGE DISPOSAL

CONSTRAINTS AND OPPORTUNITIES

A Thesis submitted in two volumes

to

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by

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VOLUME II

ABSTRACT

The problems of disposing of sewage sludge, possibly by re-use on agricultural land are considered in the context of the interaction of traditional pollution control philosophies, policies and strategies of EEC member states.

After briefly reviewing the evolution of the 'pragmatic' policies controlling the discharge of trade effluents to rivers or sewers, in England and Wales, investigations focus on problems caused by heavy metal contamination of sludge.

Literature reviews are used to examine:-

How sludges become contaminated;

The extent of that contamination;

How sludges have been disposed in the past;

Some indication of future constraints on disposal by those means.

A contribution of the study is in an analysis of the evolution of the DOE/NWC 1981 Guidelines on the disposal of sludge to land. Guideline constraints are compared to those specified in proposals for an EC Directive.

A further contribution is in carrying out a case study in which the implications for trade effluent controls in an inner city catchment/treatment works area are considered, if sewage sludge at present disposed to sea, is disposed by use on agricultural land.

A simple model makes use of 1980/81 computer file data. Important features of the use of the model are in simulating the effects of reducing metal inputs from a few known key sources, and of the elimination of high sludge metal concentration cases on the achievement of simple and 95% probability of compliance with

proposed EC constraints. Results are discussed in relation to the findings of literature reviews.

The effectiveness of the current politico-economic framework is assessed.

The use of traders' perceptions of the 'rules of the game' in evaluating current controls is explored.

Technological and policy implications are deduced, conclusions reached and a basic premise questioned.

Key terms:

Control

Policy

Sewage sludge

Metals

Trade effluent.

CONTENTS

Page

VOLUME II

Preface

PART II. THE DEVELOPMENT AND USE OF A MODEL

Sections:

7.0 - The development of a model. Analyses of known inputs and outputs of an urban sewer catchment - treatment system. Data, design constraints and the specification of a simple model. .. 7/1-46

- 7.5 Conclusions. .. 7/47-48

8.0 - Applying the model; an urban case study. Introduction, assumptions, purposes and method. .. 8/1-4

8.1 - Output and input. .. 8/4-

Comments. .. -12

8.2 - Required minimum reductions of metal concentrations to achieve simple compliance with proposed EC. constraints. .. 8/21-

- 8.2.4. Conclusions. .. -28

8.3 - Probability of compliance and the distribution of sludge metal concentration cases. .. 8/36-43

8.3.1. - Effects of omission or replacement of 0, 1 or 2 highest Zn, Cu and Ni concentration cases. 8/43-

- 8.3.1.3 Conclusions. -50

8.3.2 - Reduction of input to achieve 95% probability of compliance. .. 8/60-74

- 8.3.2.2 Summary and conclusions. .. 8/74-76

8.2.5/8.3.3 Achievement of compliance - a short summary of results presented in Ss.8.2 and 8.3. .. 8/86-87

8.4 - Guide limits and compliance. .. 8/93-10C

- 8.4.3 Conclusions. .. 8/100-1C

8.4.4 A short comparative summary of results. .. 8/102-1C

8.5 Two operational considerations

(1) Uncertainty of compliance; and .. 8/103-1C

(2) An EQO approach? .. 8/106-1C

8.6 What is the potential for further reduction of metal concentrations in sludge output. .. 8/120-1

8.7 Conclusions .. 8/131-1

CONTENTS

Page

VOLUME II

PART III. EFFECTIVE CONTROL?

Sections

9.0 - Effective control of metalliferous trade effluent input to sewers, incentives, constraints and perceptions. .. 9/1-32

- 9.4 Conclusions. .. 9/32-40

10.0- 10.5 Opportunities or constraints? Some conclusions. .. 10/1-23

References

Bibliography

CONTENTS

		Page
VOLUME 1		
Preface		
PART I.	INTRODUCTION AND REVIEWS	
Part IA.	Introduction and pollution control policy.	
Sections:		
1.0 -	Constraints and opportunity - an introduction.	1/1-8
- 1.4	Conclusions. Pollution - a definition. ..	-1/8
2.0 -	The best practical means? A brief historical perspective. ..	2/1-14
- 2.4	Conclusions. ..	2/14-18
3.0 -	Pollution Control: reduction or transfer? Rationale, local discretion and the river quality surveys 1958-1980. ..	3/1-8
- 3.4	Conclusions.	3/8-9
PART IB.	The control of sewage sludge disposal.	
Sections:		
4.0 -	The scale of sewage sludge disposal and some present and some likely future constraints.	4/1-18
- 4.3	Conclusions. ..	4/18-19
5.0 -	Evolution of the DOE/NWC 1981 Guidelines on the disposal of sewage sludge on agricultural land - a case study. ..	5/1-29
- 5.6	Conclusions. ..	5/29-32
6.0 -	EEC Directive v UK Guidelines. A comparison of constraints specified in the 'Proposal for a Council Directive on the use of sewage sludge in agriculture' and the UK Guidelines. ..	6/1-14
- 6.2	Conclusions. ..	6/14-18

LIST OF TABLES AND FIGURES

Numerals preceding the decimal point refer to the major sectional number to which the figure or table relates, while others are sequential within the major sectional divisions.

Numbers in the first column indicate the sections to which figures and tables relate.

Section	Figure/Table	VOLUME I	Page
3.2	Table 3.1	Total lengths of non-tidal rivers in various quality classes in 6 river pollution surveys. ..	3/10
	Table 3.2	River surveys 1975 and 1980, changes in classified lengths of non-tidal rivers, due to changes in quality or measurement. ..	3/11
	Table 3.3	Total lengths of tidal rivers in various quality classes in 6 river pollution surveys. ..	3/12
	Table 3.4	River surveys 1975 and 1980, changes in classified lengths of tidal rivers due to changes quality and measurement. ..	3/13
	Appendix 3.1	A River Classification System ..	3/14
4.1	Table 4.1	Sludge production and disposal from English and Welsh WA areas and the UK, 1975, 1977 and 1980 survey data. ..	4/20
	Table 4.2	Annual sludge production and disposal in 16 European countries. ..	4/21
4.1.3	Table 4.3	Raw sludge equivalent of sewage sludge disposed to sea as percentage of total input from 5 European states, England and Wales. ..	4/23
4.1.4	Table 4.4	Percentages of sludge disposed to land (and of all sludge disposed) utilised and disposed to landfill or stockpile in the UK. 1975-1980 data. ..	4/24
	Table 4.5	Percent land use to which sewage sludge disposed in the UK (and major usage as percentage of all sludge disposed) calculated on the basis of 1975 and 1980 sewage sludge disposed survey data. ..	4/25
	Table 4.6	Quantities of sewage sludge disposed, and percentages of these quantities disposed to temporary and permanent grassland by ten regional water authorities.	4/26

Section	Figure/Table	VOLUME I	Page
4.2	Table 4.7	Concentrations of six metal elements in sewage sludge utilised on agricultural land (1977), or utilised on land (1980), and proposed mandatory limit values of trace elements in sewage sludge used in agriculture. ..	4/28
5.0	Figure 5.1	Sequence of analysis of events and influences contributing to the evolution of the DOE/NWC Guidelines.	5/33
5.2/5.4	Table 5.1	Recommended maximum permissible additions of metal elements in sewage sludge applied to uncontaminated non-calcareous and calcareous arable land and to permanent pasture by DOE/NWC Guidelines 1981. ..	5/34
5.4	Table 5.2	Recommended maximum trace element concentrations in sewage sludges used on agricultural and amenity land. DOE/NWC Guidelines 1981. ..	5/35
	Table 5.3	Provisional maximum permissible concentrations of elements in arable soils to be reached in 30 years or more.	5/36
	Table 5.4	Recommended opportunities and constraints on the use of sewage sludges in respect of pathogen control. U.K. Guidelines. ..	5/37
6.0		Comparison of limit values specified in an EEC proposal for a directive on the use of sewage sludge in agriculture and those recommended in the DOE/NWC 1981 Guidelines.	
6.1	Table 6.1	Maximum values of metal element concentrations in sewage sludge for use in agriculture. ..	6/19
	Table 6.2	Maximum annual application rate.	6/20
	Table 6.3	Maximum single application rate.	6/21
	Table 6.4	Maximum concentrations of metal elements in agricultural soil to which sewage sludge is applied.	6/22
	Table 6.5	Opportunities and constraints, on the use of sewage sludge in agriculture, with respect to pathogen control, as allowed by an EC proposal for a Directive. 8.10.1983. ..	6/23
7.1	VOLUME II	Known trade effluent inputs to sewers 1.4.80-31.3.81.	
7.1.2	Figs.7.1-7.4 and 7.6	Distribution of inputs to sewers have agreed flows greater than 10^6l. and recorded mean concentrations equal to or greater than 0.1 mg.l^{-1} Zn, Cu, Ni, Cr and Pb respectively	7/49-52 7/54

Section	Figure/Table	VOLUME II	Page
7.1.2	Fig. 7.5	As above but with concentrations equal to or greater than 0.01mg.l^{-1} Cd. ..	7/53
	Figs. 7.7-7.10 and 7.12.	Distribution of calculated 12 month input loads greater than 1 kg.y^{-1} Zn, Cu, Ni, Cr and Pb respectively.	7/55-58 7/60
	Fig. 7.11	As above but with loads greater than 0.1 kg.y^{-1} Cd. ..	7/59
	Figs. 7.13-7.18	Cumulative ranked percentile loads equal to or greater than 1 kg.y^{-1} Zn, Cu, Ni, Cr, Cd and Pb respectively. ..	7/61-66
7.1.3	Fig. 7.19	Cumulative percentile contributions of loads greater than 10^3 kgs. and 10^2 kgs. to total calculated loads of Zn, Cu, Ni, Cr, Cd and Pb. ..	7/67
7.1.2/3	Figure 7.20	Cumulative percentile contribution of loads greater than 10^3, 10^2 and 10^1 kgs.y^{-1} from 10 sources A-J to total calculated loads of Zn, Cu, Ni, Cr, Cd and Pb. ..	7/68
7.1.2/3	Figure 7.21	Total mass from 10 sources and from all known sources of Zn, Cu, Ni, Cr, Cd and Pb. ..	7/69
		Known trade metal inputs to sewers 1.4.80-31.3.81 cont.	
7.1.2	Table 7.1	Distribution of calculated metal input loads having an agreed flow greater than 10^6 l. and concentration greater than 10^{-1}mg.l^{-1}, except for Cd when concentrations are greater than 10^{-2} mg.l^{-1}. ..	7/70
7.1.2/3	Table 7.2	Cumulative ranked input metal loads greater than 10 kg.y^{-1}, as percentiles of total calculated loads of Zn, Cu, Ni, Cr, Cd and Pb from known trade inputs. ..	7/71
	Table 7.3	Volume of flow and number of sources of metal loads greater than 100kg.y^{-1} and rank. Also number and rank of metal inputs, in the 10^1-10^2 kg. range from the same sources. ..	7/72
7.1.4	Table 7.4a	Number of inputs of Zn, Cu, Ni, Cr and Pb greater than 1 kg, with agreed flows less than 10^6 l. or concentrations less than 0.1 mg.l^{-1} inputs of Cd greater than 0.1 kg with agreed flows less than 10^6l. and concentrations less than 0.01 mg.l^{-1}.	7/73

Section	Figure/Table	VOLUME II	Page
7.1.4.	Table 7.4b	Distribution of input loads greater than 1 kg. from ranked sources with agreed flows less than 10^6 $l.y^{-1}$.	7/74
7.2	Table 7.5 .	Percent partition of six metals from sewage entering to sewage sludges leaving English WPC works. ..	7/75
8.3	Figure 8.1	Distribution of metal concentrations in untreated (raw) sewage sludge. Cadmium, Nickel and Chromium 1980/81.	8/13
	Figure 8.2	Zinc, Copper and Lead, 1980/81.	8/14
8.1	Table 8.1	Basic data metal concentrations of input and sewage sludge output, input flow and sewage sludge production of a Yorkshire Water Authority City WPC works 1.4.80-31.3.81. ..	8/15
	Table 8.2	Selected and calculated partition ratios, with sources,used in the study of a Yorkshire Water Authority City WPC works 1.4.80-31.3.81. ..	8/16
	Table 8.3	Output load of Zn, Cu, Ni, Cd, Pb and Cr in sewage sludge, and calculated input load to a Yorkshire Water Authority City WPC works 1.4.80-31.3.81 for selected partition ratios. ..	8/17
	Table 8.4	Known trade input loads of Zn, Cu, Ni, Cd, Pb and Cr to a YWA City WPC Works 1.4.80-31.3.81 and calculated equivalent metal concentrations in sewage sludge output for selected partition ratios. ..	8/18
	Table 8.5	Five trade sources of highest known trade input loads of Zn, Cu, Ni, Cd, Pb and Cr to a YWA City WPC Works, 1.4.80-31.3.81, and calculated equivalent metal concentrations in sewage sludge output for selected partition ratios. ..	8/19
8.2	Table 8.6	Annual mean concentrations of Zn, Cu, Ni, Cd, Pb and Cr in unstabilised sewage sludge output from a YWA City WPC works 1.4.80-31.3.81 and required reduction in order to meet Mandatory limits stated in the proposal for an EC Directive. ..	8/29
	Table 8.7	Minimum required reductions of annual mean concentrations of Ni, Cd and Pb in unstabilised sewage sludge to equal proposed Mandatory limits (h) equivalent input load and equivalent percentage of inputs from highest known trade sources. 1.4.80-31.3.81 data. ..	8/30

Section	Figure/Table	VOLUME II	Page
8.2	Table 8.8	Annual mean concentrations of Zn, Cu, Ni, Cd, Pb and Cr in unstabilised, simulated digested and simulated lime stabilised sludge and reduction and percentage reduction required to meet Mandatory or Recommended limits stated in the Proposal for an EC Directive. ..	8/31
	Table 8.9	Minimum required reductions of simulated digested annual mean concentrations of Ni,Cd,Pb and Cr in simulated digested sewage sludge to equal proposed Mandatory or Recommended limits ( ), equivalent input load and equivalent percentage of inputs from highest known Trade Sources, 1.4.80-31.3.81 omitting data for dual input source Ka, except where indicated. ..	8/32
	Table 8.10	Minimum reduction of annual mean concentration of Cd in simulated lime treated sewage sludge to equal proposed Mandatory limits ( ), equivalent input load and equivalent percentage of inputs from highest known trade source. 1.4.80-31.3.81 data, omitting data for dual input source Ka. ..	8/34
	Table 8.11	Effect of omitting 0, 1 or 2 highest concentration cases on calculated mean concentrations of Pb and on simple compliance with Mandatory and Recommended Limits specified in Annex 1A of an EC proposal for a directive. ..	8/35
8.3.0	Table 8.12a	Metal concentrations in two samples of sewage sludge of 4.6 and 7.1 per cent total solids recalculated to mean total solids of 30 samples, 1980/81 data. ..	8/51
	Table 8.12b	High concentrations of Zn, Cu and Pb in unstabilised sewage sludge, equivalent input load and calculated equivalent excess input per mean day.	8/51
8.3.1.1.	Table 8.13	Effect on annual mean and standard deviation of metal concentrations in unstabilised sewage sludge, of omitting, or replacing 0, 1 or 2 highest concentration cases of Zn, Cu or Pb.	8/53

Section	Figure/Table	VOLUME II	Page
8.3.1.1	Table 8.14	The effect of omitting, or replacing, 0, 1 or 2 highest concentrations of Zn, Cu and Pb in unstabilised sewage sludge dry solids on the ability to achieve 95% probability of compliance ( ) with Mandatory and/or Recommended limits specified in Annex 1A of the EC proposal for a Directive . ..	8/54
	Table 8.15	Mean metal concentrations in unstabilised sludge and required standard deviation for 95% probability of compliance ( ) with Mandatory limits specified in Annex 1A of the EC proposal for a Directive, ( ), when 0, 1 or 2 highest concentrations are omitted, or replaced, in mean concentrations of Zn, Cu or Pb in dry solids of sludge. ..	8/55
8.3.1.2	Table 8.16	The effect of omitting, or replacing, 0, 1 or 2 highest concentrations of Zn, Cu and Pb in a simulated digested sewage sludge dry solids ( ) on the ability to achieve 95% probability of compliance ( ) with Mandatory and/or Recommended limits specified in Annex 1A of the EC proposal for a Directive ( ), if SD:$\bar{X}$ ratio in unstabilised sludge is held constant at values shown in Table 8.13 Cols. C, F and I. ..	8/56
	Table 8.17	Simulated digestion ( ) and required SD for 95% probability of compliance ( ) with Mandatory limits specified in Annex 1A of the EC proposal for a Directive, ( ), when 0, 1 or 2 highest concentrations are omitted or replaced, in mean concentrations of Zn, Cu or Pb in unstabilised sewage sludge.	
	Table 8.18	The effect of omitting, or replacing, 0, 1 or 2 highest concentrations of Zn, Cu and Pb in simulated Lime stabilised sewage sludge, where dry solids is increased by 14% ( ) on the ability to achieve 95% probability of compliance ( ) with Mandatory and/or Recommended limits specified in Annex 1A of the EC proposal for a Directive ( ), if SD stays the same percentage of mean concentrations as in unstabilised sludge as shown in table 8.13 cols. C, F and I. ..	8/58

Section	Figure/Table	VOLUME II	Page
8.3.1.2	Table 8.19	Simulated lime treatment ( ) and required SD for 95% probability of compliance ( ) with Mandatory limits specified in Annex 1A of the EC proposal for a Directive (..), when 0, 1 or 2 highest concentrations are omitted or replaced, in mean concentrations of Zn, Cu or Pb in unstabilised sewage sludge. ..	8/59
8.3.2.1	Table 8.20	Required reduction of mean metal concentrations in unstabilised sewage sludge, when SD:$\bar{X}$ ratio is held constant, and equivalent required reduction from known Trade source(s), to equal Mandatory Limits specified in Annex 1A of the EC proposal for a directive, with 95% probability of compliance. ..	8/77
	Table 8.21	Equivalent of 80 or 90 percent reduction of input from known source(s), equivalent reduced mean concentration of metals in unstabilised sewage sludge and required SD:$\bar{X}$ ratio to equal Mandatory limits specified in Annex 1A of the EC proposal for a Directive, with 95% probability of compliance.	8/78
	Table 8.22	Simulated digestion, required reduction of calculated mean metal concentrations in sewage sludge, when SD:$\bar{X}$ ratio is held constant, and equivalent required reduction from known Trade source(s), to equal Mandatory limits specified in Annex 1A of the EC proposal for a directive, with 95% probability of compliance. ..	8/80
	Table 8.23	Simulated digestion, equivalent of 80 or 90 percent reduction of metal input to sewers from known source(s), equivalent reduced mean concentration of metals in sewage sludge, and required SD:$\bar{X}$ ratio to equal Mandatory limits specified in the EC proposal for a Directive, with 95% probability of compliance.	
	Table 8.24	Simulated lime stabilisation, required reduction of calculated mean metal concentration in sewage sludge, when SD:$\bar{X}$ ratio is held constant, and equivalent required reduction from known Trade source(s), to equal Mandatory limits specified in Annex 1A of the proposed EC directive, with 95% probability of compliance. ..	8/83

Section	Figure/Table	VOLUME	Page
8.3.2.1	Table 8.25	Simulated lime stabilisation, equivalent of 80 or 90 percent of metal input to sewers from known source(s), equivalent reduced mean concentration of metals in sewage sludge, and required SD:$\bar{X}$ ratio to equal Mandatory Limits, specified in the EC proposal for a Directive, with 95% probability of compliance.	8/84
	Table 8.26	Required percent reductions of Cd mean concentrations in untreated, simulated digested or lime stabilised sewage sludge, in order to achieve 95% compliance with the proposed mandatory limit of 40 $mg.kg^{-1}$ ( ). Calculated when standard deviations are 43.819, 30, 20, 15 or 10% of the reduced mean or simulated mean.	8/85
8.2.5.	Table 8.27	Summary of Results, Simple Compliance. Summary of results of simple compliance of Zn, Cu, Ni, Cd, Pb and Cr concentrations in unstabilised, simulated digested and simulated lime stabilised sewage sludge, without or with reduction from known trade inputs, with EC proposals for Mandatory and Recommended limits. ..	8/88
	Table 8.28	Summary of Results, Simple Compliance. Summary of results of simple compliance of Zn, Cu and Pb mean concentrations with EC proposed mandatory limits in unstabilised, simulated digested and simulated lime stabilised sewage sludge, when one or two highest concentrations are omitted, or replaced.	8/89
8.3.3.	Table 8.29.	Summary of results, 95% compliance. Summary of results, 95% probability of compliance of Zn, Cu, Ni, Cd and Pb concentrations in unstabilised, simulated digested or lime stabilised sewage sludge, with or without reductions from known trade inputs, with EC proposals for mandatory limits.	8/90
	Table 8.30	Summary of results, 95% compliance. Summary of results, 95% probability of compliance of Zn, Cu and Pb mean concentrations with EC proposed mandatory limits ( ), in unstabilised, simulated digested and simulated lime stabilised sewage sludge, when one or two highest concentrations are omitted or replaced.	8/92

Section	Figure/Table	VOLUME II	Page
8.4.1	Table 8.31	Non-ferrous metal concentration limits "...indicative of the magnitude which the authority may wish to impose on the average effluent," ( ) and known Inner City sources of effluents in which mean concentrations of Zn, Cu, Ni, Cd, Pb or Cr exceed these limits.	8/108
8.4.1.2	Table 8.32	Calculated reduction of Zn, Cu, Ni, Cd and Pb input loads to sewers when excess concentrations in effluents from elite sources are reduced to just comply with guide limits ( ) and reduction as a percentage of total inputs to sewers catchment of a Leeds City WPC works from known trade sources.	8/110
8.4.1/2	Table 8.33	Calculated reduction of Zn, Cu, Ni, Cd and Pb input loads to sewers, when concentrations in effluents from 8 'elite' sources are reduced to just comply with guide limits ( ), equivalent reduced concentrations in unstabilised sludge and effect of reduction on simple compliance proposed EC Mandatory and Recommended limits.	8/111
8.4.2.	Table 8.34	Reduced concentrations in simulated digested and lime treated sludges calculated when concentrations in effluents from 8 'elite' trade sources are reduced to just comply with guide limits ( ) and effect on simple compliance with proposed EC Mandatory and Recommended limits. ..	8/113
	Table 8.35	Calculated reduced Zn, Cu, Ni, Cd and Pb mean concentrations in unstabilised sewage sludge and maximum permissible standard deviation of concentration cases required to achieve 95% probability of compliance with proposed Mandatory limits ( ), when mean concentrations of those metals in effluents from eight sources are reduced to just comply with YWA Guide limits. ..	8/114
	Table 8.36	Calculated reduced Zn, Cu, Ni, Cd and Pb mean concentrations in simulated digested sewage sludge and maximum permissible standard deviation of concentration cases required to achieve 95% probability of compliance with proposed Mandatory limits ( ), when mean concentrations of those metals in effluents from 9 sources are reduced to just comply with YWA Guide limits.	8/116

Section	Figure/Table	VOLUME II	Page
8.4.2	Table 8.37	Calculated reduced Zn, Cu, Ni, Cd and Pb mean concentrations in simulated lime treated sludge and maximum permissible standard deviation of concentration cases required to achieve 95% probability of compliance with proposed Mandatory limits ( ), when mean concentrations of those metals in effluents from 8 sources are reduced to just comply with YWA guide limits. ..	8/117
8.4.4	Table 8.38	Summary of results guide limits and compliance. Summary of results of simple compliance of Zn, Cu, Ni, Cd, and Pb concentrations in unstabilised simulated digested and simulated lime stabilised sewage sludge, without or with reduction as a result of reducing mean concentrations in effluents from 8 known sources to YWA guide limit concentrations. ..	8/118
	Table 8.39	Required SD:$\bar{X}$ ratio to achieve 95% probability of compliance of Zn, Cu, Ni, Cd and Pb concentrations in unstabilised, simulated digested and lime stabilised sludge when these are reduced as a result of reducing mean concentrations in effluents from 8 known sources to YWA guide limit concentrations. ..	8/119
8.6	Table 8.40	Mean metal concentrations in sewage sludges from WPC works receiving no industrial effluents. ..	8/139
	Table 8.41	Metal concentrations in Suburban and City WPS works sewage sludges of high domestic origin and calculated metal concentrations attributable to Trade or unaccounted for sources in sewage sludge from a City Centre WPC works. ..	8/141
	Table 8.42	Range of excess metals (a) from known and unknown trade and other unknown sources (b), as percentages of mean concentrations of six metals in unstabilised sewage sludge leaving a Leeds Inner City WPC Works. 1980/81 data. ..	8/143
	Table 8.43	Reported annual mean concentrations and ranges of 6 metals in samples of air monitored at UK rural and Leeds City sites. ..	8/145
	Table 8.44	Average deposition rate of lead and 5 other metal elements on UK agricultural land and at 6 locations.	8/147

Section	Figure/Table	VOLUME II	Page
9.2.2	Table 9.1	Agreed flows of effluent leaving 9 'elite' and two very low flow trade sources, assumed water volume and estimated combined water volume and effluent charges. 1980/81 data. ..	9/41
9.3.1	Table 9.2	Number of cases and mean concentrations of six metals in dry solids of mixed sewage sludge leaving Leeds City WPC works. Comparison of year 1.1.79-31.2.79 with year 1.4.80-31.3.81. ..	9/42
9.3.1	Table 9.3	Improvement and worsening of compliance of mean Zn, Cu, Ni, Cd, Pb and Cr concentrations in trade effluents from 9 sources, interperiod comparisons of 1.4.79-31.3.80 with 1.4.80-31.3.81 and 1.4.81-31.9.81. ..	9/43
10.3.0	Table 10.1	Simple compliance. Required percent reduction of Zn, Cu, Ni, Cd and Pb mean concentrations in unstabilised, simulated digested and lime treated sludges in order to achieve simple compliance with Mandatory sludge concentration limits specified in Annex 1A of a proposal for a Directive.	10/24
	Table 10.2	95% Probability of compliance. Required percent reduction of mean metal concentrations in unstabilised, simulated digested and lime treated sewage sludges, when SD:$\bar{X}$ ratio is held constant, to achieve 95% probability of compliance with Mandatory limits specified in Annex 1A of the proposal for an EC directive. ..	10/25
10.3.3	Table 10.3	Percent reduction of annual mean and standard deviation of metal concentrations in unstabilised sludge, when 0, 1 or 2 highest concentration cases of Zn, Cu or Pb are omitted or replaced.	10/26
10.5	Table 10.4	Average inputs of Cd and Pb to UK agricultural land receiving sewage sludge. ..	10/27

LIST OF ABBREVIATIONS USED IN THE TEXT

ADAS	Agricultural Development and Advisory Service.
ARC	Agricultural Research Council.
CBI	Confederation of British Industry.
COI	Central Office of Information.
CDEP	Central Directorate for Environmental Pollution.
COPA	Control of Pollution Act.
CUEP	Central Unit on Environmental Pollution.
DAS	Department of Agriculture for Scotland.
DHSS	Department of Health and Social Security.
DOE	Department of the Environment.
DOI	Department of Industry.
DS	Dry solids.
EC	The Council of the European Communities.
EEC	The European Economic Community.
EDTA	Ethylene diaminetetracetate.
EQO	Environmental quality objective.
HLSC	House of Lords Select Committee.
MAFF	Ministry of Agriculture, Fisheries and Food.
MHLG	Ministry of Housing and Local Government.
MPH	Metropolitan Public Health.
NFU	National Farmers' Union.
NWC	National Water Council.
OECD	Organisation for Economic Co-operation and Development.
OM	Organic matter.
PCO	Pollution Control Officer.
RCEP	Royal Commission on Environmental Pollution.
RCSD	Royal Commission on Sewage Disposal.
RWA or WA	Regional Water Authority.
also AWA	Anglian W.A.
NWWA	North West W.A.
STWA	Severn Trent W.A.
SWWA	South West W.A.
TWA	Thames W.A.
YWA	Yorkshire W.A.
SCDSS	Standing Committee on the Disposal of Sewage Sludge.
SI	Statutory Instrument.
STC	Standing Technical Committee.
TS	Total solids.
WO	Welsh Office.
WPC	Water pollution control.
WRC	Water Research Centre.
WSL	Warren Springs Laboratory.
Zn≡	Zinc equivalent.

LIST OF THE MAIN SYMBOLS AND CODING USED IN THE MODEL

A - J	Code letters of known trade sources of metal loads greater than 100 $kg.y^{-1}$ input to sewers.
K	Source of dual input 'a' and 'b' to sewers.
L_1-L_4	Code letters of known trade sources in the very low 'agreed' flows.
M	Mandatory constraints.
O	Metal concentrations, in $mg.kg.^{-1}$, in sewage sludge output.
P	Partition ratio. (see also S7.2).
r	Stabilisation concentration factor (see S7.3).
R	Recommended constraint.
S	Metal concentration, in $mg.l^{-1}$, in sewage input to WPC works.
T	Known trade total metal load.
WPC works	Water Pollution Control Works.
X	Production of mixed sewage sludge, in 10^6kg., leaving the WPC works.
Y	Flow of sewage, in 10^6l, entering the WPC works.

For symbols A - L_4 see also S7.1

For other symbols see S7.4.

PART II. THE DEVELOPMENT AND APPLICATION OF A MODEL

7. THE DEVELOPMENT OF A MODEL

7.0 Introduction

A.

In view of

a) the costs involved in sewage treatment and disposal;

b) the increased emphasis on financial efficiency in sludge disposal operations;

c) the prospect of more stringent controls on heavy metals in sewage sludges disposed to sea;

d) the publication of a proposal for a European Council Directive on the use of sewage sludge in agriculture; and

e) the issuing and confirmation of a committal to a timetable for the implementation of the outstanding sections of Part 2 of the Control of Pollution Act 1974;

this study now seeks to examine, by means of a case study, how and to what extent certain metal inputs may need to be reduced in order to achieve economically efficient disposal of sewage sludge.

Purposes

1. To construct a model to investigate the interrelationship of specified metal inputs to and outputs from the sewer/treatment works system.

For a stated WPC works, and for a stated period -

2. to use the model to quantify how much, if any, of the load of a stated metal entering the WPC works may need to be reduced in order to meet specified output constraints;

3. to assess to what extent any reduction in metal loads may be achieved by the realistic reduction of metal loads from known point sources;

4. where necessary to indicate the extent to which any calculated reduction cannot be met from point sources for which data is available;

5. to assess to what extent and by what means compliance with the

proposal for an EC directive could be met if sludges were used on agricultural land;

6. to make suggestions as to how such a model might also be used in conjunction with the Environmental Quality Objectives approach to control of effluent outputs from WPC works to rivers;

and further -

7. to suggest ways by which the reliability of such a model might be improved; and

8. use the findings of the study to discuss economic and policy aspects of controlling metalliferous inputs to the sewerage system.

B. Method

A meeting took place with Yorkshire Water Authority officials and the general approach of the study discussed.

In relation to Knostrop Low Level WPC works, mixed sewage sludge from which is currently being disposed by dumping at sea, the following data was requested for the period 1979-81:

a) Solids and metal concentrations of mixed sewage sludges leaving the WPC works;

b) Solids and metal concentrations of crude sewage entering the WPC works;

c) Subject to coding to meet confidentiality requirements, metal concentrations of metalliferous trade effluent inputs to sewers;

d) Annual production of mixed sewage sludges leaving the WPC works;

e) Flows of crude sewage entering the works;

f) Agreed flows of coded trade effluent inputs to sewers.

A map of the sewer system of the WPC works catchment area was also requested but was not made available. The possibility of obtaining information regarding metal loads entering sewers from domestic, commercial, institutional and run off sources was also discussed, but information was

not available.

Data supplied

Analytical data supplied was in the form of computer print outs while flow data was in the form of photocopies of log sheets or of computer file. Also made available were two YWA handbooks - 'Sludge recycling practice', and 'Code of Practice for the control of trade effluent draining to public sewers'.

Assessing the data

Considerable time was spent in collating, checking and organising the data made available, particularly in relation to the six basic parameters - metal concentrations and production of mixed sewage sludges; metal concentrations and flow of crude sewage entering the WPC works; and metal concentrations and agreed flow of coded trade effluents.

It was found that -

a) received metal concentrations of crude sewage related to the period 1.1.79 to 9.1.80 only;

b) received metal concentrations of mixed sewage sludges related to the period 1.1.79 to 19.2.81 only; however,

c) metal concentrations of mixed sewage sludges leaving a barge terminal were available for the period 20.1.81 - 30.11.81, but during the 31 days of overlap between b) and c) there were only 3 analyses of sludges leaving the WPC works to compare with 3 analyses of sludges leaving the barge terminal;

d) no metal concentration data was available over the extended Christmas/New Year periods of 1979, 1980 and 1981;

e) agreed flows of coded trade effluents were made available for the period 1.4.80 - 31.3.81 only;

f) it was also found that in addition to mixed sewage sludges and final effluent outputs from the WPC works, other outputs were:

i) storm water pumped directly to river for which flow but not analytical data was available; and

ii) an output to a lagoon understood to comprise humus from biological filters and 'top water'. An estimate of flow is available for this output, but again no analytical data.

Design decisions

On the basis of available data the use of a purely linear model was regarded as inappropriate. It was decided:

a) To construct a very simple model.

b) To further simplify the model by splitting it into parts.

c) To run the model for the period 1.4.80 - 31.3.81, the only period when both concentration and agreed flows of trade effluent inputs to sewers are available.

d) To calculate effective partition of metals from crude sewage entering the WPC works to metal loads in mixed sewage sludges produced for the period 1.4.79 - 31.3.80. Making the rather naive assumption that crude sewage data for the period 1.4.79 - 9.1.80 is representative of that period.

e) In addition to use partition ratios derived from published sources as a check on results achieved, and in so doing provide a range of results.

f) In the absence of crude sewage concentrations for the period chosen to construct the model so that the partition ratios can be used with trade input and sewage sludge output data to predict effects of reducing metal concentration of input on output.

g) To arrange trade effluent concentrations and agreed flows in a tableaux format. Input loads would be ranked and cumulative ranked loads calculated for each metal for which adequate data was available.

h) The model would be run using the constraints specified in Annex 1A of the proposed EEC directive.

i) In order to comply with the requirement for the stabilisation of

sewage sludges used in agriculture written into the EEC proposal, the effects of anaerobic digestion and lime treatment of sewage sludges on metal concentrations would be simulated.

7.1. Known trade effluent inputs to sewers

7.1.1. Introduction and purposes

Metal concentrations and agreed flows of 40 coded trade effluent inputs to sewers were made available for the year 1.4.80 - 31.3.81. At the time of writing these are the only point source metal inputs to sewers available to the author. The data was studied carefully:

To find the distribution of metal loads from these sources.

To find the relative importance of different sources of each metal, and if there was an elite group of sources which justified further study.

To examine how the loads from any elite group are made up.

To assess the adequacy of the data, and

To detect any particular difficulties.

7.1.2. Methods and Results

Annual mean concentrations were calculated for each point source and arranged with agreed flows from those sources in a tableaux format. Annual metal loads were calculated for each input. The sum of the known trade loads for each metal was then calculated, being 5310.6, 750.4, 7822.4, 1920.5, 102.5, and 592.4 kilograms per year of Zn, Cu, Ni, Cr, Cd and Pb respectively.

On inspection it was apparent that:

a) There is a wide distribution of agreed flows ranging from 32 - 488,983 m^3y^{-1}.

b) There is a wide distribution of mean concentrations in effluents ranging from 0.5 μgl^{-1} of Cd to 81 mgl^{-1} of Cr.

c) Concentrations of Cd are of a lower order of magnitude than other metals, data supplied being in units of μgl^{-1} compared to mgl^{-1} for other

metals.

d) For one source there was one agreed flow for two effluent inputs. The range of loads calculated from this source is designated as 'dual input data' in results and discussion below.

Distribution of inputs with agreed flows greater than 10^6 l and mean concentrations equal to or greater than 0.1 mgl^{-1} were plotted for Zn, Cu, Ni, Cr and Pb as shown in figs. 7.1-7.4 and 7.6 respectively, and in the case of Cd recorded mean concentrations equal to or greater than 0.01 mgl^{-1} are shown in fig. 7.5. Figs. 7.1-7.6 also include iso load lines drawn at logarithmic intervals.

Figs. 7.1-7.5 show clearly how the use of one agreed flow for two inputs to sewer, for which concentrations of metal are available, make it impossible to calculate accurate input loads to sewers from these sources. The range of dual input load values are shown in figs. 7.7-7.11 when metal loads are plotted.

The distributions of metal loads plotted in figs. 7.1-7.6 are summarised in table 7.1. 97 of the 183 calculated known loads are within the parameters plotted. Most of the loads lie within the ranges 10^0-10' and 10'-10^2 $kg.y^{-1}$. It is in these two ranges that all dual input data lies and includes the highest calculated input of Cadmium. See also figs. 7.5 and 7.11. Inputs shown in table 7.1 columns A and B for the ranges 10^{-2} - 10^{-1} and 10^{-1} - 10^0 $kg.y^{-1}$ are regarded as well controlled and are not likely to be significant when considering any potential reduction in total loads entering sewers. Range totals appear to be log normally distributed. See columns A - F.

There are four calculated loads greater than 10^3 $kg.y^{-1}$, the load of Nickel and that of Chromium being from the same source. As shown on figs. 7.3 and 7.4 this source had an agreed flow of approximately 4.9 x 10^8 l y^{-1}, the source of the highest input load of over 7 tonnes of Nickel,

but as shown in figs. 7.3 and 7.9, if the highest concentration case on which the mean value is calculated is omitted and the mean recalculated a load of over 4 tonnes of Nickel enters sewers from this point source.

As shown in figs. 7.1 - 7.4 and 7.6, and in figs. 7.7 - 7.10 and 7.12, summarised in table 7.1 column E there were 11 metal loads in the range 10^2 - 10^3 kgs.y^{-1}.

Difference of number of sources shown in columns H and I of table 7.1 shows the number of inputs with concentrations and flows lying outside the limits of those shown in figs. 7.1 - 7.6 were 9, 18, 19, 16, 20 and 4 for Zn, Cu, Ni, Cr, Cd and Pb respectively. Twenty-three of these input loads were of Zn, Cu, Ni, Cr or Pb equal to or greater than 1 kg.y^{-1} and of 7 inputs of Cd greater than 0.1 kg.y^{-1} as shown in table 7.4a.

Distribution of all calculated input loads of 1 kg and over of Zn, Cu, Ni, Cr and Pb are shown in figs. 7.7 - 7.10 and 7.12, Cd loads greater than 0.1 kg. in fig. 7.11.

Ranked cumulative percentile loads equal to or greater than 10 kg.y^{-1} are shown in figs. 7.13 to 7.18 and summarised in table 7.2. Results are now discussed metal by metal.

Zinc

Zinc input loads greater than 1 kg. are shown in fig. 7.7. The loads may be seen as forming two groups one of 6 inputs greater than 10^2 kg.y^{-1} and 18 inputs of 31 kg.y^{-1} or less. As shown the load represented by dual input data falls in the second group and the range a-b is relatively small and not likely to have considerable effect on the total load of Zn.

Ranked cumulative input loads greater than 10 kg. calculated as percentiles of total calculated load, are shown in fig.7.13. Two input loads greater than 10^3 kg.y^{-1} account for 67.67 percent of the total

calculated Zn load. Six inputs greater than 10^2 kg.y^{-1} account for 95.42 percent, and 16 inputs greater than 10 kg.y^{-1} for 99.26 percent of total load of 5310.6 kg.y^{-1}.

Ranked cumulative input loads of 6 metals are summarised in table 7.2, where it is seen that there are more inputs of Zn greater than 10^2 kg. than for any other metal. Total load is greater than 5 tonnes, Nickel being the only total load greater. Zinc and Cr have 16 inputs of 10 kg.y^{-1} and over more than the other 4 metals shown.

Volume of flow and number of sources of Zn loads greater than 10^2 kg.y^{-1} are shown in table 7.3. Inputs of Zn greater than 1 kg.y^{-1} from sources with agreed flows or concentrations less than 10^6 l.y^{-1} or 0.1 mg.l^{-1} are shown in table 7.4a. Data summarised in these tables is discussed later.

Copper

Copper input loads equal to or greater than 1 kg.y^{-1} are shown in fig. 7.8. On the data made available no loads are greater than 10^3 kgs, only two loads are greater than 10^2 kg. and 7 greater than 10 kg.y^{-1}. Dual input range is small and likely to have little effect on total load of Cu, load 'b' is used in calculating total load of Cu from known trade inputs.

Ranked percentile cumulative loads are shown in fig. 7.14, 100% = 750.4 kg.y^{-1} a surprisingly low figure for this metal. The two loads greater than 10^2 kg. account for 76.48 percent and 7 loads greater than 10 kg. for 91.36 percent of total load. Total load of copper is less than those for Ni, Zn and Cr but greater than loads of Pb and Cd. Number of inputs greater than 10 kg.y^{-1} is less than for Zn and Cr but greater than Ni, Pb and Cd as summarised in table 7.2.

Volume of flow and number of sources of Cu loads greater than

10^2kg.y^{-1} are shown in table 7.3. Inputs of Cu greater than 1 kg.y^{-1} from sources with agreed flows or concentrations less than 10^6 l.y^{-1} or 0.1 mgl.$^{-1}$ are shown in table 7.4a. Data summarised in these tables is discussed later.

Nickel

Nickel input loads greater than 1 kg. are shown in fig. 7.9. The only load greater than 10^3 kg. predominates. There are also 3 inputs greater than 10^2 kg., 7 inputs greater than 10 kg. and 18 inputs are greater than 1 kg.y^{-1}. Although there is a difference of 33.5 kg. between highest and lowest dual input loads calculated, this is not likely to be important when calculating total load, due to the predominance of the highest Ni input. The higher of the dual input loads 'b' is used in calculating total load of Ni.

Ranked cumulative percentile total loads are calculated for the seven inputs greater than 10 kg.y^{-1} as shown in fig. 7.15. With 100 per cent = 7822.34 kg.y^{-1}, the highest input accounts for 93.08 percent, 3 inputs greater than 10^2 kg. for 97.47 and 7 inputs greater than 10 kg. for 99.31 percent of total load.

Omitting the highest concentration case from the data on which the highest load is calculated, and recalculating the mean concentration and load of this input, total Ni load was recalculated to be 4802.5 kg.y^{-1}. Cumulative percentile loads for these lower values are also shown in fig. 7.15. The highest input now accounts for 88.73 percent, 3 inputs greater than 10^2 kg. for 95.87 percent and 7 inputs greater than 10 kg. for 98.88 percent of total load.

Clearly any attempt to reduce overall Ni load input to sewers must take account of the highest load whatever that source might be.

Cumulative input data is summarised in table 7.2 total annual load of Nickel is greater than that for any other metal shown, or is second to

Zn if the highest concentration of the rank 1 load is omitted.

Number of inputs greater than 10 kg. is less than for Zn & Cr, equal to Cu but more than Pb and Cd.

Volume of flow and number of sources of Ni loads greater than 10^2kgs. are shown in table 7.3. Inputs of Ni greater than 1 kg.y^{-1} from sources with agreed flows or concentrations less than 10^6l.y^{-1} or 0.1 mg.l^{-1} are shown in table 7.4a. Data summarised in these tables is discussed later.

Chromium

The distribution of flows and concentrations of effluents containing Cr, equal to or greater than 10^6 l. and 0.1 mg.l^{-1} are shown in fig. 7.4. The very high flow, approximately 4.89 x 10^8l, the same flow as that shown for Nickel in fig. 7.3, is from the same point source as the highest Ni load and carries the highest Cr load.

All Cr loads equal to or greater than 1 kg. are shown in fig. 7.10. One load is greater than 10^3 kg., 3 are greater than 10^2 kg. and 16 greater than 10 kg.y^{-1}. The fifth load shown, of 47.35 kgs.y^{-1}, is the highest metal load from an input with an annual flow of less than 10^6 l. Agreed flow from this source, L_1 in tables 7.4a and 7.4b, is of 7.84 x 10^5 l.y^{-1}.

In view of the influence of higher loads the difficulty of calculating load from the dual input data, shown in figs. 7.4 and 7.10 is not likely to be operationally significant. The lower of the input loads 'b' is used in calculating total load of Cr.

Ranked cumulative percentiles of total load, calculated for loads greater than 10 kg.y^{-1}, are shown in fig. 7.16, 100 per cent = 1920.53 kg. One load greater than 10^3 kg. accounts for 55.68 percent, 3 inputs greater than 10^2 kg. for 77.33 percent and 16 inputs, greater than 10 kg. for 96.82 percent of total Cr load from known trade input sources.

Cumulative input data, summarised in table 7.2, shows that total annual load of Cr is less than that for Ni and Zn but greater than Cu, Pb, and Cd. Number of inputs greater than 10 $kg.y^{-1}$ are equal to those for Zn greater than for Cu, Ni, Pb and Cd.

Volume of flow and number of sources of Cr loads greater than 10^2 $kg.y^{-1}$ are shown in table 7.3. Inputs of Cr greater than 1 $kg.y^{-1}$ from sources with agreed flows or concentrations less than 10^6 $l.y^{-1}$ or 0.1 $mg.l^{-1}$ are shown in table 7.4a. Data summarised in these tables is discussed later.

Cadmium

Trade effluent input loads of Cd are of a lower order than those of other metals. To some extent this reflects the more stringent consents and enforcement put on emissions of this metal by R. Water Authorities. For this reason lowest concentrations shown in figures and tables are x 10^{-1} lower than for other metals. Thus fig. 7.5 shows concentrations equal to or greater than 10^{-2} $mgl.^{-1}$, fig. 7.11 shows loads equal to or greater than 0.1 $kg.y^{-1}$ and in fig. 7.17 loads equal to or greater than 1 kg. are represented.

As shown in fig. 7.11 there are no calculated loads of Cd greater than 10^2 kg. Three are greater than 10 kg., the highest of these being the highest calculated load for the dual input data, four loads lie in the 10^{o} - 10' kg. range including the lower load of dual input data. While 15 loads lie in the 10^{-1} - 10^{o} kg. range. Seven of the input loads shown in fig. 7.11 are from effluents with concentrations less than 10^{-2} $mgl.^{-1}$ See also table 7.4a.

When the dual input data is used at the lower load value total calculated load = 102.54 kgs. One input accounts for 54.99 percent, 2 inputs for 82.74 percent and 6 inputs for 92.56 percent of total Cd inputs

from known trade sources. See fig. 7.17.

For comparison the effect of omitting the lowest load 'b' and including the highest calculated load 'a' of the dual input data is also shown in fig. 7.17. 100 percent now = 196.95 $kg.y^{-1}$. 94 per cent higher than the former case. One load, the highest of the dual input data, now accounts for 48.95 percent, 2 loads account for 77.57 percent, and 6 loads account for 96.12 percent of total load.

On the basis of these figures summarised in table 7.2 the pattern is similar and reduction of the two highest loads is likely to have the greatest effect on overall total load. However, the load range shown for the dual input data is large and therefore requires considerable care in utilising the Cd data.

Presumably only one agreed flow is shown for the dual input data because one input is very low and the true input load of Cd lies somewhere between the two loads shown. It is also presumed that the input with the highest concentration, 8063 μgl^{-1}, of known Cd inputs was very low, otherwise steps would have been taken to further control it.

On the above basis the use of the lower load value with optional use of the higher load value and corresponding total loads may be expedient when running the model.

When dual input Ka is omitted only two Cd loads are greater than 10 kg. and are from 2 of the ten sources producing 10^2 kg. or more of other metals, as shown in table 7.3.

Lead

Data, made available for lead is sparse, but is included as concern about lead levels has led to studies of concentrations in air, dust, rainfall, water supply and in blood of occupants within the WPC works catchment area.[1, 2.]

Only two of the known trade effluent inputs are within the parameters shown in fig. 7.6, one greater than 10^2 kg. and both greater than 10^1 kg.y.$^{-1}$ both are from sources with relatively low flows.

When Pb inputs equal to or greater than 1 kg.y^{-1} are shown in fig. 7.12, a third input of 12.2 kg. is shown alongside the two mentioned above. This input has an agreed flow of 3.3×10^5 l.y^{-1} and is from source L_2 as shown in tables 7.4a and 7.4b.

Ranked cumulative percentiles of total load are shown in fig. 7.18. 100 percent = 592.42 kg.y^{-1}. One load greater than 10^2 kg. accounts for 94.7 percent, two loads for 97.90 percent, and three loads for 99.96 per cent of total calculated load.

Cumulative percentile data is summarised in table 7.2. It is seen that total Pb load of 592.4 kg.y^{-1} is greater than that for Cd but less than that for Ni, Zn, Cr and Cu, likewise the number of input loads greater than 10 kg.y^{-1} is greater than for Cd but less than for Zn, Cr, Cu and Ni.

The sparcity of available data would seem to reflect either a very specialized usage or low priority for monitoring, or both. Total load calculated for known trade inputs is surprisingly low in view of the concern being shown over environmental lead levels in the area.

7.1.3. An elite group of sources?

Cumulative ranked metal loads, greater than 10 kg.y^{-1}, as percentages of total calculated loads of Zn, Cu, Ni, Cr, Cd and Pb are shown in table 7.2. Four loads greater than 10^3 kg. above the line a - a, account for 67.67 percent Zn, 93.08 (88.73) percent Ni and 55.68 percent Cr total loads. The fifteen loads greater than 10^2 kg, above the line b..b, account for 95.42 percent Zn, 76.48 percent Cu, 97.47 (95.87) percent Ni, 77.33 percent Cr and 94.71 percent of Pb. The contribution of these inputs to total loads is also shown in fig. 7.19. It is quite clear that these

inputs make the major contributions to all loads except Cd.

Volumes of flow and source codes of the 15 loads, greater than 10^2 kg.y^{-1} are shown in table 7.3. It is shown that the 15 loads arose from 10 sources, coded A-J and ranked by volume of flow.

These sources will now be discussed individually also using the percent data shown in table 7.2. Dual input data for source Ka is omitted from calculations of totals.

A, the source of the highest agreed effluent flow of 'known' inputs 488.983 x 10^6 l.y^{-1} is the point source of 2 loads, greater than 10^3 kg. of Ni and Cr, accounting for 93.08 and 55.68 percent of Ni and Cr total loads respectively the highest ranked of all Ni and Cr loads. When highest concentration case of Ni is omitted and mean concentration of effluent re-calculated, Ni load from source A accounts for 88.73 percent of total Ni load. A is also the source of 2 loads accounting for 0.41 and 3.635 percent of Zn and Cu total loads and ranked tenth and fourth respectively.

B, the source of an agreed flow of 54.866 x 10^6 l.y^{-1} is the point source of one load greater than 10^3 kg of Zn accounting for 44.36 percent of total Zn load, the highest ranked of all Zn loads. This is also the source of 3 loads in the range 10^1 - 10^2 kg., accounting for 1.375, 1.58 and 27.75 percent of Cu, Cr and Cd total loads and ranked sixth, eighth and second respectively.

C, the source of an agreed flow of 43.226 x 10^6 l.y^{-1}, is the point source of 1 load, in the range 10^2 - 10^3 kg. of Zn accounting for 12.74 percent of total Zn load and ranked third of all Zn loads. This is also the source of 1 load, in the range 10^1 - 10^2 kg. of Cr accounting for 1.725 percent of total Cr load and ranked seventh of all Cr loads.

D, the source of an agreed flow of 20.785 x 10^6 l.y^{-1}, is the point source of 1 load greater than 10^3 kg. of Zn. This load, 23.31 percent of

total Zn load, is ranked second of all Zn loads. This is also the source of 1 load, in the range 10^1 - 10^2 kg., of Cu accounting for 1.365 percent of total load and ranked seventh of all Cu loads.

E, the source of an agreed flow of 13.708 x 10^6 $l.y^{-1}$, is the point source of 2 loads, in the 10^2 - 10^3 kg. range, of Zn and Cu, being 7.01 and 17.34 percent of total loads and ranked fourth and second of all Zn and Cu loads respectively. E is also the source of the second highest Pb load but this is relatively small accounting for 3.188 percent of total Pb load.

F is the source of an agreed flow of 13.152 x 10^6 $l.y^{-1}$, the point source of 1 load, in the 10^2 - 10^3 kg. range, of Cr accounting for 9.31 percent of total Cr load and ranked third of all Cr loads. F is also the source of 3 loads in 10^1 - 10^2 kg. range, accounting for 0.258, 0.1552 and 54.99 percent of Zn, Ni and Cd total loads and ranked fourteenth, seventh and first of all Zn, Ni and Cd loads respectively. The Cd input from this source is particularly important.

G is the source of an agreed flow of 11.878 x 10^6 $l.y^{-1}$, is the point source of 2 loads, in the range 10^2 - 10^3 kg., of Zn and Ni accounting for 2.91 and 1.58 percent of total Zn and Ni loads and ranked sixth and third of all Zn and Ni loads respectively. G is also the source of 1 load, in the 10^1 - 10^2 kg. range, of Cu accounting for 7.045 percent of total Cu load and ranked third of all Cu loads.

H the source of an agreed flow of 8.771 x $10^6 l.y^{-1}$ is the point source of 3 loads, in 10^2 - 10^3 kg. range, of Zn, Cu and Pb accounting for 5.10, 59.14 and 94.71 percent of Zn, Cu and Pb total loads respectively and ranked fifth, first and first of all Zn, Cu and Pb loads respectively. H is also the source of 1 load, in the 10^1 - 10^2 kg. range, of Cr accounting for 1.37 percent of total load and ranked eleventh of all Cr loads.

I the source of an agreed flow of 7.575×10^6 ly.$^{-1}$ is the point source of 1 load, in the 10^2 - 10^3 kg. range, of Ni accounting for 2.81 percent of total load and ranked second of all Ni loads. This is also the source of 1 load, in the 10^1 - 10^2 kg. range, of Cr accounting for 0.966 percent of total load and ranked thirteenth of all Cr loads.

J the source of an agreed flow of 3.158×10^6 ly.$^{-1}$ the lowest of the ten flows shown in table 7.3, is the point source of 1 load, in the 10^2 - 10^3 kg. range of Cr, accounting for 12.34 percent of total load and ranked second of all Cr loads.

The ten sources A-J, shown in table 7.3 are the point sources of 15 metal loads greater than 10^2 kg. and of 14 loads in the range 10^1 - 10^2kg. When shown by metal, load range, rank and proportion of known trade loads greater than 10 kg.y^{-1}, they are the sources of :

	Range 10^3kg	Rank	Range 10^2-10^3kg	Rank	Range 10^1-10^2kg	Rank	: All Loads 10 kg≤
for Zn	2	1,2	4	3-6	2	10,14	8 of 16 ,
for Cu			2	1,2,	4	3,4,6,7,	6 of 7 ,
for Ni	1	1	2	2,3,	1	7	4 of 7 ,
for Cr	1	1	2	2,3,	4	7,8,11,13,	7 of 16 ,
for Cd					2	1,2,	2 of 2 ,
for Pb			1	1,	1	2	2 of 3 and
for six metals	4		11		14		29 of 51.

A-J are the point sources of all loads greater than 10^2 kg and 29 of 51, i.e. 56.9 percent, of all loads greater than 10 kg, shown in table 7.2, including loads ranked 1-6, 1-4, 1-3, 1-3, 1-2, and 1-2 of Zn, Cu, Ni, Cr, Cd and Pb respectively.

When loads greater than 10 kg. are included A-J are the ten point sources of:

8	loads	accounting for	96.09%	of total	Zn load,
6	"	"	89.9%	"	Cu "
4	"	"	97.62%	"	Ni "
7	"	"	83.0%	"	Cr "
2	"	"	82.74%	"	Cd "
2	"	"	97.90%	"	Pb " , for which trade metal

input data has been made available.

Cumulative percentile contributions of loads greater than 10^3 kg., 10^2 kg. and 10^1 kg.y^{-1} from the ten point sources, A-J, of total calculated loads are shown in fig. 7.20. Loads in the 10^1 - 10^2 kg. range account for 0.155, 0.672, 3.25, 13.26 and 5.67 percent of Ni, Zn, Cu, Cr and Pb respectively. However 2 loads in this range account for 82.74% of total Cd load, and are particularly important to the study. When loads greater than 1 kg. are included A-J are the point sources of 5 loads accounting for 90.64% of Cd load when dual input source Ka is omitted and 47.182% of Cd load if Ka is included and Kb omitted.

Clearly the ten sources, A-J, do form an elite group. On the basis of input mass and rank A B and D form a super elite as sources of Zn, Ni and Cr. But F is important, not only as a source of a Cr load greater than 10^2 kg, but for the highest Cd load. The second Cd load being from source B. Source H is important for 3 loads greater than 10^2 kg. including the highest Cu and Pb loads.

When reliability of data is considered, it is found that inputs from sources D and G and the Pb from source H are based on 3, 3 and 4 concentration cases only, compared with 10 - 16 cases for other metal concentrations from sources A, B, C, E, F, H, I and J. Because of sparsity of Pb data it is considered necessary to include the Rank 1 input from

source H with this limitation in mind. Inputs from D and G may be optionally omitted because of their low reliability.

It is now seen that A, B, F and H are the four most important point sources accounting for 50.14, 64.15, 93.23, 67.93, 82.74 and 94.71 percent of Zn, Cu, Ni, Cr, Cd and Pb total load from known trade inputs.

When inputs from sources D and G are omitted from total loads, loads of 10 $kg.y^{-1}$ and more from

Sources B,C,E,H,A account for 94.70% of reduced total Zn

" H,E,A,B " 88.97% " " Cu

" A,I,F " 97.66% " " Ni

" A,J,F,H,I,C,B, 83.48% " " Cr

" H,E, 97.90% " " Pb

Loads of 1 $kg.y^{-1}$ and more from

" F,B,A,H account for 91.064% of reduced total Cd,

Similarly loads of 10 $kg.y^{-1}$ and more from sources E,B,A and H account for 67.96, 88.36, 94.81, 68.33 and 94.71 percent of Zn, Cu, Ni, Cr and Pb reduced total loads.

Conclusion

In the construction of a model to consider potential for reducing metal flows from known point sources, it may be useful to consider the effect of the ten sources A-J as a whole, but also in ranked cumulative order. Provision being made to optionally omit sources regarded as of low reliability. Data for sources D and G being regarded with particular caution. For the metal Cd provision should also be made for the optional inclusion or omission of the dual input sources Ka and b.

On the basis of the agreed flows shown in table 7.3 it may be convenient to classify A as having a high volume flow greater than 80,000 m^3y^{-1}, B,C and D as having medium volume flows greater than 20,000 and less than 80,000 m^3y^{-1} and E,F,G,H,I and J and also the dual input source 'K' as

having low volume flows greater than 1000 but less than 20,000 m^3y^{-1}.

7.1.4. Important low flow sources?

Some of the input loads of Zn, Cu, Ni, Cr and Pb greater than 1 $kg.y^{-1}$ and of Cd greater than 0.1 $kg.y^{-1}$ shown in figs. 7.7 - 7.12 have flows or concentrations less than those included in figs. 7.1 - 7.6 and summarised in table 7.1. These low flow or concentration inputs are summarised in table 7.4a, low flow sources being ranked by decreasing 'agreed' flows.

Zn. Of the 3 loads of Zn greater than 1 $kg.y^{-1}$ one was from the source L_2, of a flow $< 10^6$ $l.y^{-1}$ and 2 had effluent concentrations < 0.1 $mg.l^{-1}$, one of these being from source A.

Cu. Of the 9 loads of Cu greater than 1 $kg.y^{-1}$, two were from sources L_2, L_4 of flows $< 10^6$ $l.y^{-1}$ and 7 had effluent concentrations < 0.1 $mg.l^{-1}$ sources of which include A, C and F.

Ni. Of the 6 loads of Ni, greater than 1 $kg.y^{-1}$, all had concentrations < 0.1 $mg.l^{-1}$.

Cr. Of the 4 loads of Cr, greater than 1 $kg.y^{-1}$, three were from sources, L_1, L_3 and L_4, of flows $< 10^6$ $l.y^{-1}$ and 1 had a concentration < 0.1 $mg.l^{-1}$

Pb. The 1 load of Pb greater than 1 $kg.y^{-1}$ was from a source, L_2, of flow $< 10^6$ $l.y^{-1}$.

Cd. Of the 7 loads of Cd greater than 0.1 kg. all were of effluent concentrations of less than 0.01 $mg.l^{-1}$.

Low concentration inputs are regarded as well controlled and therefore not of importance to the model. Distribution of input loads greater than 1 kg. from sources, shown in table 7.4a to have agreed flows less than 10^6 $l.y^{-1}$, are shown in table 7.4b.

Source L_1, with a flow of 7.84×10^5 $l.y^{-1}$ is the point source of 1 load, in the 40-50 kg. range, of Cr ranked fifth of all Cr loads.

Source L_2, with a flow of 3.30×10^5 $l.y^{-1}$ is the point source of 3 loads, in the 10-20 kg. range, of Zn, Cu and Pb, ranked eleventh, sixth and third of all Zn, Cu and Pb loads. Source L_3 is the source of 1 load in the 1-10 kg. range of Cr. Source L_4 is the source of 2 loads, 1 in the 1-10 kg. range of Cu and 1 in the 10-20 kg. range, ranked eighth of all Cr loads. Of these sources L_1 accounts for 2.465% of total Cr load and L_2 for 0.315, 1.44 and 2.06 percent of Zn, Cu and Pb total loads respectively.

On the basis of the above data these sources appear to be relatively unimportant compared with the ten sources shown in table 7.3, however examining the number of concentrations from which mean concentrations and thus low flow loads are calculated, it is noticed that level of monitoring is very low, being based on 1 or 2 concentration cases.

It is concluded that the reliability of the metal concentration data is likely to be very low and the real operational importance of inputs from low flow sources cannot be assessed.

7.1.5. Conclusions

1. If it is necessary to reduce the load of a particular metal entering a WPC works over a stated period, in order to meet specified constraints on sewage sludge disposed by a particular route, or to reduce costs of disposal, it will be necessary to consider how and where this reduction may take place.

2. Some fraction of total load will be from diffuse or from multiple small point sources, e.g. domestic dwellings, where it may not be expedient to examine sources individually. Part of the load will come from exempted sources, part from sources where metals are complexed with organic matter.

This study sets out to calculate requirement for reduction, if

necessary, of total load and to assess if this reduction may be brought about by further controlling metalliferous inputs, low in organic matter.

From the study of the 40 known trade input source data it is concluded that:

3. Requirement for reduction should be calculated and compared with total load from sources for which data is available. If the latter is greater the following would be useful to know for a stated period;

4. Mass and percentage by which total load needs to be reduced;

5. By how much sources A-J, or a sub-group of sources A-J would need to reduce input in order to achieve the necessary reduction.

6. It might be expedient to adopt a cumulative percentile approach to reduction of percent or mass of total trade loads.

7. It is noticed that total loads of Zn, Ni and Cr, from known sources are relatively higher than for Cu and Pb and they in turn are higher than Cd as shown in fig. 7.21.

8. On the basis of reliability loads from source G and D should be treated with caution and optionally omitted when possible.

9. Alternative input data for Nickel from Source A should be used to reduce the influence of 1 highest concentration case on calculated load and total loads of Ni.

10. Calculations involving reductions of Cd, and to a lesser extent other metals, must treat dual input effluent data Ka and b with caution when calculating alternative loads and total loads, data for b being used unless otherwise stated. The dual input source is designated as K.

11. Monitoring levels should be discussed when interpreting results.

7.2. Effective Partition

7.2.0. As stated earlier, known trade effluent input data was made available for the period 1.4.80 - 31.3.81, but crude sewage metal data was only available for the period 1.4.79 - 31.3.80. During this period metal concentrations in crude sewage entering the WPC works studied were given by 25, 24, 25, 25, 25, and 1 concentration cases of Zn, Cu, Ni, Cr, Cd and Pb and calculated mean concentrations being 0.5542, 0.2186, 0.1124, 0.1774, 0.012 and 0.08 $mg.l^{-1}$ respectively.

For the same period metal concentrations in mixed sewage sludges leaving the works were given by 48, 48, 49, 49, 48 and 0 concentration cases of Zn, Cu, Ni, Cr, Cd and Pb calculated mean concentrations being 1954.98, 743.33, 216.58, 660.19, 34.20 and 0 $mg.kg^{-1}$ dry solids respectively.

Flow of crude sewage and storm sewage entering the works was 40,972.5 x 10^6 l. but untreated storm sewage pumped to river was 1,367.96 x 10^6 l. so calculated volume of sewage entering the treatment processes leading to mixed sewage sludge production was 39,604.54 x 10^6 l. Production of mixed sewage sludges leaving the works totalled 10.256 x 10^6 kg. for the same period.

It should be noted that there are considerable difficulties involved in obtaining accurate measurements of crude sewage flow and of sludge production. In the former not only are the accuracy of measuring devices a potential limiting factor but also the sewage having entered the works is pumped from one process to another. A proportion may be recycled or, in the case of a complete breakdown, may bypass some processes and flow straight into the river. In the latter the measurement depends not only on the measurement of volume or mass of wet sludges but on the representative sampling and establishment of the dry matter content of the wet sludges produced. Therefore quantitative data must be used with these limitations in mind.

7.2.1. Now if S is the mean concentration of a metal in crude sewage and Y the flow, and O the mean concentration of that metal in the sewage sludge and X the production for that period and P the effective partition of that metal from crude sewage to sewage sludge, then effective partition is calculated as

$$\frac{O \times X}{S \times Y} = P$$

and for Zn

$$\frac{1954.98 \times 10.256}{0.5542 \times 39604.54} = \frac{20050.274}{21948.836} = 0.9135.$$

Interpreting the equation, the crude sewage entering the works carried a load of 21948.836 kg. of Zn in the stated period. Mixed sewage sludge leaving the works carried a load of 20050.274 kg. Zn, the effective partition of Zn entering to the sludge produced being 0.9135.

Presumably 8.65 percent of the incoming Zn load was accounted for in Zn contained in final effluent and/or in effluent pumped to lagoons. It should be noted however that this is dependent on the assumptions that a) the metal is conserved and not lost to other outputs such as to air by vapourisation, and b) Crude sewage entering the works at metering and sampling points is the only input by which metals enter the works.

Using the equation calculated results for the period 1.4.79 - 31.3.80 may be summarised as follows:

Metal	Input in Crude sewage $kg.y^{-1}$	Output in sludge $kg.y^{-1}$	E.Partition	Residual
Zn	21948.36	20050.274	0.9135	0.0865
Cu	8657.5524	7623.5924	0.88057	0.11943
Ni	4451.5502	2221.2444	0.49898	0.501.
Cr	7025.8453	6770.9086	0.96371	0.0363
Cd	475.2545	350.7552	0.73804	0.262
Pb	ND	ND		

Thus effective partition ratios range from 0.499 for Ni, indicating that less than half the Nickel entering the works was partitioned to the sewage sludge leaving it, to 0.964 in the case of Cr. The Pb data available was quite inadequate for the effective partition to be calculated. It is relevant to note that 'A general paucity' of partition or 'removal efficiency' data for UK works was reported in 1979.[3]

Partition ratios calculated above are shown with others for UK works extracted from literature sources in table 7.5.

It should be noted that three sets of results shown are as a result of balance studies carried out over relatively short periods at Oxford sewage works. Two of these sets, reported by Lester J.N. et al. and by Stoveland S. et al. are from the same study, carried out in conjunction with Thames Water Authority and reported in 1979.

Commenting on Zn, Ni and Cr partition (removal efficiency) Stoveland states "The high removal efficiency of the primary sedimentation stage of the New Works extension at Oxford may be partly explained by prolonged period of sedimentation up to 11 h."[4] The same point being made by Lester et al. for Cu, Cd and Pb.[5] Both authors point out, however, that primary sedimentation has little effect upon dissolved metals.[6,7.]

Lewin and Rowell's study was also carried out at the Oxford sewage works and reported in 1973. Original results were presented as quantity of metal removed and have been recalculated and expressed as percentage removal efficiencies by Lester J.N. et al. from whom this data has been taken.[8]

Two sets of removal efficiencies are derived from work reported in the 1950s by Stones T. A complete balance was not available for a single sewage works but Lester and Stoveland both considered his work important enough to calculate 'hypothetical' removal efficiencies using published

results of primary sedimentation studies at a Salford Works with those for activated sludge treatment at Davyhulme Works in Manchester.[9,10]

Means of the 5 sets of results reported, shown in table 7.5 are now compared to the effective partition ratios calculated in this study, and expressed as percentages, also considered are generalised efficiencies given by Blake, W. in 1979.[11]

On inspection it can be seen that percentage partitions calculated in this study for Zn, Cu, Ni and Cr are lower than the highest published results and higher than lowest values shown for that metal. In the case of Cd, however, the percentage partition 73.8 percent, found in this study, is slightly lower than the generalised value given by Blake and considerably lower than the mean of the two Oxford studies.

Cadmium usually enters treatment works in solution and removal by biological treatment is very important. As output to lagoon from the YWA works studied, was of humus from biological filters and topwater, it may have contained a relatively high percentage of Cadmium, unfortunately there is no way of verifying this. When the difficulties of measuring Cd concentrations down to $< 10\ \mu g l^{-1}$, particularly in crude sewage are also taken into account, the effective partition of 73.8 percent Cd found in this study is regarded as acceptable.

Partitions calculated in this study for Zn, Cu, Ni and Cd do not appear to be generally high or generally low. Cr partition of 96.37 percent is regarded as very high compared to other partition ratios shown in table 7.5. However, this ratio is an exception and may be due to a mismatch of input and output concentration data.

In view of the acceptable partition ratios calculated for Zn, Cu, Ni and Cd and that all values calculated are less than 100 percent it is concluded that the X/Y ratio in the equation used is acceptable and there

is little point in exploring hypothetical adjustments to this ratio.

7.2.2. Partition ratios shown in table 7.5 are now examined by metal.

Zinc. The 91.35 percent Zn partition found in this study is lower than the 94 percent found by Stoveland at Oxford. This may be due, among other things, to the long primary sedimentation times used in the Oxford study. The YWA works result may also be depressed as a result of dissolved Zn removed during the process of biological filtration and disposed with humus to lagoon at that site.

Percentage partition given by Blake and the hypothetical partition ex. Stones are much lower. Therefore it seems reasonable to accept the 91.35 percent partition calculated in this study as a basis for further calculations using data from the same YWA works. The implications of 94 percent and 70 percent partitions will also be explored.

Copper. The 88.06 percent Cu partition found in the present study is equal to the hypothetical partition ex Stones, lower than the 96 and 92 percent given for the Oxford works, but higher than the generalised 75 percent partition given by Blake. The 96 percent removal reported by Stoveland may be slightly high due to the prolonged primary sedimentation previously discussed.

By comparison with the 92 percent of Lewin and Rowell and also the mean, the 88.06 percent Cu may again be in part due to Cu removal by biological filtration and disposed to lagoon, both results are considerably higher than the value given by Blake.

It is therefore considered reasonable to accept the 88.06 percent Cu partition calculated in this study. The implications of 92 and 75 percent partition might also be explored.

Nickel. The 49.9 percent Ni partition found in the present study is less than the 70 percent reported by Stoveland but more than the 42 and 40 percent

given for the hypothetical partition ex Stones and the generalised partition of Blake. Commenting on the 70% partition found, Stoveland observes "More significantly the total removal of nickel was double that reported previously (- - - - -), this being almost entirely a result of a very high removal during the activated sludge process."[12] The same author proceeds to discuss the factors and mechanisms by which this may happen and concludes, "It is possible that the high removal efficiencies for Nickel found in the New Works Extensions to the Oxford Sewage treatment works are indicative of high concentrations of insoluble nickel as opposed to soluble nickel."[13]

As with the other metals for which percentage partition values are given in table 7.5, the form of speciation of metals entering and proceeding through each WPC works influence the overall efficiency of partition. It is not surprising then that the 49.9% Ni found in this study is greater than the hypothetical 42% ex Stones and the generalised 40% of Blake.

It is considered reasonable to accept the 49.9% Ni found in this study. The implications of 40% partition will also be explored.

Chromium. As mentioned previously 96.37% partition of Chromium to sludge found in this study is regarded as high, being considerably higher than the hypothetical 78% calculated from Stones' data, the 67% found by Stoveland et al. at Oxford and the generalised 75% given by Blake as shown in table 7.5

Such a partition could be due to very high removal of Cr during the primary sedimentation by the formation of settleable particulates. Chemical form and solubility of influent Cr may be important factors affecting primary and to a lesser extent secondary removal. For example Bailey et al. showed that trivalent Cr was largely removed in sedimentation, leaving hexavalent species in solution.[14]

But such a high value is here considered to be more likely due, at

least in part, to a mismatch between input and output data. This is not surprising in view of the number, 25, and distribution of concentration cases of Cr in crude sewage from which the annual mean Cr concentration is calculated. A further source of error is that some of the industrially derived Cr may arrive in slugs, a problem reported by Rossin even when sampling at 3 hr. intervals.[15]

In view of this finding it is proposed to use the 96.37% partition found but also to calculate the effects of the generalised partition of 75% given by Blake.

Cadmium. The 73.8% Cd partition found in this study has already been discussed and found acceptable. It may also be useful to explore the implications of 90% partition, the mean, shown in table 7.5.

Lead. Unfortunately it has not been possible to calculate an effective partition ratio for Pb entering and leaving the YWA WPC works studied. If further investigation of Pb with the model is not to be abandoned it is necessary to use a ratio obtained from literature sources. Actual partition of Pb at the YWA works will depend on many factors such as particle size, speciation, insoluble-soluble, matrix characteristics of the sewage itself, retention times in the primary sedimentation process and the efficiency of subsequent biological treatment. In the study, reported by Lester et al. of the Oxford works an 11 hour primary sedimentation period brought about the partition of 66-76% of Pb to the primary sludge, four samples averaging 73%. Activated sludge treatment of the settled sewage partitioned 42-100% of the remaining Pb to secondary sludge, the four samples taken again averaging 73%. Thus overall partition was 73% + (73% of 27%) = 92% of Pb entering the works to the mixed sewage sludges produced.

As shown in table 7.5 results calculated from the study reported by

Lewin and Rowell, also at Oxford, give the same overall percentage partition.

Partition at the YWA works is not likely to be higher than that at Oxford unless strongly influenced by a relatively large particle size. Some of the Pb may be in the humus and top water discharged to lagoon, but there is no way of verifying this. The hypothetical ex Stones partition 95% is slightly higher than those for the Oxford works while the generalised value of 80% given by Blake is approximately 13% lower. Therefore it seems expedient to accept the 92% partition reported for the two Oxford studies but also to explore the implications of 95 and 80 per cent partition.

7.2.3. Conclusions

1. Partition results calculated in this study are influenced by sampling and analytical limitations as are those shown for the Oxford, Salford and Manchester studies. Whereas those studies took place over a limited period of intense study, the data for the present study is from sampling and analyses carried out for operational purposes over a whole year. In view of the number of cases of metal concentrations available a first response to the percentage partition ratios shown for this study in table 7.5 is that they correspond well with other values shown.

2. It is now possible to use the effective partition coefficients calculated, with exploratory alternative coefficients derived from table 7.5 in the model.

3. Unfortunately trade effluent input flows are not available for the year 1979/80 for which the above coefficients are calculated. Also, unfortunately, crude sewage data is not available for the year 1980/81 for which trade effluent flows and concentrations from 40 sources are available.

4. In order to overcome this impasse, it was decided that, in view of

the good 'fit' of the effective partition ratios shown in table 7.5, to use the Zn, Cu, Ni, Cr and Cd values calculated for 79/80 with the data available for 1980/81 as a means of demonstrating the model and using it to investigate the type of problem for which the model is designed. Also by using other values, shown in table 7.5, as previously indicated, to provide a simple form of sensitivity analysis through the range of results produced.

7.3. Effects of stabilisation methods on metal concentrations

7.3.0. In view of the constraints specified in the proposal for a directive it is now necessary to consider the effect of sludge stabilisation on metal concentrations in the sludges so treated. This is particularly necessary in view of a) the constraints on spreading unstabilised sludge from works serving year round populations greater than 5,000, and b) because of the mandatory metal concentration constraints specified in Annex 1A and less directly in Annexes 1B and 1C. See Section 6.2 concl.18.

Two methods of stabilisation are considered first Anaerobic digestion, reported as being used to treat 96% of all UK sludges stabilised[16] because reduction in organic matter during the process has the effect of increasing the concentration of metals. Secondly, lime stabilisation, reported as being used at only 2 plants to treat less than 1% of UK sludges[17] because of its effects in reducing metal concentrations in sludges and potential for raising the pH of soils to which it is applied.

7.3.1. Anaerobic digestion of sewage sludge

Basically a fermentation process, the main types of anaerobic digestion used in the UK are cold (unheated) digestion and mesophilic digestion. Temperatures at which these processes operate particularly affecting the micro flora and fauna and the rate at which breakdown of organic matter proceeds. Cold digestion, potentially a low cost process

where land availability is not limiting, takes place at ambient temperatures usually over a long period of time, 1, 2 or more years in earth banked lagoons.[18]

Mesophilic digestion takes place in concrete or prefabricated digesters, at 30-37°C required to maintain suitable digestion temperature, but due to the production of sludge gas, is a net energy producer. Retention times of 20-30 days are normal and tending to decrease.[19]

As shown in table 5.4, the 1981 Guideline recommendations allow the widest range, 7 classes, of after use for mesophilic anaerobic digested sludge and 5 classes of after use for sludges lagooned for 2 years. Table 5.4 also shows that grazing delay periods of 3 or 5 weeks are only recommended for these treatments if a minimum of 40% of organic matter has been destroyed by anaerobic digestion.

Now although the 40% reduction of organic matter is not specified in the proposed directive, because of its importance in making the case for shorter, 3 or 5 week, delay rather than the 6 weeks proposed delay period before grazing, it is now proposed to calculate the effect of 40% reduction in organic matter on metal concentrations.

Using the 20-40% inorganic content range reported by Williams in 1975 as typical of untreated sludges, it can then be calculated that at 20% inorganic content, 40% reduction in organic matter will lead to a reduction in total mass to 68% of the original dry matter and thus to an increase in concentration of conserved metal elements to 147.06%. Similarly inorganic contents of 30 and 40 percent will lead to reductions to 72 and 76 percent of original mass and increases of concentration of metal elements to 138.8 and 131.6 percent respectively. It is clearly seen that because of the diluting effects of inorganic matter, increase in metal concentrations are inversely related to inorganic matter content.[20]

Taking annual mean figures, 1979, of the Leeds WPC works, untreated mixed sludge produced had an ash content of 31.36% DS. Then, if ash content is taken as being equivalent to inorganic content, anaerobic digestion in which 40% of organic matter is 'destroyed' will reduce sludge to 72.544% of DM. mass and increase metal concentrations to 137.85%. Then untreated sludge concentrations of 2167, 807.8, 226.4 and 33.3 $mg.kg^{-1}$ D. Solids are equivalent to 2987.209, 1113.552, 312.092 and 45.904 mg.kg.D.S. of Zn, Cu, Ni and Cd respectively when sludge is digested with 40% reduction in organic matter. Thus on the basis of 1979 mean data simulated digested sludge Zn, Cu and Ni concentrations were able to comply with the Mandatory constraints of 3000, 1500 and 400 $mg.kg.^{-1}$ D.S. specified in Annex 1a of the proposal for a directive. The undigested Cd concentration would comply with the M value of 40 $mg.kg^{-1}$ D.S. specified but simulated digested Cd concentration would not - when 40% reduction in organic matter was required, as recommended in the guidelines. However the proposal for a directive does not specify the degree of O.M. reduction and it is noted that if the 1979 sludge was stabilised with 26.75% reduction of O.M. Cd concentration would then equal the proposed M constraint. Annual mean concentration of Cd in crude sewage entering the Leeds works in 1979 was 0.01103 $mg.l^{-1}$ based on 29 cases. [21,22].

It is concluded that, on the basis of the limited data available to this study it would appear that very low levels of Cd concentration in crude sewage may give rise to Cd concentrations in sewage sludge which if digested with 40% reduction in organic matter may then not comply with the proposed Mandatory values but when less 'efficiently' digested sludge will. In the absence of specification of degree of digestion in the proposal for a directive a) efficient digestion is penalised and b) consequently the case for a shorter delay period, before grazing takes place, is weakened.

by 20% are 1805.8, 673.2, 188.6 and 27.7 $mg.kg^{-1}$ respectively.

Thus this form of chemical stabilisation has the effect of reducing metal concentrations in sludges, possibly allowing sludges which would not meet Annex 1A mandatory metal concentration constraints when untreated to meet those constraints when lime stabilised. But because of increase in dry solids there is more mass of sludge to handle, transport and dispose of, thus increasing costs.

Because of the effects of stabilisation on metal concentrations in sludges, as distinct from the total mass of metals to be disposed of R.D. Davies of WRC has suggested, "...it would be logical if metal limits in sludges for agricultural use applied to raw sludge before stabilisation rather than to the digested product."[30]

In some areas the lime stabilisation will provide a bonus to the farmer due to the lime content and consequent high pH of the sludge. For instance in the area where Ellesmere Port sludge is disposed/utilised "soil pH tends to fall due to the gradual leaching of calcium,"[31] and a local ADAS officer "...estimates that in the Ellesmere Port area a lime dressing of 1.25 tonne/ha/year is advisable."[32]

In the absence of any other form of lime subsidy it is not surprising to find that "the lime stabilisation and land disposal venture was found to be successful, with local farmers eager to accept the sludge."[33]

The proposal for a directive has now been amended to omit "Member States shall ensure that the pH value of the soil does not fall below six after spreading." It is now a rule that "sludge shall not be spread on soil with a pH value which will allow excessive mobility of the trace elements." If adopted the effects of lime treatment in reducing mobility of metals in some soils and concurrently reducing metal concentrations in sludges may, in some areas, be attractive to RWA officers and to local farmers, leading to a corresponding increase of lime stabilisation as a method of treating sludge.[34]

Although in the technical memorandum published prior to the Proposal for a directive "...lime treatment is not recommended" no stipulation to prevent its use is made in the proposal itself.[35]

7.3.3. Conclusion

In view of constraints specified in the UK Guidelines and in the EC proposal for a directive limiting the after-use of sewage sludge unless stabilised, and in view of the effects of stabilisation on metal concentration in sewage sludges any model developed should include the optional simulation of anaerobic and lime stabilisation effects on metal concentrations. For the purpose of the present study simulation of anaerobic digestion with 40% reduction in O.M. and simulated lime treatment based on 14% increase in total solids will be applied to the 1980/81 data to be used to indicate a) effect on compliance or non-compliance of resultant sludge, and b) required reduction of metal input to sewers to meet the Mandatory constraints specified in Annex 1A of the proposal for a directive.

7.4. The model

As already used the basic equations on which this model is built are, for a stated WPC works and catchment area and for a stated period:-

1. Effective partition of a particular metals entering the WPC works to sewage sludges leaving the works may be calculated by:

Equation 1a			Equation 1b	
$\frac{Oa \times X}{Sa \times Y}$	= Pa	and Pa	$>$pa lower and	$<$pa higher
$\frac{Ob \times X}{Sb \times Y}$	= Pb	and Pb	$>$pb lower and	$<$ pb higher
.	.		.	.
.	.		.	.
.	.		.	.
$\frac{On \times X}{Sn \times Y}$	= Pn	and Pn	$>$pn lower and	$<$ pn higher

Where in equation 1

Oa-n are the mean concentrations of metals 'a' to 'n' in mixed sewage sludges leaving the works.

X is the production of mixed sewage sludges leaving the works.

Sa-n are the mean concentrations of metals 'a' to 'n' in crude sewage entering the works.

Y is the flow of crude sewage entering the works.

Pa-n are the effective partition ratios of metals 'a' to 'n' from crude sewage to mixed sewage sludges.

pa-n $^{\text{higher}}_{\text{lower}}$ are lower and upper constraints specified for ratios P'a' to 'n', and may be derived from theoretical, literature or practical sources.

Then as X and Y are common to all metals if a) all Pa-Pn are high or low X/Y ratios may be examined for reliability, and b) if one P ratio is high or low concentration data of input and output of that particular metal may be questioned.

2. Input

For the stated WPC works and for the stated period input loads of metal may be generalised as

Equation 2a

$$Sa \times Y = ta_1x_1+ta_2x_2+\cdots+ta_nx_n + \cdots + wa_1z_1+wa_2z_2+\cdots+wa_nz_n$$

and

$$Sb \times Y = tb_1x_1+tb_2x_2+\cdots+tb_nx_n + \cdots + wb_1z_1+wb_2z_2+\cdots+wb_nz_n$$

$$\vdots$$

$$Sn \times Y = tn_1x_1+tn_1x_2+\cdots+tn_nx_n + \cdots + wn_1z_1+wn_2z_2+\cdots+wn_nz_n$$

Where

Sa-n are the mean concentrations of metals in crude sewage as in Equation 1a.

ta_1 is the mean concentration of metal a input to sewers from source t_1 of category of source t.

wb_2 is the mean concentration of metal b input to sewers from source w_2 of category of source w.

Likewise

x_1 is the input flow to sewers from source 1 of category of source t.

z_n is the input flow to sewers from source w_n of category of source W.

For convenience equation 2a may be simplified into

Equation 2b $Sa\text{-}n \times Y = Ta\text{-}n + Ua\text{-}n+\cdots+Wa\text{-}n$

Where Ta is the sum of loads of metal 'a' entering sewers from point sources t_1 to t_n of category of source t.

and Ua is the sum of loads of metal 'a' entering sewers from point sources U_1 to U_n of category of source U.

and Wn is the sum of load of metal 'a' from point sources w_1 to w_n of category of source w.

Similarly for loads of metals b to n.

Now if t_1 - t_{40} are taken to represent the 40 known trade effluent sources and Ta-n is taken to represent total input loads of metals a-n from those sources

Equation 2c then metal inputs from other 'unknown' sources = $S_{a-n}{}^{Y} - T_{a-n}$

Or by substitution in Equation 1a

Equation 2d metal inputs from other sources = $\frac{O_{a-n} \times X}{P} - Ta-n$

Similarly sludge concentration equivalent to input of total known trade load of a metal

Equation 2e $$\frac{T \times P}{X'} = Ot$$

Where Ot is the calculated concentration of that metal in sewage sludge equivalent to input load of that metal T from known trade sources.

3. Output Stabilisation

Further, if digestion, lime treatment or other method of stabilisation is used, or might be used, to stabilise sewage sludges used in agriculture, metal concentrations in stabilised sewage sludges leaving the plant may be calculated by:-

Equation 3.

$$\begin{matrix} Oaxr & = & rOa \\ \vdots & & \vdots \\ Onxr & = & rOn \end{matrix}$$

Where Oa-n are the mean concentrations of metals 'a' to 'n' in unstabilised sewage sludges produced at the works, as in equation 1a.

rOa-n are the calculated mean concentrations of metals 'a' to 'n' in the stabilised sludges produced.

r is the factor by which metals are concentrated by the process of stabilisation assuming, at this stage, that 'r' is the same for each of the metals a-n, if it is found to be operationally justifiable to use separate factors ra to rn may be substituted.

4. Output. Compliance with concentration constraints

Where constraints on use of sewage sludges on agricultural land are specified as limiting concentrations of metals in sludges used simple or percentile compliance may be required.

Simple compliance may be represented by

Equation 4a

$$\begin{aligned} Oa &\leq Ma \text{ or } Ra \\ &\vdots \\ On &\leq Mn \text{ or } Rn \end{aligned}$$

for unstabilised sludge.

Likewise

Equation 4b

$$\begin{aligned} rOa &\leq Ma \text{ or } Ra \\ &\vdots \\ rOn &\leq Mn \text{ or } Rn \end{aligned}$$

in stabilised sludge.

Similarly percentile compliance may be represented by

Equation 4c unstabilised sludge

$$\begin{aligned} Oa + (SD^{pop}\ Oa) \times s &\leq Ma \text{ or } Ra \\ &\vdots \\ On + (SD^{pop}\ On) \times s &\leq Mn \text{ or } Rn \end{aligned}$$

and Equation 4d

$$\begin{aligned} rOa + r\,(SD^{pop}Oa) \times s &\leq Ma \text{ or } Ra \\ &\vdots \\ rOn + r\,(SD^{pop}On) \times s &\leq Mn \text{ or } Rn \end{aligned}$$

Where

SD^{pop} Oa is the standard deviation of concentrations of metal a of which Oa is the mean in the undigested sludges produced from the works.

and r (SD^{pop} Oa) is the calculated standard deviation of concentrations of metal a of which rOa is the mean in the same sludges when stabilised.

Similarly for metals b to n.

s is the factor by which the standard deviation is multiplied to achieve the probability level required.

Ma and Ra are specified mandatory or recommended constraints on concentrations of metal 'a'. Similarly for metals b to n.

5a. Minimum required reduction, Simple Compliance

Minimum required reductions of metal concentrations in unstabilised sludge, in order to achieve simple compliance with Mandatory or Recommended constraints is represented by:

Equation 5a from 4a, when Oa-n is higher than Ma-n or Ra-n

$$\begin{array}{lcl} Oa - Ma \text{ or } Ra & = & O'a \\ \vdots & & \vdots \\ On - Mn \text{ or } Rn & = & O'n \end{array}$$

Where

o'a-n are the minimum required reductions of metals a-n.

As Oa-n is usually specified in $mg.kg^{-1}$, O'a-n will usually be specified in that unit.

However O'a-n may also be specified as %Oa-n

See for instance equations B9-12 below.

5b. Minimum required reduction x% probability of compliance

Similarly minimum required reductions of metal concentrations in unstabilised sludge, in order to achieve x% probability of compliance with M or R constraints is represented by:

Equation 5b from 4c when Oa-n is higher than Ma-n or Ra-n

$$\begin{array}{lcl} (Oa + (SD^{pop}Oa) \times s) - Ma \text{ or } Ra & = & O'a \\ \vdots & & \vdots \\ (On + (SD^{pop}On) \times s) - Mn \text{ or } Rn & = & O'n \end{array}$$

See notes to equation 5a and to equations 4c and d.

6. Developing the Model, some uses and equations

Using the equations already given it is now possible to systematically derive simple equations which relate selected input and output parameters of a WPC works. These are now given under the purposes they are to serve.

Purpose A.

To find the relationship between concentrations of metal in mixed sewage sludges and input loads of that metal for the same stated period. (1).

From Equations 1a and 3.

1. x% of rO = x% of O = x% of input SY

2. x% of rO = x% of O = $\frac{x}{100} \times \frac{O \times X}{P}$ = y kg of SY

3. rx mg.kg.$^{-1}$ of rO = xmgkg^{-1} of O = $\frac{x \times X}{P}$ = ykg of SY.

4. rx mg.kg.$^{-1}$ of rO = xmgkg^{-1} of O = $\frac{x \times 100}{O}$ = y% of SY.

from which

from 1. 5. y% of SY = y% of O = y% of rO

from 2. 6. ykg of SY = $\frac{y \times P \times 100}{O \times X}$ = x% of O = x% of rO

from 3. 7. ykg of SY = $\frac{y \times P}{X}$ = x mgkg.$^{-1}$ of O = rx mgkg^{-1} of rO

from 4. 8. y% of SY = $\frac{y \times O}{100}$ = x mgkg.$^{-1}$ of O = rx mgkg^{-1} of rO.

Where

O = metal concentration in mgkg^{-1} in mixed sewage sludges.

rO = calculated concentration of mixed sewage sludge when concentration O is stabilised.

X = production of mixed sewage sludge in kg x 10^6.

P = effective partition ratio.

SY = Input load of that metal to the WPC works.

x = number of mgkg^{-1} of that metal. x% = number percent.

y = number of kg of that metal. y% = number percent.

r = concentration factor if mixed sewage sludge is stabilised.

Note 1. Providing adequate mean data is available.

Purpose B

To find the relationship between concentrations of a metal in mixed sewage sludges and known trade input loads of that metal for the same stated period.

From Equation 1a, 2e and 3.

9. x% of rO = x%O = $\frac{x \times O \times X}{P \times T}$ = y% of known trade load T

10. x% of rO = x%O = $\frac{x \times O \times X}{100 \times P}$ = y kg of known trade load T or SY (1)

11. rx $mgkg^{-1}$ of rO = x $mgkg^{-1}$ of O = $\frac{x \times X}{P}$ = ykg of known trade load T or SY. (2)

12. rx $mgkg^{-1}$ of rO = x $mgkg^{-1}$ of O = $\frac{x \times X \times 100}{P \times T}$ = y% of known trade load T.

from which

from 9. 13. y% of known trade load T = $\frac{y \times T \times P}{O \times X}$ = x% of O = x% of rO

from 10. 14. ykg of known trade load T = $\frac{y \times P \times 100}{O \times X}$ = x% of O = x% of rO

from 11. 15. ykg of known trade load T = $\frac{y \times P}{X}$ = xmgkg^{-1} of O = rxmgkg^{-1} of rO.

from 12. 16. y% of known trade load T = $\frac{y \times P \times T}{X \times 100}$ = xmgkg^{-1} of O = rxmgkg^{-1} of rO.

Where in addition to symbols coded under Purpose A

T = Sum of known trade loads of category of source t.

Notes. 1. This equation is the same as given in A_2.

2. " " " " " A_3.

Purpose C

To find the relationship between concentrations of a metal in mixed sewage sludges and concentrations of that metal in crude sewage.

17. x% of rO = x% of O = x% of crude sewage conc. S.

18. x% of rO = x% of O = $\frac{x \times O \times X}{100 \times P \times Y}$ = v mgl^{-1} of crude sewage conc. S.

19. rxmgkg^{-1} of rO = xmgkg^{-1} of O = $\frac{x \times X}{P \times Y}$ = v mgl^{-1} " " " S.

20. rxmgkg^{-1} of rO = xmgkg^{-1} of O = $\frac{x \times X \times 100}{P \times Y \times S}$ = v % " " S.

from which

from 17. 21. v% of S = v% of O = v% of rO

from 18. 22. v.mgl^{-1} of S = $\frac{v \times P \times Y \times 100}{O \times X}$ = x% of O = x% of rO

from 19. 23. v.mgl^{-1} of S = $\frac{v \times P \times Y}{X}$ = x $mgkg^{-1}$ of O = rxmgkg^{-1} of rO.

from 20. 24. v% of S = $\frac{v \times P \times Y \times S}{X \times 100}$ = x $mgkg^{-1}$ of O = rx $mgkg^{-1}$ of rO.

Where in addition to symbols coded under purposes A and B

S = concentration of a particular metal in crude sewage.

v = number of mgl^{-1}.

v%= number percent.

Y = flow of crude sewage entering the works in 10^6 litres.

Purpose D

To find the relationship between concentrations of a metal in crude sewage sludge and known trade input loads of that metal T for the same stated period.

25. x% of Crude Sewage metal conc. S. $= \frac{x \times S \times Y}{T}$ = y% of T.

26. x% " " " " S. $= \frac{x \times S \times Y}{100}$ = y kg of T.

27. v mgl^{-1} of " " S $= \frac{v \times Y}{1}$ = y kg of T.

28. v mgl^{-1} of " " S $= \frac{v \times Y \times 100}{T}$ = y% of T.

from where

from 25. 29. y% of T $= \frac{y \times T}{S \times Y}$ = x% of S.

from 26. 30. ykg of T $= \frac{y \times 100}{S \times Y}$ = x% of S.

from 27. 31. ykg of T $= \frac{y}{Y}$ = v mgl^{-1} of S.

from 28. 32. y% of T $= \frac{y \times T}{Y \times 100}$ = v mgl^{-1} of S.

Where symbols are as coded under purposes A, B or C.

7. Other Purposes

The purposes and equations given are not exhaustive but are sufficient to show some of the potential of the model.

Examples of other purposes.

Other sources of input.

If inputs, or estimates of inputs from another category of sources or a single source are known, or their output equivalent can be estimated, as in the case of domestic and/or atmospheric inputs, used in section 8.6, it is possible to calculate equivalent output or input concentration or load equivalents of a particular metal by substitution in equations already given and further by substitution in basic equation 2b to then calculate input from unknown sources and output equivalent.

In the next section known mean input of metals from single sources will be substituted for T in equations B9-16.

Other outputs

The equations concentrate on the partition of metals to unstabilised and stabilised sewage sludges produced from the works. They can be adapted to calculate metal loads or concentrations in output to river or other outlets such as lagoons, provided that sufficient data is available and conservation of metals is such that effective partition to these outlets can be recalculated, or the residual partition, shown in section 7.2, is considered valid and reliable enough to be used for 'other' outputs of a particular metal.

Conversely for a required concentration in final effluent maximum input load or concentration, or reduction of input load or concentration can be calculated.

However, as stated previously use of the model is dependent on the assumptions that

a) any particular metal is conserved and not lost to other outputs such as air by vaporisation.

b) Crude sewage entering at metering or sampling points is the only input by which metals enter the works.

7.5. Conclusions

This section has been concerned with developing a simple model suitable for use with the data made available.

Available data was appraised in 7.1. The stated period to be used in the study is 1.4.1980 - 31.3.1981 the only period for which 'agreed flows' of trade effluents are available.

During that period four 'known' sources accounted for 50.14, 64.15, 93.23, 67.93, 82.74 and 94.71 percent of Zn, Cu, Ni, Cr, Cd and Pb total loads from 40 'known' trade input sources. See S7.1.3.

'Known' inputs were of metalliferous effluents of low organic matter discharged into the sewer catchments of a YWA City WPC works.

Suggestions as to how a) data might be used, and b) how the reliability of the data used might be improved, are given as conclusions in Section 7.1.5.

It was not possible to calculate an 'effective partition ratio' for the stated period, due to the absence of key data.

A range of 'effective partition ratio' values were established using a) data for the previous year, and b) values derived from literature sources, as shown in table 7.5. See S.7.2 and particularly conclusions given in S.7.2.3 concl.3).

Because of the importance attached to use of stabilised sludges explicit in the UK Guidelines and in the proposal for an EC Directive, it is concluded that "For the purpose of the present study simulation of anaerobic digestion with 40% reduction of O.M. and simulated lime treatment based on 14% increase in total solids..." should be applied.

The facility for simulating the effects of stabilisation is represented by equations 3, 4b, 4d and 5b and is provided for in equations A1-8, B9-16, C16-24, D25-32. See also S.7.3.

Minimum required reduction to achieve simple or x% probability of compliance is provided for in equations 5a and 5b.

These simple equations may be used in isolation or in conjunction with other relevant equations, particularly in this study equations B9-13. See S.8.2, 8.3 and 8.4.

The model devised is simple and does not require all the variables to be known in order to be used. It is in keeping with "...an approach in which the model builder should attempt, whenever possible to construct a mathematical model whose size and complexity reflects not so much his perception of the system, but more the information content in the experimental data available from the system."[36]

The model presented here has been broken down into simple equations which are considered to be appropriate for use, with the quantity and quality of data available, for the purposes already made explicit in S1 and S.7.0 of this study.

The model will now be put to the test of use.

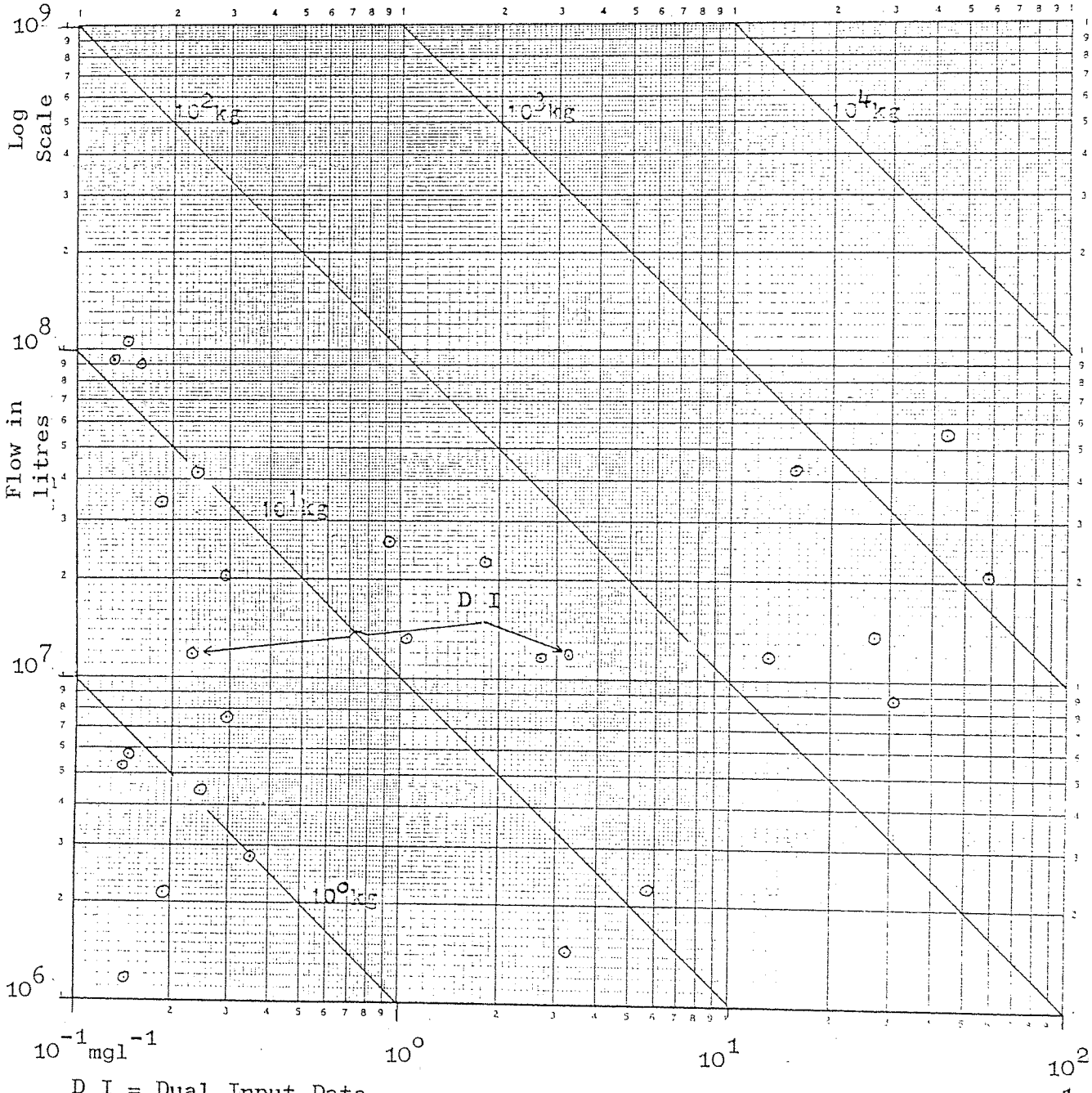
Figure 7.1

Trade Effluent Inputs to Sewers 1.4.80 - 31.3.81

Zinc

Distribution of 26 inputs to sewers having

a) Agreed flows greater than 10^6 l
b) Recorded mean concentrations of zinc equal to or greater than 0.1 mgl.



D I = Dual Input Data.

Concentration, milligrams per litre
Log Scale

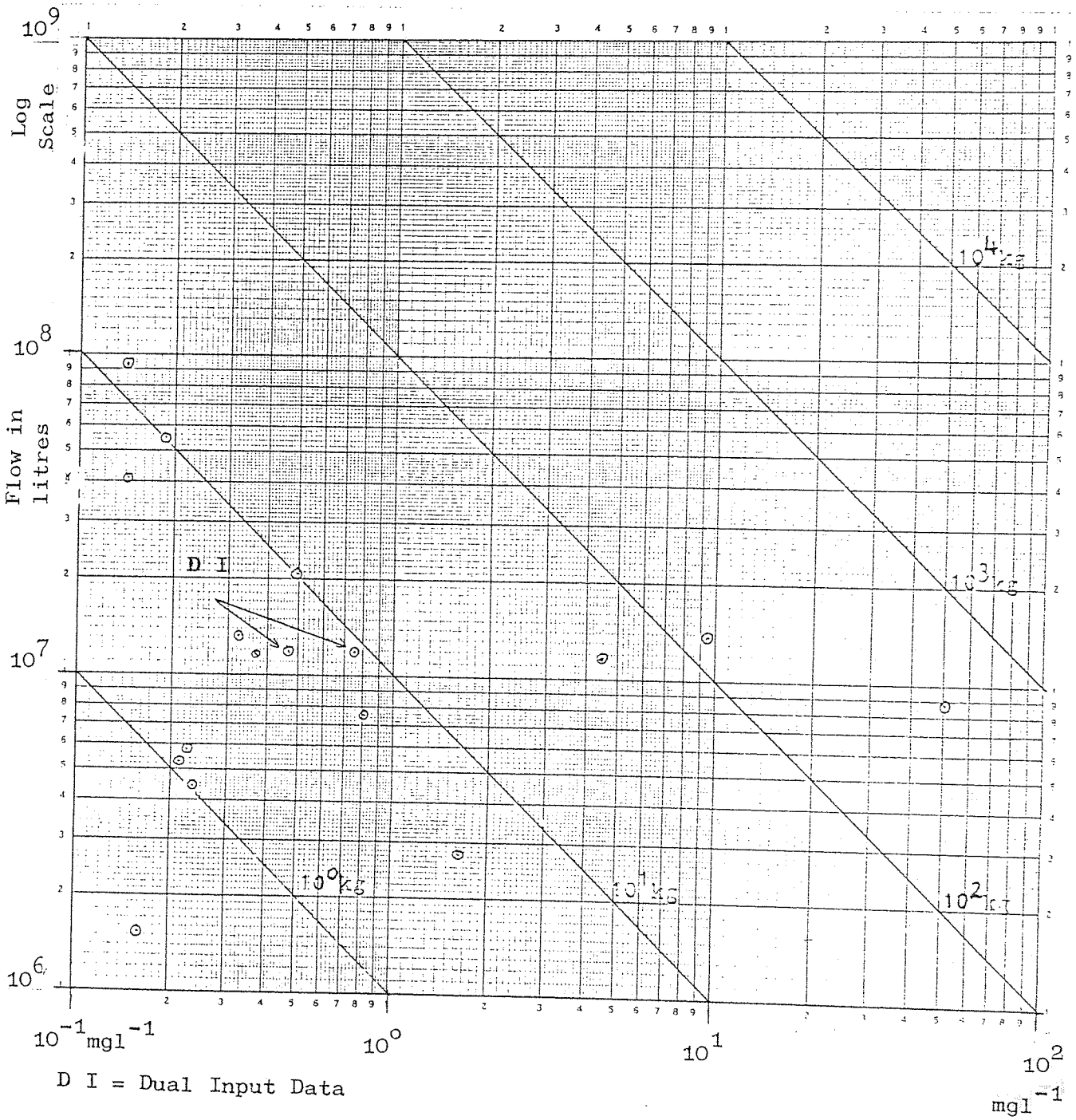
Figure 7.2

Trade Effluent Inputs to Sewers 1.4.80 - 31.3.81

Copper

Distribution of 16 inputs to sewers having

a) Agreed flows greater than 10^6 l
b) Recorded mean concentrations of copper equal to or greater than 0.1 mgl.



D I = Dual Input Data

Concentration, milligrams per litre
Log Scale

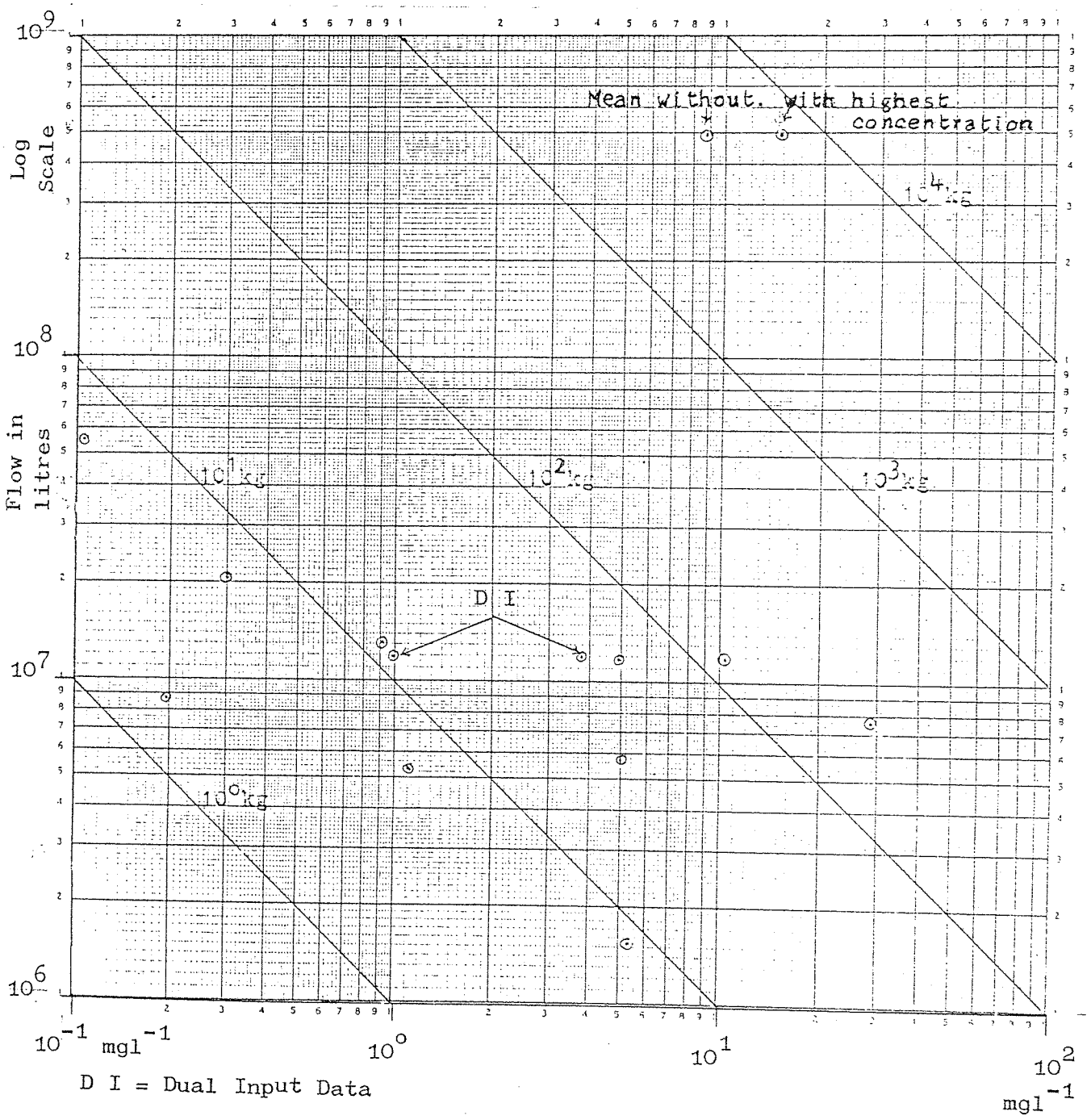
Figure 7.3

Trade Effluent Inputs to Sewers 1.4.80 - 31.3.81

Nickel

Distribution of 12 inputs to sewers having

a) Agreed flows greater than 10^6 l
b) Recorded mean concentrations of Nickel equal to or greater than 0.1 mgl.



D I = Dual Input Data

Concentration, milligrams per litre

Log Scale

Figure 7.4

Trade Effluent Inputs to Sewers 1.4.80 - 31.3.81

Chromium

Distribution of 24 inputs to sewers having

a) Agreed flows greater than 10^6 l
b) recorded mean concentrations of Chromium equal to or greater than 0.1 mgl.

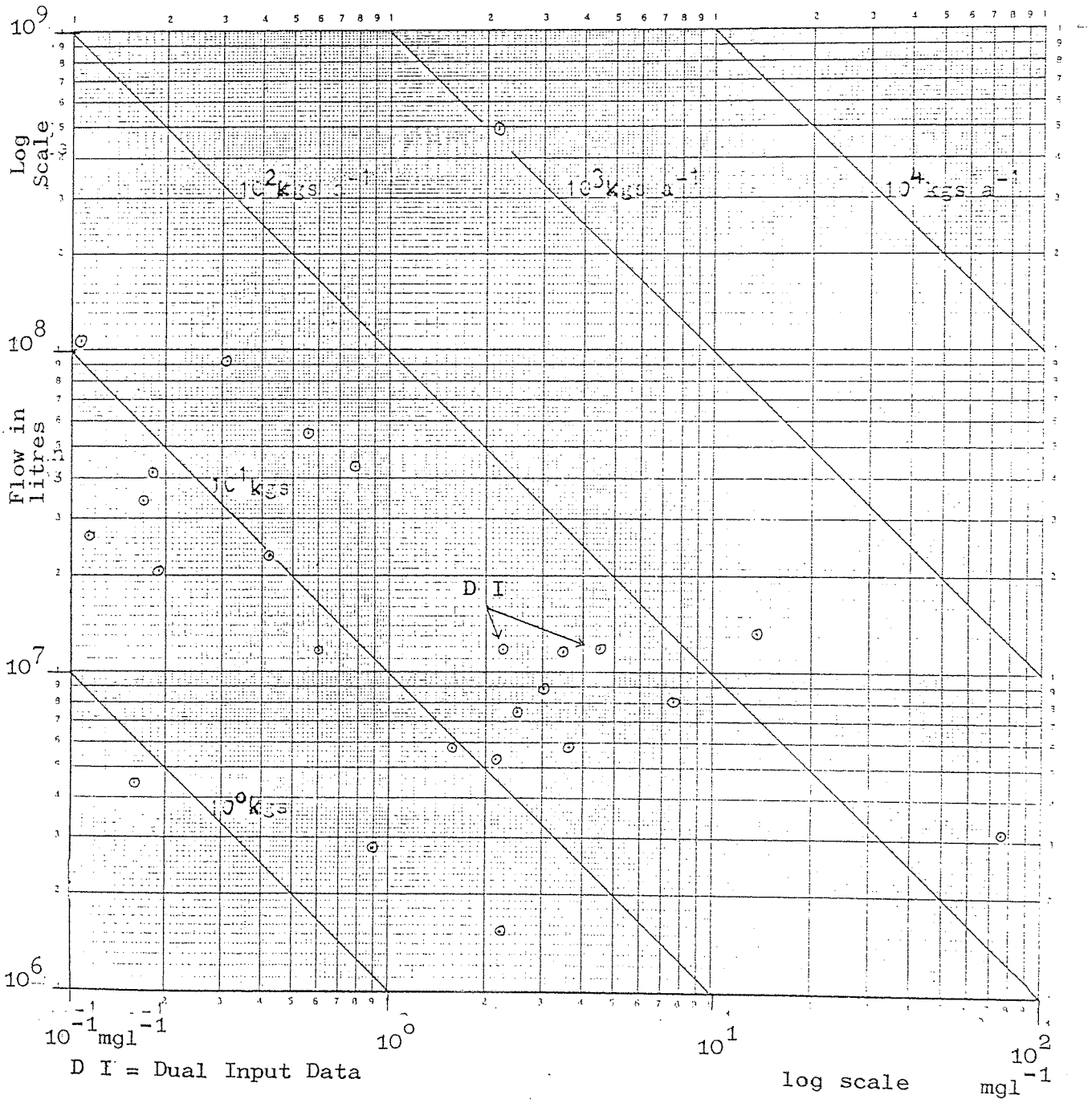


Figure 7.5

Trade Effluent Inputs to Sewers 1.4.80 - 31.3.81

Cadmium

Distribution of 18 inputs to sewers having

a) Agreed flows greater than 10^6 l
b) Recorded mean concentrations of Cadmium equal to or greater than 0.01 mgl.

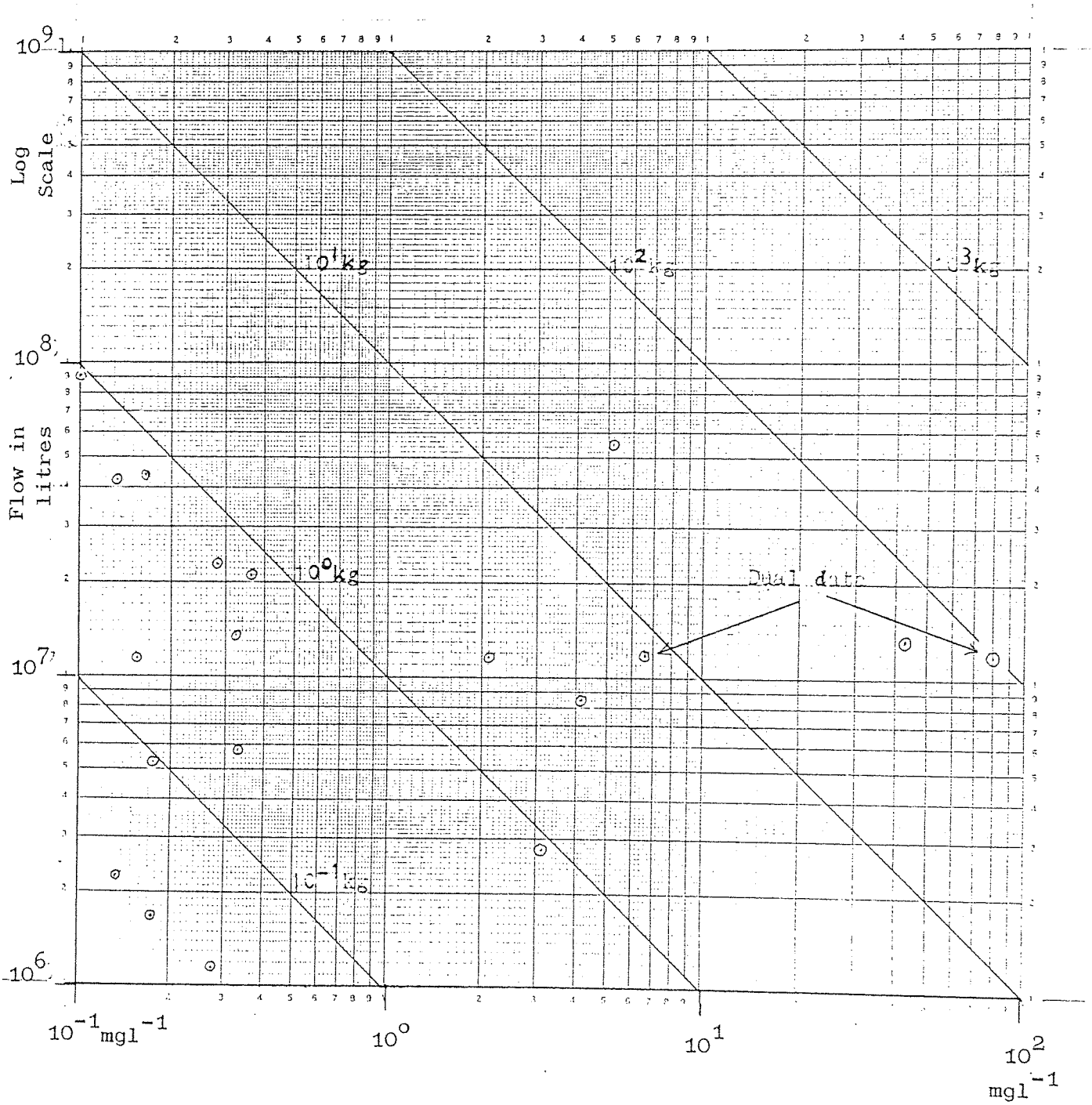


Figure 7.6

Trade Effluent Inputs to Sewers 1.4.80 - 31.3.81

Lead

Distribution of 2 inputs to sewers having

a) Agreed flows greater than 10^6 l
b) Recorded mean concentrations of lead equal to or greater than 0.1 mgl.

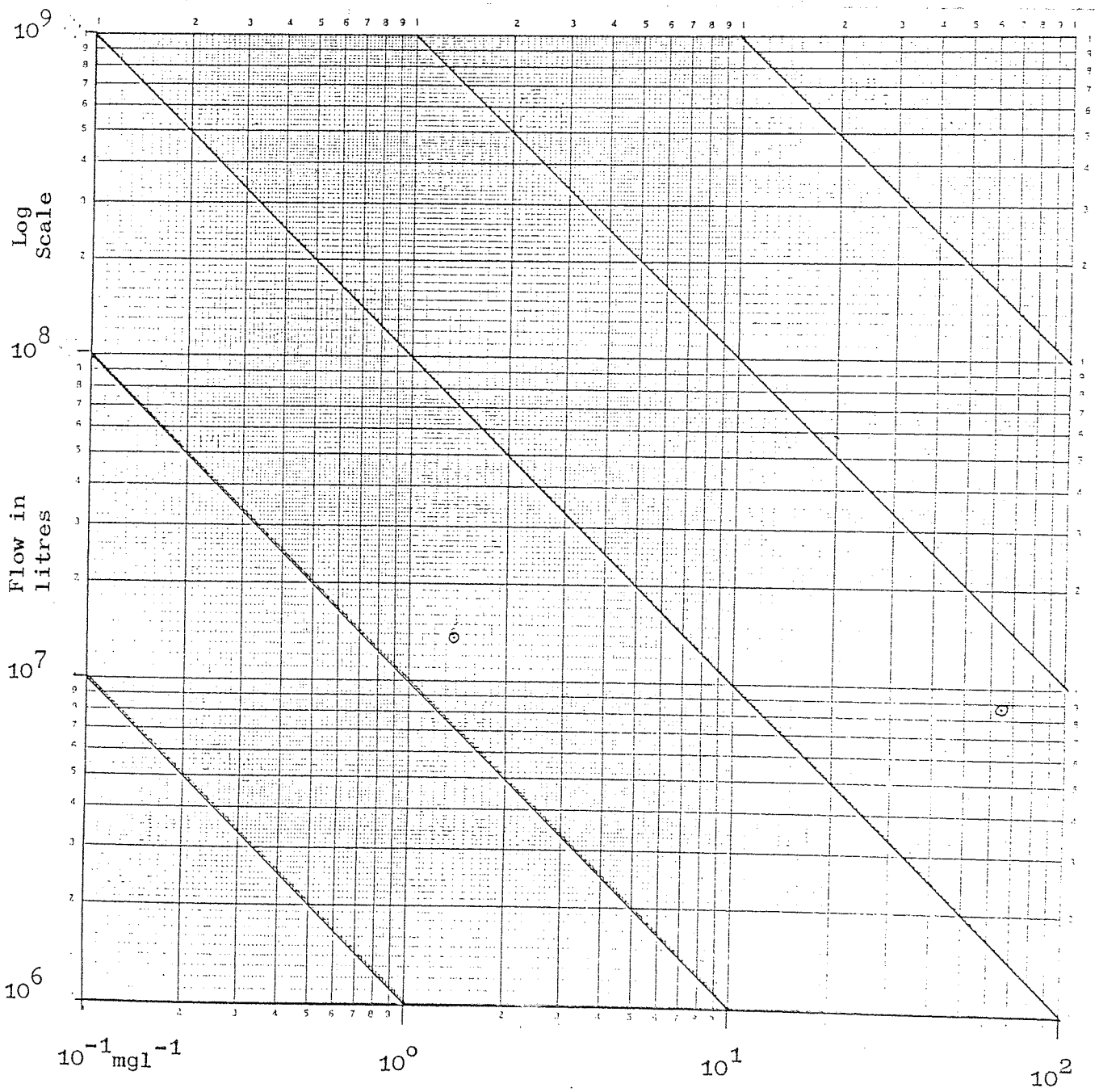
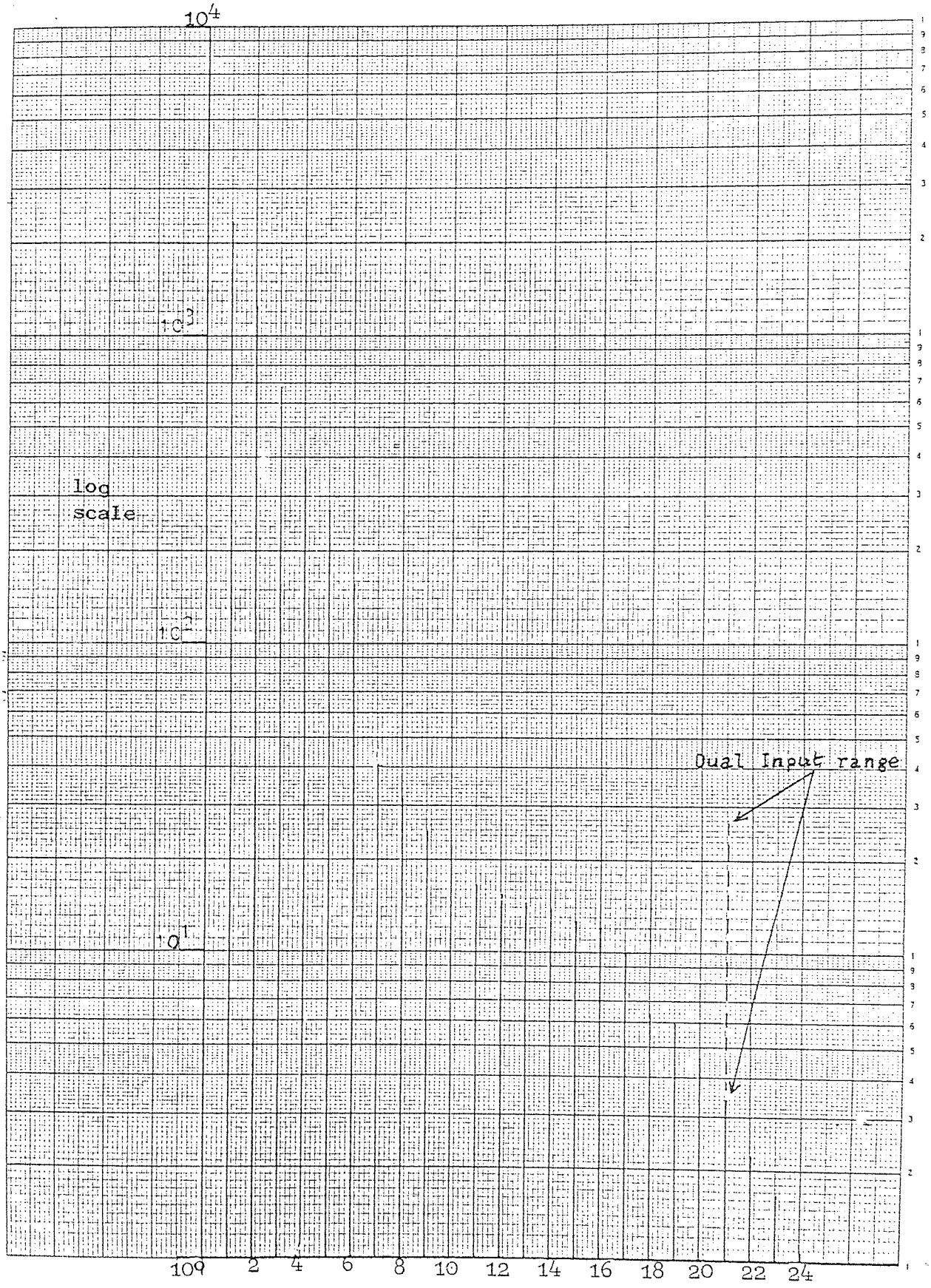


Figure 7.7

Trade Inputs to Sewers 1.4.80 - 31.3.81

Zinc

Distribution of calculated 12 month input loads greater than 1 kilogram



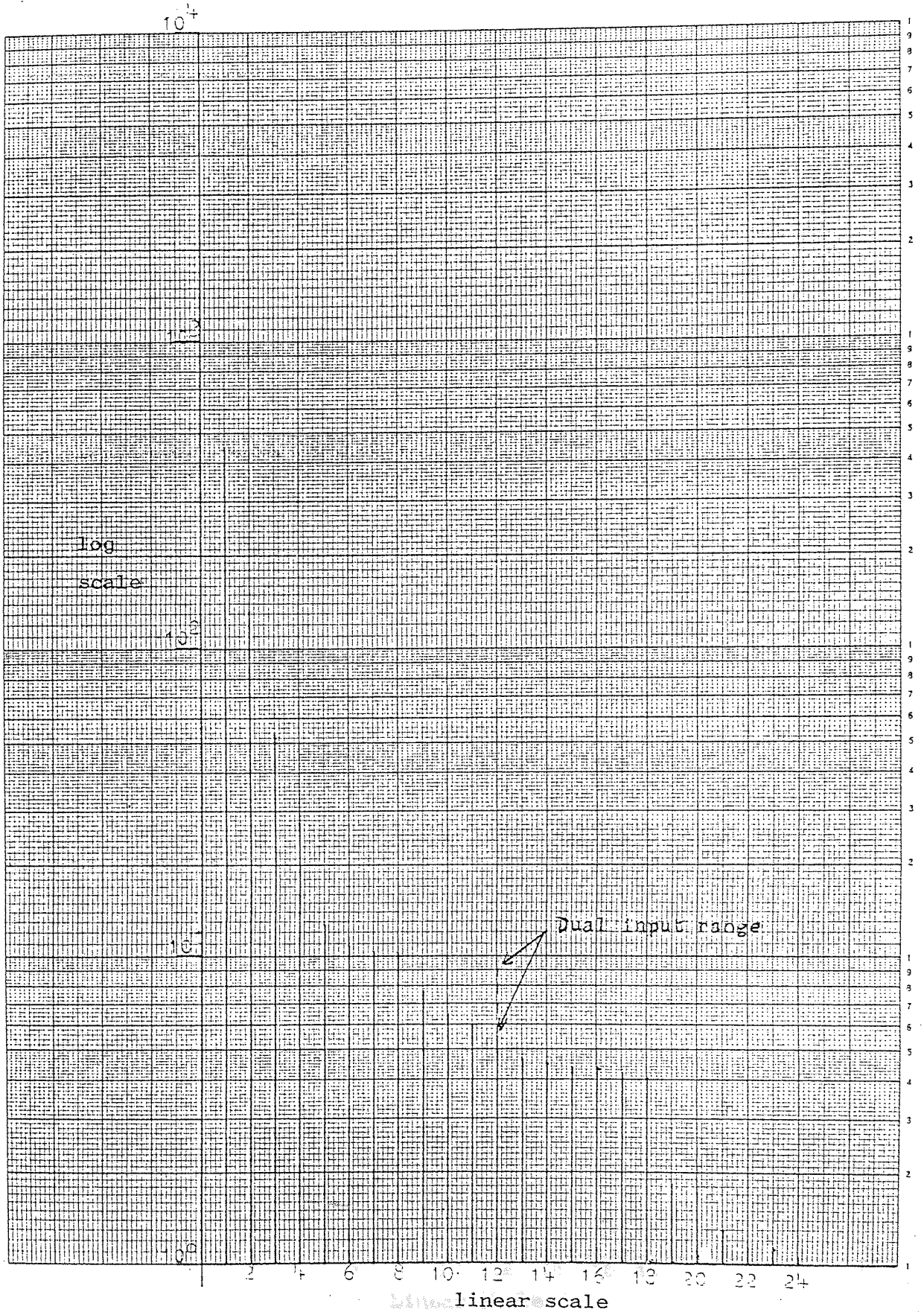
No. of calculated trade inputs greater than 1 kilogram
linear scale

Figure 7.8

Trade Inputs to Sewers 1.4.80 - 31.3.81

Copper

Distribution of calculated 12 month input loads greater than 1 kilogram



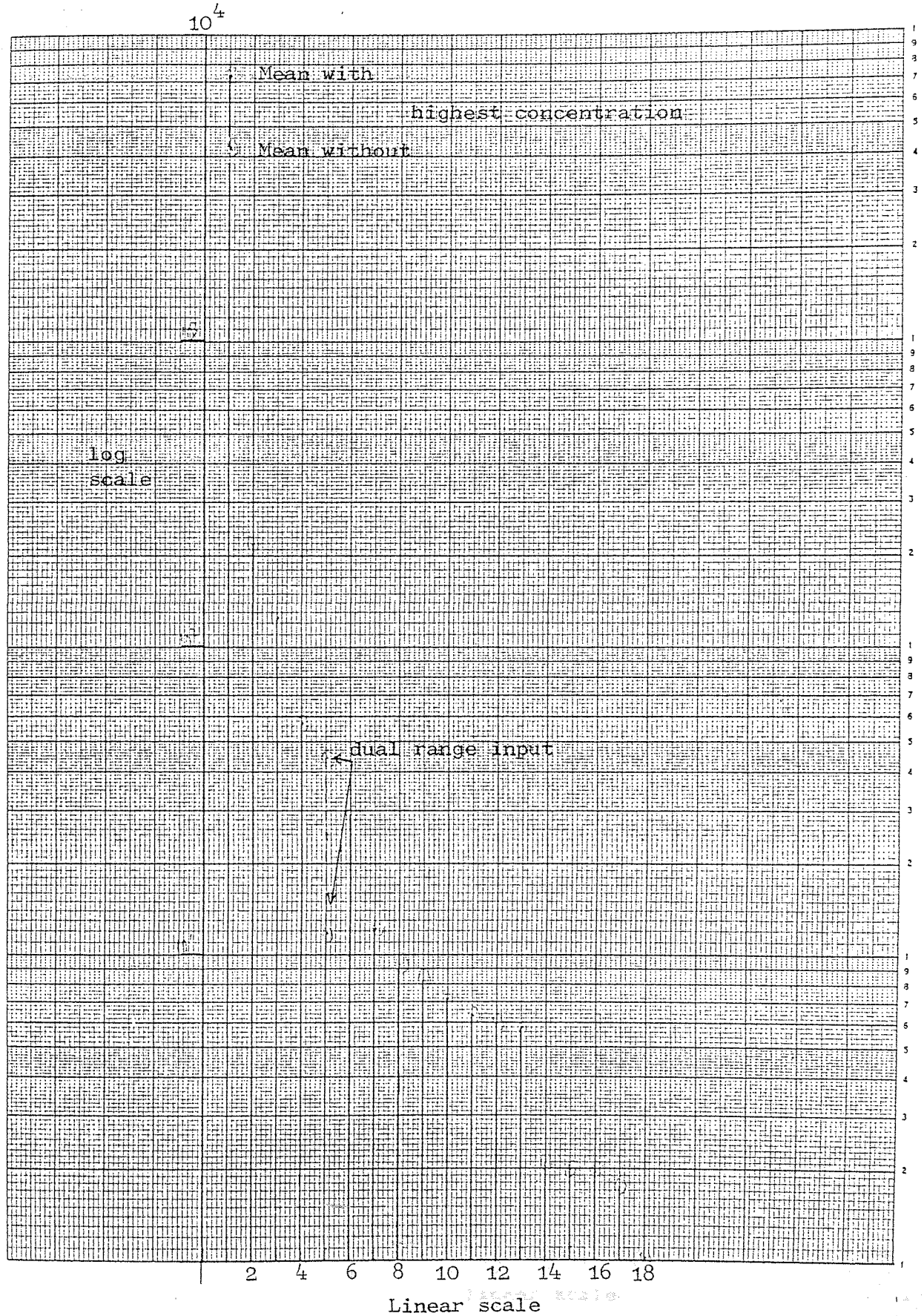
No. of calculated trade inputs greater than 1 kilogram

Figure 7.9

Trade Inputs to Sewers 1.4.80 - 31.3.81

Nickel

Distribution of calculated 12 month input loads greater than 1 kilogram



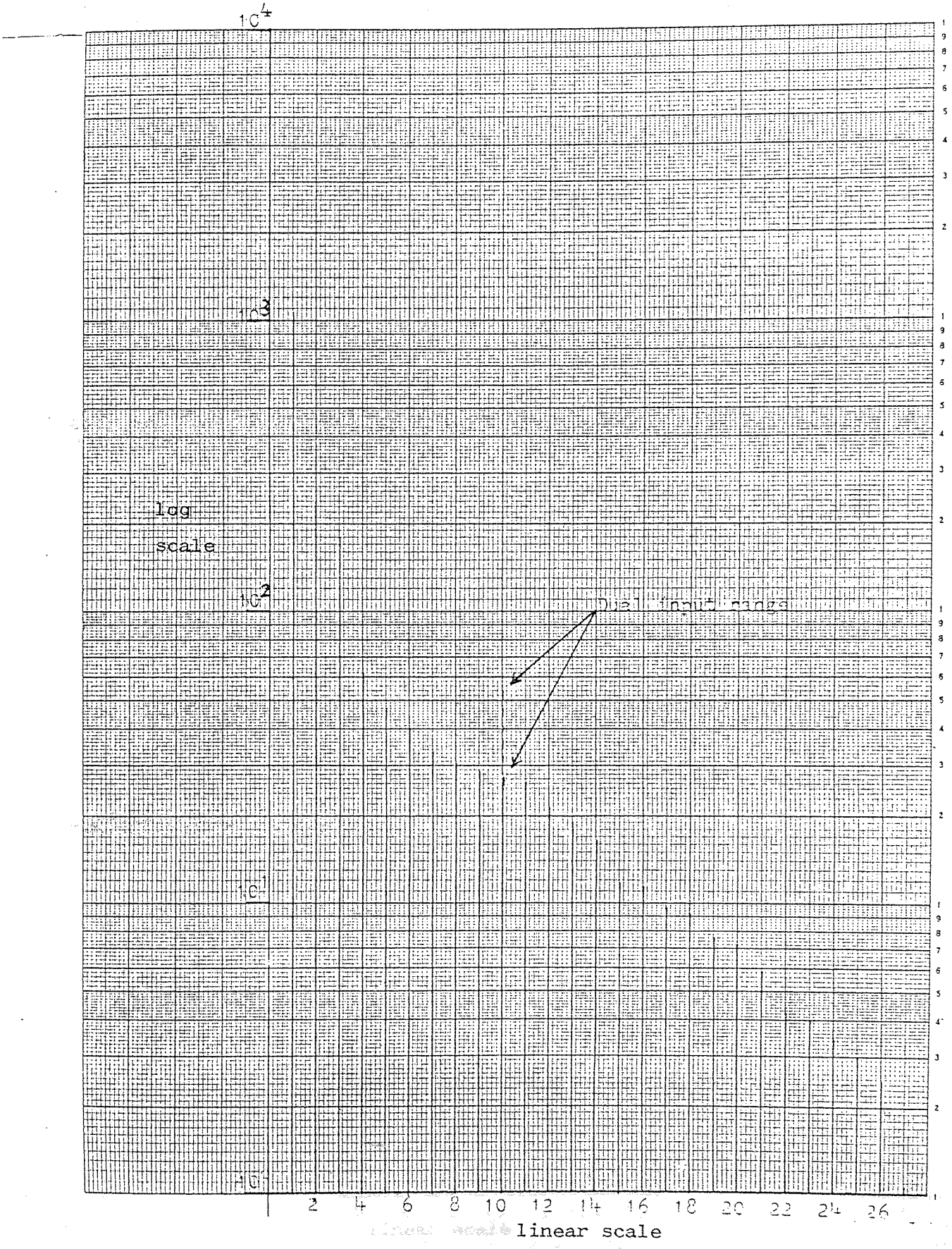
No. of calculated trade inputs greater than 1 kilogram

Figure 7.10

Trade inputs to sewers 1.4.80 - 31.3.81

Chromium

Distribution of calculated 12 month input loads greater than 1 kilogram



No. of calculated trade inputs greater than 1 kilogram

Figure 7.11

Trade inputs to sewers 1.4.80 - 31.3.81

Cadmium

Distribution of calculated 12 month input loads greater than 0.1 kilogram

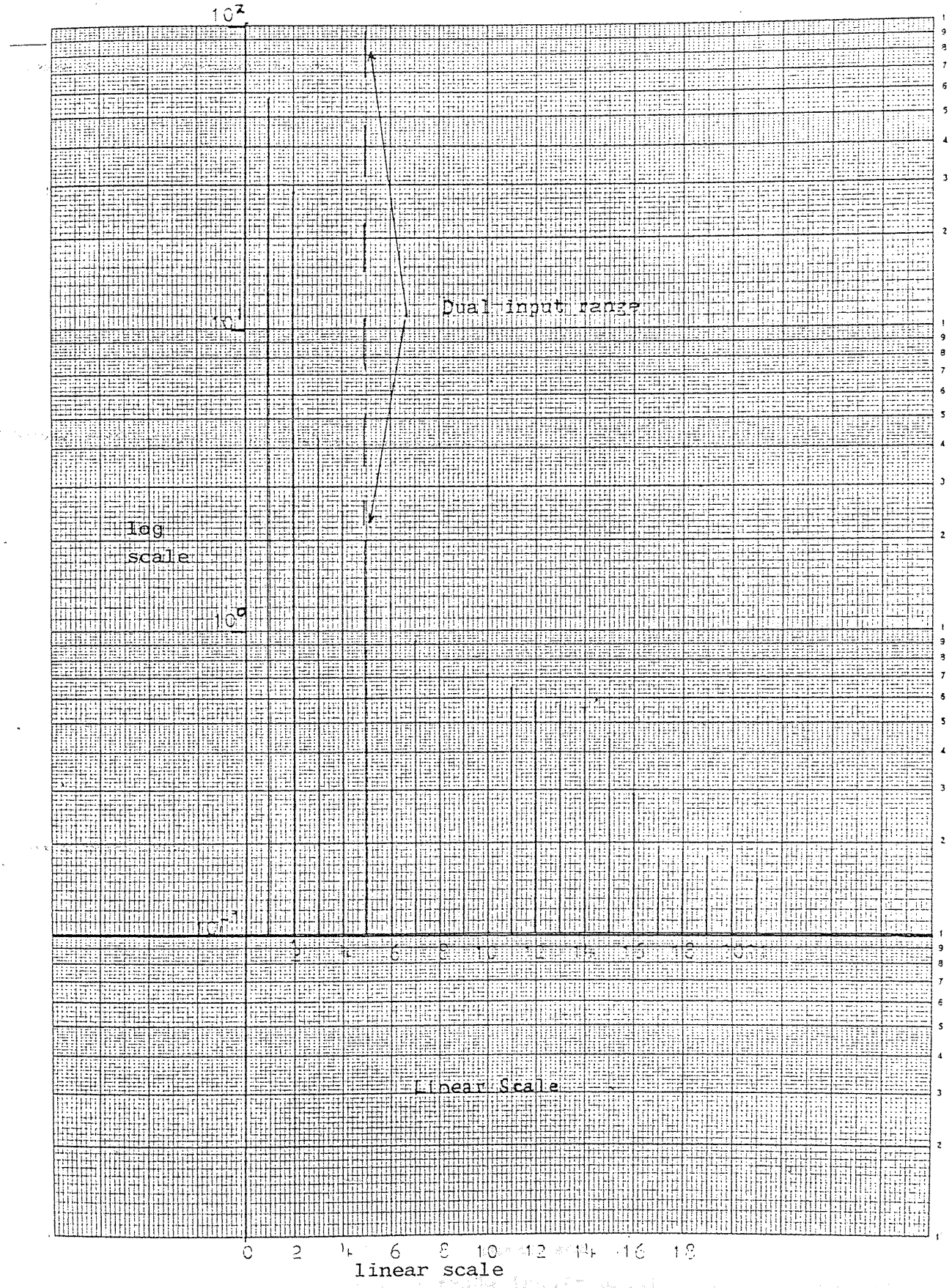
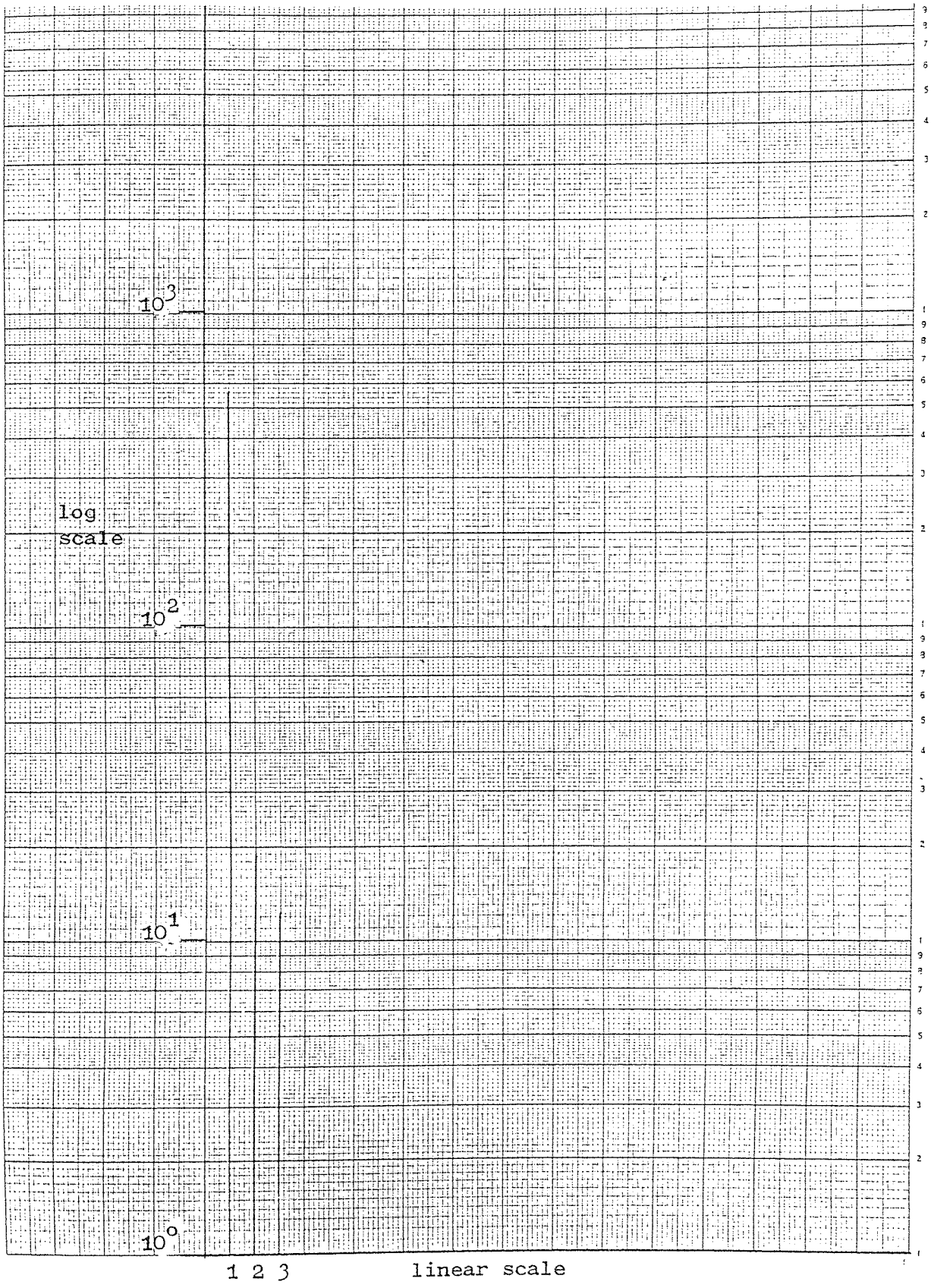


Figure 7.12

Trade Inputs to Sewers 1.4.80 - 31.3.81

Lead

Distribution of calculated 12 month input loads greater than 1 kilogram



No. of calculated trade inputs greater than 1 kilogram

Figure 7.13

Trade metal inputs to sewers 1.4.80-31.3.81

Zinc

Cumulative metal loads greater than 10 kg per 12 months

as a percentage of total calculated trade load

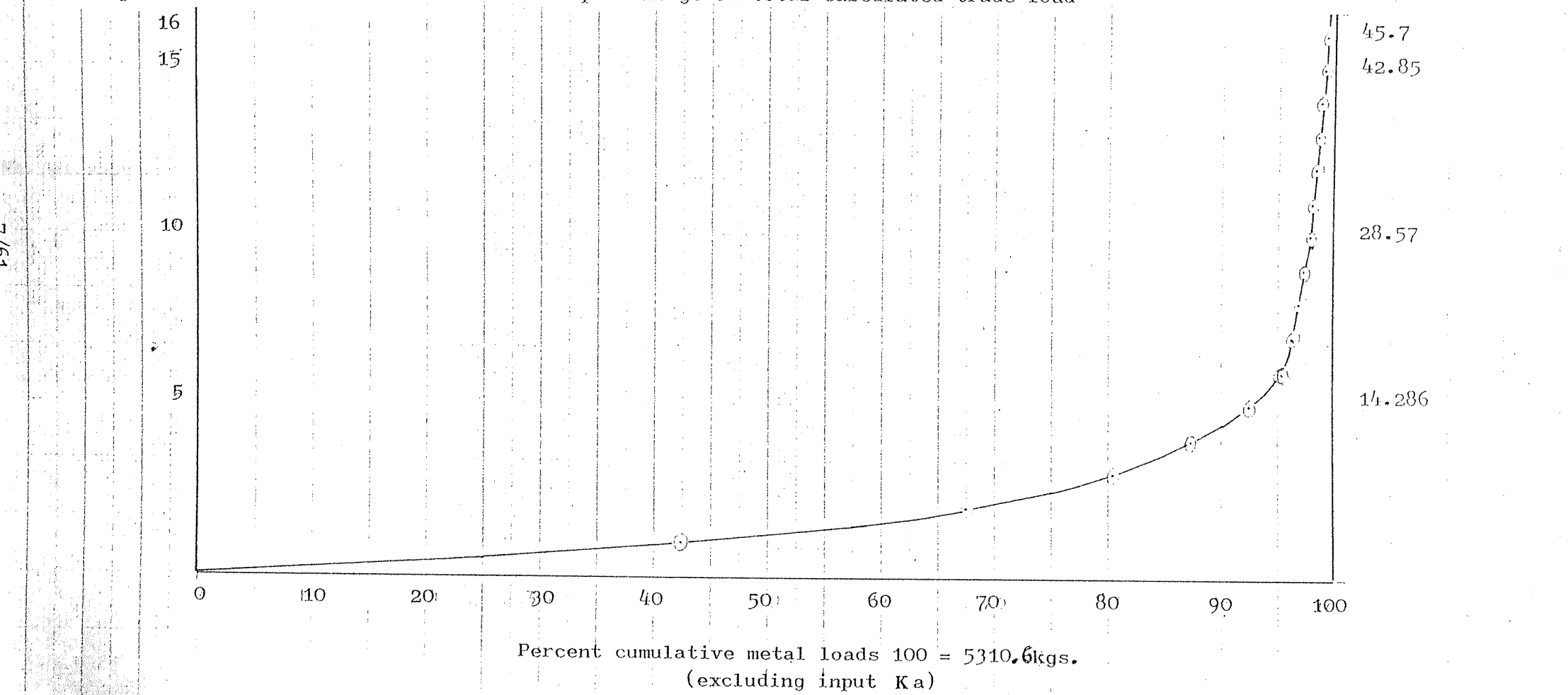


Figure 7.14

Trade metal inputs to sewers 1.4.80-31.3.81

Copper

Cumulative metal loads greater than 10 kgs per 12 months
as a percentage of total calculated trade load

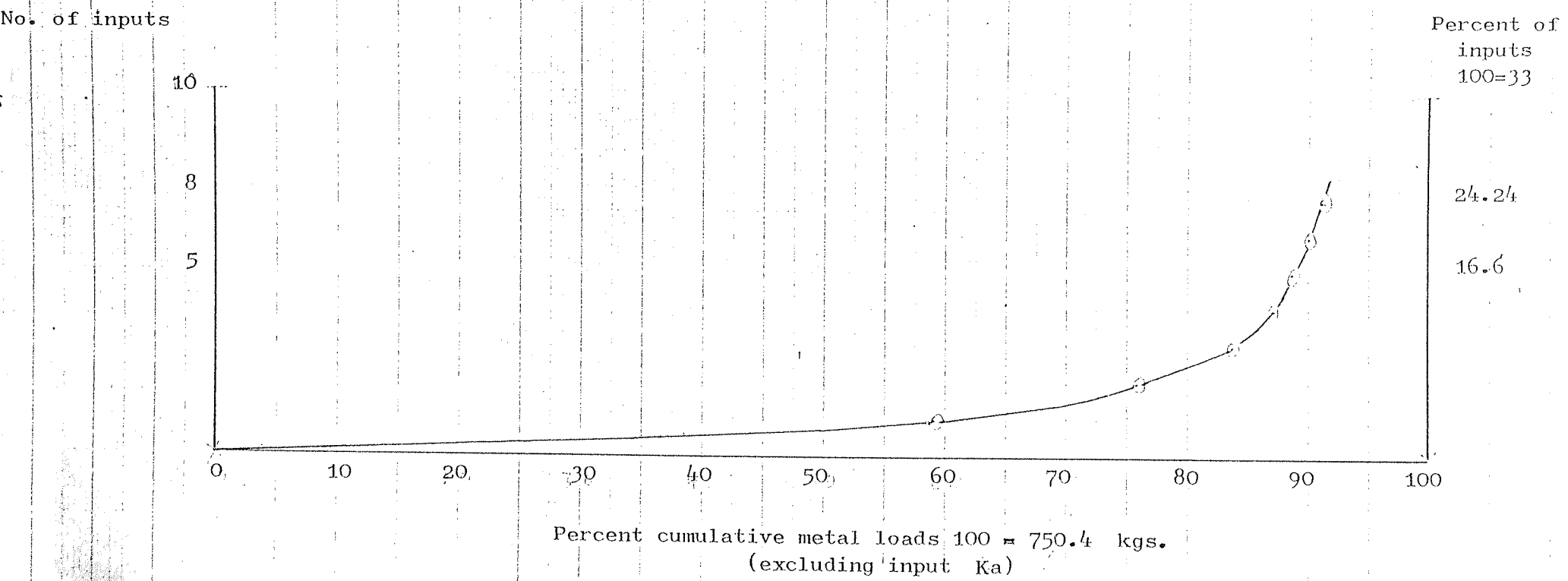


Figure 7.15

Trade metal inputs to sewers 1.11.80-31.3.81

Nickel

Cumulative metal loads greater than 10 kg per 12 months
as a percentage of total calculated trade load

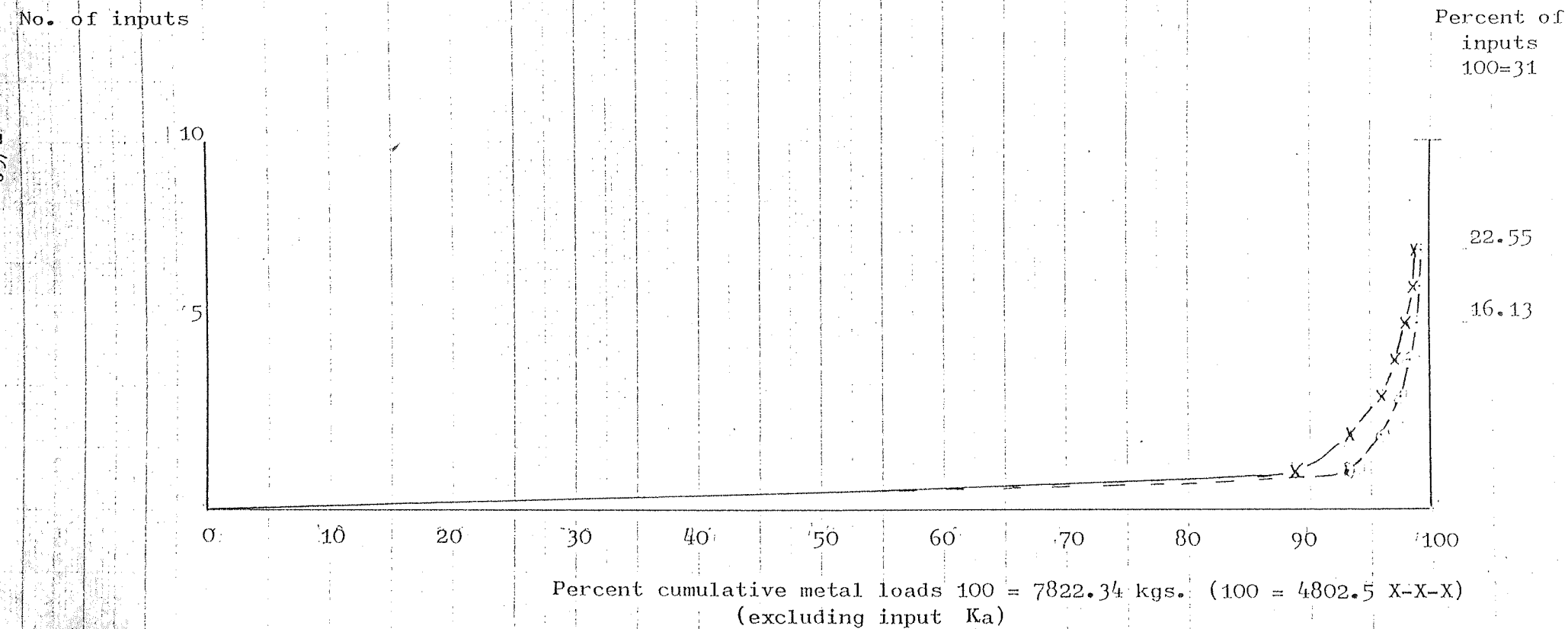
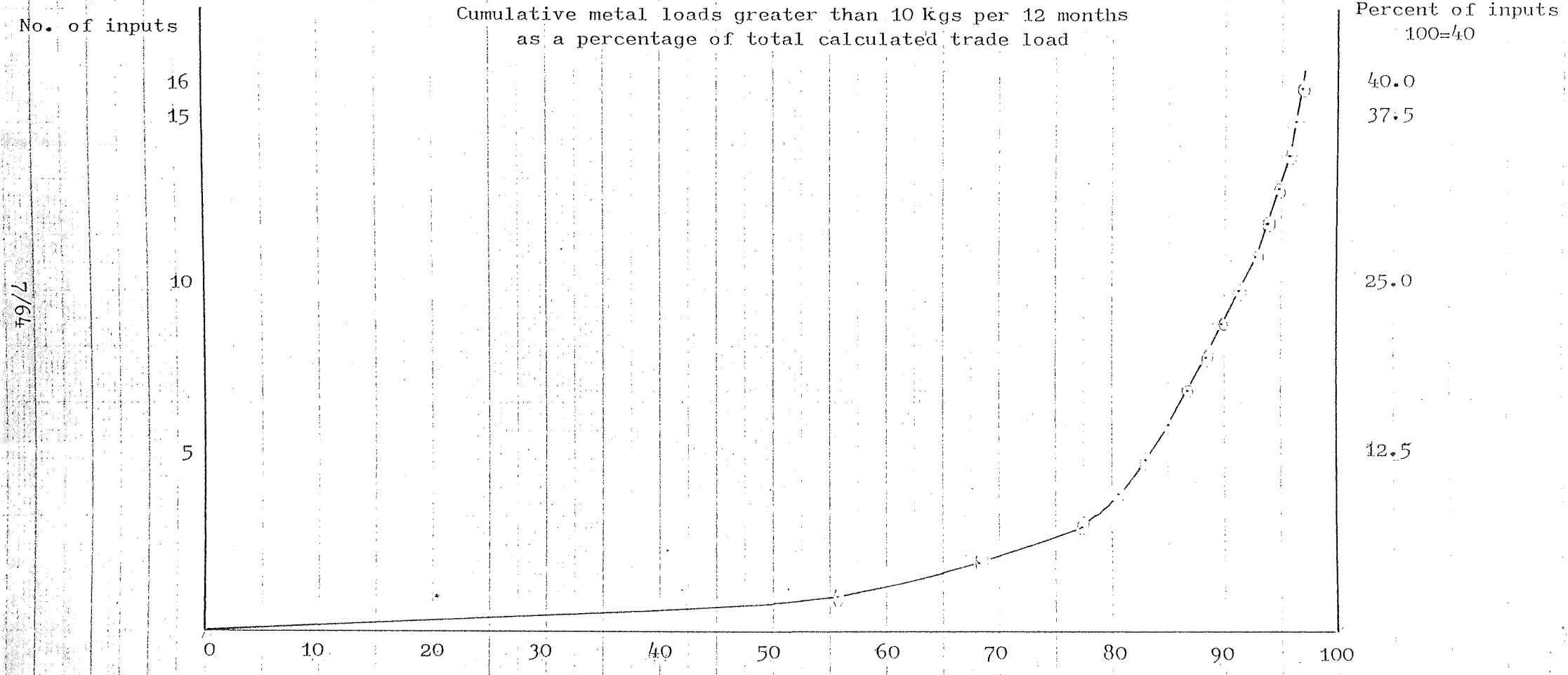


Figure 7.16

Trade metal inputs to sewers 1.4.80-31.3.81

Chromium

Cumulative metal loads greater than 10 kgs per 12 months as a percentage of total calculated trade load



Percent cumulative metal loads 100 = 1920.53 kgs.
(excluding input Ka)

Figure 7.17

Trade metal inputs to sewers 1.4.80-31.3.81

Cadmium

Cumulative metal loads greater than 1 kg per 12 months
as a percentage of total calculated trade load

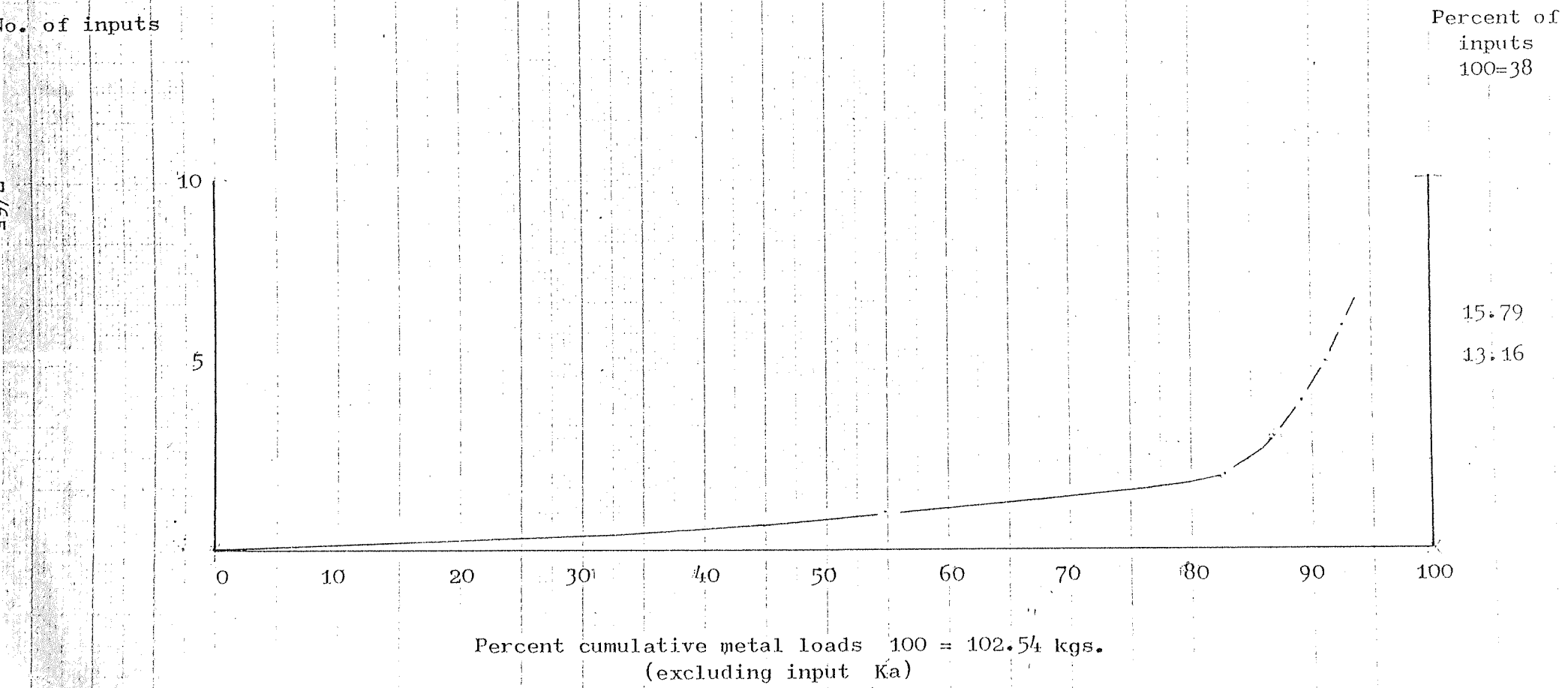


Figure 7.18

Trade metal inputs to sewers 1.4.80-31.3.81

Lead

Cumulative metal loads greater than 10 kg per 12 months

as a percentage of total calculated trade load

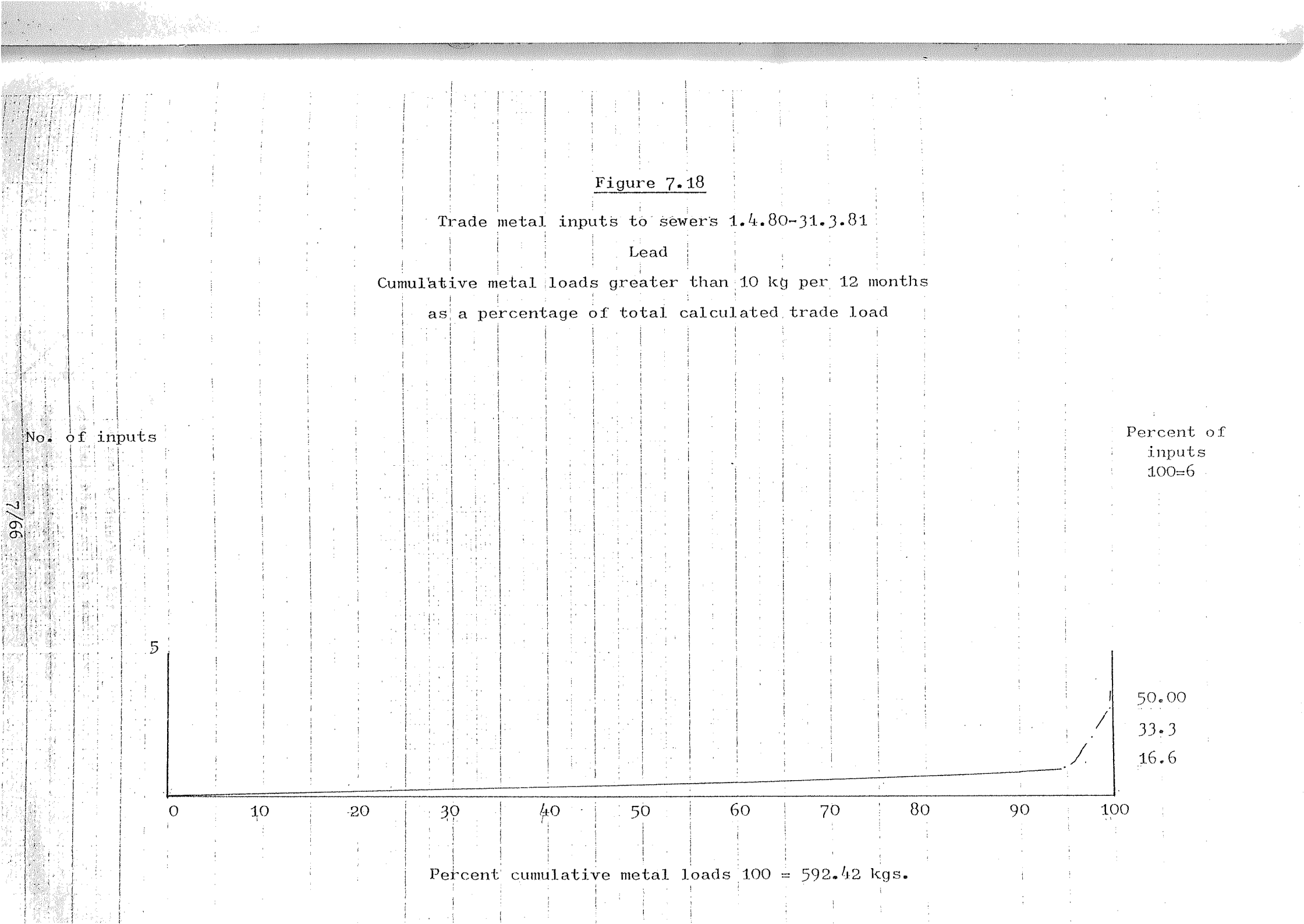


Figure 7.19

Trade metal inputs to sewers 1.4.80-31.3.81 YWA City Data
Cumulative percentile contributions of loads greater than 10^3kg yr^{-1}, and 10^2kg.yr^{-1}, to total calculated loads of Zn, Cu, Ni, Cr, Cd and Pb.

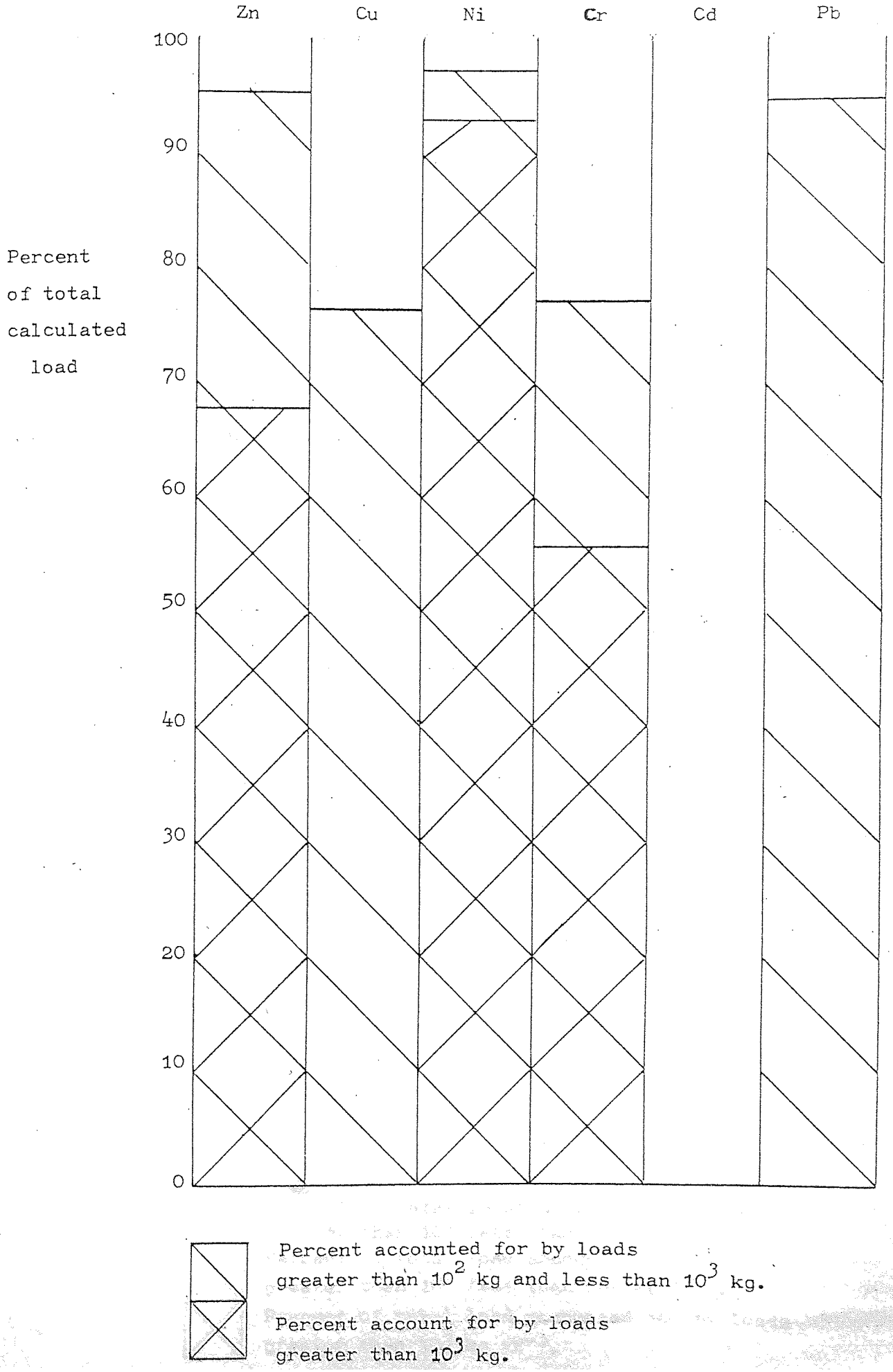


Figure 7.20

Trade metal inputs to sewers 1.4.80-31.3.81 YWA City data
Cumulative percent contributions of loads greater than 10^3kg, 10^2kg and 10^1kg yr^{-1}, from 10 sources A-J, to total calculated loads of Zn, Cu, Ni, Cr, Cd and Zn

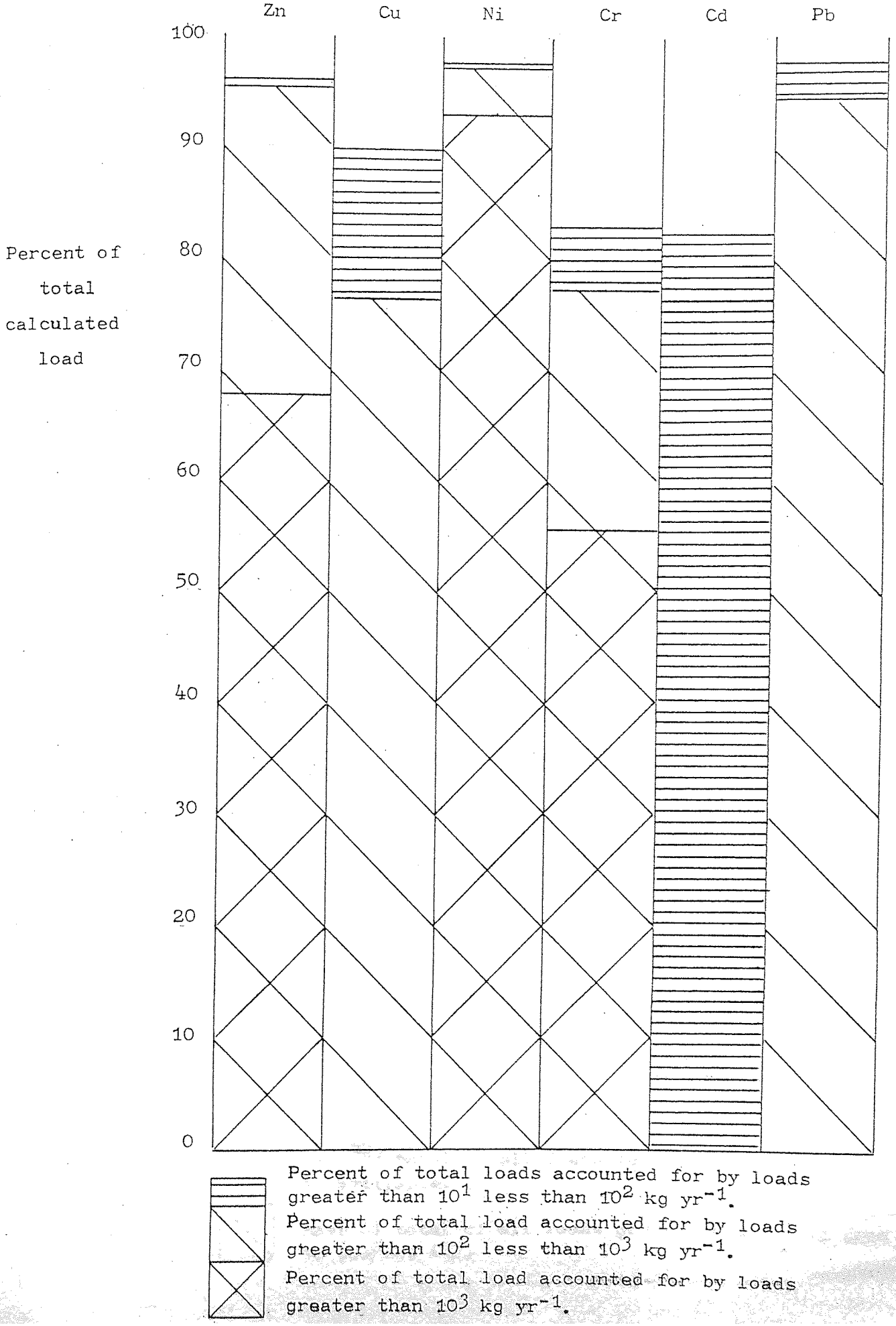


Figure 7.21

Trade metal input to sewers 1.4.80-31.3.81 YWA City data

Total mass from all sources and total mass over 10 kg.y^{-1} from 10 sources, A-J, of Zn, Cu, Ni, Cd and Pb for which data is available.

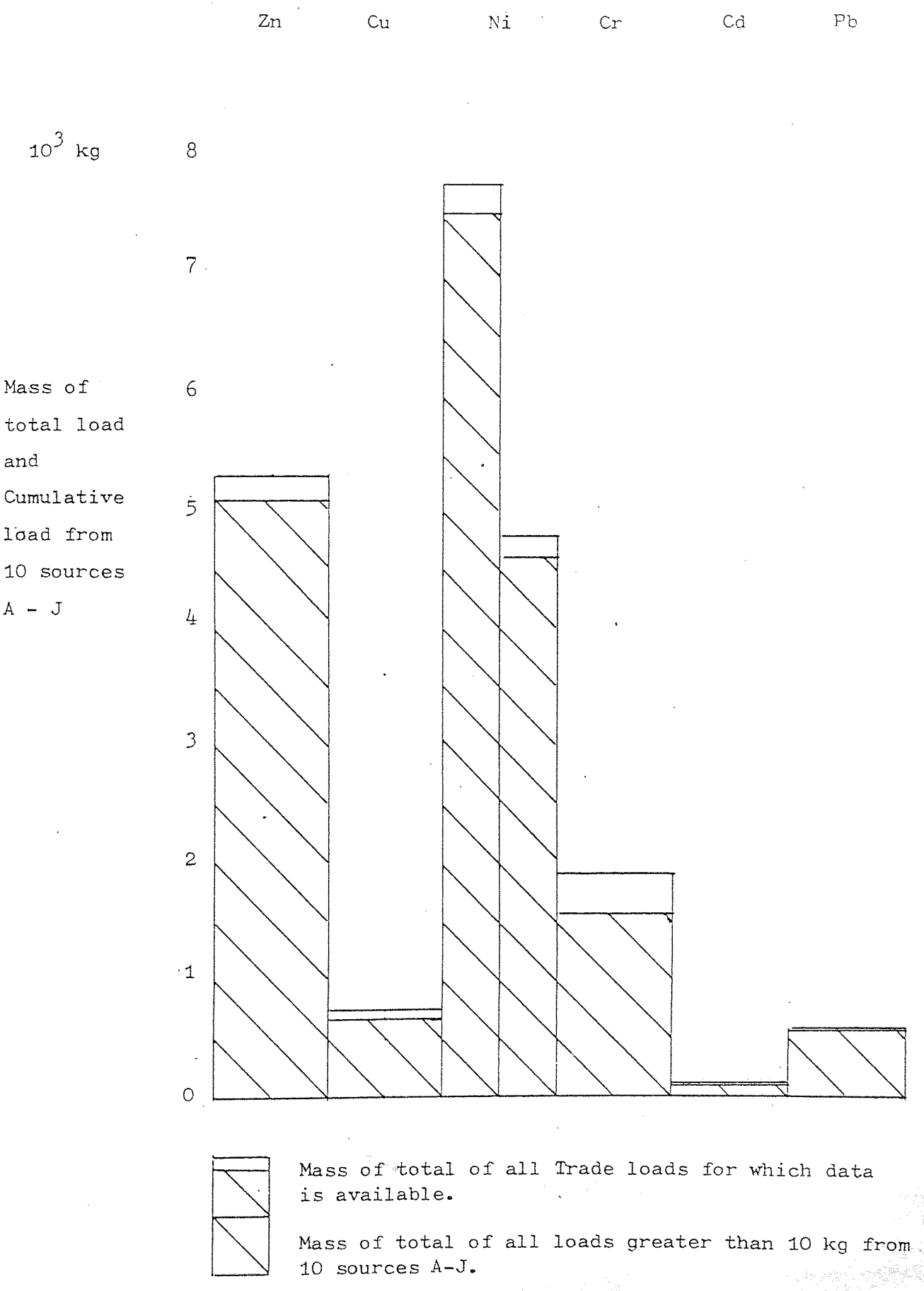


TABLE 7.1

Trade metal inputs to sewers 1.4.80-31.3.81

Distribution of calculated metal input loads having an agreed flow greater than 10^{6}l, and concentrations greater than 10^{-1}mgl.$^{-1}$, except for Cd when concentrations are greater than 10^{-2}mgl.$^{-1}$

	Range of Loads						Number of Inputs		
Column	A	B	C	D	E	F	G	H	I
Loads in kg	10^{-2}-10^{-1}	10^{-1}-10^{0}	10^{0}-10^{1}	10^{1}-10^{2}	10^{2}-10^{3}	10^{3}-10^{4}	Uncor. Total	a. Corrected Total	b. All Known Loads
Zinc		5	7^{x}	9^{x}	4	2	27	26	35
Copper		1	10^{xx}	3	2		16	15	33
Nickel		0	5	5^{xx}	2	1	13	12	31
Chromium		1	9	12^{xx}	2	1	25	24	40
Cadmium	4	9	3^{x}	3^{x}			19	18	38
Lead				1	1		2	2	6
Totals	4	16	34^{xxxx}	33^{xxx}_{xxx}	11	4	102	97	183

Notes

a. Correction so that dual input = 1 Load
b. All trade inputs for which coded data was made available.
x. Includes 1 of dual input.
xx. Includes 2 of dual input.

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TABLE 7.2.

Trade metal inputs to sewers 1.4.80 - 31.3.81

Cumulative ranked input metal loads greater than 10 kg.y^{-1}, as percentiles of total calculated loads of Zn, Cu, Ni, Cr, Cd and Pb from known trade inputs.

Rank Order	Percentile cumulative metal input loads (c) Zn	Cu.	Ni(d)	Cr	Cd (e)	Pb
1	44.36	59.14	93.08(88.73)	55.68	54.99(48.95)	94.71
2	67.67	76.48	95.89(93.3)	68.02	82.74(77.57)	97.90
3	80.41	83.525	97.47(95.87)	77.33	(92.20)	99.96
4	87.40	87.16	98.20(97.08)	80.53		
5	92.51	88.62	98.78(98.02)	83.00		
6	95.42	89.995	99.16(98.63)	85.08		
7	96.19	91.36	99.31(98.88)	86.80		
8	96.78			88.38		
9	97.24			89.87		
10	97.66			91.27		
11	97.97			92.65		
12	98.26			93.77		
13	98.54			94.77		
14	98.79			95.63		
15	99.03			96.23		
16	99.26			96.82		
100%= kg	5310.6	750.4	7822.4(4802.5)	1920.53	102.54(196.95)	592.42

a —— a Line above which cumulative percentiles are due to loads greater than 10^3 kg.

b _ _ b Line above which cumulative percentiles are due to loads greater than 10^2 kg.

c Excluding dual input data, 'a' unless otherwise noted.

(d) Recalculated omitting highest concentration of Rank 1 load.

(e) Including dual input 'a', omitting dual input 'b'.

TABLE 7.3

Trade metal inputs to sewers 1.4.80 - 31.3.81

Volume of flow and number of sources of metal loads greater than 100 kgy^{-1} and rank. Also number and rank of metal inputs, in the 10^1-10^2 kg range from the same sources.

	Point Source	Flow	Load Range kg		Metals and Load Rank					
	Code	$10^6 ly^{-1}$	10^2-10^3	10^3	Zn	Cu	Ni	Cr	Cd	Pb
	A	488.983		2	d^{10}	d^4	X^1	X^1		
	B	54.866		1	X^1	e^6		c^8	d^2	
	C	43.226	1		X^3			c^7		
	D	20.785		1	X^2	e^7				
	E	13.708	2		X^4	X^2				e^2
	F	13.152	1		e^{14}		e^7	X^3	a^1	
	G	11.878	2		X^6	a^3	X^3			
	H	8.771	3		X^5	X^1		d^{11}		X^1
	I	7.575	1				X^2	e^{13}		
	J	3.158	1					X^2		
Totals	10	666.102	11	4	6	2	3	3	0	1
Totals			15 X				15X			

Notes

X load greater than 100 $kg.yr^{-1}$

a also the source of a load >50 <60 $kg.y^{-1}$

b also the source of a load >40 <50 $kg.y^{-1}$

c also the source of a load >30 <40 $kg.y^{-1}$

d also the source of a load >20 <30 $kg.y^{-1}$

e also the source of a load >10 <20 $kg.y^{-1}$

TABLE 7.4a

Number of Inputs of Zn, Cu, Ni, Cr and Pb greater than 1 kg, with agreed flows less than 10^6 l. or concentrations less than 0.1 mg.l^{-1}. Inputs of Cd greater than 0.1 kg. with agreed flows less than 10^6 l. and concentrations less than 0.01 mg.l^{-1}

	Flow		Concentration		Concentration		Total
Metal	No.	10^6 l.yr.$^{-1}$ Source code	No.	0.01 mg.l^{-1} Source Code	No.	0.1 mg.l^{-1} Source Code	
Zn	1	x L2			2	A	3
Cu	2	x L2L4			7	x A,C,F	9
Ni					6		6
Cr	3	x x L1L3L4			1		4
Cd			7	A			7
Pb	1	x L2					1
Total	7		7		16		30

Notes: The Source Codes given are for a) Sources with flows less than 10^6 l, and
b) Source Codes where source is one of the 'Top ten', see Table 7.3.
x Load over 10 kg.

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TABLE 7.4b

Distribution of input loads greater than 1 kg. from ranked sources with agreed flows less than 10^6 l.y^{-1}. (a) (b)

	Input load range in kilogrammes per year					
	1-10	10-20	20-30	30-40	40-50	
Metal						Total Loads
Zn		$L2^{11}$				1
Cu	L4	$L2^{6}$				2
Ni						
Cr	L3	$L4^{8}$			$L1^{5}$	3
Cd						
Pb		$L2^{3}$				1
Total Loads	2	4			1	7

Notes:
a. sources ranked by size of flow, L1-L4.
b. sources at input greater than 10 kg.y^{-1} show rank of all input loads shown in Table 7.2.

TABLE 7.5

Percentage partition of six metals from sewage entering to sewage sludges leaving English WPC works

Source	Location	Zn	Cu	Ni	Cr	Cd	Pb
Lester J.N. et al.	Oxford		96			89	92
" ex L. and R.	"		92a			91a	92a
" ex Stones, T.	Salford/ Manchester		88b				95b
Stoveland S.et al.	Oxford	94		70	67		
" ex Stones, T.	Salford/ Manchester	74c		42c	78c		
Mean of above	Various	84	92	56	72.5	90	93
Present Study	Leeds	91.35	88.06	49.9	96.37	73.8	ND
Blake, W.		70	75	40	75	75	80

Notes:

a. Results calculated and presented by Lester et al. from data published in 1973 by Lewin and Rowell.

b. Hypothetical results calculated and presented by Lester et al. from data reported by Stones, T. of metal partition as a result of primary sedimentation at Salford sewage works and of activated sludge removal at Davyhulme Works in Manchester.

c. Hypothetical results calculated and presented by Stoveland et al. from Stones, T., Salford and Manchester data.

Sources;

Lester, J.N., Harrison, R.M. and Perry, R. The balance of heavy metals through a sewage treatment works. 1. Lead, cadmium and copper. Science of the total environment Vol.12, 1979, pps. 13-23.

Stoveland, S., Astruc, M., Lester, J.N. and Perry. The balance of heavy metals through a sewage treatment works. 2. Chromium, Nickel and Zinc. Science of the total environment, Vol.12, 1979, pps. 25-34.

Blake, W. Determination of acceptable levels of heavy metals in effluents discharged to a foul water sewer. In Management and control of heavy metals in the Environment, International Conference Report, CEP 1979.

8. APPLYING THE MODEL

8.0. Introduction

The model is now applied to the Yorkshire Water Authority City WPC works using mean data for the year 1.4.80 - 31.3.81, the only year for which trade metal input data has been made available. Basic data for that year is shown in table 8.1.

Unfortunately no data for metal concentrations entering the WPC works is available for the same period. It is therefore necessary to borrow the partition coefficients 'P' calculated for the previous year (see section 7.2) and to use these together with higher and lower partition ratios derived from the literature, as shown in table 8.2. By using basic equation 1a (S7.4) and derived equations A(1-8) and B(9-16) it is now possible to apply the model without the use of crude sewage metal concentration or input flow data. Input flow data, although available, is regarded as a potential source of further error, and is optionally omitted.

Accuracy of results will be limited by the accuracy of the partition coefficients 'P' used and this must be borne in mind when interpreting the range of results calculated by the use of 2 or 3 partition ratios for each metal. Accuracy of results is also limited by the reliability of annual metal concentration, data O, and the sludge production, data Y. As shown in table 8.1 annual mean concentrations of Zn, Cu, Ni, Cd and Cr are based on 30 'cases' for which concentrations are available, equivalent to one case per 12.16 days. Times of sampling or types of sample are not given. Reliability of Pb annual mean concentration is regarded as particularly low, being based on 9 cases equivalent to 1 case per 40.5 days. However Pb data is included for the purpose of using the model, with the above reservation in mind.

Assumptions

First it is assumed that errors in the primary data, from which the annual mean data shown in table 8.1 is derived, tend to cancel out and that mean metal concentration and sludge production data is reliable enough to demonstrate the use of the model as a tool and to give insights and answers which are operationally usable.

Second, the factors which bring about the settlement of metals in primary and secondary treatment of sewage have been shown to be complex.[1] Here the operational assumption is made that although the proportion of metal settled in primary sludge to that settled in secondary sludge may alter for any calculated reduction of metal input, overall partition ratio of a particular metal input to works, to output in mixed sludge is not affected, or not significantly affected by the reductions calculated in this study.

Third, that in simulating the processes of stabilisation by anaerobic digestion or by lime treatment metals contained in the sludge are conserved, either directly or indirectly and there is no increase in metal load from sources outside the system.

Purposes

The purposes of this section are in keeping with those specified in section 7.0.

Using the available data and focussing on the metals Zn, Cu, Ni, Cd, Pb and Cr the model with a specified range of partition ratios is applied to the YWA Inner City WPC works for the period 1.4.1980 - 31.3.1981.

1. To investigate the relationship of specified metal inputs to and outputs from the sewer catchment/treatment system.

2. To quantify how much, if any, of the load of a stated metal entering the WPC works may need to be reduced in order to achieve simple compliance

with Recommended (R) and/or Mandatory (M) concentrations of metals in sewage sludge output stated in annex 1A of the EC proposal for a directive on the use of sewage sludge in agriculture of 8.10.1982.

3. To assess if simple compliance with R or M values proposed can be achieved by reduction from 'known' trade point sources when sludge is unstabilised, simulated digested or lime stabilised.

4. To assess if 95% probability of compliance with M or R values proposed can be achieved by reduction from known sources with or without reduction of standard deviation.

5. To assess the effect of eliminating anomalously high Zn, Cu and Pb concentrations in unstabilised, simulated digested and lime stabilised sewage sludges on the achievement of simple 95% probability compliance with R and M values, with or without reduction of standard deviation.

6. To assess the effect of enforcing YWA Guide Limits on achievement of simple and 95% probability of compliance with proposed M or M and R limits.

7. To assess to what extent concentrations in sludge output can be attributed to unknown sources.

Procedure

The model is now applied using stated equations and partition ratios to calculate for the metals Zn, Cu, Ni, Cd, Pb and optionally Cr the following:

1. The relationship between known output and input, and of known input with output. In addition to generating information to be used in subsequent calculations, this process is also used to establish the 'fit' of the various parameters used in the model.

2. a. Using mean concentrations of metals in unstabilised sewage sludge as a basis simulated mean concentrations in digested and lime treated sludges

are calculated.

b. Reductions in mean concentrations required for simple or 95% probability of compliance with proposed Mandatory or Recommended limit values are calculated.

3. Four strategies for achieving the required reductions necessary for compliance are applied as follows.

A. For simple compliance

Reduction of mean concentrations in the three sewage sludges by

a. reduction of input of metal to sewers from highest known trade effluent sources;

b. by eliminating 0, 1 or 2 anomalously high concentration cases and recalculating mean concentrations in the 3 sewage sludges; and

c. later in section 8.4 by simulating reduction of known inputs to YWA specified Guide limits.

B. For 95% probability of compliance.

Reduction by means of the above three strategies and where necessary reduction of standard deviation, a major factor in the probability formula used.

4. Equivalence of stated output with input and input with output of the sewer WPC works system are used with data from literature sources in order to give some indication of the output equivalent of inputs from unknown sources. See section 8.6.

8.1. Output and Input

Method. Using the basic data, shown in tables 8.1 and 8.2 annual loads of metal leaving the WPC works, O x X, are calculated, as shown in table 8.3, to be 11076.775, 5322.321, 3098.835, 323.249, 7438.392 and 5321.452 kilograms of Zn, Cu, Ni, Cd, Pb and Cr respectively.

Using basic equation 1, or derived equation A2, annual input loads to the WPC works are calculated as shown in table 8.3, to be:-

Results.

For Zn. When partition is .94, .9135(a) or .70, input is calculated to be 11783.803, 12125.643 or 15823.964 kg. respectively.

Calculated inputs for this range of ratios having a range of 4040.16 kg. The input calculated using 79/80 ratio being 341.84 kg. more than input calculated for the highest input ratio but 3698.321 kg. less than the input calculated from the lowest partition ratio.

Similarly

For Cu. When partition ratio is .92, .8806 or .75 calculated input is 5785.132, 6043.971 or 7096.428 kg. respectively, a range of 1311.296 kg. Input using the 79/80 ratio being 258.839 kg. more than input calculated from the highest ratio but 1052.457 kg. less than input from the lowest partition ratio.

For Ni. When partition ratio is .499 or .4 calculated input is 6210.091 or 7747.0875 kg. respectively, but these inputs are less than the sum of calculated known trade loads 7822.4 kg. input shown in table 8.1. This may be because the sum of calculated Trade Loads is too high or the partition ratios used above are too high. When a lower partition ratio of .35 is tentatively introduced calculated input is 8853.816 kg. Calculated inputs now have a range of 2643.725 kg. between the lowest input calculated on the basis of the 79/80 ratio and the highest input on the basis of the extra low ratio. 1979/80 ratio input is 1536.998 and 2643.723 kg. less than that calculated on the basis of the lower and lowest ratios respectively.

For Cd. When partition ratio is .9 or .738 calculated input is 359.165 or 438.006 kg. respectively. Input calculated on the basis of the 79/80 ratio being 78.841 kg. higher than that for the higher ratio.

For Pb. When partition ratios are .95, .92 or .80 calculated input is 7829.886, 8085.209 or 9297.99 kg. respectively, a range of 1468.104 kg.

For Cr. When partition ratios is .9637 or .75 calculated input is 5521.897 or 7095.27 kg. Input calculated on the basis of the 79/80 ratio being 1573.373 kg. less than that calculated on the lower ratio.

Comment

In view of the wide ranges of input loads calculated, the use of alternative partition ratios should be continued. Similarly the use of the extra low partition ratio .35 or of the alternative Ni input data for source A would seem to be required if feasible results are to be obtained.

The operational practicality and limitations of these expediencies on calculated results and inferences will emerge as the model is used further.

Note

Partition ratios calculated on the basis of 1979/80 data are underlined.

Output equivalent of calculated input of known trade loads to a YWA inner city WPC works. 1.4.80 - 31.3.81.

Method By applying equations B15 and 14, see section 7.4, the relationship between input loads T of Zn, Cu, Ni, Cd, Pb and Cr from known trade sources to output concentrations O will now be explored, using basic data shown in table 8.1 cols. 1, 2 and 5 and partition ratios shown in table 8.2. Dual input data for input source Ka is omitted from all calculations of input loads T except when specifically stated. Similarly when stated input load from source D of 1237.95 kg., based on 3 cases only, is optionally omitted from input loads of Zn and results recalculated.

Results

The following results are shown in table 8.4.

For Zn. For a calculated annual input, from known trade sources, of 5310.6 kg (T) when partition ratios are .94, .9135 or .70, equivalent output concentration O^T is calculated, using equation B15, to be 706.677, 686.754 or 526.249 $mgkg^{-1}$ dry solids in output sewage sludge being 45.067, 43.796 or 33.560 per cent of mean annual concentration respectively.

Optionally omitting 1237.95 kg from Source D, based on 3 concentration cases only, 4072.66 kg of input (T), when partition ratios are again .94, .9135 or .70, is calculated to be equivalent to 541.945, 526.667 or 403.576 mg kg^{-1} in dry solids of sewage sludge being 34.5615, 33.587 or 25.737 percent of the mean annual concentration O of Zn in sewage sludge.

Similarly for Cu. For a calculated annual input of 750.4 kg (T) when partition ratios are .92, .8806 or .75, equivalent concentration O^T is calculated to be 97.730, 93.545 or 79.672 mg.kg DS. in sewage sludge, being 12.971, 12.416 or 10.574 percent of annual mean concentration of Cu in sewage sludge.

For Ni. For a calculated input of 7822.4 kg (T) when partition ratios are .499, .4 or .35, equivalent output is 552.573, 442.944 or 387.576 mgkg DS of SS, being 125.963, 100.972 or 88.351 percent of annual mean concentration O respectively.

Results greater than 100% of output concentration O, when partition rates are .499 and .4, are not feasible suggesting that actual mean partition ratio may be as low as .35 or that calculated input load T is high, or a combination of both.

If highest case of individual concentrations from source A is

omitted, and annual mean and annual load from that source is recalculated, total load T from known sources is calculated to be 4802.5 kg.

Unless otherwise stated, the .35 partition ratio will now be applied when total input load T from known trade sources is given its full value of 7822.4 kg. Partition ratios of .499 and .4 will be applied when T is given the lower total of 4802.5 kg.

Then for input of 4802.5 kg. Ni (T) when partition ratios are .499 or .4 equivalent output is calculated to be 339.248 or 271.942 mg kg. DS. in sewage sludge (SS) being 77.334 or 61.991 percent of annual mean concentration O respectively.

For Cd. For a calculated input of 102.54 kg.(T) when partition ratios are .9 or .738, equivalent output is 13.064 and 10.713 $mgkg^{-1}$ DS of SS, being 28.550 or 23.411 percent of annual mean Cd concentration O in sewage sludge respectively.

Or if input from source Ka is included, and Kb omitted, calculated input of 196.95 kg. when partition ratios are .9 or .738, equivalent output is 25.092 or 20.576 $mgkg^{-1}$ DS in sewage sludge being 54.835 or 44.965 percent of annual mean concentration O respectively.

For Pb. For calculated input of 592.42 kg.(T) when partition ratios are .95, .92 or .80 equivalent output is 79.671, 77.155 or 67.092 $mgkg^{-1}$ DS in sewage sludge being 7.566, 7.327 or 6.371 percent of annual mean concentrations O in sewage sludge, respectively.

For Cr. For a calculated input of 1920.53 kg.(T), when partition ratios are .9637 or .75, equivalent output is 262.007 or 203.907 $mg.kg^{-1}$ DS in sewage sludge, being 45.7 or 35.566 percent of annual mean concentration of Cr.(O) in sewage sludge respectively.

Comment

Calculated output concentrations and percentages of annual mean

concentrations (O) of a particular metal in sewage sludge are directly proportional to partition ratio for a given input.

Known trade input loads of Ni are equivalent to a higher percentage of annual mean concentration in sewage sludge than any other metal followed by those for Cr and Zn, Cd, Cu and Pb in descending order.

Thus potential for reduction of inputs from known sources is very limited in the metals Cd, Cu and Pb compared with Ni, Cr and Zn.

With regard to Nickel the infeasibility of calculated equivalent outputs when the 2 highest partition ratios are used with full value of input T again raises difficulties as to whether this is due to too high a partition ratio or to calculated input of T being too high, or both. It is therefore necessary to continue the optional use of a) the extra low partition ratio .35 and of lower input 'T' calculated as described previously. It is noted however that the lowest partition ratio is not necessary, when lower levels of input from Source A or resultant total input lower T from known trade sources are used.

The problem posed by the dual input of Cd from source K of inputs Ka and Kb, shown in figs. 7.5 and 7.11, is clearly shown, in table 8.4 col.4, percent equivalent of input T of output O is almost doubled when Ka is included and Kb omitted rather than vice versa. Presumably the output equivalent of the 'true' input from source K will lie somewhere between the two values given. In view of this it is necessary to continue the optional use of data for input Ka.

Equivalent of input of Zn, Cu, Ni, Cd, Pb and Cr from highest known trade input sources. Although equivalent output from known inputs is operationally informative it is not practical to consider any required reduction just in terms of a general reduction in T. Too many sources are involved and many input loads are too small for reductions to make a significant contribution to overall reduction of input T. However, as

shown in section 7.1, a few sources make a high overall contribution to T.

Equivalent outputs of inputs from 5 sources are now calculated.

Method. Using equations B15 and 14 the output equivalent of Zn input from source B, Cu input of H or H + E, Ni input of A, Cd input of F or F+B, Pb input of H and Cr input of A are now calculated. The effect of an 80% reduction of input load from these sources is also calculated.

Results.

The following results are shown in table 8.5.

For Zn. Calculated annual input of 2355.946 kg. of Zn from source B, when partition ratios are .94, .9135 or .70, is equivalent to output concentrations of 313.504, 304.665 or 233.46 mg kg^{-1} DS. in sewage sludge, being 19.993, 19.429 or 14.888 percent of annual mean concentration O in sewage sludge respectively.

80% reduction in input load from B being equivalent to a reduction of 15.994, 15.543 or 11.910 percent of O.

For Cu. For a calculated input of 443.813 $kg.y.^{-1}$ of Cu from source H when partition ratios are .92, .8806 or .75 equivalent output concentrations were 57.80, 55.326 or 47.121 $mgkg^{-1}$ DS in sewage sludge being 7.672, 7.343 or 6.254 percent of annual mean concentration O respectively; an 80% reduction of input load from source H being equivalent to a reduction of 6.138, 5.874 or 5.163 percent of annual mean concentration O in dry solids of sludge.

Similarly for a calculated input of 573.915 $kg.y.^{-1}$ from sources H+E when partition ratios are .92, .8806 or .75 equivalent percentage of annual mean concentration O in sewage sludge are 9.921, 9.496 or 8.087 percent respectively and an 80% reduction of inputs from H+E is equivalent to 7.937, 7.597 or 6.47 percent of O.

For Ni. For a calculated annual input of 7280.957 kg. from source A when

partition ratio is .35 equivalent output concentration was 360.75 $mgkg^{-1}$ DS in sewage sludge being 82.235% of annual mean concentration 0, an 80% reduction of input from source A being equivalent to 65.788% of 0.

Or if the highest case of concentration is omitted and annual mean and annual load of input from source A recalculated then 4261.08 kg. from source A when partition ratios are .499 or .4 then equivalent output concentrations are 301.002 or 241.284 mgkg. DS in SS being 68.615 or 55.002 percent of annual mean concentration 0 respectively; an 80% reduction of lower input from source A being equivalent to 54.89 or 44.002 percent, respectively, of 0.

For Cd. For a calculated input of 56.383 kg. from source F when partition ratios are .9 or .738 equivalent output concentrations are 7.1835 or 5.89 mgkg. DS in SS being 15.698 or 12.873 percent of annual mean concentration 0; an 80% reduction in input from source F being equivalent to 12.558 or 10.298 percent, respectively, of 0.

Similarly for a calculated input of 84.842 kg. of Cd from sources F+B when partition ratios are .9 or .738 equivalent output is calculated to be 23.622 or 19.37 percent of 0; 80% reduction from sources F+B being equivalent to 18.898 or 15.496 percent, respectively, of 0.

For Pb. For a calculated input of 561.081kg. Pb from source H when partition ratios are .95, .92 or .8 equivalent output is calculated to be 75.457, 73.074 or 63.543 $mgkg^{-1}$ DS in SS equivalent to 7.167, 6.94 or 6.034 percent of annual mean concentration 0 respectively; an 80% reduction of input from H being equivalent to 5.733, 5.552 or 4.828 percent of 0.

For Cr. For a calculated input of 1069.406 kg. of Cr from source A when partition ratios are .9637 or .75 equivalent output is calculated to be 145.893 or 113.541 $mgkg^{-1}$ DS in SS equivalent to 25.447 or 19.804 percent of annual mean concentration 0; an 80% reduction of input from source A being equivalent to 20.358 or 15.843 percent of 0.

Comment

It is apparent from the results that in spite of the range of outputs calculated for a given input when different partition ratios are used a reasonable indication of the 1 or 2 highest input sources' potential to reduce output concentrations in sewage sludge can be gained, subject to the reliability of the data used. In the case of input and output data of Pb this reliability is likely to be low, as it is based on a low number of cases, it is however included to demonstrate the use of the model and provide a basis for discussion.

With 80% reduction potential for reducing Ni concentrations by 44-66%, approximately, from source A alone is particularly striking, the same reduction of source A also has the potential for reductions of Cr by 16-20%. A similar range of reduction of Cd is possible from sources F+B, while B itself has the potential of reducing Zn concentration in sludge by approximately 12-16%. H has the potential for reducing Cu and Pb inputs by 5-6%, H + E provide potential for 6.5-8% reduction of Cu.

The possible use of this potential in calculating required reductions to meet limits specified in the EC proposal for a Directive will now be considered.

FIGURE 8.1

Distribution of metal concentrations in Untreated (Raw) Sewage Sludge

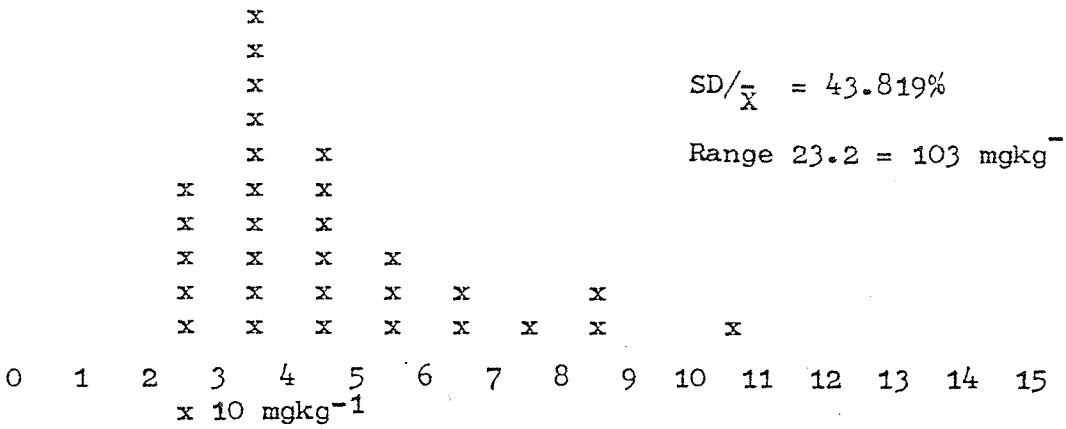
Cadmium, Nickel and Chromium 1.4.80 - 31.3.81

Proposed EC Mandatory limit value 40 mgkg.DS.

Cd $\bar{X}$ = 45.76 $mgkg^{-1}$ SD. 20.056. Cases 30.

$SD/\bar{X}$ = 43.819%

Range 23.2 = 103 $mgkg^{-1}$

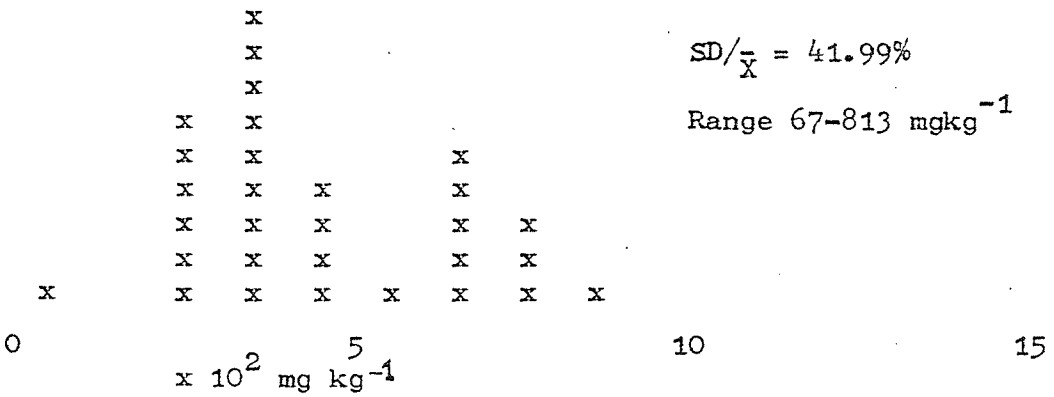


Proposed EC Mandatory limit value 400 $mgkg^{-1}$ DS.

Ni $\bar{X}$ = 438.68 $mgkg^{-1}$ SD. 184.209 Cases 30.

$SD/\bar{X}$ = 41.99%

Range 67-813 $mgkg^{-1}$



Proposed EC Recommended limit value 750 $mgkg^{-1}$ DS

Cr $\bar{X}$ 573.4 mgkg SD. 187.66 Cases 30

$SD/\bar{X}$ = 32.729%

Range 129-871 $mgkg^{-1}$

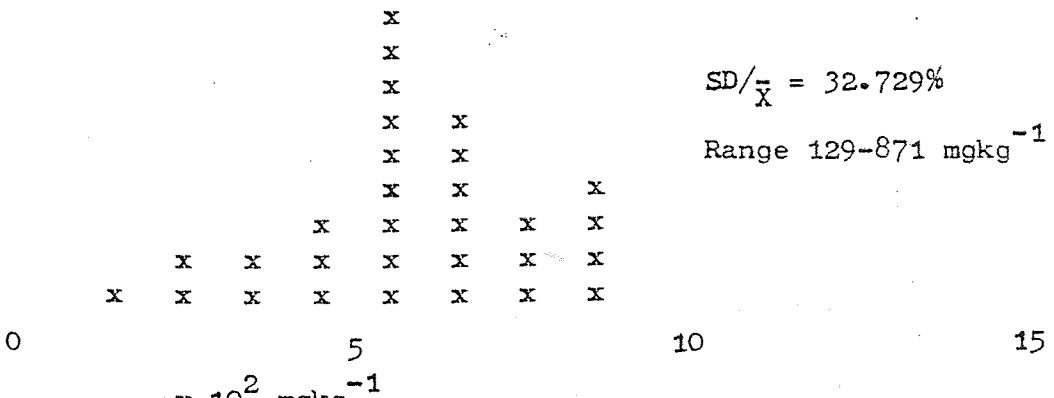
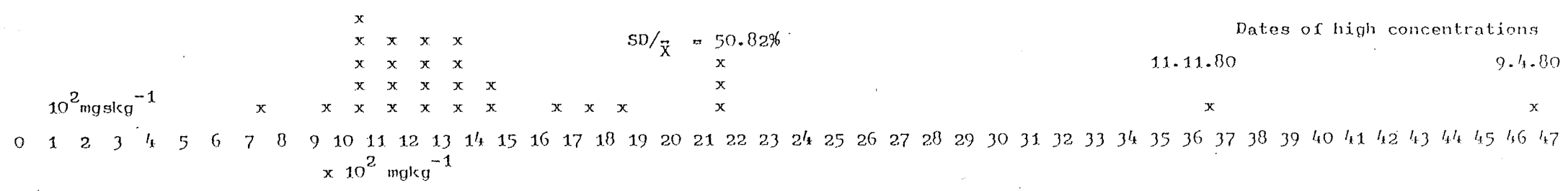


FIGURE 8.2. Distribution of metal concentration in Untreated Sewage Sludge, Zinc, Copper & Lead 1.4.80 - 31.3.81

Proposed EC Mandatory limit value 3000 $mgkg^{-1}$ DS.

Zn $\bar{X}$ = 1568.06 $mgkg^{-1}$, SD = 796.887, Cases 30, Range 775-4620 $mgkg^{-1}$

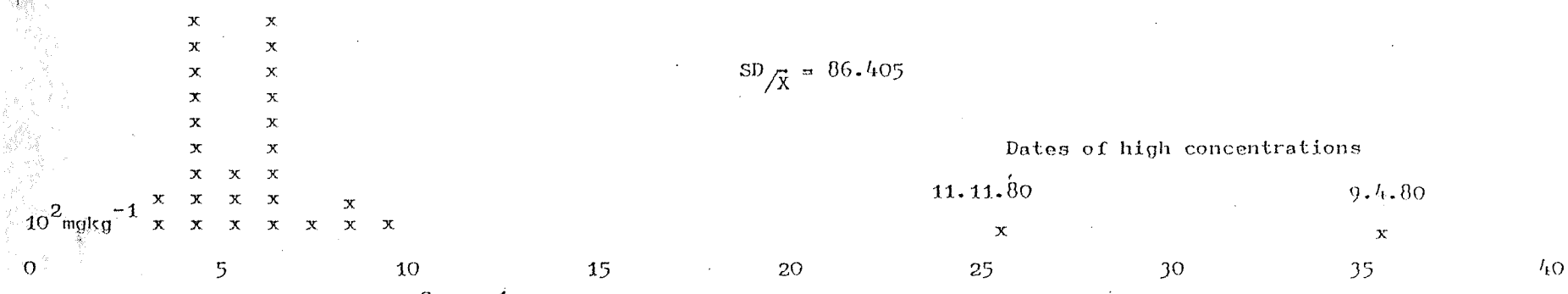
$SD/\bar{X}$ = 50.82%



Proposed EC Mandatory limit value 1500 $mgkg^{-1}$ DS.

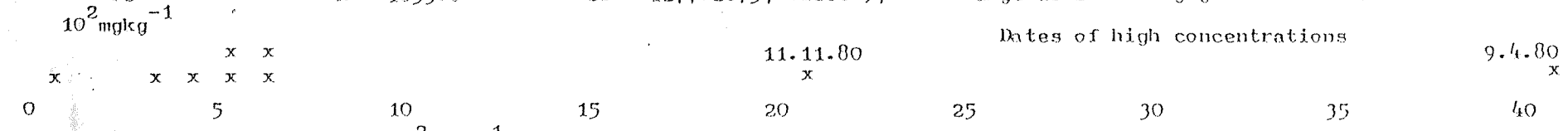
Cu $\bar{X}$ = 753.443 $mgkg^{-1}$ SD = 651.030, Cases 30, Range 359-3540 $mgkg^{-1}$

$SD/\bar{X}$ = 86.405



Proposed EC Mandatory limit value 1000 $mgkg^{-1}$ DS.

Pb $\bar{X}$ = 1053.8 SD = 1277.2075, Cases 9, Range 12.2-4100 $mgkg^{-1}$ $SD/\bar{X}$ = 121.2



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TABLE 8.1

Basic data metal concentrations of input and sewage sludge output, input flow and sewage sludge production of a Yorkshire Water Authority City WPC works 1.4.80-31.3.81

Column	1		2	3	4	5
Source of Data	YWA	YWA	YWA		YWA	YWA
Symbol	O		X	S	Y	T
Parameter	Output mean Conc. Metal in SS.	Cases in Mean	Annual Production SS	Input mean concentration in S.S. sewage entering Works	Input Annual Flow	Input, known Trade Loads
Unit	$mgkg^{-1}DS$	No.	$10^6 kg$	mgl^{-1}	$10^6 l$	kg p.a.
Metal/Notes				a.	b.	c.
Zn	1568.06	30	7.064	ND	37,378.688	5310.6
Cu	753.443	30	"	"	"	750.4
Ni	438.68	30	"	"	"	7822.4 (4802.5)d
Cd	45.76	30	"	"	"	102.54
Pb	1053.8	9	"	"	"	592.42
Cr	573.32	30	"	"	"	1920.53

Notes:
a. No data is available for this period.
b. In the absence of data for metal concentrations in crude sewage for this period, 'Input annual flow' data is optionally omitted from calculations where possible.
c. Omitting data for the source Ka of dual input Ka+b.
d. When highest concentration of cases, on which output from Source A is based, is omitted from mean concentration of A, output of Source A and total known trade input load total T.

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TABLE 8.2

Selected and calculated partition ratios, with sources, used in the study of a Yorkshire Water Authority City WPC works 1.4.80-31.3.81

Column	1	2	3	4
Source of Data	Literature	This study calculated 1979/80 data (g)	Literature	This study hypothetical
Symbol	P	P	P	P
Parameter	Partition ratio			
Unit	numerical			
Level	High		Low	Extra Low
Metal				
Zn	.94 a	.9135	.70 b	
Cu	.92 c	.8806	.75 b	
Ni		.499	.40 b	.35 f
Cd	.90 c	.738		
Pb	.95 d	(.92 e)	.80 b	
Cr		.9637	.75 b	

Notes:

a. Ex Stoveland S et.al. See table 7.5.

b. Ex Blake W. " "

c. Mean of Lit. values see table 7.5.

d. Ex Lester J.N. et al. from data of T. Stones see table 7.5.

e. Ex Lester J.N. et al. " "

f. Hypothetical ratio found necessary in the course of this study table 8.4 col.4.

g. As no data for metal concentrations in crude sewage was available, for the stated WPC works, during the period 1.4.80-31.3.81.

TABLE 8.3

Output load of Zn, Cu, Ni, Cd, Pb and Cr in sewage sludge, and calculated input load to a Yorkshire Water Authority City WPC works 1.4.80-31.3.81 for selected partition ratios.

Column Source of Data Symbols	1 Table 8.1 col.1 x col.2 O x X	2 Table 8.2 P	3 Calculated $\frac{O \times X}{P}$
Parameter	Output mean load metal in DS of SS	Partition ratio	Input load
Units	kgy^{-1}		kgy^{-1}
Metal			
Zn	11076.775	.94	11783.803
"	"	.9135 a	12125.643
"	"	.70	15823.964
Cu	5322.321	.92	5785.132
"	"	.8806 a	6043.971
"	"	.75	7096.428
Ni	3098.835	.499 a	6210.091 c
"	"	.40	7747.0875c
"	"	.35 b	8853.816
Cd	323.249	.90	359.165
"	"	.738 a	438.006
Pb	7438.392	.95	7829.886
"	"	.92	8085.209
"	"	.80	9297.99
Cr	5321.452	.9637 a	5521.897
"	"	.75	7095.27

Notes:
a. Partition ratio calculated on the basis of 1979/80 data.
b. Low partition ratio found necessary in this study. See table 8.4.
c. Not feasible, if known Ni input is at highest calculated value shown in Table 8.1 col.5.
O as in table 8.1.
X " " "
P " " 8.2.

TABLE 8.4.

Known trade input loads of Zn, Cu, Ni, Cd, Pb and Cr to a YWA City WPC Works 1.4.80 - 31.3.81 and calculated equivalent metal concentrations in sewage sludge output for selected partition ratios

Column	1	2	3	4
Source of Data	Table 8.1 Col.5	Table 8.2	Calculated (a)	Calculated (b)
Symbols	T (total)	P	O^T	$O^T/_O$
Parameter	Input known trade loads	Partition ratio	Equivalent output conc.	Equivalent of Total output conc.
Units	kgy^{-1}		$mgkg^{-1}$ DS in SS	%
Metal				
Zn	5310.6	.94	706.677	45.067
"	"	.9135c	686.754	43.796
"	"	.70	526.249	33.560
Zn omitting Source D(g)	4072.66	.94	541.945	34.5615
	"	.9135c	526.667	33.587
	"	.70	403.576	25.737
Cu	750.4	.92	97.730	12.971
"	"	.8806c	93.545	12.416
"	"	.75	79.672	10.574
Ni	7822.4	.499 c	552.573	125.963nf
"	"	.40	442.944	100.972nf
"	"	.35 d	387.576	88.351
"	4802.5e	.499	339.248	77.334
"	"	.40	271.942	61.991
Cd	102.54	.9	13.064	28.550
"	"	.738c	10.713	23.411
"	196.95(h)	.9	25.092	54.835(h)
"	"	.738c	20.576	44.965(h)
Pb	592.42	.95	79.671	7.566
"	"	.92	77.155	7.327
"	"	.80	67.092	6.371
Cr	1920.53	.9637c	262.007	45.700
"	"	.75	203.907	35.566

Notes:
a. Calculated using equation B15. See section 7.4.
b. Calculated using equation B14. See section 7.4.
c. Underlined partition ratios are calculated on the basis of 1979/80 data for the same works, as shown in Table 8.2 Col.2.
d. Lower partition ratio found necessary as higher ratios used produce results which are not feasible.
e. Omitting highest concentration case, when calculating Source A input.
nf. Not feasible.
g. Source D input is based on only 3 concentration cases.
h. Hypothetical if dual input Kb is omitted and Ka included in total known trade load input.

TABLE 8.5

Five trade sources of highest known Trade input loads of Zn Cu Ni Cd Pb and Cr to a YWA City WPC Works, 1.4.80-31.3.81, and calculated equivalent metal concentrations in sewage sludge output for selected partition ratios.

Column	1	2	3	4	5	6
Source of Data	Table 7	Figs.7.7-7.12	Table 8.2	Calculated (a)	Calculated (b)	(f)
Symbols		T	P	O^T	% OT/O	% OT/O from 80%
Parameter	Source	Input load	Partition Ratio	Equivalent Output	Percentage of Annual Mean	Reduction Percentage of Annual Mean
Units	Code	kgy^{-1}		$mgkg^{-1}$ DS in SS	%	%
Metal						
Zn	B	2355.946	.94	313.504	19.993	15.994
			.9135	304.665	19.429	15.543
			.7	233.46	14.888	11.910
Cu	H	443.813	.92	57.80	7.672	6.138
			.8806	55.326	7.343	5.874
			.75	47.121	6.254	5.163
	H+E	573.915	.92	74.745	9.921	7.937
			.8806	71.544	9.496	7.597
			.75	60.934	8.087	6.47
Ni	A	7280.957	.35 d	360.75	82.235	65.788
	omitting highest conc.					
	A	4261.08	.499	301.002	68.615	54.89
			.4	241.284	55.002	44.002
Cd	F	56.383	.9	7.1835	15.698	12.558
			.738	5.89	12.873	10.298
	F+B	84.842	.9	10.809	23.622	18.898
			.738	8.864	19.37	15.496
Pb	H	561.081(g)	.95	75.457	7.167	5.733
			.92	73.074	6.94	5.552
			.8	63.543	6.034	4.828
Cr	A	1069.406	.9637	145.893	25.447	20.358
			.75	113.541	19.804	15.843

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(Table 8.5 continued)

Notes:

a. Calculated using equation B15 see Section 7.4.

b. Calculated using equation B14 see Section 7.4.

c. Underlined partition ratios are calculated on the basis of 79/80 data.

d. Lower partition ratio found necessary as higher ratio results, are not feasible. See tables 8.3 and 8.4.

e. Omitting highest concentration of source A data.

f. 80% of percentage in Col.5 equivalent to 80% reduction Cols. 2 and 4, i.e. input load and equivalent output concentration.

g. Input data for Pb is based on a lower level of monitoring than for other metals. Reliability is therefore likely to be low.

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8.2. Simple Compliance

Simple compliance is here taken to mean the comparison of a mean metal concentration with the specified constraint without the involvement of probability theory.

8.2.1. Simple compliance of unstabilised sludge, minimum required reductions and equivalent minimum input load reductions from highest known trade sources.

Method. Annual mean concentrations of Zn, Cu, Ni, Cd, Pb and Cr in dry solids of unstabilised sewage sludge are compared with M or R limits specified in Annex 1A of the EC proposal for a directive, minimum required reductions of sludge concentration and of equivalent inputs from highest known trade input sources are calculated.

Results. Results shown in table 8.6. Annual mean concentrations of Zn, and Cu are considerably less than both M and R limits, while Cr concentrations, for which no limit is specified is considerably less than the R limit.

Minimum required reductions to achieve simple compliance with M values are 38.68, 5.76 and 53.8 $mgkg^{-1}$ DS in SS, being 8.817, 12.587 and 5.105 percent of Ni, Cd and Pb mean concentrations O respectively. As shown in col. 6 required reductions are less than the equivalent output concentrations of known trade inputs.

Equivalent reductions from known trade sources are shown in table 8.7 to be:

Ni. When partition ratio is .35 the required reduction of 38.68 $mgkg^{-1}$ DS in SS is equivalent to an input load of 760.673 kg, 10.722% of input from source A.

Or omitting the highest concentration case on which the mean and hence the input load is based and recalculating mean and load.

When partition ratios are .499 or .4 the required reduction of 38.68 $mgkg^{-1}$ is equivalent to a reduction of input loads of 547.566 or 683.089, being 12.85 or 16.031 percent of input from source A respectively.

Cd. When partition ratios are .9 or .738 the required reduction of

5.76 $mgkg^{-1}$ DS in SS is equivalent to 45.21 or 55.134 kg, being 80.183 or 97.784 of input from source F, and 53.287 or 64.984 of input from sources F+B respectively.

Although reductions of 90+% of inputs from trade sources are reported in the literature a planned reduction of 97.784% from F alone is of doubtful operational feasibility, whereas reduction from the two sources F+B may be quite practicable.

Pb. When partition ratios are .95, .92 or .8 the required reduction of 53.8 $mgkg^{-1}$ DS in SS is equivalent to input loads of 400.045, 413.09 or 475.054 kg. being 71.299, 73.624 or 84.668 percent of input from source H respectively.

Comment. From the above it is seen that simple compliance of mean concentrations of Ni and Pb can be achieved by reduction of input from single sources and of Cd from 1 or 2 sources if partition ratios lie within the range shown in table 8.7 col.2.

8.2.2. Simple Compliance, simulated stabilised sewage sludge.

Minimum required reductions of annual mean concentrations of metal in simulated stabilised sewage sludge, to obtain simple compliance with proposed Mandatory limits and equivalent input loads from highest known trade input sources.

Simulated Stabilisation. See also section 7.3.

Method. Applying simulated anaerobic digestion and lime treatment to YWA City WPC Works, on the basis of 14 available cases mean ash content of sewage sludge was 34.627% of dry solids, from which it was calculated that an aerobic digestion with 40% reduction of organic matter would concentrate metals by a factor of x1.354, assuming no volatilisation of metals or loss in drainage water. Similarly simulation of lime treatment with 14% increase in dry solids would dilute metals by a factor of x.8772, but also, assuming that the lime or other agents used were not themselves sources of Zn, Cu, Ni, Cd, Pb or Cr.

Mean concentrations of Zn, Cu, Ni, Cd and Pb in simulated digested and lime stabilised sewage sludges were compared with proposed M limit

values and Cr concentrations with proposed R value. Minimum reduction of these metals to achieve simple compliance with the proposed values were then calculated.

Results. Results are shown in table 8.8.

Zn. Both digested mean and lime treated mean concentrations of Zn in SS are less than M and R limit values.

Cu. Digested mean concentration is less than M but more than R values. Lime treated mean concentration is less than M and R values.

Ni. Lime treated mean concentration is less than M but more than R value. Digested mean concentration exceeds the M limit value requiring a minimum reduction of 193.973 $mgkg^{-1}$ DS. in simulated digested sludge to equal the M limit. As indicated in cols. 5b and 6 this reduction, equivalent to 32.657% of the simulated digested mean, is less than the equivalent concentration O^T from known input trade sources.

Cd. Simulated digested and lime treated mean concentrations exceed M limit values. Digested mean exceeds M limit value by 21.959 $mgkg^{-1}$ DS in SS, being equivalent to 35.441% of simulated mean dry sludge concentration. As indicated in col.6 this is greater than equivalent concentration O^T of known trade inputs, when data for source Ka is omitted.

Simulated lime treated mean ooncentration exceeds M limit by 0.141 $mgkg^{-1}$ DS in SS being 0.351% of mean lime treated sludge concentration. As indicated in col.6 this is less than the equivalent concentration O^T from known trade input sources.

Pb. Simulated lime treated mean concentration is less than M but more than R value.

Simulated digested mean concentration exceeds M limit by 426.845 $mgkg^{-1}$ DS in SS, being equivalent to 29.915% of mean digested concentration. As indicated in col.6 this greater than equivalent concentration O^T from known trade input sources.

Cr. No mandatory limit is specified for Cr. Simulated lime treated mean concentration is less than R value. Simulated digested mean concentration exceeds M value by 26.75 $mgkg^{-1}$ DS, equivalent to 3.385% of mean digested sludge concentration, less than the equivalent concentration o^T from known trade input sources.

Comment

No M limit is specified for Cr. Zn and Cu mean concentrations in SS already comply with M values. Compliance of the sludge with M values can therefore be achieved if required minimum reductions of Ni, Cd and Pb mean concentrations in simulated digested sludge and Cd in lime treated sludge can be achieved.

It is feasible to make reductions of known inputs to produce the required reductions of Ni in simulated digested and of Cd in lime treated sludge.

Required minimum reductions of Cd and Pb concentrations in simulated digested sludges are greater than equivalent output of input from sources known to this study when Cd input from Ka is omitted. It is therefore not feasible to achieve simple compliance of simulated digested sludges, with proposed M values, solely by reduction of Cd and Pb inputs known to this study.

In view of these findings the model will now be used to calculate the equivalent reduction required from highest known sources to bring about minimum reductions required for metal concentrations to meet proposed M limits and in the case of Cr R limit. Where necessary the effect of including input of Cd from Ka, and omitting Kb, will be assessed.

Method. Calculations are carried out as for unstabilised sewage sludge using equations B11 and B12.

Results. Simulated digested sludge (see table 8.9)

Ni. When partition ratio is .35 the required reduction of 193.973 $mgkg^{-1}$ in simulated digested sludge is equivalent to 143.259 $mgkg^{-1}$ in unstabilised sludge and 2891.3805 kg. of input load, 39.712% of input from source A.

Or omitting highest concentration case on which the mean and hence load of input from source A is based, when partition ratios are .499 or .4 required reduction is equivalent to 2028.019 or 2529.954 kg. of input load, 47.594 or 59.374 percent of lower input from source A.

Cd. The required minimum reduction of 21.959 $mgkg^{-1}$ in simulated digested sludge is equivalent to 16.218 $mgkg^{-1}$ in unstabilised sludge, which when partition ratios are .9 or .738 is equivalent to 127.292 or 155.234 kg. of input respectively, both loads being greater than the calculated total load T, 102.54 kg. from known trade sources when input from source Ka is omitted, in table 8.8. However if data for source Ka is included, and that for Kb is omitted, then at partition ratios of .9 or .738, the required reduction is equivalent to 83.316% or not feasible from input from sources Ka + F, but is equivalent to 70.233 or 85.650 percent of inputs from sources Ka + F + B.

It should be noted however that these hypothetical reductions are likely to be greater than the real input from dual input source Ka + b, which on available data, would be some quantity between input calculated for Ka and that for Kb, as shown in figs. 7.5 and 7.11.

Pb. The required minimum reduction of 426.85 $mgkg^{-1}$ in simulated digested sludge is equivalent to 315.247 $mgkg^{-1}$ in unstabilised sludge will be equivalent to an input of 2344.113 kg. or more, when partition ratio is .95 or less, which is greater than total input from sources known to this study, as already shown in table 8.8 col.6.

Cr. A is the main source of inputs of Ni and Cr as shown above Ni concentration in stabilised sludge required reduction. Any reduction of Ni from this

source might bring about reduction of Cr. Although no M limit is stated for Cr reduction required to comply with the proposed R limit is calculated.

Reduction of 26.275 $mgkg^{-1}$ DS Cr in simulated digested sludge, to meet the proposed R constraint, is equivalent to 19.405 $mgkg^{-1}$ in unstabilised sludge, which, when partition ratios are .9637 or .75, is equivalent to input loads of 142.244 or 182.774 kg. and equivalent to a reduction 13.301 or 17.091 percent of Cr input load from Source A.

Results. Simulated lime treated sludge. See table 8.10.

Cd. In order to achieve simple compliance with the proposed M limit a minimum reduction of 0.141 $mgkg^{-1}$ of Cd in mean concentration DS of simulated lime treated sludge was required, equivalent to 0.161 $mgkg^{-1}$ in unstabilised sludge, which at partition ratios of .9 or .738 is equivalent to 1.262 or 1.539 kg. of input, being equivalent to a reduction 2.238 or 2.729 percent of input from source F.

Comment

It is shown that minimum required reduction of Cd in lime treated sludge to achieve compliance with proposed M limit is operationally possible by reduction of input from source F, and similarly minimum required reductions of Ni and Cr, to meet M and R limits respectively, in simulated digested sludge appear to be operationally achievable by a reduction of 40-59% of Ni and of 13-17% of Cr inputs from source A.

Required reduction of Cd is unlikely to be achieved, and of Pb cannot be achieved in simulated digested sludge from inputs from trade sources known to this study.

8.2.3.

The effect of eliminating 1 or 2 highest concentration cases on calculated mean concentration of Pb in unstabilised and simulated digested and lime stabilised sludges on simple compliance with proposed mandatory

and recommended limits.

Distribution of concentration cases on which the Pb mean concentration in unstabilised sludge and hence in simulated digested and lime stabilised sludges, is characterised by two anomalously high concentrations, the effect of eliminating 1 or 2 of these highest concentrations on simple compliance will now be considered. See fig. 8.2.

Method. Distribution of Pb concentration cases is discussed later in connection with probability theory and compliance. For the purposes of considering simple compliance of Pb concentrations in unstabilised, simulated digested and lime stabilised sludges the effect of simply omitting 0, 1 or 2 highest concentration cases and recalculating mean concentrations in SS output is shown in table 8.11. Compliance of recalculated mean concentrations with proposed M and R limit values is also indicated.

Results. Results are shown in table 8.11.

The effect of omitting 0, 1 or 2 highest concentration cases is to reduce calculated mean concentrations from 1053.8 to 672.9 or 469.171 $mgkg^{-1}$ DS in unstabilised sludge, equivalent to reducing from 1426.845 to 911.1066 or 635.258 $mgkg^{-1}$ DS in simulated digested sludge and from 924.393 to 590.268 or 411.577 $mgkg^{-1}$ DS in simulated lime treated sludge respectively.

As M and R limits are 1000 and 750 $mgkg^{-1}$ DS it can be seen that lime treated sludge already complies with M limit. With the omission of 1 highest concentration case unstabilised, simulated digested or lime treated sludges are able to comply with M and R, M or M and R limits respectively. With reduction of 2 highest concentration cases simulated digested sludge complies with M and R limits.

Comment

With the omission of one highest concentration case, of 9, Pb mean concentrations in all 3 sludges are able to comply with the proposed M limit.

8.2.4. Conclusions

Simple compliance with proposed EC M and R limit values. Taking the results shown in tables 8.8 - 11 it is shown clearly that with the present framing of the proposed directive the use of lime treatment of sludge, if acceptable, may be operationally preferred to anaerobic digestion as a method of stabilisation when compliance of metal concentrations in sludge to those specified in Annex 1A of the proposal for a directive are considered.

Tables 8.9 and 8.10 also show that when a reduction from known sources is feasible a very small number of trade sources may play a key role in this reduction.

In the case of Pb the elimination of anomalously high concentrations in sludge output may provide a strategy for achieving compliance with proposed limits.

Although reductions from known input sources could reduce Cd mean concentrations in unstabilised and lime treated sludges to comply with proposed M limit values, the required reduction in simulated digested sludge may not be feasible from inputs known to this study.

Dual input data for Ka + b, in which one agreed flow is presented for two outputs, is a serious limitation when potential reduction of Cd input from known trade sources are calculated.

TABLE 8.6

Annual mean concentrations of Zn, Cu, Ni, Cd, Pb and Cr in unstabilised sewage sludge output from a YWA City WPC works 1.4.80 - 31.3.81 and required reduction in order to meet Mandatory limits stated in the proposal for an EC Directive

Column	1	2	3	4	5	6
Source of Data	Proposed EC Directive(a)		Table 8.1	Calculated	$O - M/O$	Col.5 and table 8.4 Col.4
Symbols	M	R	O(b)	O-M		$\frac{O-M}{O} \gtrless \frac{O^T}{O}$ (c)
Parameter	Mandatory Limits	Recommended	Annual mean conc.	Required Reduction	Req.Reduction as percent of O	
Units	$mgkg^{-1}$ Ds in SS		$mgkg^{-1}$ DS in SS	$mgkg^{-1}$ DS in SS	%	
Metal						
Zn	3000	2500	1568.0	-	-	—
Cu	1500	1000	753.443	-	-	—
Ni	400	300	438.68	38.68	8.817	<
Cd	40	20	45.76	5.76	12.587	<
Pb	1000	750	1053.8	53.8	5.105	<
Cr	NR	750	573.32	-	-	—

Notes:
a. Annex 1A, OJC 264 p.6 8.10.82.
b. In unstabilised sewage sludge.
c. Required reduction as % of O greater or smaller than output equivalent of total known trade input T.
NR. No Mandatory requirement.

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TABLE 8.7

Minimum required reductions of annual mean concentrations of Ni, Cd and Pb in unstabilised sewage sludge to equal proposed Mandatory limits (h) equivalent input load and equivalent percentage of inputs from highest known trade sources.
1.4.80 - 31.3.81 data

Column	1	2	3	4(a) 4(b)
Source of Data	Table 8.5	Table 8.2	Calculated (a)	Calculated (b)
Symbols	O	P	≡T	% T A,F,B etc.
Parameter	Output annual mean conc. Req.Reduction	Partition Ratio	Equivalent Input load	Equivalent percentage of Known Trade Source Load
Units	$mgkg^{-1}$ DS SS		kgy^{-1}	% of Code (f)
Metal				
Ni	38.68	.35(d)	780.673	10.722 of A
	Omitting highest conc. of A (e)			
	38.68	.499	547.566	12.850 of A (e)
	"	.4	683.089	16.031 of A (e)
Cd	5.76	.9	45.21	80.183 of F
		.738	55.134	97.784 of F (g)
	5.76	.9	45.21	53.287 of F+B
		.738	55.134	64.984 of F+B
Pb	53.8	.95	400.045	71.299 of H
		.92	413.09	73.624 of H
		.8	475.054	84.668 of H

Notes:
a. Calculated using equation B11.
b. Calculated using equation B12.
c. Underlined partition ratios are calculated on the basis of 79/80 data.
d. Lower partition ratio found necessary as higher ratio results, table 8.4, are not feasible.
e. Recalculated omitting highest concentration case from data on which the mean is based.
f. Percentage of known trade source inputs of Ni, Cd and Pb to sewers shown in table 8.5 cols. 1 and 2.
g. Such a high reduction is of doubtful operational feasibility.
h. See table 8.6 note a.

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TABLE 8.8

Annual mean concentrations of Zn, Cu, Ni, Cd, Pb and Cr in unstabilised, simulated digested and simulated lime stabilised sludge and reduction and percentage reduction required to meet Mandatory or Recommended limits stated in the Proposal for an EC Directive.

Column	1a	1b	2	3	4	5a	5b	6
Source of Data	Proposed Directive(a)		Table 8.1	0 x 1.354(b)	0 x 0.8772(c)	rO-M	$rO-M/_{rO}$	Col.5b & Table 8.4 Col.4
Symbols	M	R	O	rO	rO			
Parameter	Limits		Unstabilised	Sim.An.Dig.	Sim.Lime-treated	Required to meet M		Potential to meet from known input sources
	Mandatory	Recommended	An.mean conc.	mean conc.	mean conc.	Reduct'n of mean conc.		
Units			$mgkg^{-1}$ dry solids in sewage sludge				% rO	% rO $\gtrless$ $\%O^T/_{O(d)}$
Metal								
Zn	3000	2500	1568.06	2123.153		-	-	-
Zn	"	"	"		1375.502	-	-	-
Cu	1500	1000	753.443	1020.162		-	-	-
Cu	"	"	"		660.920	-	-	-
Ni	400	300	438.68	593.973		193.973	32.657	< (d)
"	"	"	"		384.810	-	-	-
Cd	40	20	45.76	61.959		21.959	35.441	> (d)
Cd	"	"	"	"	40.141	0.141	0.351	< (d)
Pb	1000	750	1053.8	1426.845		426.845	29.915	> (d)
Pb	"	"	"		924.393	-	-	-
Cr	NS	750	573.32	776.275		26.275	3.385	< (d)
Cr	NS	"	"		502.916	-	-	-

Notes:
a. See table 8.6 note a.
b. See this study section 7.3.
c. See this study section 7.3.
d. As in the model %rO is equivalent to %O it is possible to compare the required reduction as %rO with concentrations attributable to inputs from known trade source inputs, expressed as $O^T/_{O}$% (Table 8.4 col.4) to get an indication of potential for reduction from known trade source inputs.

$\geq$ Required reduction greater than concentration attributable to known trade sources.
$\leq$ " " less " " " " " "

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TABLE 8.9

Minimum required reductions of simulated digested annual mean concentrations of Ni, Cd, Pb and Cr in simulated digested sewage sludge to equal proposed Mandatory or Recommended limits (g) equivalent input load and equivalent percentage of inputs from highest known Trade Sources, 1.4.80-31.3.81 omitting data for dual input Source Ka, except where indicated.

Column	1	2	3	4	5a	5b
Source of data	Table 8.8 Col.5a	Col.1 ÷ 1.354	Table 8.2	(a)	(b)	
Symbols	rO	O	P	≡ T	≡ $T/_T$	A F B etc.
Parameter	Required reduction in digested sludge	Equivalent reduction in unstabilised sludge	Partition ratio (c)	Equivalent input load	Equivalent percentage of known trade source load.	
Units	$mgkg^{-1}$DS in SS	$mgkg^{-1}$DS in SS		kg p.a.	% of source	
Metal						Source Code
Ni	193.973	143.259	.35 (d)	2891.3805	39.712	of A
		Omitting highest concentration of A(e)				
	193.973	143.259	.499	2028.019	47.594	of A(e)
	"	"	.4	2529.954	59.374	of A(e)
Cd	21.959	16.218	.9	127.292	64.632	of T(f)
		"	.738	155.234	78.819	of T(f)
		"	.9	127.292	83.316	of Ka + F(f)
		"	.738	155.234	NF	of Ka + F(f)
	"	"	.9	127.292	70.233	of Ka+F+B(f)
	"	"	.738	155.234	85.650	of Ka+F+B(f)
Pb	426.845	315.247	.95	2344.113	>100	
Cr	Required reduction to meet Recommended Limits (h)				Required to Meet R	
"	26.275	19.405	.9637	142.244	13.301	of A
			.75	182.774	17.091	of A

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(Table 8.9 continued)

Notes:

a. Calculated using equation B11.

b. Calculated using equation B12.
Input load of sources T are shown in table 8.4 col.2.
Input loads of sources A, B and F shown in table 8.5 col.2.

c. Underlined partition ratios are calculated on the basis of 79/80 data.

d. Extra low partition ratio found necessary to produce feasible results. See table 8.4.

e. Alternative lower input from source A calculated when highest concentration case is omitted from calculation of mean.

f. Omitting data from source Kb and including data for Ka.

g. See table 8.6 note a.

h. No Mandatory limit is specified for Cr.

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TABLE 8.10

Minimum reduction of annual mean concentration of Cd in simulated lime treated sewage sludge to equal proposed Mandatory limits (d), equivalent input load and equivalent percentage of inputs from highest known trade source. 1.4.80-31.3.81 data, omitting data for dual input source Ka.

Column	1	2	3	4	5a	5b
Source of Data	Table 8.8 Col.5a	Col.1 ÷ 0.8772(e)	Table 8.2	(a)	(b)	
Symbols	r O	O	P	≡T	$\equiv T/T^F$	
Parameter	Required reduction in L.Treat. sludge.	Equivalent reduction in unstabilised sludge	Partition Ratio (e)	Equivalent input load	Equivalent percent of known trade source load	
Units	$mgkg^{-1}$ DS in SS	$mgkg^{-1}$ DS in SS		kg p.a.	%	Source code
Metal						
Cd	0.141	0.161	.9	1.262	2.238	of F
			.738	1.539	2.729	of F

Notes:

a. Calculated using equation B11.
b. Calculated using equation B12.
c. Underlined partition ratio is calculated on the basis of 79/80 data.
d. OJC 264 p.6 8.10.1982.
e. As in table 8.8 col.4 based on 14% increase in dry solids due to added lime.

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TABLE 8.11

Effect of omitting 0, 1 or 2 highest concentration cases on calculated mean concentrations of Pb and on simple compliance with Mandatory and Recommended Limits specified in Annex 1A of an EC proposal for a directive (e).

Column	1	2	3	4	5	6	7	8	9		
Cases	30	29a	28b	30	29a	28b		8a	7b		
Date Source	(Table 8.8 Col.2)			Col.1x 1.354c (Table 8.8 Col.3)	Col.2x 1.354c	Col.3x 1.354c	Col.1x 0.8772d (Table 8.8 Col.4)	Col.2x 0.8772d	Col.3x 0.8772d		
Parameter	Mean concentrations in undigested sludge			Mean concentrations in simulated dry sludge			Mean concentration in simulated Lime stabilised sludge				
Constraints										Proposed	
										e Mandatory	e Recommende
Units			mgkg^{-1} dry solids in sewage sludge								
Metals											
Pb	1053.8			1426.845			924.393*			1000	750
Pb		672.9**			911.1066*			590.268**		"	"
Pb			469.171**			635.258**			411.557**	"	"

Notes:
a. Omitting 1 highest concentration case and recalculating the mean concentration.
b. " 2 " " " cases " " " "
c. Concentration factor calculated if 40% reduction of organic matter. see S7.3.
d. Dilution factor calculated if 14% increase in dry solids. see S7.3.
e. In OJC 264 Annex 1A p.8. 8.10.82.
* Complies with M but not R limits.
** Complies with M and R limits.

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8.3 Probability of Compliance and the implications of anomalously high metal concentrations in sewage sludge.

8.3.0. The practical problems of compliance, or degree of compliance, are not discussed or specified in the proposal for a directive on the use of sewage sludge in agriculture[2] or the technical memorandum which accompanies it.[3] Article 3 of the proposal does state that "Member states shall ensure that the Mandatory values laid down in Annexes 1A, 1B and 1C are complied with when sludge is spread."[4] Article 4 then states quite clearly that "Sludge having a concentration of one or more elements in Annex 1A higher than the Mandatory values may not be used in Agriculture."[5] From this it is inferred that the critical parameter for liquid sludge is the concentration of metals in the tanker about to leave the works, specified in terms of concentration in dry matter as in the limit values specified in Annex 1A. However article 10 states: "Sludge and the soil on which it is spread shall be analysed in accordance with the schedule Annex II"[6] which states, "As a rule sludge is to be analysed at least every six months. Where changes occur in the characteristics of the sewage being treated the frequency of analyses must be increased. If the results of the analyses do not vary significantly over a full year the sludge may be analysed every 12 months.[7] The annex then lists the parameters to be covered by analyses.

From the above it is assumed, for the purposes of this study, that if sampling is to take place at infrequent intervals it is necessary to consider the problem of compliance when investigating the potential for further control of trade effluent inputs to meet the proposed requirements of the directive.

Using probability theory it may be predicted that providing the sample analyses are representative and concentrations are normally distributed then there is 95% probability that concentrations are equal to or less than $\bar{X} + (SD \times 1.645)$.[8] From this it is seen that controlling the standard deviation may be as important as controlling the mean.

Theoretically quite small SDs should be achievable by storing several days' production of sewage sludge. But unless some form of homogenisation and mixing is used this may not be achievable in practice.

A study of a large London treatment works where primary and surplus activated sludge were combined and digested, primary digestion average detention time being 30 days, followed by storage in secondary anaerobic digesters with capacity for 25 days, is reported by Beckett. He reports that concentrations of metals derived from sequential daily composite samples were log normally distributed in mgl^{-1} of raw sewage entering the works and in mgl^{-1} and $mgkg^{-1}$ dry solids in tanker loads of sludge leaving the works. He concludes from this May-December 1973 study that "There are two main effects analyses of crude sewage, and of sludge removed at stages during its treatment, show an approximately log normal distribution in all but the lowest concentrations, and the range of values decreases during treatment,"[9] and observes, "Control procedures planned to hold the heavy metal content of sewage or sludge below some specified level should recognise this."[10]

In view of this comment, and of the constraints specified in Annex 1A of the proposal for a directive, 1980/81 metal concentrations in unstabilised sludge from the YWA City WPC works were plotted as shown in figs. 8.1 and 8.2. Distributions are of two distinct types, those for Cd, Ni and Cr having ranges of 1.744, 1.701 and 1.294 times their means, Standard deviations being 43.819, 41.99 and 32.729 percent of means respectively, forming close distributions, that of Ni appearing to be bimodal, but the number of cases being too small to confirm or negate that impression.

Zn, Cu and Pb distributions, shown in fig. 8.2, are characterised by ranges of concentrations of 2.452, 4.222 and 3.879 times their means, and standard deviations 50.82, 86.405 and 121.2 percent of means respectively. Zn and Cu distributions are characterised by close clusters positively skewed or possibly bimodal distributions but each further skewed by two very high concentrations. Pb, for which only 9 cases are available, also consisted of a small cluster of 6 cases, a very low

concentration, 1.158% $\bar{X}$, and 2 very high concentrations.

Having pointed out that "it is commonly supposed that domestic or background sources make a proportionately smaller contribution to the Cd Ni and Cr load of the sewage than do its Cu, Zn or Pb load..."[11] Beckett was able to support this supposition by comparing concentrations in raw sewage during Christmas week with those for the previous week. Concentrations of Cu, Zn and Pb during Christmas week being 43.617, 40.078 and 46.164 percent respectively of those presented by Beckett for the previous week, percentages of corresponding concentrations of Cd, Ni and Cr were 35.714, 22.727 and 30.137 respectively. This grouping corresponds with the groupings of distribution shown in fig. 8.2 and fig. 8.1 respectively. The Cd, Ni and Cr shown in fig. 8.1 may then be regarded as probably having a higher percentage of metal of trade effluent origin than the Zn, Cu and Pb shown in fig. 8.2.

When percentages derived from Beckett's comparison of metal concentrations in Christmas week/previous week are compared with percentage of $SD/\bar{X}$ in the present study the following is found:-

	Ex. Beckett London 1973. Raw Sewage Xmas conc./ Previous week conc.%	This study YWA City WPC 1980/81 $SD/\bar{X}$ % Unstabilised sewage sludge
Pb	46.154	121.2
Cu	43.617	86.405
Zn	40.078	50.82
Cd	35.714	43.819
Cr	30.137	32.729
Ni	22.727	41.99

On observation rank order is the same except for the juxtaposition of Cr and Ni, an effect which may well be influenced by the balance of local industries. The rank order would suggest the size of $SD:\bar{X}$ ratio found in this present study may reflect the size of domestic and background contribution to metal concentrations in sewage sludge output of the YWA WPC works.

Occurrence of Highest concentrations

Further examination of the data on which distribution of Zn, Cu and Pb, (fig.8.2),are based reveals that highest concentration of each of these metals are from a sample taken on 9.4.80, a Wednesday following a Bank Holiday monday, the second highest concentrations of same metals are for a sample taken on 11.11.80, a Tuesday.

Now these high concentrations could be due to errors of sampling, preparation or analyses or of some other activity being carried out in the sewerage system, or at the treatment works by the YWA itself, or by its agents. If not the possibility that a causal input of metals originating from one point source, by accident or by volition must be given serious consideration. Possible point sources being from Public Authorities, Public Services, Institutions, Crown Works and Trade works. The possibility of an enhancing domestic effect must also be considered.

The effect of solids.

It is noticed from the data that total solids in sewage sludge on 9.4.80 and 11.11.80 were 4.6 and 7.1 percent respectively, compared with a mean of 6.2783% for the 30 days on which metal concentration data are available. Now metal concentrations expressed as $mgkg^{-1}$ 'Dry matter' of sewage, as required by the proposed Directive Annex 1A, are just as much a function of dry solids content as of metal content of liquid sludge. Therefore, if it is assumed that the total solids contents given above are the same, or close to, those on which the metal concentrations are calculated, they may be compared by comparing their equivalents for mean values of total solids, as shown in table 8.12a. It is seen that for Sample A and Sample B taken on 9.4.80 and 11.11.81 respectively 4620 and 3640 mg Zn kg^{-1} are recalculated to be 3385 and 4116.4 $mgkg^{-1}$ of mean total solids, 3540 and 2530 mg Cu kg^{-1} are recalculated to be 2593.7 and 2861.1 $mgkg^{-1}$ of mean total solids and 4100 and 2100 mg Pb kg^{-1} are recalculated to be 3004

and 2374.85 $mgkg^{-1}$ of mean total solids.

It is seen that Zn and Cu concentrations which in Sample A gave higher concentrations than those for sample B by 980 and 1010 $mgkg^{-1}$ respectively are at mean total solids less than those for sample B by 731.4 and 267.4 $mgkg^{-1}$ respectively. The rank having reversed and the difference narrowed. While Pb concentration from sample A when recalculated to mean total solids is still greater than concentration recalculated from sample B, but the difference between the sample concentrations has narrowed from 2000 in the original samples, to 629.15 $mgkg^{-1}$ in those recalculated to mean total solids. Recalculated concentrations still lie well clear of the rest of the concentrations shown in fig. 8.2.

Now to carry this line of enquiry further it would be necessary to know if the total load of solids entering the works for the suspected period was considerably less than usual, daily output of sludge might give a reasonable indication of this but unfortunately, although it is known that less than average sludge solids was tankered away during the week containing 9.4.80, this may well be due to the influence of the Bank Holiday itself, storage effect is not known.

But if solids load entering the works was reduced beyond normal fluctuations and thus having the effect of giving high concentrations of Zn, Cu of Pb in sludge for normal input loads,would it not have a similar effect on Cd, Ni and Cr concentrations? On examination it is found that on 9.4.80 concentrations of Cd, Ni and Cr lie 1 interval above, 1 interval below and 1 interval below their respective medians while on 11.11.80 Cd Ni and Cr concentrations were two intervals above the median, the highest interval and the highest interval respectively, Ni and Cr highest intervals being adjacent to distribution clusters as shown in fig. 8.1.

It is concluded from the above that:-

a) Any consideration of high, or low values of metal concentrations in

liquid sludge presented as concentrations in dry solids must take account of variation in percentage total solids in that liquid;

b) As the concentrations of Zn, Cu and Pb on 9.4.80 and 11.11.80 do not lie on, extend the cluster or lie near to the clusters of other concentrations their excess metal content is probably due to some Water Authority activity or an input made with or without Water Authority permission from 1 point source, but possibly more, on each occasion.

c) Although an enhancing social effect cannot be ruled out it is noticed that in Beckett's comparison, Xmas week concentrations of Zn, Cu and Pb were less than half of those in the previous week.

d) That the high SDs of Zn, Cu and Pb concentrations, found in this study are due to the presence of the two very high concentrations rather than reflecting degree of domestic input.

How feasible are these high concentrations?

Before proceeding it is useful to attempt to further understand what the high concentrations of Zn, Cu and Pb may represent in terms of input.

If data already presented is taken at its face value and concentrations for 9.4.80 shown in fig. 8.2 are recalculated for mean total solids as shown in col.4 of table 8.12a, then as shown in table 8.12b, when Zn, Cu and Pb concentrations are 3385, 2593.7 and 3004 $mgkg^{-1}$ and partition ratios are .9135, .8806 and .92 respectively then using equation B11 calculated equivalent input for a mean day is 71.715, 57.003 and 63.193 kg, being 38.494, 40.17 and 41.042 kg. of Zn, Cu and Pb in excess of mean input per mean day. It should be noted that calculated input per mean day is based on dividing per annum data including the days of high concentration by 365 and therefore the excesses calculated slightly under-estimate excess over mean of days when there were no high concentrations.

If input per mean day is calculated without the 2 highest concentrations equivalent respective excess causal inputs of Zn, Cu and Pb are

42.371, 44.025 and 53.323 kg, the last for Pb being of very low reliability. See table 8.12b, NB note (f).

But the sludge from which these samples were taken was most unlikely to represent 24 hours mean production at these high concentrations. If, hypothetically it is imagined that the sample was taken from 5-6 hours of mean sludge production of the high concentration shown in table 8.12b then this would represent an approximate excess input of 10 kg of Zn, Cu and Pb during that period.

How might an extra 10 kg or so enter sewers, over a short period of time, from a point source? One possible answer is from the accidental or deliberate emptying of a tank containing high concentrations of the metals in question. In this connection it was noticed that metal concentrations of effluent, from one low input flow source, were such that 10^3 litres of effluent, at the face value of those concentrations, would have contained 18 and 13.8 kg of Zn and Cu respectively. Although the date of sampling in this case lay 4 months outside the study period, the case clearly shows how such small inputs of high concentration can have considerable effects on concentrations of metals in sewage sludge output, which in turn may have considerable effects on the mean and standard deviation and thus potential compliance of a sewage sludge to proposed, or existing, constraints.

It is concluded that the occurrence of high concentrations of Zn, Cu and Pb such as those for 9.4 and 11.11.80 are quite feasible and causal inputs, by accident or by design, may be relatively small and therefore when unauthorised difficult to control.

However if excess is thought to be due to an unauthorised input, certain point sources must be highly suspect because of their past history of input profile. It remains to be seen if computer 'fingerprinting' of sources reported to be used by Wessex Water Authority to track down sources of river pollution, can be refined for use in tracking down sources of

unauthorised inputs to sewers.[12]

Whether the two occasions of high concentrations of Zn, Cu and Pb considered above are two isolated incidents occurring at the beginning and approximately half way through a financial year, or as 2 cases in 30 they represent, approximately, inputs on 24 days throughout the year, is not known. If the latter is the case then it may be possible to regard the distributions of Zn, Cu and Pb as bimodal rather than being log normally distributed. If this were the case possible control strategies might more easily be inferred.

The effect of eliminating 1 or both of the high concentrations of Zn, Cu and Pb, shown in fig. 8.2, on 95% probability of compliance will now be considered.

8.3.1. Effect of omission or replacement of 0, 1 or 2 highest concentration cases of Zn, Cu and Pb on annual mean concentrations, standard deviations and on 95% probability of compliance with proposed EC M and R limits.

In view of the finding that 2 anomalously high concentration cases, occurring on 9.4 and 11.11.81, strongly influence standard deviation and annual mean concentrations of Zn, Cu and Pb in unstabilised sludge output from the YWA WPC works, their effect on the 95% probability of compliance of sludges with proposed EC M and R limits is now investigated.

8.3.1.1. Unstabilised sludge

Method. Mean, standard deviation and SD:$\bar{X}$ ratio of Zn and Cu concentrations were calculated omitting 0, 1 or 2 highest concentrations of 30 cases, shown in fig. 8.2. Similarly for Pb, but because of the low number of concentration cases, SD and hence SD:$\bar{X}$ ratio, were calculated replacing omitted high concentrations by recalculated mean values to maintain an N of 9.

Results. Results are shown in table 8.13.

Mean concentrations of Zn, Cu and Pb reduce from 1568.06, 753.443, 1053.8 $mgkg^{-1}$ to 1462.827, 657.379, 672.9 $mgkg^{-1}$ on omission of 1 highest concentration, and to 1385.07, 590.5, 469.171 $mgkg^{-1}$ respectively on omission of 2 highest concentrations. The fall in SD is steeper reducing from 796.887, 651.03, 1277.2075 to 559.986, 390.003, 571.42 with 1 highest omission, to 378.641, 152.376, 188.305 respectively with 2 highest omissions. Fall in SD:$\bar{X}$ ratio being from 50.82, 86.405, 121.2 to 38.281, 59.326, 84.919 percent with 1 omission to 27.337, 25.805, 40.136 percent with two omissions.

Comment

Results show that omission of 1 or 2 highest concentrations have a considerable effect on mean concentrations calculated, reduction is greatest for Pb. An even larger reduction takes place in SD and SD:$\bar{X}$ ratio.

95% Probability of Compliance

Method. Holding SD at values shown in table 8.13 and applying the one tailed probability deviant 1.645 in the formula $\bar{X}$ + 1.645 SD, theoretical critical concentration is calculated, as if Zn, Cu and Pb distributions were normal, below which 95% probability of compliance can be achieved for mean concentrations which are then compared with proposed M and R limits.

Results. Results are shown in table 8.14. Single ticked values comply with M limits only, double ticked values comply with M and R limits.

Critical concentrations of Zn, Cu and Pb reduce from 2878.9, 1824.4, 3154.8 to 2384.00, 1298.9, 1612.9 $mgkg^{-1}$ respectively when 1 highest concentration is omitted and to 2007.9, 841.2, 778.9 $mgkg^{-1}$ respectively when 2 highest concentrations are omitted.

Zn critical concentration complying with M limit without omission.

With 1 omission Zn complies with M & R and Cu with M limit.

With omission of 2 highest concentrations Zn and Cu concentrations

comply with M and R limits and Pb with M limit.

Comment.

It is clearly seen that on the basis outlined above, if two anomalously high concentrations of Zn Cu and Pb in sewage sludge could have been eliminated all three metal mean concentrations and standard deviations would allow 95% probability of compliance with proposed M limit values to have taken place. However, the problem of compliance is now in part due to the high standard deviations when used in the probability of compliance formula.

Required standard deviation for 95% probability of compliance, when 0, 1 or 2 highest concentrations are omitted, are now calculated.

Results. Maximum standard deviations, and resultant SD:$\bar{X}$ ratios at which 95% probability of compliance with proposed M limit are shown for Zn Cu and Pb in table 8.15, and compared with unreduced SDs shown in table 8.13.

When 0 highest concentration case is omitted,

a. No reduction in Zn SD is required.

b. Reduction of Cu SD from 86.405 to 60.232 percent of mean is required.

c. Compliance of Pb by reduction of SD only is not feasible.

When 1 highest concentration case is omitted,

a. No reduction of Zn SD is required.

b. No reduction of Cu SD is required.

c. Reduction of Pb SD from 84.919 to 29.55 percent of mean is required.

When 2 highest concentration cases are omitted,

a. No reduction of Zn SD is required.

b. No reduction of Cu SD is required.

c. No reduction of Pb SD is required.

Comment.

Reduction of standard deviation might provide a useful strategy in achieving compliance of unreduced mean concentrations of Cu with the proposed

M limit. But on the basis of available data Pb concentrations would still require omission of at least 1 and probably 2 highest concentration cases from the mean.

8.3.1.2. Achievement of 95% probability of compliance of stabilised sewage sludges with proposed EC limit values. Methods used, in section 8.3.1.1, with unstabilised sludges are now extended and applied to simulated digested and lime stabilised sludges.

8.3.1.2.1. The effect of omitting or replacing 0, 1 or 2 highest concentrations of Zn, Cu or Pb in simulated digested sewage sludge on achievement of 95% probability of compliance with proposed M and R limit values. Without or with reduction of standard deviation.

Method. Holding percent SD:$\bar{X}$ ratios to those in unstabilised sludge, as shown in table 8.13, digestion with 40% reduction of organic matter is simulated and 95% probability concentrations calculated when 0, 1 or 2 highest concentration cases are omitted.

Results. Results are shown in table 8.16.

When 0, 1 or 2 highest concentrations are omitted Zn, Cu and Pb calculated concentrations reduce from 3898.031, 2470.238, 4271.599 $mgkg^{-1}$ DS in SS to 3227.936, 1758.711, 2183.867 $mgkg^{-1}$ DS and to 2718.697*, 1138.985*, 1054.631 $mgkg^{-1}$ DS in SS respectively.

Starred concentrations indicate that with omission of 2 highest concentrations Zn and Cu concentrations are able to achieve 95% probability of compliance with the proposed M limits, Pb concentration is unable to comply with the proposed limit value.

Beckett reports that one of the effects of digestion and storage was in the narrowing of range of metal concentrations.

Results shown in table 8.17 show required SD in simulated digested

sludge to achieve 95% probability of compliance with proposed M limit when 0, 1 or 2 highest concentrations are omitted.

When 0 highest concentration case is omitted

a) A maximum Zn SD of 25.106% of mean concentration is required.

b) A maximum Cu SD of 28.591% of mean concentration is required.

c) Compliance of Pb by reduction of mean concentration is not feasible.

When 1 highest concentration case is omitted

a) A maximum Zn SD of 31.285% of mean concentration is required.

b) A maximum Cu SD of 41.655% of mean concentration is required.

c) A maximum Pb SD of 5.93% of mean concentration is required.

When 2 highest concentration cases are omitted

a) A maximum Zn SD of 36.454% of mean concentration is required.

b) A maximum Cu SD of 53.257% of mean concentration is required.

c) A maximum Pb SD of 34.9% of mean concentration is required.

Comment

Whether it is operationally practicable to reduce Zn and Cu SDs so that compliance can be achieved without omission of a highest concentration is not known.

Although required SDs for Zn and Cu when 1 highest concentration case is omitted may be attainable, reduction of 2 highest concentration cases gives required SDs for Zn and Cu higher than the unreduced SDs in unstabilised sludge, shown in table 8.13, and Pb SD of 34.9% of mean concentration may be operationally attainable.

It is concluded that a combination of eliminating 2 highest concentrations and reducing SDs to critical value could provide a useful strategy for achieving 95% probability of compliance of Zn, Cu and Pb mean concentrations in simulated digested sludge with proposed M limit values.

8.3.1.2.2. Simulated lime treated sludge

The effect of omitting or replacing 0, 1 or 2 highest concentrations

of Zn, Cu or Pb in simulated lime treated sewage sludge on achievement of 95% probability of compliance with proposed M and R limit values. Without or with reduction of standard deviation.

Method. Holding percent SD:$\bar{X}$ ratios to those in unstabilised sludge, as shown in table 8.13, lime treatment with 14% increase in dry solids is simulated and 95% probability concentrations calculated when 0, 1 or 2 highest concentration cases are omitted.

Results. Results are shown in table 8.18.

When 0, 1 or 2 highest concentrations are omitted Zn, Cu and Pb 95% probability concentrations reduce from 2525.371*, 1600.364, 2767.39 to 2091.245*, 1139.395*, 1414.836 and to 1761.33*, 737.901*, 683.251* $mgkg^{-1}$ DS in SS. respectively.

Starred concentrations indicate that with omission of 0 highest concentration in SS, Zn concentration is able to achieve compliance with proposed M limit.

With omission of 1 highest concentration in SS, Zn and Cu concentrations are able to achieve compliance with M and R, and M limits respectively.

With omission of 2 highest concentrations in SS, Zn, Cu and Pb concentrations are able to achieve compliance with M and R limit values.

To what extent standard deviations in unstabilised sludge can be reduced as part of the lime stabilisation process is not known. The extent of required reduction may be calculated by comparing SDs for unstabilised sludge shown in table 8.13 with calculated maximum required SDs for 95% probability of compliance.

Results. Results are shown in table 8.19.

When 0 highest concentration case is omitted

a) A maximum Zn SD of 71.795% of mean concentration is required, higher than SD in unstabilised sludge.

b) A maximum Cu SD of 77.177% of mean concentration is required, lower than SD in unstabilised sludge.

c) A maximum Pb SD of 5.022% of mean concentration is required, lower than SD in unstabilised sludge.

When 1 highest concentration case is omitted

a) A maximum Zn SD of 81.333% of mean concentration is required, higher than SD in unstabilised sludge.

b) A maximum Cu SD of 97.43% of mean concentration is required, higher than SD in unstabilised sludge.

c) A maximum Pb SD of 42.197% of mean concentration is required, lower than SD in unstabilised sludge.

When 2 highest concentration cases are omitted

a) A maximum Zn SD of 89.311% of mean concentration is required, higher than SD in unstabilised sludge.

b) A maximum Cu SD of 115.248% of mean concentration is required, higher than SD in unstabilised sludge.

c) A maximum Pb SD of 86.918% of mean concentration is required, higher than SD in unstabilised sludge.

Comment.

Whereas required SDs of Zn and Cu concentrations may be achievable without omission of a highest concentration, corresponding Pb SD, 5.022% of mean is regarded as operationally not practicable. However with the removal of 1 highest concentration required Pb SD of 42.197% of mean concentration may be practicable.

From the above it would appear that with elimination of 1 highest Pb concentration, and reduction of Pb SD to 42.197% of mean concentration, 95% probability of compliance with proposed Zn Cu and Pb M limit values might be achieved by simulated lime treated sludge.

8.3.1.3. Conclusions

From the above results it is concluded that:

a) the interrelationship of dry solids content and metal concentrations in sewage sludges should not be ignored;

b) relatively few anomalously high concentrations may highly influence both mean metal concentrations and standard deviation of those concentrations in sewage sludges;

c) the elimination, or reduction, of anomalously high concentrations may not be easy to achieve, but if compliance with EC proposed M limits becomes a requirement where sewage sludge is to be disposed by use on agricultural land, this form of control may be well worth considering;

d) high concentrations may be due to inputs from single sources of relatively small loads of metals;

e) 95% probability of compliance of Cu and Pb concentrations with proposed M limit was most easily achieved in lime treated sludge, and most difficult in digested sludge;

f) 95% probability of compliance with proposed M limit was achieved in all three sludges by Zn mean concentrations and standard deviations without reduction;

g) the importance of reducing standard deviations on 95% probability of compliance has been demonstrated;

h) when two highest concentrations of Zn, Cu and Pb concentrations were omitted, further reduction of SD was only required for 95% probability of compliance of Pb concentration in simulated digested sludge, with proposed M limit value, showing that

i) when 95% probability of compliance is required elimination of anomalously high concentrations may in itself reduce SDs to levels required for compliance with proposed M limits.

TABLE 8.12a

Metal concentrations in two samples of sewage sludge of 4.6 and 7.1 percent total solids recalculated to mean total solids of 30 samples, 1980/81 data.

Column	1	2	3	4	5	6
	Sample A	Sample B	A-B	XA	XB	XA-XB
Date	9.4.80	11.11.80		From A recalculated for 6.2783%	From B recalculated for 6.2783%	
Total Solids	4.6%	7.1%				
Metal	metal concentrations in $mgkg^{-1}$ Total Solids					
Zn	4620	3640	980	3385	4116.4	-731.4
Cu	3540	2530	1010	2593.7	2861.1	-267.4
Pb	4100	2100	2000	3004	2374.85	629.15

TABLE 8.12b

High concentrations of Zn, Cu and Pb in unstabilised sewage sludge, equivalent input load and calculated equivalent excess input per mean day.

Source of data	Table.8.12a Col.4	Table 8.2 col.2	a	Table 8.3 col3&365	
Symbol	XO	P	xI	I	xI-I
Parameter	Recalculated mean conc. (b)	Partition ratio (c)	Equivalent input load day^{-1}	Mean input mean day^{-1}	Excess input 9.4.80 day^{-1}
Unit	mgkg DS in SS		kg day^{-1}	kg day^{-1}	kg day^{-1}
Metal					
Zn	3385	.9135	71.715	33.22 (d)	38.494
Zn	"	"	"	29.344(e)	42.371
Cu	2593.7	.8806	57.003	16.883(d)	40.17
Cu	"	"	"	12.978(e)	44.025
Pb	3004.	.92	63.193	22.151	41.042
Pb	"	"	"	9.87 (e,f)	53.323

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Notes for Tables 8.12a and 8.12b.

a. Using equation B11.

b. 9.4.80 concentration recalculated to mean solids.

c. Underlined partition ratios are calculated on the basis of 1979/80 data.

d. Mean input day is derived from per annum data which includes 2 high concentration days.

e. Mean input day is derived from per annum data which excludes 2 high concentration days. See table 8.13 col. G.

f. Equivalent input calculated using mean concentration calculated on the basis of 7 concentration cases, one of which was very low.

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TABLE 8.13

Effect on annual mean and standard deviation of metal concentrations in unstabilised sewage sludge, of omitting, or replacing, 0, 1 or 2 highest concentration cases of Zn, Cu or Pb

Column	A	B	C	D	E	F	G	H	I
Cases in $\bar{X}$	30	30	30	29a	29a	29a	28b	28b	28b
Parameter	Mean	SD	SD/$\bar{X}$	Mean	SD	SD/$\bar{X}$	Mean	SD	SD/$\bar{X}$
Units	$mgkg^{-1}$ DS in SS		%	$mgkg^{-1}$ DS in SS		%	$mgkg^{-1}$ DS in SS		%
Metals									
Zn	1568.06	796.887	50.82						
Zn				1462.827	559.986	38.281			
Zn							1385.07	378.641	27.337
Cu	753.443	651.03	86.405						
Cu				657.379	390.003	59.326			
Cu							590.5	152.376	25.805
Pb Cases in $\bar{X}$	9	9	9	9ac	9ac	9ac	9bd	9bd	9bd
Pb	1053.8	1277.2075	121.2						
Pb				672.9	571.42	84.919			
Pb							469.171	188.305	40.136

Notes:
a. Omitting highest concentration case on which annual mean was based.
b. Omitting 2 highest concentration cases on which annual mean was based.
c. Adding in the new, 8 case, mean concentration.
d. Adding in 2 new, 7 case, mean concentrations.

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TABLE 8.14

The effect of omitting, or replacing, 0, 1 or 2 highest concentrations of Zn, Cu and Pb in unstabilised sewage sludge dry solids on the ability to achieve 95% probability of compliance (e) with Mandatory and/or Recommended limits specified in Annex 1A of the EC proposal for a directive (f).

Column	A	B	C		
Data Source	Table 8.13 Cols A + B e	Table 8.13 Cols D + E e	Table 8.13 Cols G + H e	Proposed Directive (f) Annex 1a	
Constraints				Mandatory	Recommended
Cases	30	29a	28b		
Units		$mgkg^{-1}$ Dry Solids in sewage sludge			
Metals					
Zn	2878.9*	2384.00**	2007.9**	3000	2500
Cu	1824.4	1298.9*	841.2**	1500	1000
Cases	9	9 ac	9 bd		
Pb	3154.8	1612.9	778.9*	1000	750

Notes:
a. Omitting highest concentration.
b. Omitting 2 highest concentrations.
c. Adding in the new mean concentration (Table 8.13 Col. D)
d. Adding in 2 new mean concentrations (Table 8.13 Col. G)
e. Using the probability formula $\bar{X}$ + 1.645 SD. distribution being treated as if normal.
f. OJC 264 p.6 8.10.82.
* Complies with M but not R limits.
** Complies with M and R limits.

TABLE 8.15

Mean metal concentrations in unstabilised sludge and required standard deviation for 95% probability of compliance (e) with Mandatory limits specified in Annex 1A of the EC proposal for a directive, (f), when 0, 1 or 2 highest concentrations are omitted, or replaced, in mean concentrations of Zn, Cu or Pb in dry solids of sludge.

Column	A	B	C	D	E	F	G	H	I	J
Cases in $\bar{X}$	30			29a			28b			
Data Source	Table 8.13 Col.A	e		Table 8.13 Col.D	e		Table 8.13 Col.G	e		
Parameter	Undig.Mean	Req.SD	SD/$\bar{X}$	Undig.Mean	Req.SD	SD/$\bar{X}$	Undig.Mean	Req.SD	SD/$\bar{X}$	
Constraints										Mandatory
Units	mgkg^{-1}DS in SS		%	mgkg^{-1} DS in SS		%	mgkg^{-1} DS in SS		%	
Metals										
Zn	1568.06	870.480*	55.513*							3000
Zn				1462.827	934.954*	63.914*				"
Zn							1385.07	981.720*	70.879*	"
Cu	753.443	453.824	60.235							1500
Cu				637.379	524.39*	82.273*				"
Cu							590.5	552.888*	93.630*	"
Pb cases in $\bar{X}$	9			9 ac			9bd			
Pb	1053.8									1000
Pb				672.9	198.845	29.55				"
Pb							469.171	322.692*	68.779*	"

Notes:

* SD shown is more than the value shown in table 8.13.

a. Omitting highest concentration case on which annual mean was based.

b. " 2 " cases " " "

c. Adding in the new, 8 case, mean concentration.

d. Adding in 2 new, 7 case, mean concentrations.

e. Calculated on the basis $\bar{X}$ + 1.645 x SD = M constraint.

f. OJC 264 p.6 8.10.82.

TABLE 8.16

The effect of omitting, or replacing, 0, 1 or 2 highest concentrations of Zn, Cu and Pb in a simulated digested sewage sludge dry solids (g) on the ability to achieve 95% probability of compliance (e) with Mandatory and/or Recommended limits specified in Annex 1A of the EC proposal for a directive (f), if SD:$\bar{X}$ ratio in unstabilised sludge is held constant at values shown in Table 8.13 Cols. C, F and I.

Column	A	B	C	Proposed Directive (f) Annex 1a	
Data Source	Table 8.14 Col.A x 1.354	Table 8.14 Col.B x 1.354	Table 8.14 Col.C x 1.354		
Constraints				Mandatory	Recommended
Cases	30	29a	28b		
Units		$mgkg^{-1}$ Dry Solids sewage sludge			
Metals					
Zn	3898.031	3227.936	2718.697*	3000	2500
Cu	2470.238	1758.711	1138.985*	1500	1000
Cases	9	9 ac	9 bd		
Pb	4271.599	2183.867	1054.631	1000	750

Notes:

a. Omitting highest concentration in unstabilised sludge.
b. Omitting 2 highest concentrations in unstabilised sludge.
c. Adding in the new mean concentrations in unstabilised sludge.
d. Adding in 2 new mean concentrations in unstabilised sludge.
e. Using the probability formula $\bar{X}$ + 1.645 SD, distribution being treated as if normal.
f. OJC 246 p.6 8.10.82.
g. Using a concentration factor of 1.354 see table 8.8 col.3.
* Complies with M but not R limits.

TABLE 8.17

Simulated digestion (g) and required SD for 95% probability of compliance (e) with Mandatory limits specified in Annex 1A of the EC proposal for a directive, (f), when 0, 1 or 2 highest concentrations are omitted or replaced, in mean concentrations of Zn, Cu or Pb in unstabilised sewage sludge.

Column	A	B	C	D	E	F	G	H	I	Table 8.17
Cases in $\bar{X}$	30			29a			28b			Proposed
Data Source	Table 8.13 Col.A			Table 8.13 Col.D			Table 8.13 Col.G			Directive Annex 1a(f)
Parameter	S.Dig.Mean	Req.SD (e)	SD/$\bar{X}$	S.Dig.Mean	Req.SD (e)	SD/$\bar{X}$	S.Dig.Mean	Req.SD (e)	SD/$\bar{X}$	
Constraints										
Units	$mgkg^{-1}$DS in SS		%	$mgkg^{-1}$ DS in SS		%	$mgkg^{-1}$ in SS		%	Mandatory $mgkg^{-1}$DS in SS
Metals										
Zn	2123.153	533.038	25.106							3000
Zn				1980.668	619.655	31.285				3000
Zn							1875.385	683.657*	36.454*	3000
Cu	1020.185	291.681	28.591							1500
Cu				890.091	370.765	41.655				1500
Cu							799.537	425.813*	53.257	1500
Pb Cases in $\bar{X}$	9			9ac			9bd			
Pb	$>$M									1000
Pb				911.107	54.039	5.93				1000
Pb							635.258	221.728	34.9	1000

Notes:
a. Omitting highest concentration in mean of unstabilised sewage sludge.
b. " 2 highest " " " " "
c. Adding in the new mean concentration in mean of unstabilised sewage sludge, Table 8.13 Col.D.
d. Adding in 2 new mean concentrations " " " " Table 8.13 Col.G.
e. Using the probability formula $\bar{X}$ + 1.645 SD distribution being treated as if normal.
f. OJC 264 p.6 8.10.82.
g. Using concentration factor of X 1.354. See table 8.8.
* SD shown in table 8.13 is less than this value. M. Mandatory limit.

TABLE 8.18

The effect of omitting, or replacing, 0, 1 or 2 highest concentrations of Zn, Cu and Pb in simulated Lime stabilised sewage sludge, where dry solids is increased by 14% (g) on the ability to achieve 95% probability of compliance (e) with Mandatory and/or Recommended limits specified in Annex 1A of the EC proposal for a directive (f), if SD stays the same percentage of mean concentrations as in unstabilised sludge as shown in table 8.13 cols.C, F and I.

Column	A	B	C		
Data Source	Table 8.14 Col.A x.8772	Table 8.14 Col.B x.8772	Table 8.14 Col.C x .8772	Proposed Directive Annex 1A (f)	
Constraints				Mandatory	Recommended
Cases	30	29a	28b		
Units	$mgkg^{-1}$ Dry Solids sewage sludge				
Metals					
Zn	2525.371*	2091.245**	1761.33**	3000	2500
Cu	1600.364	1139.395*	737.901**	1500	1000
Cases	9	9ac	9bd		
Pb	2767.39	1414.836	683.251**	1000	750

Notes:
a. Omitting highest concentration.
b. Omitting 2 highest concentrations.
c. Adding in the new mean concentration, see table 8.13 col.D.
d. Adding in 2 new mean concentrations, see table 8.13 col. G.
e. Using the probability formula $\bar{X}$ + 1.645 SD distribution being treated as if normal.
f. OJC 264 p.6 8.10.82.
g. Using a dilution factor of .8772 see table 8.8.
* Complies with M but not R limits.
** Complies with M and R limits.

TABLE 8.19

Simulated lime treatment (g) and required SD for 95% probability of compliance (e) with Mandatory limits specified in Annex 1A of the EC proposal for a directive (f), when 0, 1 or 2 highest concentrations are omitted or replaced, in mean concentrations of Zn, Cu or Pb in unstabilised sewage sludge.

Column	A	B	C	D	E	F	G	H	I	
Cases in $\bar{X}$	30			29a			28b			
Data Source	Table 8.14 Col.A x .8772			Table 8.14 Col.D x .8772			Table 8.14 Col.G x .8772			Proposed Directive Annex 1a
Parameter Constraints	S.L.T.Mean	Req.SD(e)	SD/$\bar{X}$	S.L.T.Mean	Req.SD(e)	SD/$\bar{X}$	S.L.T.Mean	Req.SD	SD/$\bar{X}$	Mandatory
Units	$mgkg^{-1}$ DS in SS		%	$mgkg^{-1}$ DS in SS		%	$mgkg^{-1}$ DS in SS		%	$mgkg^{-1}$ DS in SS
Metals										
Zn	1375.502	987.537*	71.795*							3000
Zn				1283.192	1043.652*	81.333*				"
Zn							1214.9834	1085.116*	89.311*	"
Cu	660.920	510.079	77.177							1500
Cu				576.32	561.507*	97.43*				"
Cu							517.987	596.969*	115.248*	"
Pb Cases in $\bar{X}$	9			9ac			9bd			
Pb	923.691	46.388	5.022							1000
Pb				590.268	249.077	42.197				"
Pb							411.557	357.716*	86.918*	"

Notes:
a. Omitting highest concentration in mean of unstabilised sewage sludge.
b. " 2 highest " " " " " "
c. Adding in the new mean " " " " " " (Table 8.13 Col.D)
d. " 2 new means " " " " " " (Table 8.13 Col.G)
e. Using the probability formula $\bar{X}$ + 1.645 SD, distribution being treated as if normal.
f. OJC 264 p.6 8.10.82. g. Using dilution factor x 0.8772 see table 8.8.
S.L.T. mean = Simulated Lime Treatment mean. *SD shown in Table 8.13 is less than this value.

8.3.2. Required reduction of metal input from known trade sources to achieve 95% probability of compliance of Zn, Cu, Ni, Cd and Pb mean concentrations in sewage sludges with proposed M limit values. YWA City WPC works 1980/81 data.

8.3.2.0. Introduction

Using equations B9 or B12 required reduction of Zn, Cu, Ni, Cd and Pb inputs, from known trade sources, are calculated to achieve 95% probability of compliance of mean concentrations in unstabilised, simulated digested and lime stabilised sludges with proposed M limit values.

Because of the influence of standard deviation in calculating 95% probability of compliance, as found in section 8.31, calculations of reduction are made without and with reduction of SD. Required SD is also calculated for the achievement of compliance when 80 or 90 percent reduction of input from known input sources are calculated.

8.3.2.1. Results. Although results from other tables are referenced the main findings are given

for unstabilised sludge in tables 8.20 and 8.21.

for simulated digested sludges in tables 8.22 and 8.23; and

for simulated lime treated sludge in tables 8.24 and 8.25.

In an attempt to retain clarity and as reductions of a particular metal are made from 1 or 2 highest sources, results are reported by metal.

Zn. I. Unstabilised sludge

a. Compliance without reduction of mean concentration.

Distribution of Zn concentrations in unstabilised sludge is characterised by 2 very high concentrations, as already discussed. See fig. 8.2. However if the distribution is treated as if normal then with mean and SD as shown in table 8.13 cols. 1 and 2 and using the formula $\bar{X}$ + 1.645 SD, 95% probability concentration is calculated to be 2878.9 $mgkg^{-1}$

DS in SS which, as shown in table 8.14 is less than the proposed M limit of 3000 $mgkg^{-1}$ DS in SS.

Therefore reduction from known Zn input sources is not required.

II Simulated stabilised sludge.

A. Simulated digested sludge.

If simulated digestion has the effect of concentrating metals in sludge by a factor of x 1.354, then using the probability formula $\bar{X}$ + 1.645SD the following results were obtained.

1. Without reduction of mean concentration.

As already shown in table 8.17, concentrations of Zn may achieve 95% probability of compliance with proposed M limit without reduction if SD: $\bar{X}$ ratio can be narrowed to 25.106%. This may or may not be practicable.

2. With reduction of mean concentration.

a) When SD ratio is held constant. See table 8.22 cols. 4, 5a, 5b, 2, 7 and 6.

Required stabilised mean is 1633.997 $mgkg^{-1}$ a reduction of 489.156 $mgkg^{-1}$, i.e. 23.04% of sim. digested mean 2123.153 $mgkg^{-1}$ DS in SS. This reduction is equivalent to 51.124, 52.607 or 68.652 percent of total known trade inputs T when partition ratios are .94, .9135 or .7 respectively.

But total known input sources include 1237.95 kg. Zn from source D based on 3 concentration cases only. If input from D is omitted from T, then the corresponding required reductions are equivalent to 66.664, 68.598 or 89.52 percent respectively of total known trade inputs T-D.

How practical such a reduction would be is not known, it could involve many works.

In part the problem is due to the relatively high standard deviation of Zn concentrations.

b. 80% reduction from highest known source and required SD.

If input of Zn from source B is reduced by 80% then the equivalent reduction in unstabilised and hence in simulated digested mean is of 15.994, 15.543 or 11.910 percent to 1783.576, 1793.151 or 1870.285 $mgkg^{-1}$ when partition ratios are .94, .9135 or .7 respectively. Applying the probability formula maximum required SDs are 41.46, 40.914 or 36.719 percent, respectively, of reduced means to meet the proposed M limit. See table 8.23.

If this narrowing of SDs can be achieved, then 80% reduction of input from 1 trade source B is sufficient to achieve 95% probability of compliance of Zn concentrations in simulated digested sludge with the proposed M limit.

B. Simulated lime treated sludge.

If simulated lime treatment has the effect of diluting metal concentration in sludge by a factor of x .8772, then using the probability formulas as previously the following results are obtained.

1. Without reduction of mean concentration.

If $SD:\bar{X}$ ratio is held constant, the required mean to just comply with proposed M limit, is greater than the simulated lime treated mean, 1375.502. As shown in table 8.24.

95% probability of compliance can be achieved without reduction of the simulated lime treated mean concentration or of the $SD:\bar{X}$ ratio calculated for unstabilised sludge.

As already shown in table 8.19, $SD:\bar{X}$ ratio could increase to a maximum of 71.795% for compliance with M limit to be achieved when lime treated mean concentrations is 1375.502 $mgkg^{-1}$.

Comment

Zn concentrations in unstabilised and simulated lime treated sludges are able to achieve 95% probability of compliance with proposed M limit value without reduction of the mean concentration.

When digestion with 40% reduction in organic matter is simulated the same level of compliance can be achieved when mean concentration in sludge is reduced by the equivalent of 80% reduction of input to sewer from trade source B providing that SD:$\bar{X}$ ratio is not greater than 36.719%.

As B is the source of the highest known input load of Zn to sewers reduction by the above means may provide a useful strategy by which compliance of Zn concentrations with proposed M limit could be achieved.

Similarly,

Cu. I. Unstabilised sludge.

As with Zn, distribution of concentration cases of Cu in unstabilised sewage sludge is characterised by two very high concentrations, as shown in fig. 8.2. Here distribution is treated as if normal and the 95% probability formula applied as for Zn.

1. Compliance without reduction of mean concentration.

As already shown, in table 8.15, 95% probability of compliance with proposed M limit may be achieved without reduction of mean concentration if SD:$\bar{X}$ ratio is narrowed to 60.235%, which may well be practicable.

2. Compliance with reduction from known trade input.

a. When SD:$\bar{X}$ ratio is held constant. See table 8.20.

When SD:$\bar{X}$ ratio is held constant, required reduction of mean concentration by reduction of input from known trade sources is not feasible.

b. When SD ratio is not held constant. See table 8.21.

If input from trade source H is reduced by 80% mean concentration in sludge is reduced to 707.197, 709.186 or 714.543 $mgkg^{-1}$ when partition ratios are .92, .8806 or .7 respectively, required SD:$\bar{X}$ ratios for 95% probability of compliance with proposed M limit are 68.149, 67.787 or 66.823 percent respectively.

II. Stabilised sludge.

A. Simulated digested sludge.

Cu concentrations in simulated digested sludge are calculated as for Zn.

1. Compliance without reduction of mean concentration.

a. Although 95% probability of compliance with proposed M limit cannot be achieved by unreduced mean concentration when SD:$\bar{X}$ ratio is held constant. See table 8.22,

b. It has already been shown in table 8.17 that compliance can be achieved SD:$\bar{X}$ ratio can be reduced to a maximum of 28.591%. To what extent this is practicable is not known.

2. Compliance with reduction of mean concentration.

a. Compliance by reduction of mean concentration in SS by reduction of inputs from known trade sources is not possible when SD:$\bar{X}$ ratio is held constant. See table 8.22.

b. If input from source H is reduced by 80% then the equivalent reduction in unstabilised mean and hence in simulated digested mean is 6.138, 5.874 or 5.163 percent to 957.543, 960.236 or 967.489 $mgkg^{-1}$ DS when partition ratios are .92, .8806 or .75 respectively, required maximum SDs being 34.438, 34.171 or 33.459 percent of reduced means in order to meet the proposed M limit. See table 8.23.

Similarly if reduction of simulated digested mean is equivalent to 80% reduction from sources H+E then reduced mean is calculated to be 939.19, 942.658 or 954.156 $mgkg^{-1}$ and required SDs are 36.299, 35.94 or 34.776 percent of reduced means when partition ratios are .92, .8806 or .75 respectively. See table 8.23.

If the required narrowing of SD is practicable 95% probability of compliance may be achieved with proposed M limit by 80% reduction from 1 or 2 highest known trade sources.

The equivalent effect of 90% reduction from these sources has not

been calculated but remains a possible strategy option.

IIB. Simulated lime treated sludge.

Cu concentrations in simulated lime treated sludge are calculated as for Zn, distribution is also treated as if normal.

1. Compliance without reduction of mean concentration.

a. Compliance with proposed M limit is not feasible without reduction of mean concentration when SD:$\bar{X}$ ratio is held constant. See table 8.18.

b. 95% probability of compliance with proposed M limit can be achieved without reduction of mean concentration if SD:$\bar{X}$ ratio is reduced to 77.177%, as already shown in table 8.19. Compliance by this means may be practicable. alternatively:

2. Compliance with reduction of mean concentration.

a. If SD:$\bar{X}$ ratio is held constant, compliance can be achieved if lime stabilised mean concentration is reduced to 619.486 mgkg. a reduction of 6.27% which, although not feasible at lowest partition ratio by reduction of input from source H alone, is equivalent 63.189, 66.017 or 77.519 percent reduction from known trade sources H+E, when partition ratios are .92, .8806 or .75 respectively. See table 8.24 cols. 4, 5, 6 and 7.

b. In view of this finding:

Compliance if SD:$\bar{X}$ ratio is reduced has not been calculated.

Comment

Total Cu inputs from known trade sources are equivalent to a lower percentage of Cu concentrations in sludge output than Ni, Zn, Cr or Cd and potential for reduction by 80% reduction from 1 or 2 highest known sources is equivalent to 7.937 percent or less of mean concentrations in sludge. As shown in tables 8.4 and 8.5.

A further characteristic of Cu concentrations in unstabilised sludge is their wide distribution and high SD:$\bar{X}$ ratio 86.405 percent. See fig.8.2 and table 8.13.

In spite of these limitations it has been shown that 95% probability of compliance with the proposed M limit can be achieved:

a) in simulated lime treated sludge without reduction of mean concentration when SD is 77.177%.

b) In unstabilised sludge by reduction of mean concentration equivalent to 80% reduction of input from source H when minimum SD:$\bar{X}$ ratio required is 66.823%.

c) In simulated digested sludge by reduction of mean concentration equivalent to 80% reduction of input from source H or sources H+E when minimum required SD:$\bar{X}$ ratios are 33.459 or 34.776 percent respectively.

SD:$\bar{X}$ ratios required are regarded as practicable. Therefore the strategy for achievement of compliance shown is regarded as potentially operationally useful.

Similarly

Ni. Distribution of Ni concentrations in unstabilised sludge show a bimodal distribution. Here distribution is treated as normal and the 95% probability formula applied as for Zn.

Ni. I Unstabilised sludge.

1. Compliance without reduction of mean concentration.

As shown in table 8.6 mean concentration of Ni in unstabilised sewage sludge 438.68 $mgkg^{-1}$ is greater than the proposed M limit of 400 $mgkg^{-1}$, therefore compliance is not possible without reduction of the mean concentration.

2. Compliance with reduction from a known trade input.

a. When SD:$\bar{X}$ ratio is held constant required mean is 236.583 $mgkg^{-1}$ a reduction of 202.097 $mgkg^{-1}$ i.e. 46.07%. This reduction is calculated to be equivalent to 56.022% of input from source A when partition ratio is .35. Or if lower input load from source A 4261.08 kg. Ni is adopted, the required

reduction is equivalent to 67.143 or 83.76 percent of input load when partition ratios are .499 or .4 respectively. See table 8.20.

b. 80% reduction from highest known source and required SD.

Alternatively if the reduction of mean concentration is equivalent to 80% reduction from source A calculated reduced mean is 150.081 $mgkg^{-1}$ and required SD:$\bar{X}$ ratio is 101.295% when partition ratio is .35.

If lower input for source A is again adopted 80% reduction of input from that source reduces mean concentration to 197.889 or 245.652 $mgkg^{-1}$ DS and required SD:$\bar{X}$ ratio is 62.087 or 38.196 percent when partition ratios are .499 or .4 respectively. See table 8.21.

II Simulated stabilised sludge.

A. Simulated digested sludge, with 40% reduction of organic matter.

1. Compliance without reduction of the mean concentration is not feasible.

a. If SD:$\bar{X}$ ratio is held constant, then required mean concentration is calculated to be 236.583 $mgkg^{-1}$ a reduction of 60.17%, which is equivalent to 73.167% of input from source A when partition ratio is .35. But if lower input from source A is adopted required reduction from this source is not feasible. See table 8.22.

b. Alternatively if reduction of the mean concentration is equivalent to 80% reduction from source A, reduced mean is calculated to be 203.21 and required SD:$\bar{X}$ ratio 58.87% when partition ratio is .35. Or again adopting lower input load for source A, reduced means are 267.941 or 332.613 $mgkg^{-1}$ DS. and required SD:$\bar{X}$ ratios 29.961 or 12.316 percent when partition ratios are .499 or .4 respectively, the lowest SD:$\bar{X}$ ratio regarded as unlikely to be practicable. See table 8.23.

With 90% reduction of lower input from source A reduced mean concentrations are 227.174 or 299.944 $mgkg^{-1}$ DS. and required SD:$\bar{X}$ ratio 46.247 or 20.278 percent when partition ratios are .499 or .4 respectively.

B. Simulated lime treated sludge, with 14% increase in solids.

1. Compliance without reduction of the mean concentration.

a. Compliance is not feasible when SD:$\bar{X}$ ratio is held constant.

b. When unreduced lime treated mean concentration is 384.810 $mgkg^{-1}$ DS. as shown in table 8.6 col.4. SD required for compliance with proposed M limit is approximately 2% of the mean, which although feasible is quite impracticable.

2. Compliance with reduction of the mean concentration.

a. When SD:$\bar{X}$ ratio is held constant, then required mean concentration in simulated lime treated sludge is 236.583 $mgkg^{-1}$ a reduction of 38.519%, equivalent to 46.841% of Ni input from source A when partition ratio is .35. Or adopting lower input load for source A, reduction is equivalent to 56.139 or 70.033 percent when partition ratios are .499 or .4 respectively. See table 8.24.

b. In view of the above findings the effects of 80% reduction from source A on required SD:$\bar{X}$ ratio are not presented.

Comment

Ni partition ratios are much lower than for other metals, ratios of .499, .4 and .35 indicate that 50.1, 60 or 65 percent of Ni load entering the WPC works leaves in final effluent to river or in output to lagoon.

Because partition ratios to sludge are low a correspondingly high reduction of input of Ni is required for a given reduction in Ni mean concentration in sludge.

However input of Ni from source A is equivalent to a higher percentage of output mean concentration of Ni in unstabilised sludge than any other known source for any metal, as shown in table 8.5.

Calculation of the effects of reducing input load of Ni from source A are complicated by the need to use either a low partition ratio .35 or a lower calculated input load from source A for feasibility reasons as shown

in table 8.4.

It has been shown that 95% probability of compliance of Ni concentrations with proposed M limit can be achieved by reduction of input from source A alone.

When input from source A is given full value compliance can be achieved in unstabilised, simulated digested or lime treated sludges by reductions of input of 56, 76 or 47 percent respectively when SD:$\bar{X}$ ratio is held constant.

When lower input from source A is used achievement of compliance requires greater reduction being most difficult in simulated digested sludge. When partition ratio is .499 80% or 90% reductions from source A were required respective maximum SD:$\bar{X}$ ratios being approximately 30 or 46 percent. When partition ratio of .4 a 90% reduction from source A is required for SD:$\bar{X}$ ratio to be 20%.

Clearly reduction in ambiguity regarding input loads from important sources or of metal partition ratios is highly desirable and is most likely to be achieved by increasing the number of concentration cases on which calculations are based.

Cd. As shown in fig. 8.1, Cd concentrations in unstabilised sludge show a positively skewed normal distribution.

I. Unstabilised sludge.

1. As the unstabilised mean concentration 45.76 $mgkg^{-1}$ DS. in SS is greater than the proposed M limit 40 mgkg DS compliance cannot be achieved without reduction of the mean, Cd concentration. See table 8.1 col.1.

2. Compliance with reduction of the mean concentration.

a. Holding SD:$\bar{X}$ ratio constant required mean concentration is 23.245 $mgkg^{-1}$ or less, requiring a reduction of 22.515 $mgkg^{-1}$, 49.2% of the mean. This reduction cannot be achieved from known trade inputs when source Ka is omitted. When Ka is included, and Kb omitted, required reduction is

equivalent to a reduction of 89.729% of input from all known sources or 97.5% of input from Ka+F+B when partition ratio is .9 and not feasible when partition ratio is .738.

As Ka is part of dual input Ka+b and 'real' input from source K must lie between loads calculated for Ka and Kb, required reduction of mean from known trade inputs is not feasible. See table 8.20.

b. Alternatively with 90% reduction of Cd input from sources F+B, when partition ratios are .9 or .738 respectively required SD:$\bar{X}$ ratio is 6.696 or 3.568 percent again not regarded as practicable. As F and B are the only sources, known to this study, of inputs of Cd greater than 10 kg and together account for 82.7% of inputs from all trade inputs, known to this study, when input Ka is omitted, it is concluded that although the achievement of 95% probability of compliance of Cd concs. in undigested sludge by reduction from known input sources is feasible, it is also likely to be impracticable. See table 8.21.

II. Stabilised sludge.

A. Simulated digestion with 40% reduction of organic matter.

Simulated digestion has the effect of concentrating metals mean concentration being x 1.354 of mean concentration in unstabilised sludge.

Therefore if in unstabilised sludge 95% probability of compliance although feasible by reduction from known input sources, was regarded as impracticable because of the small required SD:$\bar{X}$ ratio, then achievement of 95% compliance of digested sludge with proposed M limit is not possible. See Table 8.23.

B. Simulated lime treatment with 14% increase in solids.

If simulated lime treatment has the effect of diluting metal concentrations by a factor of x .8772 mean concentration of Cd is calculated to be 40.141 $mgkg^{-1}$ DS.

1. Compliance with M limit without reduction of the mean concentration is not feasible.

2. 95% probability of compliance with reduction of mean concentration.

a. When SD:$\bar{X}$ ratio is held constant required reduction of mean concentration by reduction of inputs from known trade sources is not feasible when input from source Ka is omitted. See table 8.24.

b. When SD:$\bar{X}$ ratio is <u>not</u> held constant, 80% reduction of input from sources F+B are calculated to reduce mean Cd concentrations to 32.55 or 33.921 $mgkg^{-1}$ when partition ratios are .9 or .738 respectively, required SD:$\bar{X}$ ratios being 13.902 or 10.895 percent respectively.

With 90% reduction of input from sources F+B reduce mean concentrations to 31.607 or 33.143 $mgkg^{-1}$ DS and required SD:$\bar{X}$ ratios are 16.142 or 12.577 percent when partition ratios are .9 or .738 respectively. Although feasible, because of the low SD:$\bar{X}$ ratios compliance by this means is likely to be of low practicality. See table 8.25.

<u>Comment.</u>

The achievement of 95% probability of compliance of Cd concentrations in unstabilised, simulated digested or lime treated sludge by reduction of inputs from trade sources known to this study is found to be not feasible or impracticable, not possible or of low practicality respectively.

In view of the effect of standard deviation on 95% probability of compliance required percent reductions of mean concentrations of Cd in unstabilised, simulated digested and lime stabilised sludges, when SD:$\bar{X}$ ratios are 43.819, 30, 20 or 10 percent were calculated. See table 8.26.

Compliance with proposed M limit has been shown to be achievable in simulated lime treated sludge when SD:$\bar{X}$ ratio is 16.142% or less, as shown above and table 8.25.

Even at 15 or 10 percent SD:$\bar{X}$ ratios require reductions in mean concentrations in unstabilised sludge of 29.888 or 24.9355 percent and in simulated digested sludge of 48.219 or 44.561 percent, approximately equal

to or higher than total inputs of Cd from sources known to this study when input from source Ka is omitted. It is therefore important to attempt to estimate inputs from sources unknown to this study. See table 8.26.

Similarly

Pb. As already discussed, Pb data is sparse and therefore regarded as of very low reliability. As shown in fig. 8.2, distribution of the 9 concentration cases in unstabilised sludge includes 2 very high and 1 very low concentration and is characterised by a mean concentration of 1053.8 $mgkg^{-1}$ DS. and, if distribution is treated as normal, by a standard deviation of 1277.2075 being 121.2% of the mean. Inputs of total known trade sources T and highest known source H respectively, at highest partition ratio, are only equivalent to 7.566 and 7.167 percent of mean Pb concentration in unstabilised sludge. See tables 8.4 and 8.5 cols.5.

I. 95% compliance in unstabilised sludge.

1. Compliance without reduction of the mean concentration is not feasible, as mean is greater than M limit value.

2a. Compliance with reduction of mean is not feasible when SD:$\bar{X}$ ratio is held constant. See table 8.20 cols. 5b and 7.

2b. With 80% reduction of input from source H, and equivalent reduction of mean to 993.385 $mgkg^{-1}$ required SD would be .004% of mean concentration. See table 8.21 col.5.

In view of these findings achievement of 95% compliance in unstabilised sludge by reduction of inputs from known sources is regarded as impracticable.

II. A. Simulated digested sludge.

In view of the concentrating effect of digestion on Pb concentration in sludge, it follows that if achievement of 95% compliance of Pb in unstabilised sludge is not practicable, reductions from known sources cannot, by themselves, result in adequate reduction of mean concentrations

in simulated digested sludge. See also tables 8.22 and 8.23.

IIB. Simulated lime treated sludge.

1. Compliance without reduction of mean concentration.

a. 95% probability of compliance without reduction of mean is not feasible when SD:$\bar{X}$ ratio is held constant. See table 8.24.

b. Required SD:$\bar{X}$ ratio is 5.022% to achieve 95% probability of compliance with proposed M limit without reduction of mean concentration. Compliance by this means is regarded as impracticable. See table 8.19 col.C.

2. Compliance with reduction of mean concentration.

a. Compliance when SD:$\bar{X}$ is held constant.

In view of the high Pb standard deviation compliance is again not feasible, as required reduction is greater than equivalent total known trade inputs. See table 8.24 cols. 5b and 7.

b. With 80% reduction of input from source H and corresponding reduction of mean concentration to 870.737, 872.409 or 879.096 $mgkg^{-1}$ required SD:$\bar{X}$ ratio is 9.024, 8.891 or 8.360 percent when partition ratios is .95, .92 or .8 respectively. See table 8.25 cols. 4 and 5.

In view of these very low SD:$\bar{X}$ ratios, and as source H accounts for 94.71% of 'known' trade inputs T, achievement of 95% probability of compliance with proposed M limit by reduction of mean concentration by reducing inputs from trade sources known to this study is probably not practical unless such steps as homogenisation of lime treated sludge were taken.

Comment

It is clearly shown that when x% probability of compliance is required anomalously high concentrations seriously affect mean concentration and SD:$\bar{X}$ ratios. Elimination of anomalously high concentrations and provision of more reliable data by increasing the number of concentration cases available of both trade input and in sludge output would appear to be

urgent requirements.

8.3.2.2. Summary and Conclusions

1. 95% probability of compliance with proposed M limit values can be achieved without reduction from known input sources:

a. by Zn concentrations in unstabilised and simulated lime treated sludges without reduction of SD:$\bar{X}$ ratio. See tables 8.14 and 8.18.

b. by Zn concentrations in simulated digested sludge if SD:$\bar{X}$ ratio is reduced to 25%. See table 8.17.

c. by Cu concentrations in unstabilised, simulated digested and lime treated sludges if SD:$\bar{X}$ ratios can be reduced to 60, 29 or 77 percent respectively. See tables 8.15, 8.17 and 8.19.

2. With reduction of input from highest known input source(s).

A. When SD:$\bar{X}$ ratio is held constant in unstabilised sludge. See figs. 8.1 and 8.2. Compliance is achieved:

a. by Cu concentrations in simulated lime stabilised sludge when inputs from trade sources H and E are reduced by 63-77.5 percent. See table 8.24.

b. by Ni concentrations in unstabilised or simulated lime treated sludge when input from source A is reduced by 56-85 or 47-70 percent respectively.

Also in simulated digested sludge, when Ni input from source A is given full value, by 73% reduction from that source. See tables 8.20, 8.22 and 8.24.

B. With 80% reduction from highest input source(s) and reduction of SD:$\bar{X}$ ratio.

Compliance is achieved

a. by Zn concentrations in simulated digested sludge when SD:$\bar{X}$ ratio is reduced to 37-41%. See table 8.23.

b. by Cu concentrations in unstabilised or simulated digested sludges when SD:$\bar{X}$ ratio is reduced to 67-68 or 33-36 percent respectively. See tables 8.21 and 8.23.

c. by Ni concentrations in unstabilised or simulated digested sludge if SD:$\bar{X}$ ratio is reduced to 38-101 or 12-59 percent respectively. The 12% SD:$\bar{X}$ when input from source A is given lower value and partition ratio is .40 is regarded as not practical. See tables 8.21 and 8.23.

d. when input from source Ka of dual input Ka+b is omitted, by Cd concentrations in unstabilised sludge when partition ratio is .9 and SD:$\bar{X}$ ratio is reduced to 4.7%. See table 8.21. Or by Cd concentrations in simulated lime treated sludge when SD:$\bar{X}$ ratio is reduced to 11-14 percent. See table 8.25. Achievement of these low SD:$\bar{X}$ ratios is regarded as not practical or of low practicality respectively.

e. likewise by Pb concentrations in unstabilised or lime treated sludge if SD:$\bar{X}$ ratio is reduced to 1 or 8-9 percent respectively. Again achievement of these ratios is regarded as not practical or of very low practicality. See tables 8.21 or 8.25.

C. With 90% reduction from highest known trade input source(s) and reduction of SD:$\bar{X}$ ratio.

Compliance is achieved

a. by Ni concentrations in simulated digested sludge when input from source A is given lower value and partition ratios are .499 or .4 and SD:$\bar{X}$ ratio is narrowed to 46 or 20 percent respectively. See table 8.23.

b. when input Ka of dual input source Ka+b is omitted by Cd in unstabilised or simulated lime treated sludge when SD:$\bar{X}$ ratio is reduced to 3.5-7 or 12.5-16 percent respectively, regarded as not practical or of low practicality respectively. See tables 8.21, and 8.25.

3. Non feasibility of compliance.

Achievement of 95% probability of compliance is not feasible for Cd or Pb concentrations in simulated digested sludges using the above strategies. See table 8.23.

4. General Conclusions

Although achievement of 95% probability of compliance with proposed M limit by reduction from highest known sources may be highly desirable.

a. It may not be necessary for Zn and Cu concentrations in the 3 sludges providing that minimum required SD:$\bar{X}$ ratios given above can be achieved.

b. Compliance of Ni concentrations in the 3 sludges may be achieved by this means, although the required SD:$\bar{X}$ ratio in simulated digested sludge is low when partition ratio is .40 being 12 or 20 percent when 80% or 90% reduction of input from source A is used, firstly lower SD:$\bar{X}$ ratios are likely to be attainable in digested than in unstabilised or lime treated sludges,[13] and secondly the required SD may underestimate the real situation and be an artifact of the expedient adopted in section 8.1 to achieve input output equivalence and feasibility. See tables 8.4 and 8.5. In practice the strategy used is probably of high practicability.

c. Achievement of 95% probability of compliance of Cd and Pb concentrations in the 3 sludges using the two strategies is not feasible, not practical or not likely to be practical.

d. It is concluded that narrowing of SD:$\bar{X}$ ratio is a generally useful strategy and effective in achieving 95% probability of compliance of Zn and Cu concentrations with proposed M limits.

e. Reduction of mean concentrations in sludges by reduction of highest known trade inputs is an important strategy, particularly for Ni.

f. The number and loads of the highest known inputs of Cd and Pb are too small to achieve 95% probability of compliance in practice using only the above two strategies.

TABLE 8.20

Required reduction of mean metal concentrations in unstabilised sewage sludge, when SD:$\bar{x}$ ratio is held constant, and equivalent required reduction from known Trade source(s), to equal Mandatory Limits specified in Annex 1A of the EC proposal for a directive, with 95% probability of compliance (a).

Column	1	2	3	4	5a	5b	6	7
Source	(b)	Table 8.1 Col. 1	Fig.8.1 or 8.2				Table 8.2	(f)
Symbols	M	O	SD/$\bar{X}$	O_R		$O-O_R$	P	T
Parameter	Mandatory Limit	80/81 Unstabilised Mean Conc.	Percent S Dev. of Mean	Required Mean (a)	Required Reduction of Mean		Partition Ratio (c)	Equivalent Reduction from Trade Source
Units	$mgkg^{-1}DS$ in SS	$mgkg^{-1}DS$ SS	%	$mgkg^{-1}DS$ in SS	$mgkg^{-1}DS$ in SS	% O		% of Code
Metal								
Cu	1500	753.443	86.405 b	619.487	133.956	17.78		NF
Ni	400	438.68	41.99	236.583	202.097	46.07	.35 (d)	56.022 of A
			or if highest conc. of Source A is omitted (e)		"	"	.499	67.143 of A(e)
					"	"	.4	83.76 of A (e)
Cd	40	45.76	43.819	23.245	22.515	49.2	NF if source Ka omitted	
					"	"	.9	89.729 of T(g)
					"	"	.9	95.5 of Ka+F+B(g
					"	"	.738	NF from Ka+F+B(g
Pb	1000	1053.8	121.2 h	334.03	719.77	68.3		NF

TABLE 8.21

Equivalent of 80 or 90 percent reduction of input from known source(s), equivalent reduced mean concentration of metals in unstabilised sewage sludge and required $SD/\bar{x}$ ratio to equal Mandatory limits specified in Annex 1A of the EC proposal for a directive, with 95% probability of compliance (a).

Columns	1	2	3a	3b	4	5 (a)	6 (b)
Source	Table 8.1 Col. 1	Table 8.2	Table 8.5 Col. 6		Col.1-Col.3b		
Symbols	O	P	T^{A-H}	% of O	red O	SD req.	Proposed Mandatory
Parameter	Annual mean conc.in Unstabilised SS	Partition Ratio	Equivalent of O% reduction from source as % of mean conc. O		Reduced mean	Required SD/red O	Limit
Units	$mgkg^{-1}$DS in SS		source(s) code	%	$mgkg^{-1}$DS in SS	%	$mgkg^{-1}$ DS in SS
			With 80% reduc'n.				
Metals							
Cu	753.443	.92	H	6.138	707.197	68.149	1500
	"	.8806	"	5.874	709.186	67.787	"
	"	.75	"	5.163	714.543	66.823	"
Ni	438.68	.35 (d)	A	65.788	150.081	101.295	400
		or if highest concentration from Source A is omitted.					
	"	.499	A(e)	54.89	197.889	62.087	400
	"	.4	A(e)	44.002	245.652	38.196	"
Cd	45.76	.9	F+B	18.898	37.112	4.73	40
			with 90% reduction				
	45.76	.9	F+B	21.26	36.031	6.696	40
		.738	F+B	17.433	37.783	3.568	"
Pb	1053.8	.95	with 80% reduction H	5.733	993.385	0.004	1000

Notes: a, b, c, d and e - as for table 8.20.

Notes: Table 8.20

a. Using the probability formula $\bar{X} + (1.645 \times SD) = M$, distribution of metal concentrations in sewage sludge being treated as if normal.

b. OJC 246 p.6. 8.10.82.

c. Underlined partition ratios are calculated on the basis of 79/80 data.

d. Lower partition ratio found necessary as higher ratio results are not feasible when input load from Source A is calculated at its highest level.

e. When highest concentration case is omitted from source A data, calculated input load from source A reduces as shown in table 8.4 Col.1.

f. Using equations B9 or B12.

g. Excluding data for dual input source Kb, including data for dual input source Ka.

h. As shown in table 8.13 col. C.

NF. Not feasible as required reduction is greater than equivalent input(s) from known source(s).

TABLE 8.22

Simulated digestion, required reduction of calculated mean metal concentrations in sewage sludge, when SD:$\bar{X}$ ratio is held constant, and equivalent required reduction from known Trade source(s), to equal Mandatory limits specified in Annex 1A of the EC proposal for a directive, with 95% probability of compliance.

Column	1	2	3	4	5a	5b	6	7
Source Symbols	(b)	Table 8.8 Col. 3	Figs.8.1 & 8.2	(a)			Table 8.2	(f)
Parameter	Proposed Mandatory Limit	rO(g) Simulated Digested mean	SD/$\bar{X}$ SD as % of Mean	req. rO Required Sim. Dig. Mean	r O- req.r O Required Reduction of mean		P Partition Ratio	% T or % T^{A-} Equivalent Red. from Trade Source
Units	$mgkg^{-1}$DS in SS			$mgkg^{-1}$DS in dig. SS		%	(c)	% of Source Code
Metal								
Zn	3000	2123.153	50.82	1633.997	489.156	23.04	.94	51.124 of T
					"	"	.9135	52.607 of T
					"	"	.7	68.652 of T
					"	"	.94	66.664 of T-D
					"	"	.9135	68.598 of T-D
					"	"	.7	89.52 of T-D
Cu	1500	1020.162	86.405	619.487	400.673	39.27		NF
Ni	400	593.973	41.99	236.583	357.39	60.17	.35(d)	73.167 of A
				omitting highest conc. of A(e)				NF
Cd	40	61.959	43.819	23.245	38.714	62.48		NF
Pb	1000	1425.762		NF See Table 8.9				

Notes: a, b, c, d, e, f and g - as in Table 8.20.

g. Using a concentration factor of 1.354. See table 8.8 col.3.

NF. Not feasible as required reduction is greater than equivalent input(s) from known source(s).

TABLE 8.23

Simulated digestion, equivalent of 80 or 90 percent reduction of metal input to sewers from known source(s), equivalent reduced mean concentration of metals in sewage sludge, and required SD:$\bar{X}$ ratio to equal Mandatory limits specified in the EC proposal for a directive, with 95% probability of compliance. (a)

Column	1	2	3a	3b	4	5	6
Source	Table 8.8 Col.3	Table 8.2	Table 8.5 col. 6		Col.1-Col.3b	(a)	(b)
Symbols	rO	P	T^{A-H}		red O	SD req.	
Parameter	Sim.digested annual mean conc. in SS.	Partition ratio	Equivalent 80% red'n. from source as % of mean conc.		Reduced mean	Required SD/red O	Proposed Mandatory Limit
Units	$mgkg^{-1}$DS in SS	(c)	Code	%	$mgkg^{-1}$DS in SS	%	$mgkg^{-1}$ DS in SS
Metal							
Zn	2123.153	.94	B	15.994	1783.576	41.46	3000
	"	.9135	B	15.543	1793.151	40.914	"
	"	.7	B	11.910	1870.285	36.719	"
Cu	1020.162	.92	H	6.138	957.543	34.438	1500
	"	.8806	H	5.874	960.236	34.171	"
	"	.75	H	5.163	967.489	33.459	"
	"	.92	H+E	7.937	939.19	36.299	"
	"	.8806	H+E	7.597	942.658	35.94	"
	"	.75	H+E	6.47	954.156	34.776	
Ni	593.973	.35(d)	A	65.788	203.21	58.87	400
			of if highest concentration from Source A omitted				
		.499	A(e)	54.89	267.941	29.961	400
	"	.4	A(e)	44.002	332.613	12.316	"
			with 90% reduction (f)				
		.499	A(e)	61.753	227.174	46.247	"
		.4	A(e)	49.502	299.944	20.278	"
Cd	61.959	.9	NF	see text and table 8.8 col.5			40
Pb	1425.762		NF	see table 8.9			1000

Notes to Table 8.23

a, b, c, d, e - as in Table 8.20.

f - 90% of Table 8.5 Col. 5.

g - Using concentration factor of x 1.354.

NF - Not feasible as required reduction is greater than equivalent input(s) from known source(s).

TABLE 8.24

Simulated lime stabilisation, required reduction of calculated mean metal concentration in sewage sludge, when SD:$\bar{x}$ ratio is held constant, and equivalent required reduction from known Trade source(s), to equal Mandatory limits specified in Annex 1A of the proposed EC directive, with 95% probability of compliance.

Column	1	2	3	4	5a	5b	6	7
Source	(b)	Table 8.6 Col.4	Fig.81 & 8.2	(a)			Table 8.2	(f)
Symbols		r O(g)	SD/$\bar{X}$	req. r O	rO-req r O		P	$\%\ T^{A-H}$
Parameter	Proposed Mandatory Limit	Simulated Lime treated Mean Conc.	SD as % of mean conc.	Req.Sim.L.T. mean conc.	Req. reduction of mean		Partition Ratio	Equivalent Red. from Trade Source
Units	$mgkg^{-1}$ DS in SS	$mgkg^{-1}$ DS in SS	%	$mgkg^{-1}$DS in SS	$mgkg^{-1}$DS in SS		(c)	% of Source Code
Metal								
Zn	3000	1375.502	50.82	1375.502	Not required			
Cu	1500	660.920	86.405	619.486	41.433	6.27	.92	63.189 of H+E
							.8806	66.017 of H+E
							.75	77.519 of H+E
Ni	400	384.810	41.99	236.583	148.227	38.519	.35d	46.841 of A
			omitting highest conc.					
							.499	56.139 of A(e)
							.4	70.033 of A(e)
Cd	40	40.141	43.819	23.245	16.896	42.092		NF
Pb	1000	923.692	121.200	452.08	471.612	51.057		NF

Notes: a, b, c, d, e, f, g - as in Table 8.20.

g. Using a dilution factor of .8772. See table 8.8 Col.4.

NF. Not feasible as required reduction is greater than equivalent input(s) from known source(s).

TABLE 8.25

Simulated lime stabilisation, equivalent of 80 or 90 percent of metal input to sewers from known source(s), equivalent reduced mean concentration of metals in sewage sludge, and required SD:$\bar{X}$ ratio to equal Mandatory Limits, specified in the EC proposal for a directive, with 95% probability of compliance. (a).

Column	1	2	3a	3b	4	5	6
Source	Table 8.8 Col.4	Table 8.2	Table 8.4		Col.1-Col.3b	(a)	(b)
Symbols	rO	P	T^{A-H} %O or %rO		red O	req. SD	
Parameter	Sim.Lime Treat. Mean Conc.in SS	Partition Ratio	Equivalent reduction from source as % of mean conc. in SS		Reduced mean conc. in SS	Required SD as percent of red.O	Proposed Mandatory Limit
Units	$mgkg^{-1}$ DS in SS	(c)	Source Code	%	$mgkg^{-1}$ DS in SS	%	$mgkg^{-1}$ in SS
Metal							
Cd	40.141	.90	F+B	18.898	32.555	13.902	40
		.738	F+B	15.496	33.921	10.895	"
				90% red (d)			
		.90	F+B	21.26	31.607	16.142	"
		.738	F+B	17.433	33.143	12.577	"
				80% red (e)			
Pb	923.692	.95	H	5.733	870.737	9.024	1000
		.92	H	5.552	872.409	8.891	"
		.8	H	4.828	879.096	8.360	"

Notes: a, b, c. - as in Table 8.20.

d - 90% of Table 8.5 col.5.

e - ex Table 8.5 col.6.

TABLE 8.26

Required percent reductions of Cd mean concentrations in untreated, simulated digested or lime stabilised sewage sludge, in order to achieve 95% compliance with the proposed mandatory limit of 40 $mgkg^{-1}$ (e). Calculated when standard deviations are 43.819, 30, 20, 15 or 10% of the reduced mean or simulated mean.

	Unstab.	Sim.Dig.	Sim.Lime Stab.
Cd Mean (Calc. Mean) $mgkg^{-1}$	45.76(a)	61.959(b)	40.141(c)
	%	%	%
$SD/\bar{X}$ %	43.819(d) if	43.819(d) if	43.819(d)
Then Required Red	49.203	62.483	42.092
$SD/\bar{X}$ % If	30	30	30
Then Required Red	41.47	66.773	33.278
$SD/\bar{X}$ % If	20	20	20
Then Required Red	34.226	51.423	25.019
$SD/\bar{X}$ % If	15	15	15
Then Required Red	29.888	48.219	20.074*
$SD/\bar{X}$ % If	10	10	10
Then Required Red	24.9355	44.561	14.428**

Notes:
a. Mean conc. Cd in untreated KLL sewage sludge 1980/81 data.
b. Calc. from (a) x 1.354 (basis of 34.627% Ash in dry solids and 40% reduction of O.M. as required by UK Guide Lines).
c. Calc. from (a) x 0.8772. (Basis 14% increase in dry solids).
d. % S.D. of untreated KLL sewage sludge 1980/81 data.
e. OJC. 264. 8.10.'82. Appendix 1A.
* Achievable at highest partition ratio (Ka omitted)
** Achievable at both partition ratios (Ka omitted).

Achievement of Compliance — A short summary of results presented in sections 8.2 and 8.3.

8.2.5. Achievement of simple compliance - a short summary

From summary table 8.27 it is seen that simple compliance of Zn, Cu, Ni, Cd and Pb concentrations with proposed mandatory limits can be achieved with or without reduction from highest known input sources, in unstabilised and lime stabilised sludges, but is not feasible for Cd and Pb concentrations in simulated digested sludge.

However, as shown in table 8.28 simple compliance of Pb concentrations could be achieved in the simulated digested sludge if 1 highest concentration case in sludge could be eliminated.

8.3.3. Achievement of 95% probability of compliance — A short summary

As shown in table 8.29, 95% probability of compliance can be achieved with or without reduction from highest known input sources by concentrations of Zn, Cu and probably Ni, in all three sludges, to proposed mandatory limits.

This level of compliance is not feasible, not practical or of very low feasibility, even with reductions from highest known sources for Cd and Pb concentrations.

However, 95% compliance of Pb concentrations may be achieved by the elimination of 2 highest concentration cases in all three sludges and possibly by one if SD:$\bar{X}$ ratios can be narrowed to 30 and 42 percent, in unstabilised and simulated lime stabilised sludges respectively, as shown in table 8.30.

Potential effects of a combination of the two main strategies (see a) i.e. by reduction from highest known sources and by elimination of highest concentration cases, have not been considered but the facility

to do so could easily be incorporated into the model along with the third strategy of reducing SD:$\bar{X}$ ratios.

However, the non feasibility or low practicality of simple compliance of Cd concentrations in simulated digested sludge and in achieving 95% compliance in all three sludges with proposed mandatory values remains. In this context it is of interest to note WRC evidence to the House of Lords Select Committee in 1983 states, "In particular, the limit proposed for Cadmium (Annex 1A) could prove to be impracticable in some cases."[14]

The problem is discussed further in relation to anticipated contributions of Cd from Domestic Sources in Section 8.6. Here it is noted that the number of trade sources for which data was made available, although compatible with 4 other metals, seemed low as total Cd load from these sources only accounted for 23.4 - 28.5% of total output concentration, when source Ka is omitted, as shown in table 8.4. The fact that there was dual input concentrations for source K but only 1 agreed flow is a further complicating factor.

TABLE 8.27

Summary of Results, Simple Compliance

Summary of results of simple compliance of Zn, Cu, Ni, Cd, Pb, and Cr concentrations in unstabilised, simulated digested and simulated lime stabilised sewage sludge, without or with reduction from known trade inputs, with EC proposals for Mandatory and Recommended limits (a).

Metal	Zn	Cu	Ni	Cd	Pb	Cr	
Simple Compliance without Reduction							Shown in Table
in Unstabilised sludge	**	**				R*	8.6
in Sim. digested sludge	**	*					8.8
in Sim.Lime Stab.sludge	**	**	*		*	R*	8.8
With reduction from known inputs							
in Unstabilised sludge	N	N	*	*	*	N	8.7
in Sim.Digested sludge	N	N	*	NFb	NF	R*	8.9
in Sim.Lime Stab.sludge	N	H	N	*	N	N	8.10

Notes:
- * complies with Mandatory but not Recommended Limit proposed.
- ** complies with Mandatory and Recommended Limit proposed.
- R* complies with Recommended Limit proposed, no mandatory limit proposed.
- N Not required.
- NF Not feasible
- NFb Requires 65-79% reduction of all known inputs of Cd or the inclusion of dual input source Ka to give required reduction.
- a OJC.264 p.6. 8.10.'82.

TABLE 8.28

Summary of Results, Simple Compliance

Summary of results of simple compliance of Zn, Cu and Pb mean concentrations with EC proposed mandatory limits (a), in unstabilised, simulated digested and simulated lime stabilised sewage sludge, when one or two highest concentrations are omitted, or replaced.

Simple Compliance Metal		Zn	Cu	Pb	Source
Omission or replacement	No.of Concs.				Table(s)
in Unstabilised sludge	1	N	N	*	8.13, 8.11
	2	N	N	N	" "
in simulated digested sludge	1	N	N	*	8.17, 8.11
	2	N	N	N	" "
in Sim.Lime stabilised sludge	1	N	N	N	8.19, 8.11
	2	N	N	N	" "

Notes:

* When stated no. of highest concentrations are removed or replaced, in mean concentration complies with the proposed Mandatory limit a.

N Not required. See tables 8.6 and 8.8.

a OJC. 264 p.6. 8.10.'82.

TABLE 8.29. SUMMARY OF RESULTS, 95% COMPLIANCE

Summary of results, 95% probability of compliance of Zn, Cu, Ni, Cd and Pb concentrations in unstabilised, simulated digested or lime stabilised sewage sludge, with or without reductions from known trade inputs, with EC proposals for mandatory limits (a).

95% Probability of Compliance with proposed Mandatory Limit	Zn	Zn %	Cu	Cu %	Ni	Ni %	Cd	Cd %	Pb	Pb %	Source tables		
1. Without Reduction of Mean	b	RSD	b	RSD	b	RSD	b	RSD	b	RSD	b	% RSD	Ni+Cd
Unstabilised Sludge	*										8.14		
" " RSD		N		60		NF[1]		NF[1]		NF[1]		8.15	8.20
Sim. Digested sludge											8.16		
" " " RSD		25		29		NF[1]		NF[1]		NF[1]		8.17	8.22
Sim.Lime Stab. sludge	*					(2)				5	8.18		8.24
" " " RSD		N		77		NP[1]		NF[1]		NP		8.19	8.24
2. With Reduction of Mean from known trade inputs.													
Unstabilised sludge	N		NF[2]		*		e	7	NF[2]	1	8.20		
" " " RSD		N		67-68		38-101		NP		NP		8.21	
Simulated Digested sludge	NP		NF[2]		*c	d	NF[2]		NF[2]		8.22		
" " " " RSD		37-41		33-36		12-59		NF		NF		8.23	
Simulated Lime Stab.sludge	N		*		*		NF[2]		NF[2]		8.24		
" " " " RSD		N		N		N		11-16 NLP		8-9 NLP		8.25	
Highest known Trade source(s) code	B		H+E		A		f F+B		H				

Notes for Table 8.29

*	complies with Mandatory Limit proposed.
a.	OJC 264 p.6. 8.10.'82.
b.	With SD: $\bar{X}$ ratio held constant.
RSD.	Required SD: $\bar{X}$ ratio.
N.	Not required.
NF.	Not feasible.
NF^1	Not feasible as mean $\geq$ proposed limit.
NF^2	Required reduction from known inputs not feasible.
NP	Not Practicable (value judgement).
c.	Only practicable when source A is at full input (see table 11a).
d.	Considered practicable except at low partition ratio with alternative lower input from source A.
e.	Not feasible without including dual input source Ka.
( )	percent SD implied but not actually shown in the table reference.
NLP	Not likely to be practicable. (Value judgement).
f.	When dual input source Ka is omitted.

TABLE 8.30. SUMMARY OF RESULTS, 95% COMPLIANCE

Summary of results, 95% probability of compliance of Zn, Cu and Pb mean concentrations with EC proposed mandatory limits (a), in unstabilised, simulated digested and simulated lime stabilised sewage sludge, when one or two highest concentrations are omitted or replaced.

95% Probability of compliance with proposed Mandatory limits. With Omission of replacement of Highest Concs. No.		Zn b	Zn % RSD	Cu b	Cu % RSD	Pb b	Pb % RSD	Source table b	Source table RSD
Unstabilised sludge	1.	N		*			30	8.14	8.15
" "	2.	N		N		N		8.14	
Sim. digested sludge	1.		31		42		6NP		8.17
" "	2.	*	36	*	53		35	8.16	8.17
Sim. Lime stab. sludge	1.	N		*			42	8.18	8.19
" " "	2.	N				*		8.18	

Notes:

* complies with mandatory limit proposed.
a. OJC. 264, p.6, 8.10.'82.
b. With SD:$\bar{X}$ ratio held constant.
RSD. Required SD:$\bar{X}$ ratio.
N. Not required.
NP. Not practicable.

8.4. Guide Limits and Compliance

8.4.0. A further strategy for reducing metal inputs to sewers and hence metal concentrations in sewage sludges is by reduction of concentrations of all or most trade effluents to a particular set of values.[15] The potential effectiveness of this strategy is now considered using YWA Guide Limits in conjunction with the model.

Purpose. On the basis of the 1980/81 data available to this study, to find to what extent compliance with proposed Mandatory values Zn, Cu, Ni, Cd and Pb concentrations in unstabilised and simulated digested and lime stabilised sludges could be achieved if concentrations of those metals in effluents from 'known' inputs were reduced to YWA Guide limits.

The forty coded trade effluents for which 1980/81 concentrations (and flow data) were available were compared with the "...possible limits of concentration' of metals given in YWA's code of practice for the control of trade effluent to public sewers."[16]

Using the agreed flows reduction of input loads of metals to sewers was calculated for each effluent and in total, if concentrations were reduced to Guide limits, percent reduction of total equivalent input was also calculated.

Effect of percentage reductions of input on metal concentrations in unstabilised and in simulated digested and lime treated sludges calculated. Effects on simple and 95% probability of compliance with the proposed M and R, or M limit values were assessed.

It is important that the following results are interpreted in conjunction with the statement accompanying the Guide limits that

> "These limits are only indicative of the magnitude which the authority may wish to impose on the average effluent. They are not intended to be the maximum permitted values, as the actual chemical control conditions to be embodied in a Consent or a Direction will be determined as appropriate to the local circumstances, including taking into account the total amount

of the chemical constituent which can be reasonably accepted by the treatment works." [17]

Results are shown in tables 8.31 - 8.36.

8.4.1.

Comparison of annual mean metal concentrations of known trade effluents with YWA Guide limits. 1.4.80 - 31.3.81.

Annual mean concentrations of Zn, Cu, Ni, Cd, Pb and Cr in effluents from 'known' trade sources were compared with YWA Guide limits.

Results as shown in table 8.31.

a. Eighteen trade sources produced effluents in which the mean of recorded concentrations were in excess of one or more of guide limits for Zn, Cu, Ni, Cd, Pb and Cr and/or Zinc equivalent and/or total non-ferrous metals.

b. Only marginal excess was shown in effluents from 4 sources coded 6, 15, 18 and 26.

c. Mean concentrations of 3 low flow effluents from sources L1, L2 and L4 were based on two or less concentrations, but it was noted that effluent from L2 and L4 exceeded 5 and 4 guide limits respectively.

d. Mean concentrations of effluents from sources D and G, based on 3 cases each, exceeded 3 guide limits.

e. The remaining 9 sources include the 'elite' sources A, B, C, E, F, H, I and J and input Ka of dual input source Ka+b.

f. Sources A, B, E, F and H have already been given special attention, using the model as potential sources of reduction of Ni and Cr, Zn, Cu, Cd and of Cu and Cd respectively, their respective effluents exceed 2, 3, 4, 2 and 5 Guide limits. Source H effluent, in addition to exceeding the highest number of guide limits has a total concentration in excess of 4 times the total non-ferrous metals guide limit of 30 mgl^{-1}.

g. Sources C, I and J are potential sources of reduction of Zn, Ni and Cr respectively whose effluent mean concentrations exceed 1, 3 and 2 guide limits.

Comment

Guide limits are given as dilutions. Maximum rates of discharge and quantity discharged per day are likely to be specified in consents, but as to whether maximum loads are specified is not known to the researcher.

However from the above results it would appear that if input flows were held at the 'agreed flow' levels of 1980/81, the Water Authority could make substantial reductions in input loads of Zn, Cu, Ni, Cd, Pb and Cr entering the sewers from 'known' trade sources by enforcing a reduction of mean concentrations to guide limits.

8.4.1.2. Calculated potential metal reduction from 8 known trade effluent sources when 1980/81 agreed flows are held constant if mean concentrations in effluents are reduced to guide limits. Results are shown in table 8.32 Col.D.

Omitting inputs from source D which appears to be a leachate tank on the WPC works site, Source Ka for which separate flow data is not available and low flow sources L1 L2 and L4 to improve reliability of the data and omitting Cr for which no Mandatory limit is given calculated reductions of metal inputs would be:-

from sources B,C,E,G, and H a reduction of 2,504.502 $kg.y^{-1}$ Zn.

from sources E and H " " 461.521 $kg.y^{-1}$ Cu.

from sources A, G and I " " 5,590.538 or 2570.661 $kg.y^{-1}$ Ni.

according to whether highest concentration case of source A is included or not.

from source F a reduction of 30.079 $kg.y^{-1}$ Cd.

from source H " " 517.226 $kg.y^{-1}$ Pb.

These reductions being of the order of 60, 60, 50-70, 30 and 90 percent of total input loads of Zn, Cu, Ni, Cd and Pb from the 40 'known' trade sources.

See table 8.32 col.E.

Calculated reductions from the elite sources are equivalent to a reduction of calculated total input to sewers of 15.827-21.254 Zn, 6.504 -7.978% Cu, 33.182-63.143% Ni, 6.867-8.375% Cd and 5.563-6.606% Pb, according to partition ratio used to calculate input. See Table 8.33 col. D.

8.4.2. Predicted reductions in sewage sludge concentrations and compliance.

8.4.2.1. Simple Compliance with EC proposed Annex 1A limit values.

1. Unstabilised sewage sludge.

Applying calculated percentage reductions to the mean concentrations of metals in unstabilised sewage sludge output of the YWA city works, and comparing unreduced and reduced concentrations with proposed M and R limits: Results are shown in table 8.33 cols. E and F.

Zn and Cu. Reduction is not required as unreduced and reduced concentrations comply with M and R limits.

Ni. Unreduced concentration of Ni does not comply with M or R limits. When input from source A is calculated at full or lower values reduced concentrations of Ni comply with both M and R values.

Cd. Unreduced and reduced Cd concentrations fail to comply with M or R values.

Pb. Unreduced and reduced Pb concentrations fail to comply and comply with M limit respectively.

When 1 or 2 anomalously high concentration cases are omitted unreduced and reduced Pb concentrations comply with M and R limits.

2. Simulated digested and lime treated sludges.

Results are shown in table 8.34 cols. D, E, F, G.

Zn. Reduction of mean concentrations are not required as unreduced and reduced concentrations in simulated digested and lime treated sludges comply with M and R limits.

Cu. Reduction of mean concentrations are not required as unreduced concentrations in simulated digested and lime treated sludges comply with M, and M and R limits respectively. Reduced mean concentrations comply with M and R limits in both sludges.

Ni. Unreduced mean concentrations in simulated digested or lime treated sludges fail to comply or comply with M limit value. Reduced concentrations in simulated digested sludge comply with M limit and those in lime treated sludge with M and R limits.

Cd. Unreduced concentrations in simulated digested and lime treated sludge fail to comply with M or R limits. Reduced concentrations in simulated digested or lime treated sludges fail to comply or comply with M but not R limits respectively.

Pb. Unreduced concentrations and reduced in simulated digested or lime treated sludge fail to comply or comply with M limit respectively.

When 1 anomalously high concentration case is omitted from sludge mean concentrations.

Unreduced and reduced concentrations in simulated digested or lime treated sludges comply with M or M and R limits respectively.

When 2 anomalously high concentrations are omitted unreduced and reduced concentrations in both sludges comply with M and R limits.

8.4.2.2. 95% probability of compliance with proposed M limit.

1. Unstabilised sewage sludge.

By calculating required standard deviation the effect of reducing the mean concentrations in unstabilised on 95% probability of compliance with proposed M limits is indicated.

Results are shown in 8.35 cols. D and E.

Zn. When mean concentration in unstabilised sewage sludge is reduced by 21.254, 20.654 or 15.827 percent, as shown in table 8.33 col.D, maximum required SD:$\bar{X}$ ratio if to just comply with M limit when partition ratios

are .94, .9135 or .70 are 86.90, 85.79 or 77.38 percent respectively all higher then SD:$\bar{X}$ ratio in unstabilised sludge shown in fig. 8.2.

Cu. Similarly when partition ratios of Cu are .92, .8806 or .75 require SD:$\bar{X}$ ratios are 70.73, 70.24, 68.65 percent respectively. Which although less than the SD:$\bar{X}$ ratio shown in fig. 8.2 are regarded as practicable.

Ni. Similarly when partition ratio is .35 and input load from source A given full value required SD:$\bar{X}$ ratio is 89.60%, higher than the ratio shown in fig. 8.1. When input load from source A is given lower value and partition ratios .499 or .4 required SD:$\bar{X}$ ratios are 33.79 or 22.167 percent respectively.

Cd. As reduced means calculated are still greater than proposed M limit compliance is not feasible by this means.

Pb. When partition ratios are .95, .92 or .8 required SD:$\bar{X}$ ratios are 0.98, 0.84 or 0.29 percent and not practicable.

If one or two anomalously high concentration case(s) is/are omitted from Pb mean concentration in unstabilised sludge and partition ratios are .95 or .80 required SD:$\bar{X}$ ratios are 39.77 or 38.17 or are 91.33 or 87.26 percent respectively.

Comment 1.

Achievement of compliance by this means is practicable for Zn and Cu concentrations and for Ni when partition ratios are .35 or .499 but required SD:$\bar{X}$ ratio may be difficult to achieve when input from Source A is at a lower level and partition ratio is .4.

Achievement is not feasible for Cd and only practical for Pb concentrations if one or more anomalously high concentration case(s) is/are omitted in calculating the unreduced mean concentration in unstabilised sludge.

2. Simulated stabilised sludge.

A. Simulated digested sludge.

Methods used are the same as for unstabilised sludge. Results are shown in table 8.36 cols. D and E.

When partition ratios are as shown in table 8.36 col. B then required SD:$\bar{X}$ ratios are:

Zn 48.28, 47.79 or 41.26 percent respectively

Cu 36.34, 35.98 or 34.81 " " "

Ni When input from source A is at full value. 50.283%

When input from source A is at lower value 9.064 or 0.48 percent respectively.

Cd Not feasible.

Pb Not feasible.

Or if one or two anomalously high concentration cases are omitted and unreduced mean in unstabilised sludge recalculated are

13.62 or 12.29 percent, or

51.56 or 48.56 percent respectively.

Comment 2.

Although reduction of Zn, Cu and Ni, when input load of Ni from source A is at full value, by this means gives required SD:$\bar{X}$ ratios which are regarded as attainable in practice, other Ni and Cd and Pb SD:$\bar{X}$ ratios are either not practical or not feasible, unless 2 anomalously high Pb concentration cases can be omitted when calculating unstabilised sludge mean.

B. Simulated lime treated sludge.

Methods used are the same as for simulated digested sludge. Results are shown in table 8.37 cols. D and E.

When partition ratios are as shown in table 8.7 col.B then required SD:$\bar{X}$ ratios are:

Zn 107.580, 106.307 or 96.725 percent respectively

Cu 89.138, 88.583 or 86.775 percent respectively.

Ni When input from source A is at full value 110.656%

When input from source A is at lower value

47.033 or 33.780 percent respectively.

Cd 5.324 or 4.253 " " "

Pb 9.624, 9.466 or 8.846 " "

Or if one or two anomalously high concentration cases are omitted and unstabilised mean concentration recalculated

54.07 or 52.02 percent or

112.629 or 107.990 percent respectively.

Comment 3.

Although reduction of Zn, Cu and Ni mean concentrations give required SD:$\bar{X}$ ratios which are here regarded as practicable, Cd and Pb required SD:$\bar{X}$ ratios are not regarded as practicable unless one or two anomalously high concentrations of Pb can be omitted from the calculation of mean concentration in unstabilised sludge.

8.4.3. Conclusions

The following conclusions are made on the basis of 1980/81 data and on the YWA Guide limits shown in table 8.31.

1. Metal concentrations in effluents of 10 'elite' and 3 low flow sources exceed 1 or more YWA guide limits. In 13 cases mean concentrations were in excess of 4X guide limit values.

2. Although the highest input load of Cr, 1069 kg. is from source A, mean Cr concentration of that input was well within guide limit value.

3. Mean concentrations in effluents from sources A and F, with highest inputs loads of Ni and Cd respectively, did not exceed total non-ferrous metal limit. This suggests that in any reduction using concentration limit values, reduction to individual metal limits rather than total non-ferrous metal limit may be required. (Cf. ref.18).

4. Zinc equivalent guide limit is relevant to UK Guidelines but not to EC proposed Annex 1A limit values if sewage sludge were once again disposed by use on agricultural land.

5. By using the strategy of reducing metal concentrations in effluents to guide limits reduction of metal inputs to sewers would have been 2504, 461, 5590 or 2571, 30 and 517 kg. of Zn, Cu, Ni or Ni, Cd and Pb from sources BCEGH, EH, AGI, F and H respectively, equivalent to a reduction of total equivalent input and hence of concentrations in unstabilised and simulated stabilised sludges of 15.8-21.25, 6.5-8.0, 33.2-63.1, 6.9-8.4 and 5.6-6.6 percent of Zn, Cu, Ni, Cd and Pb respectively according to partition ratios used. See Table 8.33.

6. Calculated reduced Zn, Cu, Ni and Pb concentrations in unstabilised sludges and Zn, Cu and Ni concentrations in simulated digested sludges would achieve simple compliance with proposed EC mandatory limits. But reduction of Zn and Cu concentrations is not critical to the achievement of simple compliance. See tables 8.33 and 8.34.

7. Simple compliance in simulated lime treated sludge was achievable for all metals using this strategy. Again reduction of Zn and Cu mean concentrations was not a critical requirement. See table 8.34.

8. Reductions of Cd concentrations are not adequate to achieve simple compliance in unstabilised and simulated digested sludges.

9. Calculated reductions of Cd and Pb were not sufficient to allow required SD:$\bar{X}$ ratios to be either feasible or practical in unstabilised or, in simulated digested or lime treated sludges to achieve 95% probability of compliance with proposed M values. Pb compliance could be achieved when 1 or 2 anomalously high concentration cases were omitted from mean concentration in unstabilised sludge. See tables 8.35-8.37.

10. Reduction of Cd concentrations in input from source F is not adequate to achieve simple or 95% probability of compliance of reduced Cd concentrations in unstabilised or simulated digested sludge to proposed mandatory values. Reduction of inputs from sources unknown to this study would be required.

Reduction of the Cd guide limit should be considered, but if halved,

reduction of Cd still only from source F would be inadequate.

Ambiguity of input from source Ka of dual input source Ka+b is a further complicating factor.

11. If control by enforcing Guideline limits is used the importance of eliminating anomalously high concentrations, particularly of Pb, should not be underestimated. Elimination of the causes of these high concentration cases appears to be at least as important as the reducing of 'known' inputs of Pb by reduction of concentrations to YWA guide limits, particularly so when % probability of compliance is required.

12. But the above findings are qualified by the condition that agreed flows are held constant at 1980/81 levels, whereas if the trader perceiving the use of further dilution as an acceptable and economically preferable method of reducing mean concentrations in his effluent, increases flow the required level of input load would not necessarily drop but might increase.

Although control of metal concentrations in trade effluents entering sewers might provide a reasonable basis for controlling metal concentrations in final effluents leaving WPC works it does not in itself provide an adequate basis for controlling metal input loads and hence metal concentrations in sewage sludges leaving the WPC works.

8.4.4. A short summary of results

Short summaries of results are shown for simple compliance in table 8.38 and for 95% probability of compliance in table 8.39.

1a. By comparison of table 8.38 with table 8.27 it is seen that a similar pattern of simple compliance is obtained when by reduction of input from highest known trade source(s) to that shown when by reduction of known inputs to Guide limits.

b. One important difference is that compliance of Cd concentration in unstabilised sludge is not feasible by reduction to guide limit concentrations

of Source F only, as shown in table 8.38. Whereas 53-65 percent reduction of load input from sources F+B is able to achieve simple compliance with proposed M limit. See table 8.7 and 8.27. It should be noted however that effluent from source B has a medium flow but concentration is less than Guide limit.

2. Similarly by comparing table 8.39 with the lower part of table 8.29 it is seen that when 95% probability of compliance is required a similar pattern emerges.

a. Zn and Cu concentrations achieving compliance in 3 sludges.

b. Ni concentrations have a wider range of minimum required SD:$\bar{X}$ ratios when inputs are reduced to Guide limit concentrations than when 80% or 90% reduction of load from Source A takes place.

Lowest SD:$\bar{X}$ ratios being in both tables when Ni from Source A is given a lower input value and partition ratio of .40 is used.

c. Compliance of Cd and Pb concentrations by both means in 3 sludges is again not feasible, not practical or of low practicability.

8.5. Two operational considerations

8.5.1. Uncertainty and compliance

The model has been applied and results reported when using data from samples and measurements taken over a 12 month period. The length of period being regarded as expedient in view of the number of concentration cases of metals in sewage sludge and in trade effluents, and particularly as the only agreed flows of trade effluent inputs, made available, were for a 12 month period. A shorter period or a rolling period could be used providing that the required basic data, including agreed flow of trade inputs, was available.

The proposal for a directive requires "As a rule, sludge is to be analysed every 6 months. Where changes occur in the characteristics of the sewage being treated the frequency of analyses must be increased." [19] But

the basis of compliance has not been stated in the proposed directive. It is important, therefore, to consider briefly how statements of type and degree of compliance and monitoring may affect interpretation of the results obtained in this study.

The setting of standards may be strongly influenced by compromise at the political stage of negotiation. With this in mind the following possibilities are considered.

If powers of interpretation are left with national or local agencies[20] perhaps as an expediency in achieving an initial negotiated agreement, UK legal instruments will still be required to frame the type of compliance requirement passed down to local agencies. The type or degree of requirement may also be stepped to achieve a gradual tightening of compliance over a period.[21]

If statutory limits on metal concentrations in sewage sludge as proposed in Annex 1A are a compulsory inclusion in a final directive, requirement for compliance is in effect, if not in words, likely to lie between the most relaxed and the strictest of the 3 options discussed below.

a) Simple compliance based on the mean over a stated period while allowing individual cases to exceed limits. This type of compliance might be interpreted as "... implying an interest solely in long term accumulations."[22]

b) A less relaxed stipulation would be that "95% of the samples for parameters conforming to those specified in ...". As required in the EC Directive "Concerning the quality required of surface water intended for the abstraction of drinking water."[23] As can be seen from figs. 8.1 and 8.2 of 30 concentration cases in unstabilised sludge 28, 28, 16 and 15 cases of Zn, Cu, Ni and Cd and 7 out of 9 cases of Pb are less than the proposed mandatory limit being equivalent to 93.3, 93.3, 53.3, 50 and 77.7 percent of cases thus all metals would fail on this basis.

c) Introducing probability of compliance beyond the actual sample cases taken to estimate the compliance in the model 95% probability of compliance has been considered. In view of comments by WRC staff that "Apart from being grossly non uniform, sewage sludge, particularly crude sludge, is difficult to homogenize because of its fibrous content,"[24] it is difficult to consider any higher degree of compliance being possible.

Account must also be taken of location of sampling point and of the uncertainties of sampling and analyses.

Ideally sampling should be from each tanker prior to spreading on agricultural land, but more practically from the storage tank from which the tankers are filled, the processes of treatment and storage of sludge having an effect on concentrations and standard deviation of metals in samples taken. It is therefore desirable that data from samples taken should be used when applying the model.

Uncertainties of sampling and measurement may be taken account of by setting confidence limits on the data used and subsequently adjusting the deviant in the probability formula accordingly. Subsequent classification of sludges might be as satisfactory, unresolved and unsatisfactory.[25]

The extent of the unresolved area depending in part on the level and type of sampling and on the accuracy and precision of measurement. Even with sludge samples specially ground and homogenised to pass a 0.5mm sieve an inter-laboratory study carried out by WRC found mean accuracy, i.e. maximum probable deviation of results for a crude sludge and a digested sludge to be for Zn 9.5 and 11.1, Cu 9.9 and 8.9, Ni 12.7 and 11.5, Cd 23.7 and 12.0, and Pb 13.2 and 10.6 per cent respectively showing greater accuracy in digested than in crude sludge.[26] The lowest mean accuracy being Cd in crude sludge.

A simple application of $\pm$ 25% unresolved area to Cd and say Ni concentration distributions, shown in fig. 8.1, indicates that at least 9

concentration cases out of 30, i.e. 30%, would still not comply with proposed mandatory limit. Zn, Cu and Pb distributions would still be marred by 2 high concentrations, in each case.

It is concluded that the simple and 95% probability of compliance used in this study are representative of the least and most demanding of the types of compliance that might be required by a Directive on the use of sewage sludge in agriculture. Location of sampling point, number and type of samples and mean accuracy of measurement will affect the quality of input data. Tuning of the deviant, particularly by computer may be practised to take account of 'unresolved' cases.[27]

8.5.2. An EQO approach?

Four strategies for reaching compliance with M or M and R limit values stipulated in Annex 1A of the EC proposal for a directive on the use of sewage sludge in agriculture have now been considered.

If, as in the recent Cadmium directive,[28] the UK policy commitment to the principle of using environmental quality objectives (EQOs) is able to prevail and the final directive, if any, were to allow optional use of finally agreed Annex 1A values, at least in the short term, with greater stress being placed of limits to application and soil concentrations stipulated in Annex 1B and 1C, how would that affect the use of the model and findings of this study?[29]

It was the original intention of this study that the model should be capable of plugging in to the computerised records of a Water Authority area sludge disposal unit. It would then be possible to assess the effects of reductions calculated on a practical application basis.

If proposed mandatory limits for Ni, Cd and Pb concentrations of 50, 3 and 100 $mgkg^{-1}$ dry soil, respectively, are adopted and it is desirable to dispose of sludge from the city works studied to agricultural

land, the type and magnitude of required reductions already discussed will be highly relevant. The potential for Nickel reduction from source A, the lack of adequate known trade inputs of Cd and Pb, and the operational advantages of eliminating anomalously high concentrations in sludges, whatever the cause, would seem to be highly operational factors in accommodating to an EQO approach.

Even without a directive controlling the use of sludge in agriculture, providing the KLL works problem of non-digestibility of primary sludge can be solved and a return to disposal by use on agricultural land provides an economic strategy, it is suggested that reduction of metals particularly Ni and Cd would be highly desirable. Unless N_2 values were limiting, they would allow higher application rates per unit of travel cost. If N_2 was limiting the same would apply over a longer period in allowing spreading on land within shorter distance of travel to be continued over a longer period.

As pointed out in section 7.5 the model could also be used in connection with the calculation of final effluent emissions and in the establishment and control implications of EQOs in the aquatic environment.

This extension of use is now becoming urgent as RWAs are required through COPA 74 to meet the requirements of implementing the EC Directives. The Directive "on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community,"[30] and the related Directive "On limit values and quality objectives for Cadmium discharges,"[31] which specifically states required EQO Cd concentrations, are of particular relevance to the WPC works studied.

TABLE 8.31

Non-ferrous metal concentration limits "...indicative of the magnitude which the authority may wish to impose on the average effluent," (g) and known Inner City sources of effluents in which mean concentrations of Zn, Cu, Ni, Cd, Pb or Cr exceed these limits.

Metal Guide Limit in mgl^{-1} Sources	Zn 10	Cu 5	Ni 4	Cd 2	Pb 5	Cr 5	Zn≡ 35	Tot.Non-Fe. h. 30	No. of Excesses Total
	exceeding above guide limit								
A			x				x		2
B	xf						x	x	3
C	x								1
D	x_f^c						xc	xc	3
E	x	x					x	x	4
F				x		x			2
G	xc		xc				xc		3
H	x	xf			xf^d		x	xf	5
I			xf				xf	(x)	3
J						xf		x	2
L_1						x_f^a			1
L_2	x_f^a	x_f^a			xa		xa	xa	5
L_4		x_f^b				x_f^b	xb	xb	4
6			(x)				(x)		(2)
15						(x)a			(1)
18			(x)				(x)		(2)
26			(x)b				(x)b		(2)
Ka				xe					1
Total	18	7	4	6	2	2	5	12	8	46
Mean									2.5555

Notes for Table 8.31

a. Concentration, or total based on 1 sample case only.

b. Concentrations, " " "2 " cases "

c. " " " " 3 " " "

d. " " " " 4 " " "

e. Ka is one input of dual input Ka + b for which only 1 flow is available.

f. Mean concentration, more than four times the guide limit.

( ) Relatively slightly in excess of guide limits.

g. YWA Code of Practice for the Control of Trade Effluent Draining to Public Sewers 21.1.76, Appendix D.

h. Total non-ferrous metals excluding alkali and alkaline earth metals.

x Exceeds Guide limit.

TABLE 8.32

Calculated reduction of Zn Cu Ni Cd and Pb input loads to sewers when excess concentrations in effluents from elite sources are reduced to just comply with guide limits (d) and reduction as a percentage of total inputs to sewers catchment of a Leeds City WPC works from known trade sources

Column	A	B	C	D	E
Source	Ex Table 8.31 Elite Sources Exceeding Guide Limit	Recalculated basic data file Present Total input from Col.A Sources	Flow x Guide Limit Total input from Col.A Sources at Guide Limit	Col.B-C Total Annual Reduction	Col.D÷T as Col.1 shown in Table 8.4 Reduction as Percentage of Inputs from Known Trade Sources
Unit	Code	kgy^{-1}	kgy^{-1}	kgy^{-1}	%
Metal					
Zn [a]	B,C,E,G,H	3829.322	1324.82	2504.502	61.496
Cu	E,H	573.916	112.395	461.521	61.503
Ni	AGI	7624.282 [b]	2033.744	5590.538	71.468
	AGI	4604.405 [c]	2033.744	2570.611	53.528
Cd	F	56.383	26.304	30.079	29.33
Pb	H	561.081	43.855	517.226	87.3

Notes:

a. Omitting input from source D.
b. Source A load given full value.
c. Source A given lower load, calculated omitting highest concentration case.
d. As given in Appendix D of YWA Code of Practice for the ontrol of trade effluent draining to public sewers ref.

TABLE 8.33

Calculated reduction of Zn, Cu, Ni, Cd and Pb input loads to sewers, when concentrations in effluents from 8 'elite' sources are reduced to just comply with guide limits (d), equivalent reduced concentrations in unstabilised sludge and effect of reduction on simple compliance proposed EC Mandatory and Recommended limits.(e)

Column	A	B	C	D	E	F
Source	Table 8.31	Table 8.32 Col.D.	Table 8.2	Col.B/Table 8.3 Col.3	Table 8.1 Col.1	Col.Ex (100-D)%(f)
Parameter	'Elite' sources exceeding Guide limit.	Reduction of input if at guide limit conc.	Partition ratio	Reduction as % of calculated input load	Mean conc.in unstabilised SS.	Reduced conc.in unstabilised SS
Unit	Code	kgy^{-1}		%	$mgkg^{-1}$	$mgkg^{-1}$
Metal						
Zn[a]	BCEGH	2504.502	.94	21.254	1568.06**	1234.789**
	"	"	.9135	20.654	"	1244.185**
	"	"	.70	15.827	"	1319.879**
Cu	EH	461.521	.92	7.978	753.443**	693.335**
	"	"	.8806	7.636	"	695.910**
	"	"	.75	6.504	"	704.442**
Ni	AGI	5590.538b	.35	63.143	438.68	161.684**
	"	2570.661c	.499	41.395	"	257.089**
	"	"	.40	33.182	"	293.116**
Cd	F	30.079	.9	8.375	45.76	41.928
			.738	6.867	"	42.6175
Pb	H	517.226	.95	6.606	1053.8	984.188*
	"	"	.92	6.397	"	986.386*
	"	"	.8	5.563	"	995.179*
Pb-1Hcc	H	517.226	.95	10.337	672.9**	603.340**
	"	"	.8	8.707	"	614.311**
Pb-2Hcc	H	517.226	.95	14.826	469.17**	399.612**
"	"	"	.8	12.485	"	410.595**

continued/

Table 8.33 (continued)

Notes

a. Omitting input from source D.

b. Input load from Source A given full value, .35 partition applies.

c. " " " given lower value, .499 and .4 partition applies. see Table 8.4 note d.

d. As given in Appendix D of YWA Code of Practice for the control of trade effluent draining to public sewers.

-1Hcc. When 1 highest concentration case is omitted or replaced and mean concentration of Pb in unstabilised sludge recalculated.

-2Hcc. When 2 highest concentration cases are omitted or replaced and mean concentration of Pb in unstabilised sludge recalculated.

* Simple compliance with EC proposed Mandatory limit, 3000, 1500, 400, 40 and 1000 $mgkg^{-1}$ of Zn, Cu, Ni, Cd and Pb respectively.

** Simple compliance with EC proposed Mandatory and Recommended Limit 2,500, 1000, 300, 20 and 750 $mgkg^{-1}$ respectively.

e. See OJC 264/6 8.10.1982.

f. As % input = % output. See equation A5 (in S7.4).

TABLE 8.34.

Reduced concentrations in simulated digested and lime treated sludges calculated when concentrations in effluents from 8 'elite' trade sources are reduced to just comply with guide limits (d) and effect on simple compliance with proposed EC Mandatory and Recommended limits. (e)

Column	A	B	C	D	E	F	G
Source	Table 8.31 'Elite' sources exceeding YWA Guide limit	Table 8.2 Partition ratios	Table 8.33 Col.D. Reduction of Calculated input	Table 8.8 Unreduced conc.in Sim. dig.sludge	DX(100-C)%(f) Reduced conc. in Sim.dig. sludge	Table 8.8 Unreduced conc. in sim.L-treated sludge	Fx(100-C) %(f) Reduced conc. in Sim. Lime-treated sludge
Unit	Code		%	$mgkg^{-1}DS$	$mgkg^{-1}DS$	$mgkg^{-1}$ DS	$mgkg^{-1}$ DS
Metal							
Zn a	BCEGH	.94	21.254	2123.153**	1671.983**	1375.502**	1083.153**
	"	.9135	20.654	"	1679.649**	"	1091.406**
	"	.70	15.827	"	1787.116**	"	1157.801**
Cu	EH	.92	7.978	1020.162*	938.776**	660.920**	608.192**
	"	.8806	7.636	"	942.262**	"	610.452**
	"	.75	6.504	"	953.815**	"	617.934**
Ni	AGI	.35	63.143b	593.973	218.920**	384.810*	141.829**
	"	.499	41.395c	"	348.098*	"	225.518**
	"	.40	33.182c	"	396.879*	"	257.122**
Cd	F	.9	8.375	61.959	56.770	40.141	36.779*
	"	.738	6.867	"	57.704	"	37.385*
Pb	H	.95	6.606	1426.845	1332.5905	924.393*	863.328*
	"	.92	6.397	"	1335.567	"	865.260*
	"	.8	5.563	"	1347.473	"	872.969*
Pb-1Hcc	H	.95	10.337	911.107*	816.925*	590.268**	529.252**
	"	.8	8.707	"	831.776*	"	538.873**
Pb-2Hcc	H	.95	14.826	635.256**	541.074**	411.557**	350.540**
	"	.8	12.485	"	555.943**	"	360.174**

Notes: as for Table 8.33.

TABLE 8.35

Calculated reduced Zn, Cu, Ni, Cd and Pb mean concentrations in unstabilised sewage sludge and maximum permissible standard deviation of concentration cases required to achieve 95% probability of compliance with proposed Mandatory limits (e), when mean concentrations of those metals in effluents from eight sources are reduced to just comply with YWA Guide limits (d).

Column	A	B	C	D	E	F
Source	Table 8.31	Table 8.2	Table 8.33 Col.F.	Cols.F-C/1.645(f)	Cols.D/C	Table 8.6 col.1 (e)
Parameter	'Elite' sources exceeding YWA Guide Limits	Partition ratio	Reduced mean concentration in Unstabilised S. sludge	Max. required Standard Deviation.	$SD/\bar{X}$	Proposed Mand. limits
Unit	Source Code	numeral	$mgkg^{-1}DS$		%	$mgkg^{-1}DS$
Metal						
Zn a	BCEGH	.94	1234.789	1073.076	86.90*	3000
"	"	.9135	1244.185	1067.363	85.79*	"
"	"	.70	1319.879	1021.350	77.38*	"
Cu	EH	.92	693.335	490.374	70.73	1500
"	"	.8806	695.910	488.808	70.24	"
"	"	.75	704.442	433.622	68.65	"
Ni	AGI	.35b	161.684	144.873	89.60*	400
"	"	.499c	257.089	86.876	33.79	"
"	"	.40c	293.116	64.975	22.167	"
Cd	F	.9	41.928	NF	NF	40
"	"	.738	42.6175	"	"	"
Pb	H	.95	984.188	9.612NP	0.98 NP	1000
"	"	.92	986.386	8.276 "	0.84 "	"
"	"	.8	995.179	2.931 "	0.29 "	"
Pb-1HCC	H	.95	603.340	241.130	39.97	1000
"	"	.80	614.311	234.461	38.17	"
Pb-2HCC	H	.95	399.612	364.978	91.33	1000
"	"	.80	410.595	358.301	87.26	"

Notes: see attached

Table 8.35

Notes:

	a - e	As for Table 8.33
+	f	Rearranging the probability formula $M = \bar{X} \times 1.645$ SD.
	NF	Not feasible
	NLP	Not likely to be practical
	NP	Not practical.
	*	Required SD higher than SD of Unstabilised sludge concentrations shown in figs. 8.1 and 8.2.

TABLE 8.36

Calculated reduced Zn, Cu, Ni, Cd and Pb mean concentrations in simulated digested sewage sludge and maximum permissible standard deviation of concentration cases required to achieve 95% probability of compliance with proposed Mandatory limits (e), when mean concentrations of those metals in effluents from 9 sources are reduced to just comply with YWA Guide limits (d).

Column	A	B	C	D	E	F
Source	Table 8.31 'Elite' sources exceeding YWA Guide Limits. Source Code	Table 8.2 Partition Ratio	Table 8.34 Col.E Reduced mean concentration in Sim.digested sludge	(Cols F-C)/1.645(f) Max.required Standard Deviation	Cols. D/C	(e) Proposed Mand. Limits
Unit		numeral	$mgkg^{-1}$ DS		$SD/\bar{X}$ %	$mgkg^{-1}$ DS
Metal						
Zn a	BCEGH	.94	1671.983	807.305	48.28	3000
"	"	.9135	1679.649	802.645	47.79	"
"	"	.70	1787.116	737.315	41.26	"
Cu	EH	.92	938.776	341.170	36.34	1500
"		.8806	942.262	339.050	35.98	"
"		.75	953.815	332.028	34.81	"
Ni	AGI	.35b	218.920	110.079	50.283	400
"	"	.499c	348.098	31.551	9.064 NLP	"
"	"	.40 c	396.879	1.897	0.48 NP	"
Cd	F	.9	56.603	NF	NF	40
"	"	.738	57.704	NF	NF	"
Pb	H	.95	1332.59	NF	NF	1000
"	"	.92	1335.567	NF	NF	"
"	"	.80	1347.473	NF	NF	"
Pb-1Hcc	H	.95	816.925	111.292	13.62	1000
"	"	.80	831.776	102.263	12.29	"
Pb-2Hcc	"	.95	541.074	278.982	51.56	1000
"	"	.80	555.945	269.942	48.56	"

Notes: As for table 8.35.

TABLE 8.37

Calculated reduced Zn, Cu, Ni, Cd and Pb mean concentrations in simulated lime treated sludge and max. permissible standard deviation of concentration cases required to achieve 95% probability of compliance with proposed Mandatory limits (e), when mean concentrations of those metals in effluents from 8 sources are reduced to just comply with YWA guide limits (d).

Column Source Parameter Unit	A Table 8.31 'Elite' sources exceeding YWA Guide Limits Source Code	B Table 8.2 Partition Ratio	C Table 8.34 Col. F Reduced mean concentration in Sim. Lime Treat.S. $mgkg^{-1}$ DS	D (Cols.F-C) /1.645(f) Max. required Standard Deviation	E Cols. D/C SD/$\bar{X}$ %		F (e) Proposed Mand. Limit $mgkg^{-1}$ DS
Metal							
Zn a	BCEGH	.94	1083.153	1165.2565	107.580*		3000
"	"	.9135	1091.406	1160.2395	106.307*		"
"	"	.70	1157.801	1119.878	96.725*		"
Cu	EH	.92	608.192	542.133	89.138*		1500
"	"	.8806	610.452	540.759	88.583*		"
"	"	.75	617.934	536.210	86.775*		"
Ni	AGI	.35 b	141.829	156.943	110.656*		400
"	"	.499c	225.518	106.068	47.033*		"
"	"	.40 c	257.122	86.856	33.780		"
Cd	F	.9	36.779	1.958	5.324	NP	40
"	"	.738	37.385	1.590	4.253	NP	"
Pb	H	.95	863.328	83.083	9.624	NP	1000
"	"	.92	865.260	81.909	9.466	NP	"
"	"	.80	872.969	77.222	8.846	NP	"
Pb-1Hcc	H	.95	529.252	286.169	54.070		1000
"	"	.80	538.873	280.320	52.020		"
Pb-2Hcc	H	.95	350.540	394.808	112.629		1000
"	"	.80	360.174	388.952	107.990		1000

Notes: As for table 8.35.

TABLE 8.38

Summary of Results Guide Limits and Compliance

Summary of results of simple compliance of Zn, Cu, Ni, Cd and Pb concentrations in unstabilised, simulated digested and simulated lime stabilised sewage sludge, without or with reduction as a result of reducing mean concentrations in effluents from 8 known sources to YWA guide limit concentrations. a.b.

	Zn	Cu	Ni	Cd	Pb		
Simple Compliance Without Reduction						Table	See also Table
in Unstabilised SS.	**	**				8.33	8.6
in Sim. digested SS.	**	*				8.34	8.8
in Sim.Lime Stab. SS.	**	**	*		*	8.34	8.8
With reduction to Guide Limit							
in Unstabilised SS	N	N	**	NF	*	8.33	
in Sim. digested SS.	N	N	*	NF	NF	8.34	
in Sim. Lime Stab. SS.	N	N	**	*	N	8.34	

Notes:

* complies with Mandatory but not Recommended limit value.

** " " " and " "

N Not required

NF Not feasible

a Mandatory or Recommended limit values specified in Annex 1a of the EC proposal for a directive. OJC 264/7 8.10.82.

b As given in Appendix D of YWA code of practice for the control of trade effluent draining into public sewers.

TABLE 8.39

Required SD:$\bar{X}$ ratio to achieve 95% probability of compliance of Zn, Cu, Ni, Cd and Pb concentrations in unstabilised, simulated digested and lime stabilised sludge when these are reduced as a result of reducing mean concentrations in effluents from 8 known sources to YWA guide limit concentrations. a, b.

	Zn % RSD	Cu % RSD	Ni % RSD	Cd % RSD	Pb % RSD	Source tables
Unstabilised Sludge						
" " RSD	77*-87*	68-71	LP 22-89*	NF	3-10 NP	8.35
Sim. digested sludge						
" " RSD	41-48	35-36	NP 2-110*	NF	NF	8.36
Sim. Lime Stab. Sludge						
" " RSD	97*-108*	87*-89*	34-111*	4-5 NP	9-10 NP	8.37

Notes:

a. Mandatory and Recommended limit values specified in Annex 1A of the EC proposal for a directive OJC 264/7 8.10.82.

b. As given in Appendix D of YWA code of practice for the control of trade effluent draining into public sewers.

* SD:$\bar{X}$ ratio required is greater than that shown for unstabilised sludge in fig. 8.2.

NF Not feasible.

NP Not practical.

LP Low practicability.

8.6. What is the potential for further reduction of metal concentrations in KLL 1980/81 sludge output?

With the use of the model it has already been shown that, on the basis of the explicit assumptions and partition ratios used, calculated input loads from known trade sources, made available to this study were equivalent to 25.737-45.067% of Zn, 10.574-12.971% of Cu, 61.991-88.35% of Ni, 23.411- 28.55% of Cd, 6.371-7.566% of Pb and 35.566-45.7% of Cr annual mean concentrations in sludge output. However the problem remains of assessing the potential for reduction of metal inputs to sewers from Trade or other sources for which data is not available to this study. See table 8.4.

One technique used to get an indication is to compare concentrations in sludges produced during normal working periods, with those in sludges produced during an annual holiday, particularly Christmas shut down periods.[32] A further technique used in the water industry and for research is by comparing sludge concentrations from the study area with other sludges in the same or other areas which are known to receive little or no inputs of metals from trade sources.[33] Or thirdly by comparing results obtained by the above 2 methods.

Unfortunately no metal concentration cases are recorded for Christmas shutdown periods of 1979, 1980 or 1981 for the Study WPC works. Therefore, despite the limitations, some of which are discussed briefly, of the second method when used on its own, it is now applied.

Population weighted and arithmetic mean concentrations of 6 metals in sewage sludges from 44 WPC works reported as receiving 'no industrial effluents' are shown in table 8.40. Comparing the concentrations it is inferred that the concentrations of Zn, Cu, Cr, Cd and Pb increase with population size. Nickel concentrations do not display this trend. Average population served by the 44 WPC works is 8,900. 9 of the WPC works serving an average population of 18.100 produced digested sludge.

Undigested sludge from the remaining 35 WPC works is calculated to have concentrations of 567, 265, 39, 95, 5.8 and 223 $mgkg^{-1}$ dry solids of Zn, Cu, Ni, Cr, Cd and Pb respectively, while average population served is much lower, 6,534 persons.[34] See table 8.40 col. C.

These concentrations are now compared with the 'estimated standard analysis' used in the 1980 survey for WPC works serving a year round population of 5,000 or less, shown in Col. D. The estimated concentrations have a slightly lower concentration of Zn and Cd, considerably lower concentrations of Ni, Cr and Pb, while concentration of Cu is higher. Estimated concentrations being based on work carried out by WRC and Anglian WA.[35]

Using the separated sewer system, R.D.Davis of WRC obtained samples from a purely residential area of Stevenage which were then processed in a laboratory scale treatment 'works' giving the concentration of metals in a 'domestic' sludge shown in Col. F. Of particular importance are the low Ni, Cd and Pb concentrations of 8, 2 and 60 $mgkg^{-1}$ sludge dry solids respectively.[36]

Column E shows estimates, derived from WRC, given in a JURUE, U. Aston publication in which the nickel concentrations shown in columns D and F are reconciled by the author's note that "Run off appears to raise typical sludge Nickel levels from 8 $mgkg^{-1}$ to 30 $mgkg^{-1}$.[37] To what extent the increase in Cd and Pb from 2 to 5 and 60 to 120 $mgkg^{-1}$, respectively, are for this reason is not stated.

From the above it is concluded that for a small works receiving no or negligible amounts of trade effluents it would be reasonable to expect metal concentrations of Zn 515-570, Cu 265-300, Ni 30-39, Cd 5-5.8, Pb 120-223 and Cr 40-95 $mgkg^{-1}$ sludge dry solids.

Knostrop Low Level WPC works is a large works serving a population equivalent of 137,500 in an inner city area with considerable industrialisation. In addition to receiving metals from domestic, institutional and trade sources, it receives enhanced levels directly or indirectly from

diffuse sources such as atmospheric deposition, run off from buildings, pavements, roads and other impermeable surfaces and by leaching. Enhanced levels of metals may also be due to the local water supply and particularly of Pb from pipework in older parts of the city.[38]

Thompson and Dickens of Thames WA suggest that "Worcester Park sludge is almost wholly domestic in origin and may therefore be taken as the ideal target for contaminant concentrations."[39] Worcester Park WPC works serves a large, $>100{,}000$, suburban population in West London. Reported mean concentrations of Zn, Cu, Ni, Cd, Pb and Cr of 1045, 291, 194, 13, 189 and 108 $mgkg^{-1}$ of digested sludge dry solids are shown in table 8.41, Col. A.[40]

Conversion factors of x0.6 indicated by Davis,[41] or x0.73855 (i.e. $\frac{1}{1.354}$), as found for the high ash sludge in this study, are used to convert concentrations of metals in the digested sludge to undigested sludge equivalents, real equivalent values probably lying between the two sets of concentrations. See table 8.41 cols. B and C. By comparison with the range of concentrations in undigested sludges from small works derived from table 8.40 and given above the Worcester Park concentrations of Zn, Ni and Cd are higher, particularly Ni, while Cu, Pb and Cr lie within the ranges given, in table 8.40, for smaller works.

Also shown in table 8.41 are concentrations of metals in undigested sludge from 3 Yorkshire WA WPC works.[42]

a) A spa city works receiving 2% settleable solids and 10% of flow from known trade sources.

b) An outer city works receiving 16% settleable solids and 4% of flow from known trade sources, serving an area adjacent to

c) The inner city works receiving 23% settleable solids and 13.7% of flow from known trade sources, focussed on in this study. See table 8.41 cols. DEF.[43]

In view of the concentrations shown in table 8.40 and table 8.41

cols. BCDE it is regarded as operationally reasonable to suggest that an outer city or suburban undigested sludge without significant trade source point inputs of metals would have a concentration range of Zn 700-800, Cu 200-300, Ni 47-100, Cd 5.6-7.4, Pb 125-190 and Cr 70-80 $mgkg^{-1}$ dry solids as shown in Col. G. If these estimates are accepted, then by subtraction from Col. F, calculated range of concentrations attributable to trade and unknown sources in sludge leaving the inner city works would be Zn 768-868, Cu 453-553, Ni 339-392, Cd 38.4-40.2, Pb 864-929 and Cr 493-503 $mgkg^{-1}$ dry solids, being respectively 48.98-55.35, 60.12-73.4, 77.28-89.36, 83.92-87.85, 81.99-88.16 and 85.99-87.73 percent of metal concentrations in the unstabilised sludge leaving the inner city WPC works. It is noted that the accuracy of this finding is particularly limited for Pb as the mean concentration shown in Col. F is based on 9 cases only.

Another limitation of using the above type of deductions is that metal concentrations in sludges are just as much a function of dry solids present as of metals present. Thus additional settleable solids from trade sources if of low, or relatively low, metal content could actually have a diluting effect on metal concentrations in sludge produced. However, on the basis of unpublished data[44] percentage settleable solids from trade sources, shown in table 8.41 cols. DE and F, diluting effect, if any, is likely to be small, and effect of these inputs on concentrations of metals in sludge output of suburban or outer city WPC works attributable to non-trade sources is likely to lie within the ranges shown in Col. G.

Subtracting previously calculated percentage ranges of metals equivalent to known trade inputs T, (table 8.4), from ranges equivalent to inputs from trade, known and unknown, and unaccounted for sources, equivalent ranges of metals from unknown trade and unaccounted for sources are Zn 3.91-29.61, Cu.47.15-62.83, Ni 0-35.12, Cd < 55.37-64.44, Pb 74.42-81.79 and Cr 40.29-52.16 percent of metal concentrations in KLL undigested

sewage sludge. See table 8.42 Cols. 1,2,3 and 4. The width of ranges given for Zn 25.7% and Ni 35.12% are in part due to the use of alternative levels of inputs of total loads from known trade sources as shown in table 8.4. The width of range given for Cd >9.07% is limited by uncertainty regarding the extent to which source Ka contributes to the Cd load from dual input source Ka+b.

On the basis of calculations presented above, 47.15-62.83% and 40.29-52.16% of Cu and Cr concentrations in the WPC works sludge output are attributed to unknown trade and other sources, and seem to indicate there is further potential for input reduction, as with Zn and Ni compliance with proposed EC limits appears to be readily achievable using one or two of the four strategies previously proposed. It is now important to examine Pb and Cd inputs in more detail.

Pb. Perhaps due to practice current in 1979-83 of disposing of KLL sewage sludge to sea, monitoring of concentrations of Pb in the sludge appears to have been given a low priority mean concentration being made up of 9 cases only including 2 very high and 1 very low concentration cases.

In view of this it is necessary to consider that the mean concentration of 1053.8mg Pb kg^{-1} dry solids sewage sludge may be unrepresentatively high. Omitting one or two highest concentration cases the mean is recalculated to be 672.9 or 469.17 $mgkg^{-1}$ then subtracting the outer city and suburban range of 125-190 $mgkg^{-1}$, see table 8.41 Col. G, 71.76-81.42% of the 672.9 mgkg or 59.5-73.36% of the 469.17 $mgkg^{-1}$ is attributable to trade and unaccounted for sources and 59.92-71.45% or 42.52-59.06% of those respective Pb means concentration is attributable to unknown trade and other sources. From this it can be seen that although the loads of Pb unaccounted for are undoubtedly less when mean concentrations of Pb are reduced, the percentage of those mean concentrations which is in excess of that expected from a sludge receiving only the known non-trade and known

trade inputs still remains as high as 42.5-71.45% of the recalculated mean concentrations of Pb in sludge. See table 8.42.

An attempt is now made to get some indication of the contribution of airborne Pb.

Unknown sources. Atmospheric pollution

Mean concentrations and ranges of 6 metals in air monitored at 3 Leeds sites, shown in table 8.43, are taken from the first year report of a 20 site national survey carried out in 1976/77 by Warren Springs Laboratory.

As shown in cols. 2, 3 and 4, monitoring sites were located in an outer city residential area, an older inner city residential/industrial area and in the eastern city centre area.[45]

Unfortunately concentrations shown for the outer city area are based on monthly samples taken in July, August, September and November 1976 only. However, results are considered worth including in the survey with the comment that "As far as can be judged concentrations are significantly lower than at other sites in Leeds."[46] A conclusion of the survey report is that "in general, concentrations tended to be about 50-80% higher in winter than in summer."[47] Increasing concentrations by 15-20% to compensate for this imbalance of summer/winter data still gives concentrations less than those shown for Zn, Cu, Ni, Cd and Pb in cols. 3 and 4 and similar to those shown for Cr. Indicating that there were enhances levels of air pollution in the inner city area. Mean concentrations of Zn, Ni and Cr were higher in samples taken from the Vicar Lane site than the Town Street site but the reverse applied to concentrations of Cu, Cd and Pb. It is not known to what extent these results are due to differences in height of monitoring stations, a factor which appears to be seldom considered in air pollution monitoring. Proximity of trade emission sources to the Town Street site are possible causal factors.

By comparison with the range of concentrations from a national survey of 7 rural sites, 1976 data, shown in table 8.43 col. 1, it can be seen that the range of concentrations of Zn, Cd, Pb and Cr is less for the rural sites than for the 3 Leeds sites. Cu concentration range at rural sites was less than the inner city sites but greater than the outer city site, this may be related to the low number of samples in the latter.[48] Range of Ni concentrations from rural sites was greater than the Leeds sites, due to very high concentrations at the Trebanos, W. Glamorgan, site.[49]

Also shown in table 8.43 col. 5 are mean annual concentrations of Pb in samples of air taken from 6 sites in and near to Leeds in 1979/80 and 1980/81, the concentrations are less than found in the national survey Town Street and Vicar Lane sites, but greater than that for the outer city site.

The Leeds lead survey results may also be compared with British Standard Deposit Gauge results again taken at 6 sites when mean deposition of Pb in 1979/80 and 1980/81 was found to be 385 and 456 $\mu gm^{-2}day^{-1}$ respectively or 420.5 $\mu gm^{-2}day^{1}$ over the two year period,[50] equivalent to 153.4825 $mgm^{-2}y^{-1}$ or 153.4825 $kgkm^{-2}$ or 1 tonne Pb per 6.5154 km^2 per annum. See table 8.44.

Taking a course estimate that 40% of the inner city works catchment area is impervious and equivalent to 741 hectares,[51] then on the above calculations 1.137 tonnes y^{-1} of Pb would be deposited on the impervious area alone. Then even in the most unlikely event of all this Pb load entering the WPC works it would only account for 14.52% or less of the calculated input loads of Pb, shown in table 8.3 col. 3, when mean sludge concentration is 1053.8 $mgkg^{-1}$, but approximately 31% if the real mean is as low as 469.17 $mg.kg^{-1}$ shown in table 8.41 col.F.

On the basis of total deposition, shown in table 8.44 it is suggested that approximately two thirds of the inner Leeds deposition may be attributed to trade and unknown sources, equivalent to approximately 9.68% of

calculated input, shown in table 8.3.

Comment

The poor reliability of the mean 1980/81 Pb sludge concentration of 1053.8 $mgkg^{-1}$ is a serious limitation in calculations involving that parameter. It is subject to this reservation that the following comments are made.

In view of the 74.42-81.79% of sludge concentration attributed to unknown trade and other sources, it is concluded that Pb concentrations in air, although potentially a source of significant loads of Pb in sludges or receiving waters is small by comparison with the percentages given above and that attributed to enhancement over suburban levels is even less.

The monitoring in the Leeds lead survey were located in the neighbourhood of three lead works and it may be that deposition : air concentration ratios were higher in those areas, due to higher particulate size, than in the inner city area as a whole. But mean air Pb concentrations of the lead survey sites were lower than those from the national multielement survey inner city and city centre sites. One possible reason for this is traffic density in the inner city area. In this connection it is relevant to note, in a recent Royal Commission report, that "In Germany, for example, a reduction in the maximum permitted concentration of lead in petrol from 0.4 g/l to 0.15 g/l at the beginning of 1976 was paralleled by a decrease in ambient air lead concentrations ranging from 65 percent in some inner city areas to about 20 percent in some rural areas." [52]

It is concluded that excess Pb from unknown trade and other sources may include significant quantities of Pb from aerial sources. But 'unknown' trade sources would appear to account for a much higher percent of input load. 'Known' trade sources available to this study are 40 metal industry inputs. Input loads are calculated on the basis of RWA monitoring of effluent inputs to sewers from these courses. Therefore input

from 'unknown' trade sources may be

a) from trade sources known to the RWA but not to this study,

b) from sources known to this study but over and above the loads represented by the WA monitoring procedure or

c) from sources unknown or not yet monitored for Pb by the WA.

To what extent institutions and other exempted sources contribute is also an unknown.

From the distribution of Pb concentrations, shown in fig. 8.2 and the findings of the present study, summarised in tables 8.27-30 and 8.38-39 it is seen that the elimination of atypically high concentrations of Pb in sewage sludge and of their causal inputs appear to be a high priority.

In view of the very high percentage of sludge concentration attributable to 'unknown' trade and other sources, calculated in table 8.42 col. 4, and of the concern shown in carrying out the Leeds blood Pb survey and by the inclusion of 3 Leeds sites in the 20 site national survey carried out by WSL, it is surprising to find that in the data made available to this study only 6 trade inputs to sewers were monitored for Pb.

A further unknown is to what extent scrubbings to reduce lead pollution by aerial emission, and sweepings to reduce dust may themselves have been, directly or indirectly, disposed of as effluents to sewers.

Cd. Unlike Pb, Cd concentrations in sludge are relatively well monitored, and on a par with monitoring of zinc equivalent metals. At the low concentrations at which Cd occurs accuracy of measurement is difficult in a non uniform substance like sewage sludge. A further source of error may be in measurement of Cd in trade effluents where the concentrations were normally expressed in μgl^{-1} rather than mgl^{-1} as for other metals. Of the 38 out of 40 'known' trade sources, for which data was made available, monitored for Cd only 7 had annual mean concentrations in excess of 100 μgl^{-1}.

Similarly calculated input load of Cd entering sewers of 359.165-438.006 kgy^{-1} is of a different order of magnitude to those shown for Zn, Cu, Ni, Pb and Cr, but so are Guideline and proposed EC controls. See table 8.3.

Unknown sources. Atmospheric deposition

Measurement of concentrations of Cd in air and of total deposition are limited by the sampling and analytical techniques available. Interpretation of available data often being limited by frequent presentation of data as $<$. 1976/77 Cd concentration ranges and means for samples of air taken at the 3 Leeds national survey sites are shown with a range of concentrations found by AERA for rural sites in table 8.43. Again it is seen that inner city maxima and mean Cd concentrations of the Town Street site are higher than the Vicar Lane or outer city Roundhay sites and higher than the range of means found at rural sites. Although the Vicar Lane site has a mean expressed as <4.1 and therefore difficult to interpret, maxima is 125% of that found at the Roundhay site. It is therefore deduced that there is some enhancement of Cd concentrations in the inner city area over the surrounding area. Deposition rate data shown in table 8.44 is also limited by $<$ signs the 3 gms $ha^{-1}y^{-1}$ given by Critchley is for UK agricultural land and is approximately one third of that given for New York.

If again impermeable catchment area of the Leeds WPC works is taken as 741 ha then at 3 gms $ha^{-1}y^{-1}$ total deposition would be 2.223 kgy^{-1}

at 6 gms " " " " 4.446 "

at 9 gms " " " " 9.669 "

again in the unlikely event of all Cd deposited on the impervious area entering the sewers and the WPC works, then from data shown in table 8.3 the 3 or 6 or 9 $gms.ha^{-1}$ are equivalent to 0.508-0.619 or 1.015-1.238 or 1.523-1.857 percent of calculated input to sewers respectively. In view of the calculation that unknown trade and other unaccounted for sources accounted for $>$ 29.09 but $<$ 55.37-64.44 percent of Cd concentrations, see

table 8.42 col.4 calculated by reference to table 8.3 col.3 to be equivalent $\geq$104.48 but $\leq$198.87-231.446 kgs. In spite of the $\leq$ it is considered that although atmospheric deposition may make a significant contribution to Cd entering sewers it is likely to be a very low percentage of inputs from unknown sources. Uncertainty due to the $\leq$ is due to uncertainty as to the real value of input of Cd from dual input source K, highlighting the need, if modelling is to be used, of resolving this type of unknown in the input data.

Again 'unknown' trade sources may be a) from trade sources of Cd known to the RWA but not to this study, b) from sources of Cd known to this study but over and above the loads represented by the RWA monitoring procedure or c) from sources unknown or not yet monitored by the RWA.

It is not the purpose of this study to identify possible sources, but it does seem from the data and calculations shown above that further screening of potential, or known, Pb and Cd sources may be expedient. If the distribution of effluent loads found in the category of trade sources already examined is not atypical a high percentage of 'unknown' trade input load will be derived from few high input sources.

Like Pb, Cd is perhaps too useful and becoming utilised in every-day products such as vinyl paints, wallpapers, dyes, plastics, tyres, batteries and electrical contacts creating problems when waste is disposed by incineration, or as solid or liquid waste via tip or by disposal to sewers. The possibility of a route via stack emission scrubbings to sewers must also be considered. [53]

Further, the time may now have come to consider if Crown properties and institutional establishments may also require to be controlled.

One further category are the service industries themselves, for example in the paint used for yellow roadmarkings, the dilemma is put by the Royal Commission on Environmental Pollution, stating:

"Lead chromate pigment has largely been replaced by organic dyestuffs, though it continues to be used for yellow road markings. In general though we understand that there are no uses for which lead compound must be included in paint, though in many cases the available alternative pigments or additives function less well, may cost more, and sometimes present potential hazards of their own - as for example cadmium sulphate, which could be an alternative to lead chromate for road markings." 54

Certainly there seems to be a case for a coordinated drive between the RWA and other local services to identify and eliminate or reduce Pb and Cd inputs to air water and land.

A long term benefit of a directive such as that proposed on the use of sewage sludge in agriculture will be in providing the priority and urgency necessary to locate and control inputs of Cd and Pb to sewers.

8.7. Conclusions

The model has been applied to 1980/81 data for the YWA City works. It is therefore to that period and that location that results and conclusions apply. Some conclusions will,or may,have a wider significance.

As results, comments and conclusions of sections 8.1-8.6 have been already presented separately it is the purpose of these conclusions to discuss the data, methods and strategies used in the study in relation to the purposes listed in section 8.0.

1. Limitations of data used.

The data made available for this study had been gathered by YWA for its own purposes for the day to day running of the city WPC works, for the control of trade effluents entering sewers, and for charging purposes at a time when sewage sludge was being disposed to sea.

For the purposes to which the model was applied the following limitations became apparent.

a. Zn inputs.

Sources D and G were calculated to have input loads to sewers of

1237.95 and 154.652 kgy^{-1}. Zn but the mean concentrations used in calculating these loads were each based on 3 concentration cases only, and therefore of low reliability. It was therefore deemed necessary to optionally omit data for D or G to improve reliability.

b. Ni input.

Difficulty in quantifying input from source A and/or partition ratio in order to achieve feasibility, as discussed in 2a below, provided an unanticipated limitation. It highlights a difficulty, when mean is based on 13 concentration cases only, one high or low value may have considerable influence on the calculated mean.

c. Cd. Although otherwise well monitored, calculation of input load and potential for reduction of Cd inputs was seriously limited by the impossibility of quantifying the real input from source K which although having 1 agreed flow had two mean Cd concentrations a and b the highest of which was very high and optionally omitted except when otherwise stated, possibly underestimating potential for Cd reduction.

d. Pb data was sparse, data was only available for 6 trade sources only 2 of which were based on 12 or more concentration cases. Similarly mean concentration of Pb in unstabilised sludge was based on 9 concentration cases only, 2 of which were anomalously high and 1 of which was very low.

e. Of the 40 trade sources for which data was available annual mean concentrations of all metals from 19 sources was based on 3 or less concentration cases.

f. A further limitation was in the absence of metal concentrations in crude sewage during the period 1980/81 studied. Necessitating the expedient of using partition ratios calculated on the basis of the previous year's data or derived from literature sources.

g. One of the effects of these limitations is to make the results found in this study less tidy than might be wished. However the general picture that emerges from these results is clear enough to be used as a basis of

further action.

It is concluded that increasing the level of monitoring would not only increase the reliability of the data but also the validity of results obtained by use of the model. Validity of results might also be increased if the model could be run over a shorter period, but basic data and particularly of 'agreed flows' of trade effluent precluded this option.

2. Relationship of known inputs to output and of known output to input of the sewer catchment/treatment system.

a. With the finding that when calculated input load from Ni from source A was given full value and the partition ratios .499 or .4 were used total inputs from known sources were equivalent to 126 or 101 percent of output clearly this cannot be feasible. In order to obtain feasible results when source A was given full value a lower partition ratio .35 was introduced. Alternatively in order to use the partition ratios .499 or .4 input load from source A was recalculated omitting 1 highest effluent Ni concentration case, the effect being to reduce calculated input from source A by 41.5% from 7281 to 4261 $kg.y^{-1}$ and total known inputs of Ni by 38.6% from 7822.4 to 4802.5 $kg\ y^{-1}$. The disparity between results subsequently obtained when source A was given full load or lower load tending to blurr the implications of results when calculating the reduction required to achieve 95% probability of compliance of Ni concentration in simulated digested sludge, particularly when lower input for source A was used with .4 partition ratio.

b. In spite of the above limitations it was found that inputs of trade loads from known sources of Zn, (Zn omitting source D), Cu, Ni, Cd, Pb and Cr accounted for 33.5-45, (26-34.6), 10.6-13, 62-88.3, 23.4-28.5, 6.4-7.6 and 35.6-45.7 percent of mean concentrations in unstabilised sludge respectively. See table 8.4.

The low level of Pb from trade sources known to this study, as measured by % output, may reflect low priority of monitoring, but does seem to warrant further investigation. On the above data potential for reduction of Pb from known input sources is relatively small.

c. Although known trade inputs accounted for only 10.6-13 percent of Cu mean concentration in unstabilised sludge, achievement of simple and 95% probability compliance with proposed M limit was both feasible and practical in all 3 sludges when required reductions were made from inputs from 1 or 2 known sources.

d. Equivalent input of mean output load of Zn, Cu, Ni, Cd, Pb and Cr in unstabilised sludge were 11,784-15824, 5785-7096, 6210-8854, 359-438, 7830-9298 and 5522-7095 $kg.y^{-1}$ respectively. Hierarchy of input load size being Zn, Pb, Ni, Cu, Cr and Cd in descending order. See table 8.3.

Input level of Pb may be unrealistically high but as calculated reflects the influence of 2 atypically high Pb concentration cases included in calculating mean concentration and hence load of sludge output.

Equivalent input load of Cd is of a lower order than that of other metals but so are constraints.

The wide ranges of equivalent input loads calculated above make the calculation of percent of inputs from unknown sources difficult. See Section 8.6 and 5 below.

3. Achievement of simple compliance with proposed Mandatory and Recommended limit values.

Three of the strategies demonstrated using the model were:

a. With any required reduction in concentration in sludge being made by calculated reduction from highest known input sources; see summary table 8.27.

b. By reduction of concentrations in effluents from 8 known trade sources

to YWA Guide limit concentrations; see summary table 8.38. And

c. For Zn, Cu and Pb by elimination of 0, 1 or 2 anomalously high concentration cases in sludge output. See summary table 8.28.

Simple compliance with M limit was achievable without reduction of Zn and Cu in all three sludges and by Ni and Pb in lime treated sludge.

Simple compliance with M limit was achievable by Ni concentration in unstabilised and simulated digested sludges by using strategy 'a' or 'b', and of Cd in unstabilised sludge by strategy 'a' and in simulated lime treated sludge by 'a' or 'b'.

Pb compliance in unstabilised sludge could be achieved by strategy 'a' or 'b'.

Simple compliance of Cd and Pb concentrations in simulated digested sludge was not feasible by either strategy 'a' or 'b'.

Using strategy 'c' although not necessary for Zn and Cu, simple compliance of Pb concentrations in all 3 sludges was achieved if 1 anomalously high concentration was omitted and mean concentration in unstabilised sludge recalculated. See table 8.11 or summary table 8.28.

Presumably elimination of 1 or 2 anomalously high concentration cases could be achieved by eliminating causal factor(s).

Achievement of simple compliance of Cd concentration in simulated digested sludge remains unfeasible.

4. Achievement of 95% probability of compliance.

In addition to strategies a b and c a fourth strategy 'd' reduction of SD:$\bar{X}$ ratio becomes important when the probability formula $Y = \bar{X} + 1.645$ SD is used, when Y = upper constraint.

The pattern emerges that by combining strategy a and d or b and d required compliance of Zn Cu concentrations in all 3 sludges, Ni in unstabilised and simulated lime treated and highly probable in simulated

digested sludge can be achieved. But achievement of compliance of Cd and Pb concentrations by use of strategies a or b with d is either not feasible, not practical or of low practicality. See summary tables 8.29 and 8.39.

However using strategies 'c' and 'd' 95% probability of compliance can be achieved by Zn, Cu and Pb concentrations without reduction from known sources if 1 or 2 anomalously high concentration cases are omitted, mean concentration in sludges recalculated and SD:$\bar{X}$ ratio lowered. See summary table 8.30.

The importance of eliminating anomalously high concentration cases, when probability of compliance is required, is twofold reducing the mean and the standard deviation both factors in the probability formula. See summary table 8.30 and tables 8.14-8.19. Fall in SD:$\bar{X}$ ratio was found to be steeper than fall in mean.

5. The failure to provide a strategy for reaching simple compliance of Cd concentrations in simulated digested sludge and 95% probability of compliance in all 3 sludges with proposed M value emphasises the importance of trying to establish where inputs of metals are coming from. The sheer cost of monitoring probably limiting the YWA efforts in this direction.

The attempt made in section 8.6 to establish the extent of contribution of unknown input sources of Zn Cu Ni Cd Pb and Cr does however indicate that when inputs from domestic sources have been taken into consideration equivalent ranges of metal inputs from unknown sources are calculated to be Zn 3.91-29.61, Cu 47.15-62.83, Ni 0-35.12, Cd<55.37-64.44, Pb 74.42-81.79 and Cr 40.29-52.16 percent of metal concentrations in undigested sewage sludge. See table 8.42.

On the basis of available data atmospheric deposition although significant, accounts for a small percentage of these inputs. See tables 8.42-8.44.

6. If sewage sludge from the YWA city works is once again to be applied to agricultural land and if an EC Directive with the proposed M limits specified in Annex 1A is adopted, control of metal concentrations in sludge output will become important. Although controlling metal concentrations in trade effluents discharged to sewers or directly to river may be adequate to meet discharges in final effluent or to river measured in mgl^{-1}. Discharges in the form of sludge to land are measured and controlled in $mgkg^{-1}$ dry solids it is therefore necessary that control should be established over trade input loads to sewers and if necessary those from exempted sources. The definition of a well controlled effluent may need to be reappraised.

Although control of Cr was not found to be critical, as no M limit is specified it is now used as an example. Mean concentration of Cr input from source A was only 44% of Guide limit concentration, because of the high volume of input, load was 1069 kgy^{-1} and was shown in table 8.5 col. 5 to account for 20-24.4 percent of mean Cr concentration in unstabilised sludge.

At much lower load level but of more significance is input of Cd from source B with medium volume of flow as discussed in section 8.43 conclusion 12, compliance can be achieved by reducing load rather than mean concentration to a Guide limit.

7. Tightening of control over Cd input loads to sewers would now seem to be a high priority.

Reviewing measures taken by the European Communities in respect of cadmium between 1977 and 1979 and inventory of emissions into the environment Van Wambeke makes the following statements:

a. "One of the most polluting branches of industry is without doubt electroplating, a sector to which the national experts have given priority."[55]

b. "Concentrations of the order of 1 m/gl of Cd in the effluent can easily be reached in almost all industries using cadmium, and recycling the process water can considerably reduce the amount of cadmium discharged into the aquatic environment."[56]

c. "The cost of operating purification plants is inversely proportional to their size."[57]

Re the electroplating:

"This sector appears partly responsible for the sometimes abnormally high cadmium content in the sewage sludge of industrial or mixed origin."[58]

d. "The problems of reducing cadmium emissions in this sector and by other small users might be solved by installing centralised treatment plants responsible for collecting sludge and effluent from small and medium sized surface treatment companies or by granting aid to cadmium users to install purification plant."[59]

In view of these remarks conclusions and quotations it is now necessary to consider the politico-economic framework within which the traders and RWAs operate.

TABLE 8.40

Mean metal concentrations in sewage sludges from WPC works receiving no industrial effluents.

Units			$mgkg^{-1}$ Dry Solids			
Column	A	B	C	D	E	F
Source of data	DOE/NWC 1981	DOE/NWC 1981	Calculated from DOE/NWC 1981	DOE/NWC 1980 survey	R.C. Pocock	R. D. Davis
Type of sludge	Digested and Undigested	Digested and Undigested	Undigested			Lab.Undigested
Calc. of mean	Population weighted	Arithmetic	Arithmetic	Estimated Std. Analysis	Estimate	
Zn	656	640	567	515	515	600
Cu	332	309	265	300	380	250
Ni	41	42	39	30	8(30)a	8
Cr	156	129	95	40	50	
Cd	7.5	7.2	5.8	5	5	2
Pb	270	238	223	120	120	60
Average population	8,900	8,900	6,534	Inserted in 1980 Survey for Works 5000	ND	ND
No. of works	44	44	35	where no reported analysis available ND	ND	Laboratory

Notes for Table 8.40

A DOE/NWC Survey of Sewage Sludge Composition (1977 Data) NWC Dec. 1981 Table 8.

B " " " " " " " Table 9.

C Calculated on the basis of population and concentrations shown in " Table 9.

D DOE/NWC Sewage Sludge Survey, 1980 Data. August 1983. Appendix E.

E Jurue Reducing Metals in the Environment, Report for DOE January 1983 pps. 2/6 and 2/7.

F Davis R.D. Control of Contamination Problems in the treatment and disposal of sewage sludge WRC Tech. Report TR156 December 1980, para. 4.5.3.2.

TABLE 8.41. Metal concentrations in Suburban and City WPS works Sewage Sludges of high domestic origin and calculated metal concentrations attributable to Trade or unaccounted for Sources in sewage sludge from a City Centre WPC works.

Column	A	B	C	D	E	F	G	H	I
Data Source	Thames WA.	Calc. from A	Calc. from A	YWA Outer City	YWA Spa City	YWA This Study	On inspection Outer City & Suburban	Calc. F-G Trade & Unaccounted for Sources	Calc. H/F Trade & Unaccounted for sources
Sludge Type.	Digested	Undigested b.	Undigested c	Undigested d.	Undigested e	Undigested f	Undigested	Inner City	Inner City
Indust'l. Cont. %	(a)	(a)	(a)	(i) SS 16% Flow 4%	(i) SS 2% Flow 10%	(i) SS 23% Flow 13.7%	Not significant		%
Unit			mg kg^{-1} dry solids						
Metal							Range	Range	Range
Zn	1045	696.6	771.8	869	1032	1568.06	700-800	768-868	48.98-55.35
Cu	291	193.9	214.9	311	409	753.44	200-300	453-553	60.12-73.4
Ni	194	129.3	143.3	61	47	438.68	47-100	339-392	77.28-89.36
Cd	13 h (10)	8.6 h (6.6)	9.6 h (7.4)	5.6	6.3	45.76	5.6-7.4	38.4-40.2	83.92-87.85
Cr	108	71.9	79.8	1283	80	573.32	70-80	493-503	85.99-87.73
Pb	189	125.9	139.6	192	ND	1053.8(j)	125-190	864-929	81.99-88.16
Pb-1Hcc						672.9*	125-190*	482.9-547.9	71.76-81.42
Pb-2Hcc						469.17*	125-190*	279.17-344.17	59.5-73.36
Average Population	>100,000			316,000	31,100	137,500			

Notes for Table 8.41

Column A — Ex Wood L.B. et al. Table 2 p.267 in Utilisation of Sewage Sludge on land WRC Conf. Report, Nov. 1979.

(a) 'Almost wholly of domestic origin'. Thompson L.H. and Dickens W.J. p.30 Conf. Report Nov. 1979.

(h) Cd in Mogden sludge attributable to domestic origin. Dakers, J.L. and King in Water, Science and Technology, London 1981, p.55.

Column B b — Calculated from A by multiplying by the factor of 0.6.

C — " " " " " 0.73855.

D d — Ex Hudson, J.A. and Fennel H. Disposal of sewage sludge to land. Water Pollution Control 1980. Table 8, p.374.

E e — " " " " "

F.f — Ex YWA Cimputer Archive Data for 1980/81 used in this study. Leeds City WPC Works.

(j) — (based on 9 cases only).

D E F i — YWA unpublished data 1/4/79-31/3/80.

SS — Settleable solids attributable to known trade source. % of Total Load.

Flow — Volume of Flow " " " % " Flow.

Pb-1Hcc — Omitting 1 anomalously high concentration case and recalculating mean conc. of Pb.

Pb-2Hcc — " 2 " " cases " " Pb.

TABLE 8.42

Range of excess metals (a) from known and unknown trade and other unknown sources (b), as percentages of mean concentrations of six metals in unstabilised sewage sludge leaving a Leeds Inner City WPC works. 1980/81 data.

Column	1	2		3		4		
		a	b	a	b	a	b	c
Source of Data	Table 8.41 Col.F Mean Conc.of metals in SS from Leeds University WPC Works. (c)	Table 8.41 Col.I Trade & unaccounted for sources of metals as percent of mean conc.		Table 8.4 Known Trade Inputs metals as percent of mean conc.		Col.2a-3b Unknown Trade and other sources of metals as percent of mean concentration.	Col.3b-2a	Col.4b-4a
Parameter	mean conc.	Range		Range		Range		Range width
Unit	$mgkg^{-1}$ DS sludge	% of mean conc.		% of mean conc.		% of mean conc.		% mean conc.
Metal								
Zn	1568.06	48.98 - 55.35		25.74 - 45.07		3.91 -	29.61	25.70[d]
Cu	753.44	60.12 - 73.4		10.57 - 12.97		47.15 -	62.83	15.68
Ni	438.68	77.28 - 89.36		54.24 - 88.35		0 -	35.12	35.12[d]
Cd	45.76	83.92 - 87.85		23.41 -	<54.83 >28.55	>29.09 <55.37 -	64.44	<35.35 > 9.07e
Cr	573.32	85.99 - 87.73		35.57 - 45.7		40.29 -	52.16	11.87
Pb	1053.8 (f)	81.99 - 88.16		6.37 - 7.59		74.42 -	81.79	7.37
Pb-1Hcc	672.9 (g)	71.76 - 81.42		9.97 - 11.84		59.92 -	71.45	11.53
Pb-2Hcc	469.17(h)	59.5 -- 73.36		14.3 - 16.96		42.52 -	59.06	16.54

Notes for Table 8.42

a. Excess to those expected in a sludge from a catchment of compatible size receiving little or no input from industrial sources, calculated using methods shown in table 8.41.

b. Other than those contributing to a catchment receiving little or no industrial input.

c. As in table 8.1.

d. The large range is due to the use of alternative 'known trade loads' as as shown in Table 8.5 Cols. 2 and 5.

e. Signs $>$ and $<$ are necessary due to presence of source Ka +b dual input data Table 8.5 col. 2 and 5.

f. Mean concentration of Pb based on 9 conc. cases only.

Pb-1Hcc omitting 1 anomalously high conc. case and recalculating mean conc. Pb.

Pb-2Hcc " 2 " " cases " " "

TABLE 8.43

Reported annual mean concentrations and ranges of 6 metals in samples of air monitored at UK rural and Leeds City sites.

Column	1	2			3			4			5	
		A	B	C	A	B	C	A	B	C	A	B
Location	UK Rural a	Round Hay School Leeds Outer City b			Town St. Leeds City		Inner c.	Vicar Lane Leeds City Centre d			6 Sites Leeds e	
Grid Ref.	Various	44/373323			44/249345			44/304335			Various	
Height of Station	"	10m			7m			15m			11	
Parameter		Annual range	mean	cases	range	mean	cases	range	mean	cases	Jul.79-Jun.80 mean	Jul.80-Jun.81 mean
Metal Units		ngm^{-3}		No.	ngm^{-3}		No.	ngm^{-3}		No.	ngm^{-3}	
Zn	13-200	75-308	151	4	64-496	260	12	102-542	306	12		
Cu	11-56	5.1-31	12	4	8-184	38.3	12	10.2-58.1	26.2	12		
Ni	$\leq$2-83f	2.5-14	6.7	4	5.5-23	12.8	12	6.0-32.3	17.9	12		
Cd	$\leq$1.1-$\leq$3.6	1.74-6.15	2.97	4	1.7-11.4	4.9	12	$\leq$1.85-8.4	$\leq$4.1	11		
Pb	17-230	143-738	316	4	299-1140	744	12	268-1160	577	12	526.6	375
Cr	0.5-15	8.1-29	13.7	4	4.3-31	15.2	12	.94-34.9	16.8	12		

Notes on Table 8.43

a. Cawse, P.A. A survey of Atmospheric Trace Elements in the UK results for 1976, Harwell AERE quoted in b) table 3.

b. McInnes, G. Multielement Survey: Report of first year's results Warren Springs Lab. LR277(AP) 1978, 1976/77 data site No. 2058.

c. Ibid 1976/77 data site no. 2059.

d. Ibid " " " 2060.

e. Thorpe and Armley (Wortley Environmental Lead Survey. Unpublished document table B8. Leeds City Dept. EH, C & T.

f. c.f. Max Nickel conc. "Almost certainly arising from continued Nickel smelting in the area" of Trebanos. Cawse P.A. a survey of atmospheric trace elements in the UK. Results for 1974. AERE,Harwell report R8038 p.6 HMSO.1975.

TABLE 8.44

Average deposition rate of Lead and 5 other metal elements on UK agricultural land and at 6 locations.

Location	Period	Average deposition rate gms.ha^{-1} y^{-1} Pb	Cd	Zn	Cu	Ni	Cr	Source
UK Agric.land		250	3.0	750	200	50	25	a
Gt. Helmshore Lancs.	68/69-72	131	ND	2910	200	36	9	b
Styrrup Notts.	1972-75	450	< 60	1200	230	63	88	c
Stevenage	1975	465.7g		582.5	186.9			d
Leeds	June 79-May 81.	1534.8						e
C.Swansea	72-73	620	< 200	1000	360	220	53	f
N. York.	72-75	790	9.1	ND	ND	66	ND	f

Source:

a) Critchley R.F. (WRC). An assessment of trace metal inputs and pathways to the marine and terrestrial environments. In Proceedings of Int. Cont. on Heavy metals in the environment, Heidelberg, Sept. 1983, pp. 1108-1111. Table 3.

b) Wadsworth G.A. and Webber J. (ADAS). Deposition of minerals and trace elements in Inorganic Pollution and Agriculture,MAFF reference book 326,April 1980 p.52 table 3.

c) Cawse P.A. (AERA). Deposition of trace elements from the atmosphere in the UK. MAFF ref. book 326, London,HMSO.1980 p.41.

d) Mance, G. and Harman M.M.I.(WRC) in Helliwell P.R. Ed. Urban storm drainage. Int. Conf. U. Southampton April 1978, p.610 table 4.

e) Thorpe and Armley/Wortley environmental lead survey. Unpub. document. Leeds City Dept. Environmental Health, Cleansing and Transport. Feb. 1982 table B9.

f) Quoted in Cawse P.A. c) above p.30 table 2.

Note: g) 54% contribution to run off see Mance G. ref. d.

9. EFFECTIVE CONTROL OF METALLIFEROUS TRADE EFFLUENT INPUT TO SEWERS, INCENTIVES, CONSTRAINTS AND PERCEPTIONS

9.0 Introduction

In view of the levels of Zn, Cu, Ni, Cd and Pb loads calculated to be entering and concentrations in sewage sludge leaving the KLL WPC works in 1980/81, international pressure to reduce sludge disposals to sea, the required reductions necessary if sludge is to be disposed to agricultural land, particularly if the proposal for an EC directive controlling that use is adopted, the question is now posed 'Why have the level of metal inputs to sewers not been reduced already?'

Purposes

In attempting to answer the above question the purposes of this section are:-

To assess the effects of incentives and constraints on traders producing metalliferous effluents.

To examine some ways in which incentives or constraints might become more effective.

To try to assess the scale of some of the changes required, and

To discuss some of the policy implications involved.

In seeking to achieve these purposes an attempt is made to deduce and examine some 'rules of the game' as perceived by a trader against the current background of UK policy and legislation.

Background

Relevant UK policy, international commitments and legal and voluntary frameworks have been outlined in Sections 2, 3, 4 and 5. Four aspects of policy are of particular importance: Commitment to the EEC, commitment to other international agreements controlling marine pollution, the passing but delayed implementation of COPA 1974, and the use of

voluntary agreements.

Recently the period 1979-81 was marked by general intense depression and anxiety in the metal industries and has also been a time of criticism, change and severe financial constraints on RWAs.[1,2.]

The present situation regarding trade effluents may also be seen as resulting from attempts made to improve the quality of rivers. See Section 3. In December 1981 the NWC, commenting on "River Quality: the 1980 survey and future outlook" gave two reasons for improvement in river water quality stating, "Some improvements have resulted from investment in wastewater treatment by industrialists and connections of polluting trade effluents to sewers."[3]

The word 'polluting' here is of significance and presumably applies to the effluent which directly discharged to river. Now traders and RWAs are reluctant to be charged or charge for direct discharges to rivers.[4] So it is presumed that the discharges did not comply with a consent and the trader had the option of accepting the cost of pretreating the effluent to the point at which the residual effluent complied with the consent to discharge to river, and was then regarded as non polluting, or diverting the polluting effluent, and accepting the cost of any pretreatment necessary to comply with required consent, or be tolerated, when discharged to sewer. RWAs appear to be confident in the control and dilution that such an arrangement confers.[5] Dischargers are required to pay trade effluent charges for loads received into sewers. Presumably traders adopting this strategy are either persuaded and/or find it financially advantageous to do so!

In view of these changes four controlling factors are now considered.

9.1.

An examination of the influence of charges, consents, enforcement and resource conservation on effluent control.

Charges

In the absence of regular charges on 'residual effluents' discharged to rivers, charges on trade effluents to sewers are now considered.

Unit costs charged by RWAs for trade effluents received into sewers are usually based on a voluntary agreement made between the CBI and NWC in 1976 prior to the coming into force of sections 43 and 44 of COPA 1974.

The objective of this agreement was stated by the CBI, in evidence to the HLSC "To ensure that the trader pays a fair charge for the service rendered for the reception, conveyance, treatment and disposal of his effluent."[6]

As in the Royal Commission standards in 1908[7], the key variables in the charging formula are based on oxygen demand and on suspended solids of the particular effluent. T. Newton of YWA, giving evidence to the HLSC stated: "We have no charges for toxic substances and heavy metals."[8] Explaining why metals and toxic substances were not charged for, another WA official quoted from the CBI/NWC agreement, "There should be no charge for toxic constituents as their concentrations should be so limited by consent conditions as to render the waste capable of satisfactory treatment and disposal by the Authority."[9]

From this statement it would appear that the CBI, or its members, cannot complain against the tightening of consents on metal and toxic substances discharged in effluents, except on the basis that the waste is already 'capable of satisfactory treatment and disposal by the Authority'. Interpretation may then depend on the route and the location by and at which the disposal is to take place.

In the case of sludge disposal to sea, interpretation of this clause may allow a higher concentration of, say, Nickel, to be disposed to sea than if disposed to agricultural land. Nickel concentration in sludge disposal/

used on agricultural land being currently controlled as part of the zinc equivalent concept used in the UK guidelines, Ni being regarded as eight times as toxic to plants as Zn and the effects of Zn, Cu and Ni being regarded as additive. Whereas Ni appears on the 'grey' list of substances named in the Oslo agreement as requiring 'special care' before dumping at sea. The interpretation of 'significant amounts', usually taken to mean 0.1 ppm, making regulation both by the WA and in the licensing of disposal by MAFF difficult.[10]

So for example it may be that Ni content of the Knostrop Low Level WPC Works sludge has been allowed to rise while sludge is 'capable of satisfactory treatment and disposal' by being dumped at sea. The allowing of Cd, a 'black' list substance[11] to rise to a concentration of 45.76 $mg.kg^{-1}$ dry solids may cause greater conflict of interest between Water and licensing authorities.

But disposal of sludge to sea from the City location is now a higher cost route than disposal of sludge to land. What are the effects on charges made by the water authority for trade effluents discharged to sewers?

The CBI/NWC agreed charging formula may be expressed as

$$\text{Unit charge } m^{-3} = R + P + \frac{ot}{os} B + \frac{st}{ss} S \ .^{12}$$

R, P, B and S being based on regional costs for reception, primary treatment, biological treatment and sludge treatment and disposal respectively. Ot and St being the oxygen demand and suspended solids of a particular trade effluent, usually calculated over a twelve month period and Os and Ss being the standard regional strengths of these two parameters, in combined sewage, calculated over 2 years. A minimum charge of $\frac{1}{2}$ B is exercised.

Now assuming that steps have been taken by a trader to ensure that the metalliferous effluent input to sewers from his works had an oxygen

demand equal to or less than half the regional combined strength, then on the basis of YWA 1980/81 unit costs, such effluent with 30 or 60 or 90 mgl^{-1} of suspended solids would have an effluent charge of 6.14 or 6.47 or 6.8 pence per m^3. For 100,000 m^3 of such effluent discharged to sewers charges would be £6,140 or £6,470 or £6,800 per annum respectively. Being 63.51 or 66.94 or 70.36 percent of the charge for an effluent having the same volume and the regional average, combined sewage oxygen demand and suspended solids strengths.[13]

It can be seen that:

a) Doubling or tripling the 30 mgl^{-1} of suspended solids, for instance by increasing metal concentrations in the effluent, has a relatively small effect on the unit or 100,000 m^3 charges, thus while volume stays constant the basis of charging offers little incentive to the trader to reduce inputs of metals to sewers.

b) As basic elements of RPB and S in the formula are based on regional costs over a two year period there is little loss to traders if sludge disposed from their effluent catchment area to land, say, requires higher transport costs so that it can be spread more thinly due to high metal content or if sludge disposal moves from a lower cost to higher cost route or conversely gain if disposal costs are reduced. Indeed with this buffered economic feedback, on the basis of effluent charges levied, local traders may prefer a high cost local disposal route, if by that means they are allowed to 'dispose' of more waste to sewer per £1 of charge made.

On the basis of figures shown it can be seen that if a trader goes to the expense of reducing his effluent suspended solids from 90 mgl^{-1} to 30 mgl^{-1} possibly involving additional capital and running cost expenditure on a liquid waste treatment plant and further expenditure on liquid waste disposal, the same volume of effluent would still have 90.294% of the original charge.

But increased costs of moving from a lower cost to higher cost disposal must be paid for. They would be paid for by all disposers of the region as regional costs are pooled.

However 'fair' or 'unfair' this may be judged to be depends on how one perceives and interprets the 'rules of the game'. There does seem to be strong elements of Polluters pay rather than the Polluter Pays principle involved.[14] Moreover this is a covert system of cross subsidising particular types of highly polluting activity in which the basic rules are based on a voluntary agreement the local and regional implications of which can only be guessed at unless confidential information is available. The effect may be seen as quite contrary to the Polluter Pays principle in that there is little or no financial incentive to reduce pollution by trade metal inputs to sewers.

The above findings are in agreement with written evidence submitted to the HLSC by Environmental Data Services, who refer to the findings of a study focussed on the W. Midlands, carried out at JURUE, University of Aston,[15] that in the absence of a specific charge being made on heavy metals or other toxic substances the Polluter Pays Principle was breached in two senses, a) in areas where uniformity has not been reached in consent limits "...companies meeting tighter limits are in effect subsidising companies with less stringent consent conditions,"[16] and b) "...in the absence of a specific incentive for dischargers to reduce the metal content of their effluent, the constraints imposed by metals on environmentally acceptable disposal routes involve higher costs of sludge disposal to the community in that metal contaminated sludges have to be incinerated instead of being more cheaply disposed of to land."[17] The memorandum also points out that in not disposing a low metal sludge to land a valuable resource was being wasted.[18]

The present study is not concerned with specific consents, but the

findings do confirm that there is little incentive to the trader to reduce metal input to sewers. On the contrary, on the basis of these charges it may be good business to maximise metals in effluent disposed to sewers and to put a great deal of effort into persuading, and getting others to persuade, by political or other means, the water authority through its officials to accept, or tolerate, the highest level of input to sewers possible, if by doing so the trader's costs of liquid waste treatment and disposal are being saved. But it is here submitted that when this leads to higher cost disposal the basic premis by which metals are not charged for in the CBI/NWC formula is being breached.

Under these circumstances there are considerable grounds for the domestic water rate payers perceiving themselves as victims of a voluntary charging agreement, to which they were not a party. Thus any grounds for accepting 'Public' rather than 'Polluter(s)' responsibility for additional costs of treatment and/or disposal is tenuous.[19] As put by the Association of County Councils to the HLSC, "There is a substantial case for ensuring that industry bears the true cost of treatment of effluents where such costs arise."[20]

A further criticism of the omission of metals from the charging formula is that charges do little to encourage'good housekeeping', or the conservation of valuable metal resources.

In the complete absence of metals in the charging formula, the basis of which precedes the formation of the RWAs, it is not surprising that the Jurue team report, of metalliferous effluent producing firms contacted in the West Midlands, "it is their view that environmental legislation is imposed on them."[21]

The Consent system

In the absence of statutory standards controlling metal inputs to sewers and in view of the ambivalent economic incentives trade effluent

charges, per se, provide for traders to reduce metal inputs to sewers, the main burden of control must fall on the consent system.

Now although Consent making has a statutory basis and some limits are defined in statutes,[22] many limits including those on metals are still left to be stipulated or negotiated at local level. The negotiation process involves, amongst other things, the taking into consideration of limitations such as space and of economic and social factors. Unlike the national control exercised by HM Industrial Air Pollution Inspectorate, RWA pollution prevention officers do not have control of the effluent treatment processes used, or the way in which they are used, by a trader.[23] Effectively then each consent may require considerable individual, and often confidential, negotiation.

But in acknowledging the traders defence of using 'Best practicable means' officers, required to take account of local trading and employment conditions will, in some locations, find a direct conflict between more lenient consents and the making, imposing and enforcing of the very consents assumed to be operative and enforced by the RWA in the basic premis, given as quoted above, from the CBI/NWC 1976 agreement, for not needing to charge for metals and toxins. (see ref. 9).

Further considerations in the making of consents are concerned with protecting the treatment processes of the WPC works and thus consents on metals entering sewers will be framed according to quantity and quality of other inputs of metal to the sewer catchment of the WPC works. The effect of the WPC works final effluent on the receiving water is also considered, this will be affected by the ratio of the volume of effluent to volume of receiving water and the state of that water. When as in the late sixties and currently, since 1978, receiving waters are categorised the consents of the RWA's own WPC works are to be made in accordance with the use to be made of the receiving water. Thus when short term objectives are expedient

lower grade effluents may be allowed to enter lower grade stretches of rivers such as R. Aire at Leeds, while higher grade effluents required for higher grade rivers provide the requirement for tighter consents to be applied to some trade inputs.[24]

The NWC's own recommendations for reviewing discharge consents to rivers admit "Because the objective is to obtain best value for money, this will not necessarily result in the same conditions being applied to adjacent discharges, and certainly will not result in the same conditions being applied across the country.[25]

As mentioned earlier negotiated consents for metalliferous trade effluents accepted into sewers are also likely to be influenced by the sludge disposal route used, or intended, and the economically limiting effects that metal concentrations may have on economically efficient disposal.

Existing consents may add to the difficulty of achieving 'fairness' or parity in consent making. In this connection RCEPs 10th report expresses concern at the failure of DOE to implement section 37 of COPA '74.[26]

Similarly concern is expressed at DOE's use of exemptions[27] and of the chronic slippage allowed in officially declared implementation timetables. Thus RWA officers operate backed by weak pressure from central government and continued uncertainty as to implementation requirements and timetables. In this situation RCEP comment on DOE policy in 1983, "Almost the only exceptions to the exemptions it makes are those necessary to implement in the United Kingdom the European Community Directives dealing with: dangerous substances discharged into the aquatic environment, (...) the quality of bathing water, (...), the quality of fresh waters, (...) the quality of surface water intended for abstraction for drinking water, (...) the quality of shellfish waters, (...) and the discharge of dangerous substances into ground water (...)."[28]

Economic recession is also likely to have an effect on consent making and enforcement through the stress and work loads imposed on pollution control officers.

Enforcement

Disparity of consents, a period of economic recession and financial constraint make for difficulties of enforcement. The RCEP observe, "One effect of economic recession may be to make people more willing to tolerate existing levels of pollution if the alternative is seen to be a further decline in local employment."[29] But point out "It is in any case, a mistake to think that lowering standards will necessarily help to preserve employment or encourage enterprise. Such an approach is short-sighted and risks setting new 'time bombs'",[30] and point out that "Any industry treated in this way is effectively being subsidised by the environmental neglect. Like any subsidised industry it will be vulnerable to the withdrawal of its subsidy, which may happen as a result of local, national or international pressure to improve pollution control,"[31] and conclude, "The cost of removing the subsidy may well be greater than the original benefit."[32]

Unfortunately, as the Commissioners must be well aware, the subsidy has been used intermittently for nearly 90 years, some areas becoming environmental poverty traps in which Pollution Control and Planning Officers must operate. Perhaps, as in the case of the Mersey estuary, having to await a serious crisis to generate the pressure required to implement latent plans for remedial action.[33]

Unidentified pollution sources, contravention, historic consents and financial crises make uniform enforcement difficult or impossible. Below are two reactions.

Identification of a polluting source via the sewer system may be difficult due to dilution occurring. Mean Cd concentration in KLL sewage being 0.012 mgl^{-1} in 1979/81. C. Bergstrom of the Swedish Environmental

Protection Agency reports, "The most effective way to find them has shown to be by searching in the telephone catalogue and in branch magazines."[34]

But the PCO may have a very good idea as to the source of input, his problems include the establishment of proof of contravention which may be difficult and costly in catchments serving industrial areas. Development of reliable means of continuous sampling, or of finger printing discharges received at the WPC works may provide alternative strategies for the future.[35,36]

Contravention may be due to human error. But it is interesting to find the colourful Works Director of T. Gameson Ltd. commenting resentfully in 1978, "You can be a good boy, but the cost is money and effort and a terrible bitterness as you see your orders lost to competitors whose costs in these areas are nil." He suggests that PCOs should "...get to know all, repeat all, purchasers of noxious substances. They should be made to prove pro rata purchases of reagents and to produce invoices for regular solids removal."[37] For as the same author observes in 1979, "... dumping it down the drain and paying two or three hundred quid when you get caught is still the cheapest way of dealing with effluent, which is precisely why it is going on all the time."[38]

Behind the emotive front, the cry is similar to A. E. Fletcher's in 1888, see p.2/5 and reflects the limitation that, unlike Alkali inspectors and their successors, H.M. Industrial Air Pollution Inspectorate, in 1980 as in 1876 pollution control officers do not have a statutory right to approve processes or insist on proper maintenance and methods of use of emission treatment plants. Secondly the author appears to be reminding officers that evidence should be required by them when 'Best Practical Means' is pleaded as a defence.[39]

The protest against the lack of parity is in keeping with the finding of a recent report that "while the UK system is rather flexible

with the possibility for concessions, in some ways this can introduce greater uncertainties for the regulated firm than the imposition of rigid standards."[40] Lack of parity is then seen to be another factor making enforcement difficult.

Court fines could, in future, play a more prominent enforcement role. It is here suggested that they are no substitute for

a) providing financial incentives and feedback through the trade effluent charging system to the trader encouraging the reduction of metal loads entering sewers;

b) taking whatever steps are necessary to improve the trader's perception of the impartiality, fairness and justification for the system and standard of consents to which he is required to conform.

By providing a firm set of standards to which sewage sludge and/or final effluents from WPC works are required to conform to, EC Directives will themselves provide a less arbitrary base, an external pressure, increasing the level of urgency of PCOs and providing a justification for increasing the level of conformity.

Detection of contravention is a difficult and costly business, particularly where inputs are to sewers in industrialised areas. More sophisticated monitoring and detection methods may lead to higher predictability of contravention identification. Use of courts will then be largely limited by the perceived cost: benefit to the RWA. Magnitude of penalties may then be expected to be revised to reflect the will, or lack of will, of local and central authorities to make the system work.

Resource wastage

Where resources such as water and metals are being disposed to sewers it might be expected that potential savings to be gained by reducing requirement and/or by recovery might provide financial feedback leading to

economies. But authors of a recent study of 'The impact of environmental regulations on technological processes in the UK sugar and metal plating industries' report: "Some suppliers believe that, perhaps 5% of all platers still have no effluent treatment equipment at all."[41] Several effluent treatment equipment suppliers had noted a change in the pattern of equipment being sought, it was found "in the 1970s, equipment for both effluent treatment (to meet regulatory requirements) and for recovery (to save water and materials) was being ordered. In 1980's equipment only for effluent treatment is being ordered. In many cases, where e.g. £20,000s of effluent treatment equipment is being currently ordered, the customer is now unwilling to spend perhaps another £5,000 for a more efficient system with recovery cycles, even if this could result in savings of £2,000 or more annually. The argument seems to be that the increased cost of credit cannot be offset against future materials and water cost savings because interest rates are just too high, and many firms are already at their credit limits for financing day to day activities."[42]

Conditions and period covered by the report, presented to OECD in July 1982, are the same as those affecting traders in the 1980/81 period for which data is available to this study. Findings suggest that availability of low cost fixed interest loans might be an important factor if resource conservation is to be facilitated.

9.2. Incentives for reduction of water and metals.

9.2.1. Incentives for reduction of water and metal inputs to sewers.

Two hypothetical case studies.

In order to examine ways in which incentives or constraints might become more effective use is once again made of the 1980/81 data for 40 'known' trade input to the sewer catchment of the YWA Knostrop Low Level WPC works.

Using two hypothetical cases further consideration is given to

present financial forces acting through the RWAs charging system, to required change of direction of those forces and to how that change of direction might be achieved. Output from elite sources is again examined and an attempt made to identify changes in traders perceptions of the 'rules of the game' that are desirable to foster.

1. Present incentives and costs.

Two hypothetical cases.

Trader A. Agreed flow of effluent 489,000 m^3.

Calculated input of Ni and Cr to sewers 4.3 - 7.3 and 1 tonnes respectively.

Process water losses are omitted from calculations

∴ Vol. of water entering the process is taken to equal volume of water in effluent to sewers.

Water charge was made up of a volume charge, 20p m^{-3} plus a standing charge, assumed to be £1686 for use of a 10" inferential meter.

∴ Charge for supply of 489,000 m^3 water = £99,668.

Effluent charges.

If it is assumed that:-

a) The trader takes steps to maintain oxygen demand Ot of his effluent equal to, or less than half the regional average Os; and

b) The effluent with 100% of 1980/81 metal concentrations has an St value of 100 mgl^{-1}; and

c) If metal concentration is increased or reduced there is a proportional increase or reduction in St.

$$\text{Unit, } m^3\text{, charge} = R + P + \frac{1}{2}B + \frac{St}{Ss}S$$

YWA 1980/81 Effluent charge is calculated to be

$1.48 + 2.58 + 1.75 + (\frac{100}{191} \times 2.11) = 6.913$ p m^{-3} or £33,804.57 for 489,000 m^3.

Case 1. Trader A decides to reduce the volume of water coming into the plant but takes no steps to reduce metal loads in effluent leaving the plant.

Then on the basis of the above charging rates:

Water charges might reduce as follows:

Flow	Standing Charge		Water Charge		Total	Charge
%	£		£		£	%
100	1868	+	97,800	=	99,668	100
50	1868	+	48,900	=	50,768	50.937
25	1868	+	24,450	=	26,318	26.406
12.5	1868	+	12,225	=	14,093	14.140

Effluent charges might reduce as follows:

Flow	Flow	St.	Charge m^{-3}	Effluent Charge	Charge
%	m	mgl^{-1}	p	£	%
100	489,000	100	6.913	33,804.57	100
50	244,500	200	8.019	19,606.45	57.99
25	122,250	400	10.288	12,504.77	36.99
12.5	61,125	800	14.678	8,953.40	26.486

by addition combined effluent and water charges are:

Flow	Flow	St.	CWEC	Charge	Saving
%	m^3	mgl^{-1}	£	%	£
100	489,000	100	133,472.57	100	0
50	244,500	200	70,374.45	52.726	63098.12
25	122,250	400	38,822.77	29.087	94649.80
12.5	61,125	800	23,046.4	17.267	110426.17

From these calculations it is seen that if the trader can reduce water purchased to 50, 25 or 12.5 percent of original volume, respective water charges reduce to 50.937, 26.406 or 14.140 of the original charge, and save £48900, £73350 or £85575 respectively in water charges.

If effluent flow is, correspondingly, reduced to 50, 25 or 12.5 per cent of original volume, and St strength is inversely increased, effluent

charges reduce to 57.999, 36.99 or 26.486 percent saving £14,198, £21,562 or £24,851 respectively in effluent charges.

Corresponding combined water and effluent charges (CWEC) reduce from £133,472.57 to £70,374.42, £38,822.77 or £23,046.4, i.e. from 100 to 52.726, 29.087 or 17.267 percent of the original charge saving £63098, £94649.80 or £110426 respectively although no reduction of the annual St load and thus the assumed annual metal load has taken place.

On the basis of the above assumptions and figures, market forces appear to be encouraging the reduction in volume of water purchased and effluent discharged but provide very little incentive to reduce metal or settleable solid loads.

Indeed it may be perceived as very good business to minimise water and effluent charges as long as metal or st concentrations comply with consents or are tolerated.

Case 2. As in case 1 but the trader is required to reduce metal load by maintaining St at 100 mgl^{-1}.

Effluent Charges when St is maintained at 100 mgl^{-1}

Flow	Flow	St	Charge m^{-3}	Effluent Charge	Charge
%	m^3	mgl^{-1}	p	£	%
100	489,000	100	6.913	33804.57	100
50	244,500	100	6.913	16902.28	50
25	122,250	100	6.913	8451.14	25
12.5	61,125	100	6.913	4225.57	12.5

Decrease in effluent charge is proportional to decrease in volume.

If water charges are as in Case 1.

Combined water and effluent charge.

Flow %	Flow m^3	St. mgl^{-1}	CWEC £	Charge %	Saving £
100	489,000	100	133472.57	100	0
50	244,500	100	67670.28	50.700	65802.29
25	122,250	100	34769.14	26.050	98703.43
12.5	61,125	100	18318.57	13.725	115154.00

In spite of the standing charge component of the water charge now incorporated into the CWEC, reduction in charge more nearly reflects reduction in flow than in case 1.

Savings in annual CWEC are large £65,802, £98703 or £115,154 and as ongoing savings may not only be used to offset any capital, increased running costs of treatment plant and or increased waste disposal charges incurred in reducing St and assumed metal input load to sewers by 50, 75 or 87.5% of the original load, but by reducing a recurrent charge may be able to reduce future costs.

However in financial terms a comparison of CWECS in case 1 and case 2 shows that savings due to metal reduction, as reflected in St, in case 2 are equivalent to £2074.17, £4053.63 or £4727.83 equivalent to 2.026, 3.037 or 3.54 percent of the original CWEC charge, and 4.1, 4.1 or 4.1 percent of savings when annual St and assumed metal loads have been reduced to 50, 25 and 12.5 percent, respectively of their original values. Increased treatment and waste disposal costs are likely to exceed these comparative savings. A trader having carried out this paper exercise will perceive that it is still good business to reduce volume of water without reducing load of metal input to sewers if any penalties for doing so are not too high.

Suggested changes

From the above two cases it is seen that it would be in the interest of the RWAs and the general public they serve to alter the rules of the game so that the reduction of water and effluent volumes and therefore charges without reducing annual metal load is discouraged financially, but reduction of water and effluent volumes with corresponding reduction of annual metal loads is simultaneously encouraged. The charging formula must increase the comparative savings of Case 2 over those of Case 1 making it 'good business' or at least not bad business to provide necessary treatment to bring about such reductions.

It is suggested that charges on metal concentrations in effluents should be introduced in such a way that charges on well controlled effluents are not increased, and in some cases reduced, but progressively penalise increasing metal concentrations particularly above guide limits, so that further reductions in volume without reducing load are no longer cost effective. In which case direct conflict between traders response to market forces and RWA enforcement of consents will be reduced or disappear.

9.2.2. Incentives for reduction of water and metal inputs to sewers, eleven known sources of trade inputs.

To further examine some ways in which incentives or constraints might become more effective results and insights gained from the two hypothetical cases are now applied to trade effluents known to this study.

Potential for savings by reduction of combined water and effluent charges, potential for resource conservation and some indication of the effects of including metal concentrations in the charging formula are of particular concern.

If the 40 effluents, for which data has been made available to this study, are classified by volume of agreed flow, it is found that there are 4 high volume effluents greater than 80,000 m^3, 8 medium volume effluents,

less than 80,000 and greater than 20,000 m^3, 22 low volume effluents less than 20,000 and greater than 1000 m^3 and 6 very low volume effluents of less than 1000 m^3y^{-1}.

Metal concentrations and load of many of the effluents from these sources are well controlled.

Volume of flow, water volume charges and estimated CWECs are given for 11 sources of trade effluents, one or more concentrations in which were shown, in table 8.31, to have exceeded YWA guide limits are shown classified by volume in table 9.1. They include 1 high volume, 2 medium volume, 6 low volume and 2 very low volume effluent sources and are therefore, on the basis of volume classes given above, a reasonably representative sample. Nine of the eleven are 'elite' sources, i.e. with an input in 1980/81 of 100 kg or more of one or more metals.

As each trade source is considered comments are made on the basis of the limited evidence available to this study.

One high flow source.

A, the source of data used in the hypothetical cases 1 and 2, appears to have potential for savings of £100,000 or more in water and effluent charges. Considerable savings in metal used may also be made by reducing the 4.26 - 7.28 and 1.07 tonnes of Ni and Cr disposed to sewer.

Nickel input could be reduced by 2305.658 - 5325.025 kgy^{-1} by reduction of Ni concentrations to guide limits.

If concentration could be maintained at guide limit when flow was reduced to 50, 25 or 12.5% cf. Case 2, load of Ni entering sewers could then be reduced to 22.95 - 13.43, 11.475 - 6.715 or 5.737 - 3.357 percent of 1980/81 input.

Cr concentration is well controlled and would require a reduction in effluent volume of more than 50% before guide limit was reached.

As respective 1980/81 prices of Ni and Cr were approximately £3900 and £4150 per tonne savings in metal feed stock could be considerable.

Two medium flow sources

'B' with an agreed flow of 54866 m^3y^{-1}, has potential for making more modest savings in water and effluent charges, but possibly £10,000. As the source of the highest 'known' input load of Zn and of mean Zn concentration in excess of 4 x the YWA guide limit, on the basis of the strategy shown in Case 1, B may be perceived as if approximately 75% of the flow, by which this concentration was reduced to guide limit, had already taken place with corresponding savings in water and effluent charges. B also has potential for annual savings by reducing the 2.36 tonnes of Zn input to sewers. Zn feed stock price being approximately £395 $tonne^{-1}$.

At 1980/81 flow Zn input to sewers could be reduced by 1807 kg. if Zn concentrations were reduced to guide limit concentration. If Zn concentration were maintained at guide limit values when flow was reduced to 50 or 25 percent, Zn input would decrease to 11.64 or 5.82 percent of 1980/81 load. B is also the source of the second highest 'known' input of Cd, 28.5 kg, reduction of this load, although highly desirable would not take place with effluent concentration at guide limit until flow had been reduced to less than 25% of 1980/81 volume.

'C' although not of the same strategic importance as A or B could make modest but real savings of £5000 - £9000 by reduction of the 1980/81 flow of 43,226. Input load of 676 kg. Zn could be reduced by 244 kg. if mean Zn concentration were reduced to guide limit and to 33% or 16.5% of 1980/81 load if concentrations were held at that limit while reducing flow to 50 or 25 percent of 1980/81 value.

Six low flow sources

'E' with a 1980/81 flow of 13708 m^3y^{-1}, has estimated water and effluent charges of £3,655 - £4,112 and thus potential for savings is low.

E is the source of input load of 371 kg of Zn and of 130 kg of Cu. Loads would be reduced to 37 and 53 percent of these values if metal concentrations were at guide limits. On the basis of the strategy used in hypothetical Case 1, E may be perceived as having already made savings equivalent to 100% of 1980/81 water and effluent charges. If concentrations of Zn and Cu were maintained at guide limits and 50% reduction in flow took place respective loads would be reduced to 18.5 and 26.5 percent of 1980/81 Zn and Cu loads.

'F' with a 1980/81 flow of 13152 m^3y^{-1}, has estimated water and effluent charges of £3,507 - 3945 and potential for savings is low. However F is the source of 179 kg. Cr and the highest 'known' load, 56 kg. of Cd. Reduction to 37 and 47 percent of Cr and Cd loads could be achieved if respective concentrations were reduced to guide limits. F may thus be perceived as using Case 1 type strategy and having already made considerable savings in water and effluent charges.

Whereas the Cr load is not of strategic importance the Cd load is, and could be reduced to 23.5 or 11.75 percent of 1980/81 load if concentration of Cd were maintained at guide limit but volume reduced to 50 or 25 percent of flow.

'G' with a 1980/81 flow of 11878 m^3y^{-1}, has estimated water and effluent charges of £3,167 - £3563 so potential for saving is low. G is poorly monitored, on the basis of 3 metal concentration cases it appears to be the source of Zn and Ni loads in excess of 100 kg reduction of which, e.g. by complying to guide limits, is desirable but does not appear to be strategically important.

'H' with a 1980/81 flow of 8771 m^3y^{-1} and water and effluent charges of £2339 - 2631 has very limited opportunities for savings. But as previously observed H with three concentrations more than 4 X, two of which are more than 10 X, guide limits, may be perceived as using a Case 1 type

strategy and to have already made large savings if water required to dilute these concentrations to guide limits is considered. H is the source of the highest 'known' loads of 444 and 561 kg.y^{-1} of Cu and Pb respectively. At 1980/81 flow reductions $\geq$90% of these loads could be achieved by reducing Cu and Pb concentrations to guide limits. Of less strategic importance a reduction of $\geq$60% of 271 kg. Zn load could be achieved by the same means.

'I' with a 1980/81 flow of 7575 m^3y^{-1} and estimated water and effluent charges of £2020 - £2272, has only slight, if any, opportunities for savings of charges. I has however a mean Ni concentration considerably in excess of 4 X guide limit and therefore may be perceived as using Case 1 type strategy and already made volume reductions saving in charges. Reduction of input load of 220 kg. Ni to 14% of present value by reducing mean Ni concentrations to guide limits is desirable but, comparatively, not strategically important. Savings in Ni input could offset costs of reagents used in more efficient effluent treatment.

'J' with a 1980/81 flow of 3158 m^3y^{-1} and estimated water and effluent charges of £842 - £947 has virtually no opportunity for savings in charges. J has, however, a mean Cr concentration in excess of 10 X the guide limit and thus may be perceived as having already made water and effluent savings. Reduction of 237 kg Cr load is again desirable but does not appear to be strategically important. At 1980/81 flow $\geq$90% reduction of Cr load could be achieved if mean concentration was reduced to guide limit.

2 Very Low flow sources

Any discussion of metal concentrations and loads from sources L_2 or L^4 is severely limited as available data is based on 1 or 2 concentration cases respectively for each element. But it is also for this reason that they are included.

L_2. With a 1980/81 agreed flow of 330 m^3y^{-1} has estimated water and effluent charges of £88 - £98. It is here presumed that these charges have no significant potential for reduction. However on the basis of one concentration case per metal element L_2 is found to be the source of effluent which exceeds by 5 - 7 times Zn, Cu and Pb guide limits. Although calculated inputs of these metals are small 17 - 12 kgy^{-1}, it is the degree of unknown regarding inputs from this source which is important. How does the level of monitoring affect emphasis on efficient use of treatment plant? What are the perceived rules of the game?

L_4 with a 1980/81 agreed flow of 204 m^3y^{-1} and estimated water and effluent charges of £50 - £61. It is here presumed that there is no scope for charge reduction. However on the basis of only 2 concentration cases per metal element is the source of effluent mean concentrations exceeding 5 X and 16 X Cu and Cr guide limits, but input loads are low 4 and 16 kgy^{-1} respectively. Again it is the degree of unknown regarding inputs, possible effects on efficiency of treatment used and on perceptions of those concerned, that such a low level of monitoring may have, which are questioned here.

'D' appears to be a leachate tank on YWA property although control of effluent from this tank is important it is not relevant to the present discussion and has been omitted.

Comment

When consents are unknown and their influence is omitted the following conclusions are reached.

A has by far the greatest potential for savings in water and effluent charges and in metal feedstock used.

Substantial improvement in treatment could be made with very short pay back time if guide limit compliance was required.

B and C might make modest savings in water and effluent charges, B also has potential for savings in feedstock Zn used.

But E, F, G, H, I and J are low flow sources with 1980/81 agreed flows of 13,708 - 3,158 m^3. Thus potential for savings on water and effluent charges are small or slight, but may be potentially sufficient to pay towards purchase of reagents to ensure better use of existing treatment plant.

Relative to YWA guide limits all 11 of the trade sources shown in table 9.1 might be seen as having responded to market forces by reducing dilution water to the point that one or more concentrations exceed guide limit values. Cf. hypothetical case 1.

Management of B, H, I, J and the very low flow sources L_2 and L_4 appear to be taking advantage of market forces shown in case 1, and may be regarded as having already made savings of dilution water in excess of 75% by having one or more mean concentrations greater than 4 X guide limit, indeed H, J and L_4 may be regarded as having already made water and thus effluent reductions in excess of 90% by having one or more mean concentrations in excess of 10 X guide limit. They may be regarded and regard themselves as good business men responding to market forces.

With these powerful financial disincentives traders may perceive 'efficient' use of existing treatment plant as being in such a way as to minimise waste disposal costs and to optimise disposal to sewer.

Introduction of metal concentrations into the charging formula could provide the financial incentive to improve efficiency of use of existing plant and to look for cost effective ways of minimising disposal of metals to sewers.

But potential savings of metal resources cannot be realised if only 'end of line' total loss systems of effluent treatments are employed.

In process reduction of water use and thus potentially of CWEC may be achieved by use of integrated treatment, electrolysis, ion exchange, reverse osmosis and, in some processes, reconcentration by evaporation by allowing recirculation of rinse waters. Some integrated treatments and electrolytic methods are particularly suited to metal recovery and/or reuse.

With careful use metals may also be recovered from ion exchange resin regeneration plants when market forces or other motives warrant it. But the control of potentially polluting effluents from such plants must be considered.

Without the inclusions of metal parameters in the charging system it is again found that strong financial forces appear to account for traders' behaviour in increasing input of metals to sewers in direct opposition to, and throwing a quite unnecessary burden on consent and enforcement procedures.

9.3. Use of treatment plant

9.3.1. To what extent can reduction be achieved with proper use of existing treatment plant?

It is now necessary to pose the following key question. To what extent can reduction to YWA guideline concentrations be achieved with existing trade effluent treatment plants?

If as previously suggested, in areas of low category receiving waters, trade effluent charges, consents or enforcement may not provide incentive to obtain consistent and effective control of metal concentrations and loads in trade effluents entering sewers, it may be that traders' existing treatment plants are not being used efficiently.

Some support is shown for this by again comparing mean metal concentrations in sewage sludges leaving KLL works in 1979 with those for

the 1980/81 period. Mean Ni concentrations rose by 93.76% i.e. 48.39% of the mean 1980/81 concentration was due to this increase. Similarly a mean Cd concentration rose by 37.42% i.e. 27.23% of mean 1980/81 concentration was due to this increase. It is possible then that these increases could be due to short term crises or changes made at a time of severe recession when treatment plants were not used efficiently to meet demands made upon them or by a dramatic short term increase in trade. Also by comparison it was found that mean concentrations of Zn Cu and Cr in sludge decreased between 1979 and 1980/81 by 27.64, 6.73 and 18.95 percent i.e. by 38.20, 7.21 and 23.38 percent of the 1980/81 mean concentration. Possibly due to fall in trade. See table 9.2.

Now although agreed flows for the 40 trade effluents are not available for the periods 1979/80 and 1.4.81-31.9.81 metal concentration cases for those effluents are. Comparisons are made between mean metal concentrations for the 3 periods but as the last period is short consideration is also given to the number of concentrations above guide limits and of extremely high concentrations.

For sources A, B, C, E, F, G, H, I, J, whose mean metal concentrations in the study period 80/81 exceeded guide limits, improvement and worsening of compliance is shown in table 9.3. The trends shown are:

1. Compliance of Zn and Cu concentrations from source E have been improving throughout the period and in 1.4. - 31.9.81 mean concentrations complied with guide lines.

2. Although compliance of Zn mean concentrations from C and G, Ni mean concentrations from A and G, and Cd mean concentrations from F worsened between 79/80 and 80/81 periods they have in 1.4 - 31.9.81 improved to comply with guide limits.

3. Compliance of mean Ni concentration from I has remained similar throughout and in 1.4 - 31.9.81 exceeds 3 times YWA guide limit.

4. Compliance of mean concentrations of Zn from B, Zn from H, is worse and in 1.4 - 31.9.81 concentrations are greater than X 10 and X 3 of guide limits respectively.

5. Compliance of mean concentrations of Cu from H and Cr from J is much worse and concentrations are greater than X 10 of guide limits.

6. Compliance of mean concentration of Pb from H is very much worse and in 1.4 - 31.9.81 concentration is greater than X 10 of guide limit. As with Zn and Ni concentrations from G, reliability of Pb concentrations from H and hence interpretation are limited by the number of concentration cases available.

Now interpretation of the above trends must be subject to caution as 81/82 data could substantially worsen from the period 1.4 - 31.9.81 shown if 1 or more very high concentrations occur during the winter period.

Reduction in concentrations may be due to a fall off in trade but also may indicate that treatment of metals in effluent from A, C, E and G and Cd from F can be adequate if plant is used efficiently. Whether this really is the case or not must be subject to on site investigation. Reduction of Ni from A and Cd loads from F have already been shown to be important. In the absence of agreed flows for the period 1.4 - 31.9.81 it is not possible to say to what extent loads of metals have been reduced if at all. But market forces favour reduction, rather than increases, in volume and hence in water and effluent charges.

However the trend shown by metal concentrations of Zn from B and H, of Cu from H, of Pb from H, and of Cr from F and J gives grounds for concern. Mean concentrations are being allowed to rise, four of the six mean concentrations are greater than 10 X guide limits. Again effect on load cannot be calculated in the absence of agreed flow data. Results may be interpreted as suggesting that treatment plant and/or strategy of treatment plant use are inadequate if achievement of compliance with YWA

guide limits is to be required.

To a lesser extent the same conclusion applies to mean Ni concentration in effluent from source I.

Conclusions

On the basis of the very small sample and limited data available it is concluded that:

1. If reduction of metal concentrations to guide limits were required, much of the required reduction might be achieved with existing treatment plant.

2. There is little point in considering requirement and costs for new plant unless serious consideration is also given to ways of reducing the disincentives to efficient use of existing and proposed new plant.

3. The number of traders whose effluent treatment is critically limited by existing plant, rather than use of plant, appears to be very small.

9.3.2. Investment in new plant?

It has now been shown that of the 40 trade sources of effluents known to this study comparatively few, possibly 5 or less, might require new treatment plant if required reductions of metals are to be achieved.

What purpose(s) would investment in new plant seek to achieve? To enable reductions of metal concentrations to be achieved so that existing or new consents can be complied with? and/or to achieve reduction of metal input load and therefore allow the RWA to use less costly sludge disposal methods? and/or to make the trader less vulnerable by reducing the scale of metal and water resources lost?

These purposes are not necessarily incompatible. However, it is important that it should be quite clear through the consent system if load reduction of particular metals is required. If the third purpose is to be achieved consideration must be given as to how load can be reduced.

Further

Are all other trade and exempted sources of metals to be required, and made to, comply with the same concentration, load or other limits?

Or, is it convenient to make required metal load reductions from relatively few sources, particularly where this reduction might most readily be achieved?

If the former it is important that the trader should know and perceive that an equitable policy is being carried out and be aware of the basis on which it is justified. If the latter, there may be a case for more favourable financial assistance for capital and possibly in current expenditure.

To what extent is the YWA able to predict, at least in non-tidal river areas, constraints likely to be required for the next 5, 7 or 10 years?

Clearly answers to these questions have implications for the choice of new treatment plant and also of financial or other incentives required to overcome initial and future uncertainty barriers.

For the purposes of the rest of this section it is now assumed that sludge will be required to meet, directly or indirectly, metal limit values similar to or as specified in Annex 1A of the EC. proposal for a directive, if sewage sludge is once again disposed by use on agricultural land or by harmonization clauses, if sea disposal of sludge from Knostrop Low Level WPC works is allowed to continue.

Further, it is assumed the calculated reductions found in Section 8 would, with the exception of Cd, be adequate to meet required reductions and would also be adequate to reduce metal concentrations in the WPC works final effluent in order to meet requirements of other Directives concerned with water pollution.

Sites and size of treatment plants

On the basis of 1980/81 data it seemed that high flow source A and medium flow source B might require provision of more efficient treatment plants. With reduction and potential for recovery of Ni and Cr from A and Zn from B. Both A and B can make considerable savings in water and effluent charges and by reduction of feed stock metal purchases. Reduction may have already taken place at Source A.

However any new treatment plant requirements of low flow sources F, H, I and J have little chance of being offset by other savings. But reduction from these sources particularly from F and H has been shown to be desirable.

If these are low flow sources do they require renewal of small treatment plants, or are they low flow sources because they have already made large savings of water, and require more extensive treatment plants?

Clearly financial incentives must cater for high, medium, low and where necessary, very low flow effluent treatment.

Some financial incentives

At face value 'polluter pays' clauses in EEC agreements allow 15% subsidies on new plant to be made until 1986. Whether this subsidy allowance is to be extended beyond that period is not yet known.

A trader needing to find 85% of new capital for treatment plant may require considerable credit. But as the 1982 study of the metal plating industry found -

a) many firms were already at their credit limits for financing day to day activities, and

b) "... increased cost of credit cannot be offset against future materials and water cost savings because interest rates are just too high."[43]

The above suggests that there may be a case for providing low cost fixed interest credit if such changes are to be facilitated. Such credits could, if deemed advantageous, be linked with a requirement to use a certain type of treatment, such as in process treatment to reduce rather than transfer pollutant load, in keeping with the pollution reduction at source policy of the third EEC environmental programme.

A third type of financial assistance is in writing down capital expenditure against tax. It has been pointed out, in another context, that shortening write off period is not advantageous to 'tax exhausted' companies.[44] Some flexibility in writing down capital expenditure is therefore desirable.

Along with these positive financial measures firms must be reminded that they have been enjoying a hidden subsidy in allowing or tolerating present levels of metalliferous input and be left in no doubt that the subsidy is now being withdrawn. Further, if metals are now introduced into the trade effluent charging formula, traders will have an incentive to avoid extra charge on high or very high metal concentrations in effluents.

Clearly if a firm is being treated as a special case and required to make reductions well beyond the norm there may be a case for further financial assistance, possibly through the charging system, when this reduction is seen as being cost effective to the RWA.

However if constraints on space or capital are so limiting as to not allow the use of an adequate in process or effluent treatment plant, the use of a central treatment plant, if necessary run by the RWA, might if combined with a rigorous enforcement of new consents, now be worth further consideration. Such a plant might for example make use of ion exchange resin modules, with great economy of trader's space. If necessary service could be extended to pick up and central treatment of spent metalliferous process solutions.[45, 46]

Such a service although putting an extra burden on the RWA might be worth further consideration if:

It gives the authority the required control of inputs to sewers; and

It is cost effective in allowing saving in sewage sludge disposal; and

It provides a means whereby vulnerable firms can minimise capital, but obtain the degree of treatment required by expenditure on current account.

Although the number of metal industry traders who might be interested in such a scheme does not appear to be large, geographical distribution within the catchment area appears to be favourable. Consideration of such a strategy may now be timely, and expedient.

9.4. Conclusions

1. Effects of incentives and constraints on traders producing metalliferous effluents.

A. The charging system.

In relying on a charging system based on the CBI/NWC formula which omits charging for metals and other potentially toxic substances:

a) The economic feedback implicit in the Polluter Pays Principle, to traders with metalliferous effluents is very weak or negative unless high levels of oxygen demand or suspended solids are involved; and

b) Contrary to that principle encourages the maximising of disposal of metals to sewers and as such does not encourage pollution reduction;

c) Because of this an undue burden is placed on the consent making and enforcement system; further -

d) The application of the social clauses implicit in the 'best practical means' defence may in some locations give rise to consents, or tolerance of polluting effluents, which are contrary to the expressed basic premis upon which the omission of metals and toxic substances from the charging formula is held to be justified;

e) As calculated at present trade effluent charges do little to encourage resource conservation;

f) or the reduction of metals or other potentially toxic substances. Consequently lowest cost sludge disposal is not facilitated.

g) The use of regional costs to the complete exclusion of local costs in the agreed formula may also be buffering financial feedback within the RWA itself.

h) Because of g) the balance of perceptions of the trader as a source of revenue and as a polluter may be distorted.

Further and more value laden and hence potentially more controversial,

i) Because metals and potentially toxic substances are not included in the charging formula, they do not always receive the level of monitoring and hence potential for control, that their influence on efficiency of WPC treatment processes and/or of sludge disposal would seem to justify.

B. Categorisation, Legislation and the Consent System

j) Although legislation and the consent system may be quite adequate to control trade effluent inputs to sewers in areas with high quality receiving waters or high quality demanding use, or where industries generating metalliferous effluents are relatively thinly spread or are in high priority areas,

k) The very flexibility of the statutory provision and latitude for interpretation may make for a great deal of uncertainty in some areas. At best not discouraging and at worst fostering the use of short term expedients, including contravention, particularly in areas of lower grade receiving waters, such as the R. Aire at Leeds.

l) Enforcement, made difficult by financial constraints on staff and monitoring resources of RWAs, has been undermined by short, medium and long term uncertainties of trader, RWA officials and the public as to when and how outstanding sections of COPA 74 are to be implemented, interpreted

and applied.

m) The rules of the game appear to encourage short term expedients for today, but in areas which most need long term change do little to reveal constructive rule changes or encourage good housekeeping, long term planning, or, in spite of the government's expressed concern over strategic metals, prepare for efficient use of resource materials in the future.[47]

n) In the Leeds area it appears to be 'good business' to reduce volume of effluents but to allow metal concentrations to increase, and/or to be cost effective to reduce treatment and waste disposal costs while maximising disposal of metals in effluent input to sewers.

o) Furthermore the uncertainties of when rules will be changed and how rules will be interpreted may lead to slow uptake of innovative processes and so hamper the development of a home base, and thus potential for export from, the new pollution control industries.[48,49].

2. Ways in which incentives or constraints might become more effective.

A. Charges

The CBI and RWAs should either support the CBI/NWC formula or the social clauses implicit in the 'best practical means' defence or unless it is intended to review the whole basis of the charging formula the introduction of metal concentrations into that formula should now be considered. If it were not politically acceptable, desirable or cost effective to charge for very low concentrations of metals, the introduction of a steeper set of charges on metal concentrations above a base limit, such as the guide limit or lower, might be acceptable as being in keeping with the basic principle of not charging for metals in well controlled metalliferous effluents purported to underlie the present CBI/NWC formula.

Applying an exponential scale of charges on concentrations of all, or critical potentially toxic metals, above the levels found in, say, a purely domestic effluent could provide a suitable strategy.

Such a scheme could, if charges were levied on selected metals rather than on total metal or total nonferrous metal concentrations, make, and be seen to make, a positive contribution through financial incentives to improving, final effluent quality and facilitating efficient sludge disposal.

Furthermore if an exponential scale of charges were used it need not penalise traders producing already well controlled effluents. Particularly so if the threshold of minimum biological treatment charge, based on oxygen demand, can also now be lowered, at least for those paying for metals in effluents.

By judicious inclusion of metals, charges would encourage better housekeeping and provide incentives to industry to become more strategically prepared for the future by reducing wastage of scarce resources such as water and metals.

Such a scheme might also be attractive to RWAs in that it would maximise the use of already existing monitoring and administrative procedures, while having the potential for facilitating savings of costs, possibly of sewage treatment, but particularly of expensive after treatments of effluents and sludge and in sludge disposal.

Effectiveness of such a scheme might be enhanced if scale of charges for metals are clearly seen to be stepped over time. Traders can then perceive the financial disadvantages of delaying any necessary improvements to process or treatment plants.[50]

Although only a relatively small number of trade sources may produce effluents with threshold concentration values above which charges will be effectively increased, the potential advantages and disadvantages of such an incremental change should now receive serious consideration.

B. Consents and Enforcement

There seems to now be a strong case for increasing the parity of consents and enforcement.

If guide limits are to be used values, particularly of Cd, may need revision to reflect the relatively strict constraints on disposal of effluents or sludge.

Consents should if possible reflect the need for metal load as well as concentration reduction. This will be particularly important until metal concentrations are included in the charging formula.

In view of the limiting effects that metals, particularly at high concentration may have on treatment processes and costs of sludge disposal, level and effectiveness of monitoring, particularly of low and very low flow metalliferous effluents might now be reassessed. The possibility of introducing RWA owned continuous sampling equipment may now be timely as UK legislation is implemented to accommodate present and future EEC directives. By reducing uncertainty directives may now allow more positive action to take place as well as providing the crises by which such changes become justified.

C. Resource wastage, use of existing plant and financial aids to purchase of new process or treatment plant.

If metal charges are introduced into the charging formula and or consent parity and enforcement are increased, efficiency of use of existing plant should be increased. Traders should then be encouraged to perceive the opportunities for savings from efficient use, and low cost changes to, existing plant and practices.

Within a changed framework traders may then become more receptive to advice. Questions of by whom and how that advice should be provided would then become pertinent.[51]

Provision of direct subsidy, low cost fixed interest loans, or flexibility of capital write down may also be required in the Leeds area, by a small number of traders. The strategic importance of such provisions should not be overlooked. Provision of low cost fixed interest loans could be made provisional on the type of plant and usage of plant so funded.

The potential for reducing metals in liquid waste, in final effluents and in sewage sludge as well as the strategic reduction in feedstock requirement by use of in process treatment might be considered where such provisions are made.

Where space or money are limiting, the possibility of providing a central treatment plant might be considered.

3. On basis of the data and known sources, made available to this study, the number of traders required to make changes to use of existing plant or require new plant appears to be small.

The importance of making required reductions of load of named metal inputs from these sources on sludge disposal, particularly if once again disposed to agricultural land, is out of all proportion to their numbers.

On the basis of the distribution of cumulative loads shown in figs. 7.13 - 7.16 if typical of other categories, the number of key input sources of Pb and Cd 'unknown' to this study is also likely to be relatively few or very few, but on an input load basis, strategically important.

The strategic importance of preventing of dumping of spent process solutions must not be overlooked.

4. Some policy implications.

Perhaps the most important findings of this study concern the need for conceptual changes.

An attempt has been made to see the rules of the game from the trader's point of view. From that viewpoint the conclusion reached that the balance of incentives are at present overwhelmingly to maximise disposal to sewer. An incomplete list of forces acting upon traders, gleaned from literature and other sources, is given below.

1. Incentives to improve effluent treatment and reduce inputs of metals to sewers.

a. It will cost more to improve treatment later.

b. It will cost less if effluent charges are reduced.

c. It will cost less if process materials are saved.

d. It will cost less if water is saved.

e. It will cost less if a better product is produced.

f. There will then be no difficulty in complying with the WA Consent.

g. It might be eligible for 15% subsidy on new plant.

h. It might then be possible to take advantage of writing down the valuation on new plant quickly.

2. Incentives to maximise disposal to sewer.

a. Inertia.

b. Doubts about the future.

c. Present arrangement with WA.

d. It is good business to use local influence on the pollution control officer.

e. The CBI will back up the status quo.

f. More efficient treatment would require more skilled control.

g. By maximising disposal to sewers savings can be made in running costs.

h. By maximising disposal to sewers savings can be made in waste disposal charges.

i. By tipping the plating bath more frequently we can achieve the exacting standard required at a competitive price.

j. It will make so little difference to effluent charges it will not be worth it.

k. Effluent charges will increase anyway.

l. Capital requirement for improved treatment is too high.

m. Only 15% subsidy or less will be available.

n. Interest rates are too high.

o. If we wait long enough we may get a large subsidy.

p. Lack of time, information or experience to assess the potential financial or technical opportunities for change.

q. If my competitors are getting away with it so must I, to keep competitive.

r. The chances of getting caught are low - and if I do I can probably talk my way out of it.

s. Even if I do get caught the fine is likely to be ----

The first danger of a list like this is that it may be dismissed as emotive. But here it is presented to show how traders, particularly in firms which are not large enough to employ specialist pollution officers, might perceive the politico-economic framework in which their trade effluents are discharged to sewers in an area where final effluents from the receiving WPC works is discharged to a lower grade river.

The conceptual change required is to see the balance of forces going the other way so that the trader sees the advantages of improving effluent treatment and reduction of inputs of metals to sewers. It is to achieve this conceptual change that recommendations have already been made regarding charging, enforcement and low cost loans. Jurue has suggested that a learning curve must be set in motion.[52]

Here it is suggested that the time has come for conceptual changes at RWA and DOE level so that RWAs' role in transferring pollution in contaminated sludge by costly disposal is no longer seen as a necessary expedient, and that disposal of a less contaminated sewage sludge is seen as cost effective in enabling regional or local charges to be held down and a much greater parity to be achieved.

DOE might now consider that 'pollution reduction at source' written into the EEC third environmental programme may not be more costly to administer than the present disposal programmes, although the questions of who pays, and how, may require different answers.[53]

As under the 1973 Water Act DOE presides over the rules of the game, they might now question the vires and assumptions of the CBI/NWC charging agreement and question if the time has now come to use the charging formula to provide positive financial incentives to reduce metal inputs to sewers.

It is also noticed that although DOE presides over the rules they do not themselves fund research into pollution control technology, it is here suggested that the time has come for a coordinated policy in which the rules and financial incentives encourage ongoing short and long term reduction of pollution at source, and in doing so encourage a steady, rather than a 'killing' base for an innovative pollution reduction, rather than transfer, industry.

TABLE 9.1.

Agreed flows of effluent leaving 9 'elite' and two very low flow trade sources, assumed water volume and estimated combined water volume and effluent charges.(a) (e) 1980/81 data.

Source Code	b Notes	Volume Class	Volume m^3	Water Vol.Charge 20 p.m.$^{-3}$ £	Combined Water Vol. and effluent Charge c £	d £
A		High	488983	97,796.6	130,395.46 -	146,694.90
B	f	Medium	54866	10,973.2	14,630.93 -	16,459.80
C		"	43226	8,645.2	11,526.93 -	12,967.80
E		Low	13708	2,741.6	3,655.66 -	4,112.40
F		"	13152	2,630.4	3,507.20 -	3,945.60
G	i	"	11878	2,375.6	3,167.47 -	3,563.40
H	fff	"	8771	1,754.2	2,338.93 -	2,631.30
I	f	"	7575	1,515.0	2,020.00 -	2,272.50
J	f	"	3158	631.6	842.13 -	947.40
L_2	gfff	Very Low	330	66.0	88.00 -	99.00
L_4	h ff	"	204	40.8	54.40 -	61.20

Notes:

a. When process water losses are omitted and Volume in = volume out.

b. Source D irrelevant to the discussion, has been omitted.

c. When effluent charge is 1/3 of water volume charge.

d. " " " " 1/2 " " "

e. Elite sources had input of 100 kg or more of 1 or more metals in 1980/81 trade effluents. See S.7.13.

f. Shown in table 8.31 to have 1 mean concentration in excess of 4X YWA Guide Limits.

ff. Shown in table 8.31 to have 2 mean concentration in excess of 4X YWA Guide Limits.

fff. Shown in table 8.31 to have 3 mean concentration in excess of 4X YWA Guide Limits.

g. Quality (not shown) is based on 1 sample case only.

h. " " " " 2 cases " "

i. " " " " 3 " "

TABLE 9.2

Number of cases and mean concentration of six metals in dry solids of mixed sewage sludge leaving Leeds City WPC Works

Comparison of year 1.1.79-31.12.79 with year 1.4.80 - 31.3.81

Metal	Zn	Cu	Ni	Cd	Pb	Cr	T.S.
Year	mean concentration mg kg^{-1} dry solids sewage sludge						%
1.1.79-31.12.79	2167 a	807.8 a	226.4 b	33.3 b	ND	707.2 b	6.202
1.4.80-31.3.81	1568.06 c	753.44 c	438.68 c	45.76 c	1053.8 d	573.2 c	6.278
Difference	-598.94	-54.36	+212.28	+12.46	ND	-134.0	+0.076
	Percentage Difference						
Diff/1979	- 27.64	-6.73	+93.76	+37.42	ND	-18.95	+1.225
Diff/1980/81	- 38.20	-7.21	+48.39	+27.23	ND	-23.38	+1.211

Notes:
a. Mean concentration based on 46 cases
b. " " " 47 "
c. " " " 30 "
d. " " " 9 "
ND No data.
TS Mean Total Solids on days for which metals data is given.

TABLE 9.3

Improvement and worsening of compliance of mean Zn, Cu, Ni, Cd, Pb and Cr concentrations in trade effluents from 9 sources, inter period comparisons of 1.4.79-31.3.80, 1.4.80-31.3.81 and 1.4.81-31.9.81

Metal	Source Code	Periods compared: 79/80 with 80/81	80/81 with 1.4/31.9.81	79/80-1.4/31.9.81	Compliance with YWA Guide limit 1.4 - 31.9.81
		Relative Compliance			
Zn	B	Similar	Worsen	Worse	Exceeds X 10
Zn	C	Worsen	Appears more controlled	Worse	Yes
Zn	E	Improves	Improves	V. much improved	Yes
Zn	G a	Worsen	Similar	Worse	Yes
Zn	H	Worsen	Worsen	Worse	Exceeds, X 3
Cu	E	Improve	Appears more controlled	V. much improved	Yes
Cu	H	Worsen	Worsen	much worse	Exceeds, X 10
Ni	A	Worsen	Improves	improved	Yes
Ni	G	Worsen	Appears more controlled	Similar	Yes
Ni	I	Similar	Similar	Similar	Exceeds X 3
Cd	F	Worsen	Improve	Similar	Yes
Pb	H a	Worsen	Still very poor	V. much worse	Exceeds X 10
Cr	F	Worsen	Worsen	Worse	Exceeds X 5
Cr	J	Worsen	Worsen	much worse	Exceeds X 10

Notes:

Very much improved	less than x 0.25 of 1979/80 concentration
Much improved	less than x 0.3 " " " "
improved	less than x 0.5 " " " "
similar	other
worse	more than x 1.8 " " " "
much worse	more than x 3 " " " "
Very much worse	more than x 4 " " " "

a. Interpretation is very limited because of the low level of monitoring.

Yes. metal concentrations comply with YWA guide limits.

10. CONSTRAINTS OR OPPORTUNITIES?

SOME CONCLUSIONS

10.0

It is not the purpose of this concluding section to pick up and discuss all the foregoing results and conclusions, but rather to use some of them to seek answers to the questions posed in the introduction and to consider the implications of those answers for the future.

It has been assumed that these conclusions will be read in conjunction with and as a sequel to the conclusions given in sections 8.7 and 9.4.

10.1.

Prior to 1970 problems associated with sewage disposal seem to have been treated as of low priority, as Lena Jeger, Chairperson of the Working Party on Sewage Disposal explained, "This report is called 'Taken for Granted' because, in spite of growing contemporary interest in all forms of pollution, the disposal of sewage is taken for granted as long as it is effective and unnoticeable." On basic sanitary, amenity and water requirement grounds she concludes, "The problem cannot be washed or wished away. Nor can its solution any longer be taken for granted.[1]

There are indications that since 1970 the problems of sewage disposal have been accorded a higher priority, but ironically as sewage treatment efficiency has increased, so have the problems of sewage sludge disposal. Quantity of sewage sludge has increased although, generally, the increase in total appears to be small. See S.4.1.1. More seriously, in some areas quality of sludge has decreased as substances formerly discharged to rivers are diverted into the sludge output of WPC works.

Sewage sludge disposal is also of considerable economic and political significance, too. Of the former it is reported that in the year 1977/78 the ten RWAs in England and Wales spent £127m on sludge treatment and disposal, being approximately 40% of the £318 of total annual cost of sewage treatment and disposal.[2] Of the latter it is concluded that, as the UK has the second highest production of sewage sludge of 16 European states, "Sludge disposal in and from the UK is regarded as important to EEC or European states." See S.4.3 concl.1.

It was also concluded that "Sea Disposal from England and Wales appears to have increased from 20 to 24.46 percent in the 1975-80 period", and "However convenient this method of disposal may be, disposals from the UK, particularly to the North Sea by 'dumping' are highly vulnerable to international political pressure to reduce quantity and improve quality of sludges disposed." S.4.3 concl.3.

Symptomatic of this pressure was an attempt made at Bremen, as recently as November 1984, to get eight North Sea coastal states to declare that sea 'a special area'.[3] "The granting of such a status, ..., is demanded most forcefully by West Germany," supported by Sweden and Denmark. The Danish delegate demanding a commitment to stopping all sea dumping "... within the next two or three years".[4]

On this occasion the British view prevailed "that rather than rushing into hasty action existing treaties and forums for protection of the North Sea should first be fully exploited." The conference agreed on interim measures including the reducing of sewage discharge from rivers. Significantly "The ministers agreed to meet in Britain in 1986 or early 1987, when with British consent, the declaration of a special status for the North Sea will again be on the agenda."[5]

Such pressure must give rise to concern when costly schemes are being planned, have been initiated, or are nearing completion, for

reducing output of sewage to rivers by building trunk sewers and/or treatment plants and disposing sludge produced to sea.[6,7.]

Sludge from the YWA City WPC works, data from which has been used in Part 2 of this study, is currently disposed to sea. Incineration may provide an alternative technique for reducing the quantity of sludge to be disposed but this was found to be costly, and vulnerable to strong local opposition. (S4.3 concl. 3). Incineration does provide a 'last resort' strategic option, but does not in itself solve the problem of the disposal of the highly concentrated residue remaining from this process. (S4.3 concl. 2).

In view of the above it is perhaps not surprising to find that in 1980 71.37% of sludge produced in England and Wales was disposed to land. But competition for use of suitable landfill sites, particularly where sludges are contaminated with 'blacklist' substances such as Cadmium, may also limit the extent to which this option can be used. S4.3 concl.4 and 5.

It is also noticed that any increase in stabilisation by digestion, to reduce pathogen risk or improve aesthetic quality of sludge, or decrease volume to reduce transport costs will itself tend to increase metal concentrations in sewage sludge. See S7.3. This aspect of disposal will become particularly important if current proposals for a Council Directive on sewage sludge use in agriculture are accepted and agreed. See S6.2 concl.19.

In view of the above, and as in 1980, 48.5% of sludges produced in England and Wales were disposed by utilisation on agricultural land, it has been timely to consider for 'heavy' metals the questions posed in the introduction to this study.

10.2.

Question 1. Can sewage sludge be designed for disposal?
The question is here narrowed down to consider sewage sludge disposal by use on agricultural land. But on what can such a design be based?

Two aspects of design are of particular importance to this study: the concepts of control and constraints.

The concept of design suggests quantity and quality control of materials used, not only in absolute terms but also comparatively one with another. Secondly, it suggests constraints on quantities and qualities required in the product. These constraints being, at least in part, related to product use.

10.2.1. With regard to the first aspect, as shown in S2, pragmatic water pollution control policies extant today may be seen as a direct result of the failure to enact standards, written in the Bill, into the Rivers Pollution Prevention Act 1876, and the subsequent delegation of standard setting to local Authorities, subject to wide discretion in interpreting the strong defence clauses finally included in the Act. See S.2.4 concl.1.

Sixty years later some standards were stipulated in the Public Health Act 1936 to control substances entering sewers which might endanger human life or the fabric of the sewers.

Control of trade effluents by consents was a main innovative feature of the Public Health (Drainage of Trade Premises Act 1937). But this consent making process does not appear to have been regarded as mandatory. See S.2.4 concl.1.

The Best Practical Means approach used by the Alkali and Clean Air Inspectorate is still used to justify the use of a 'best practical means' strategy in the water pollution control consent-making process. But in the former BPM refers to the treatment process which the occupier

of premises is required to use, Inspectorate controlling process used, method of use and efficiency of use. In the latter BPM is a set of defences, taking account of circumstances, implicit in the consent-making process but not giving the controlling authority's officer statutory control over the choice of pre-treatment process used, method of use or use itself. Further, consent-making and enforcement are themselves vulnerable to national and local short-term political expedients influencing discretion. See S2.4 concl.1.

It is concluded that on the basis of evidence shown in this study, unless there are good reasons for limiting discretion the consent-making process does not in itself provide a good basis for controlling quality or relative quantity of materials entering sewers.

10.2.2. Discretion may, however, be limited by the second type of constraint on quantity and/or quality of output.

Discretion regarding volume may be limited by the capacity of sewers and/or treatment works, while discretion regarding quantity and quality of trade effluents entering sewers may also be limited where high quality receiving waters are required. It is important to acknowledge that in spite of the shortcomings of the consent-making process, the 1980 river pollution survey showed, when classified by length, 76.03 and 93.12 percent of non-tidal rivers were graded as Class 1 or classes 1 + 2 respectively. The corresponding figures for tidal rivers being 50.34 and 84.21 percent respectively. These results are in themselves evidence of extensive control. See tables 3.1 and 3.3.

But, as shown in S.3, in many locations improvement has been achieved, and acknowledged to have been achieved, by transfer of pollutants with resultant reduction of sludge quality.

Where receiving water is allocated a low quality priority, by a process of categorisation, what then? Discretion is widened with a

consequent weakening of the consent-making process as a basis for control.

But river quality or sludge quality are not necessarily alternatives. Constraints on quality of sludge disposed by use on agricultural land are currently provided by the DOE/NWC Guidelines.

As shown in S.5 the Guidelines have evolved over a relatively short period.

The Guidelines are voluntary and have been deliberately disregarded, when expedient, by RWAs.

The RCEP has urged compliance with Guidelines, but this also incurs costly compliance with constraints involving $Zn^{=}$ which appears to be scientifically unsubstantiable.

The Guidelines also contain relaxations some of which, although still conditionally defended, appear to be no longer tenable on scientific grounds.

Symptomatic of concern over these relaxations is the divergence of advice given by MAFF(ADAS) to farmers in 1982 to that specified in Guidelines published by DOE in June 1981.

Strengths claimed for the Guidelines are that (a) they provide for local conditions, and (b) they can be quickly changed when such changes are justified. But it has been shown that changes, which on the basis of evidence given are justified and necessary, have not taken place quickly. Further, because the constraints are facilitating the burden of decision-making is still left with the RWAs. See S.5.6 con1.9,10 and 11.

The non-specification of limits on metal concentrations in sludges, except in the case of Pb where sludge is utilised on grassland and on Cd where utilised in parks or gardens, may be claimed by some as a virtue. The consequence of this strategy is to pass to the RWA the difficult choices of, for instance,

a. Having to extend and/or tighten consents and/or of more rigorous enforcement to control heavy metals entering sewers;

or b. Of disposing a metalliferous sludge by applying it to land more thinly and therefore more expensively to comply with application and/or soil concentration constraints. In doing so the Zn≡ constraint may be the first limiting factor; See S.6 ref.15.

or c. Of disposing of sludge by some other means.

It is here suggested that the flexibility of the Guidelines may now also be a weakness in some areas allowing the soft but expensive option of disposing of sludges with one or more metals of relatively high content by option b above.

By contrast, the proposals for a directive do not include an overriding Zn≡ constraint or doubtful or untenable relaxations, but do provide clear cut limits on Zn, Cu, Ni, Cd and Pb concentrations in sewage sludges used in agriculture as well as firmly recommended Cr and Hg values. See S.6.1. Comparatively the Pb concentration constraint may be perceived as harshest, but on the basis of data from the 1980 Survey, 98.3% of all sludge disposed to land, had a Pb concentration equal to or less than the proposed Mandatory value. Cf S4.2 final para.

Particularly since the pH6 limit has now been amended to "... sludge shall not be spread on soil with a pH value which will allow excessive mobility of the trace elements," (See S6.2 concl.3), it is possible to conclude "... where these constraints can be met the EC proposal will in most cases allow more sludge to be applied to agricultural land than previously, particularly where currently limited by the Zn≡ recommendations of the UK Guidelines." See S.6.2 concl.11.

Further, the proposal for a directive, by specifying mandatory and recommended limit concentrations, does provide a set of firm constraints

which may be used as a basis for design. As concluded in S.6, "The limits, if adopted, will however provide RWAs with strong incentives, justification and clear base line concentrations to carry out the necessary changes in trade effluent control." See S6.2 conclusion 5.

10.2.3.

The study of the YWA City WPC works area has shown, on the basis of available data, how use of constraints specified in Annex 1A of the proposal for a directive might be used to design sewage sludge output for disposal by use on agricultural land.

Unlike some studies where intensive data gathering is carried out for the special purpose of conducting a balance study, "The data made available for this study had been gathered by YWA for its own purposes for the day to day running of the city WPC works, for the control of trade effluents entering sewers and for charging purposes when sewage sludge was being disposed to sea." See S.8.7 concl. 1. Unlike the special studies which, for financial reasons are usually of short duration, data used in this study is gathered over a long period for which 'agreed flows' of 40 trade effluents were made available 1.4.80-31.3.81.

Detailed analysis of trade effluent data, given in S.7.1, shows that 10% of the 'known' trade sources accounted for 50.14, 64.15, 95.23, 67.93, 82.74 and 94.71 percent of Zn, Cu, Ni, Cr, Cd and Pb total loads discharged from 40 'known' trade sources during the stated period.

Limitations of data used in the model are discussed in S.8.7 conclusions 1-5. Difficulties were encountered in:

1. Establishing 'effective partition ratios' and the resultant use of alternative ratios in the final model; See S.7.2; and
2. The need to improve reliability of data by

a. explicit optional omission of data, and/or

b. explicit use of alternative input data,

and the further elaboration of design;

1. To optionally simulate the concentrating or diluting effect of simulated digestion or lime treatment on metal concentrations; See S.7.3.

2. To accommodate the problem of uncertainty and compliance, discussed in S.8.51, where it is concluded "... the simple and 95% probability of compliance used in this study are representative of the least and most demanding of the types of compliance that might be required by a Directive on the use of sewage sludge in agriculture"; and

3. To accommodate the use of 4 distinct strategies used to achieve compliance.

But on the basis of results obtained it is possible to conclude "One of the effects of these limitations is to make results found in this study less tidy than might be wished. However, the general picture that emerges from these results is clear enough to be used as a basis for further action." See S.8.7 concl.1g.

10.2.4. It is now concluded that sewage sludge can be designed for disposal by use on agricultural land.

It is further concluded that although the basis and type of compliance required by a directive may require further clarification Mandatory and Recommended metal concentrations in sludges, specified in Annex 1A of the proposal for a Directive do provide a set of clear output constraints on which a design may be based. The limitation of RWA discretion provides opportunity, incentive, reason and justification to achieve the degree and consistency of compliance required. Furthermore, if as in 1977, disposal by use on agricultural land still provide the

most economical options, this will presumably be reflected in trade effluent charges and in the sewerage charge component of Water rates.[8]

10.3.0. Operational questions - some answers

10.3.1. To the question "Which metal outputs need be reduced?" The answer is dependent on the type of compliance required and the sludge type.

As shown in summary table 10.1, when simple compliance was required only Cd concentration in simulated lime treated sludge need be reduced, reduction of Ni, Cd and Pb concentrations being required in unstabilised and simulated digested sludge.

Similarly, when 95% probability of compliance is required, reduction of Cu, Ni, Cd and Pb concentrations in unstabilised and simulated lime treated sludge is required, and reduction of all 5 metals, for which mandatory limits are specified, are required in simulated digested sludge. See table 10.2.

10.3.2.

The same two factors, type of compliance and sludge type also affect the answers to the question, 'How large is the required reduction of input?'

As percent reduction of input is equivalent to percent reduction of output and vice versa, as shown in S.7.4 equations A1 and A5, therefore required percent reductions, shown in Tables 10.1 and 10.2, also indicate the equivalent required reduction of total input of a particular metal, whether regarded as a mean concentration in sewage sludge entering the works when flow is as calculated for 1980/81, see 7.4 equations C17 and C21, or more conveniently as percent reduction of mean load of metal entering the WPC works during the stated period.

As shown in table 10.1, to achieve simple compliance with proposed

Mandatory limits reduction of 8.82, 12.59 and 5.105 or 32.66, 35.44 and 29.915 or 0, 0.35 and 0 percent reduction of Ni, Cd and Pb mean concentrations are required in unstabilised, simulated digested or lime treated sludges respectively. The same percent figures indicating required reduction of mean input loads of those metals for the stated period.

If 95% probability of compliance is required an additional factor, the standard deviation, affects the size of required reduction. As seen from the distribution of metal concentration cases in unstabilised sludge, shown in figs. 7.1 and 7.2, Zn, Cu and Pb concentrations have particularly high standard deviations. If SD:$\bar{X}$ ratio is held constant at levels shown in those figures then reduction of Zn, Cu, Ni, Cd and Pb concentrations required in unstabilised or simulated digested or simulated lime treated sludges are 0, 17.78, 46.07, 49.2 and 68.3, or 23.04, 39.27, 60.17, 62.98 and 76.57 or 0, 6.27, 38.52, 42.09 and 51.05 percent respectively, the same percent reductions of equivalent mean input loads of metals being required. The percent reductions of Ni, Cd and Pb required, particularly in simulated digested sludge, being very high. See table 10.2.

But the high mean concentrations standard deviations and hence consequent high required reductions of Zn, Cu and Pb are in part due to the effect of 2 anomalously high concentration cases in 30, 30 and 9 cases of those metals respectively.

Therefore it is the purpose here to emphasise the importance of the strategy of eliminating anomalously high concentration cases in relation to the two following questions.

To simplify discussion the high Zn, Cu and Pb concentrations on a particular day are assumed to be due to the same causal factor.

10.3.3.

How many input sources need be affected?

A short answer to this question might be, probably few.

Simple compliance of Zn, Cu, Ni, Pb and Cd concentrations with Mandatory values were obtainable:

a) in simulated lime treated sludge when Cd input from 1 source was reduced. See table 8.10.

b) in unstabilised sludge when inputs of Ni, Cd and Pb from 1, 1 or 2 and 1 sources respectively were reduced, 3 or 4 sources being affected.

Thereafter non-feasibility or non-practicality of achieving compliance of Pb and Cd concentrations was limiting. See summary tables 8.27, 8.29.

But if 1 or 2 highest concentration cases in unstabilised sludge are eliminated, presumably by removing causal factors or if critical, by disposing of the batch of sludge elsewhere, then Zn, Cu and Pb mean concentrations in unstabilised sludge 1568.06, 753.443 and 1053.8 $mgkg^{-1}$ DS respectively are reduced by 6.71, 12.75 and 36.145 or 11.67, 21.63 and 55.48 percent respectively. Thus making achievement of both simple and 95% probability of compliance by reduction from known sources less severe or not necessary. Corresponding reduction of Zn, Cu and Pb standard deviations are from 796.8, 651.03 and 1277.21 by 29.7, 40.09 and 55.26 or 52.48, 76.59 and 85.26 percent respectively. See table 10.3.

With elimination of 1 highest concentration case of Pb simple compliance of Zn, Cu, Pb and Ni could be achieved by reduction of Ni from 1 known source, Source A.

Similarly if 2 highest concentration cases of Zn, Cu and Pb are eliminated 95% probability of compliance can be achieved by Zn, Cu and

Pb in all 3 sludges, if SD:$\bar{X}$ ratio of Pb in simulated digested sludge can be narrowed to 35%. See summary table 8.30.

Ni compliance can definitely be achieved in unstabilised and simulated lime treated sludge and probably be achieved in simulated digested sludge by reduction from Source A only. See summary table 8.29.

Therefore simple and 95% probability of compliance of Zn, Cu, Ni and Pb can be achieved, or probably be achieved, in all 3 sludges by reduction from 1 known source only, Source A.

The importance of this strategy is apparent.

The problem of Cd compliance remains. As shown in fig. 8.1 distribution of the 30 available sludge Cd concentration case could be regarded as bimodally distributed, but it is noticed that the 3 highest concentrations occur on days when sludge total solids are relatively low. The higher concentrations may therefore be due to the effect of relatively low dry matter dilution of a normal Cd load.

It is also noticed that 50 per cent of sludge Cd concentrations were greater than the proposed Mandatory limit suggesting that reduction from regular input sources is required.

Inputs of Cd from 'known' sources were calculated to be equivalent to 23.44-28.55 percent of mean concentrations in unstabilised sludge. See table 8.4 or S.8.6.

The extent of inputs from unknown sources was examined in S.8.6 where it was observed that 'unknown' trade sources may be

a) from sources known to the RWA but not to this study,

b) from sources known to this study but over and above loads represented by the RWA monitoring procedure, or

c) from sources unknown or not yet monitored by the RWA.

It is concluded "If the distribution of effluent loads found in the category of trade wastes already examined is not atypical a high percentage of 'unknown' trade input load will be derived from few high input sources." See S.8.6 in which case the number of key sources of Cd input loads are probably few.

Some of the key sources of metal inputs may be exempted sources and/or high volume sources currently regarded as well controlled on the basis that concentrations are lower, even much lower, than YWA Guide limits. But input load is large enough to make them now strategically important sources of Cd. See S.8.7 concl. 6.

It was also concluded that "A long term benefit of a directive such as that proposed on the use of sewage sludge in agriculture will be in providing the priority and urgency necessary to locate and control inputs of Cd and Pb to sewers." (Concluding Para. S.8.6).

10.3.4.

What strategies are available to bring about required reduction?

10.3.4.1.

With regard to the reduction of metal concentrations in sewage sludge output, 4 strategies have been used in investigations carried out in this study.

a) By reduction from highest 'known' input metal loads.

b) By reducing metal concentrations in effluents from 8 known trade sources to YWA Guide limit concentrations.

c) By elimination of 1 or 2 anomalously high concentrations of, in this study, Zn, Cu and Pb.

d) When 95% probability of compliance is required, by narrowing $SD:\bar{X}$ ratio.

As use of these strategies has already been discussed in S.8.7

conclusions 3 and 4, and in part when answering questions posed above, the only points to be made here are:-

1. Combination of strategies a and c and of b and c, although not fully investigated in this study, do provide means of lessening the burden of reduction from 'known' sources.

But "Whether the two occasions of high concentration cases of Zn, Cu and Pb, considered above, are two isolated incidents occurring at the beginning and approximately half way through a financial year, or as 2 cases in 30 they represent, approximately, inputs on 24 days throughout the year is not known."

On the basis of this observation, made in S.8.30, it is concluded,

"If the latter is the case then it may be possible to regard the distribution of Zn, Cu and Pb as bimodal rather than being log normally distributed. If this were the case possible control strategies might more easily be inferred." See S.8.30 concluding paragraph.

The priority to eliminate or reduce causal factors of such high concentrations, reduction in tolerance, and perceived tolerance, of consent contravention and observable determination to achieve and maintain the necessary quality of output will also be reinforced by the presence, if agreed, of a Directive specifying Mandatory limits for sludge metal concentrations.

10.3.4.2.

Strategies for reducing metal inputs from trade sources have been discussed in S.9 and conclusions reached in S.9.4. Therefore conclusions here are limited to the following:

1. It makes little sense for a trader, or for that matter the RWA, to be able to save the costs of disposing the equivalent of 1 tanker load of metalliferous waste as influent to sewers if by doing so that waste complexed with domestic and other sewage gives

rise to, say, a thousand tanker loads of sludge which because of high sludge metal content must then be disposed by a higher cost route.

2. WPC works by whatever name are 'sewage treatment works not metal treatment works.'[9] They are able to transfer metals but neither remove or 'destroy' them.

3. Of the techniques available to pre-treat trade effluents, dilution, although often providing water revenue, should be discouraged as this method of reducing concentration of metals in effluent, will not in itself reduce metal load of input to sewers and thus of metal load in sewage sludge output.

4. For metalliferous inputs of low organic matter content, the category of 'known' sources used in this study,'in process'recovery of metals by electrolytic means and re-use of metals and thus reduction of waste, rather than transfer of waste, should be encouraged where possible.

5. Reduction of traders' total waste may itself be indirectly encouraged by the effects of Mandatory constraints on metals in sewage sludge output of WPC works, if costs of waste transferred to disposal sites are thereby increased. (See S.9.6).

6. This in itself is in keeping with the third environmental action programme of the EEC.[10]

7. Considerable reduction of trade inputs might be achieved if existing effluent pre-treatment plants were used more efficiently.

10.3.5. General Conclusions

1. In view of the answer to question 1 and to questions 2 a,b,c and d, it is concluded that on the basis of the metal data available to this study there is no need to make 'a false choice between an

expensive and possibly ineffectual control policy, and a negative policy of allowing an unknown proportion of the damage to continue unabated.' See S.1.2.

2. Because the problem of trade effluent control is not the same as in 1937 and because of what has already been achieved, it is concluded:

3. If constraints specified in Annex 1A of the proposal for a directive are adopted, they with complementary constraints specified in the Directive No. 76/464/EEC and its 'daughter' Directive No. 83/513/EEC, although seen by some as an imposition, may now provide the opportunity to make necessary changes towards a more efficient use of sewers and sewage treatment, and a more cost-effective sewage disposal, if once again the sludge is disposed by use on agricultural land.[11,12].

10.4. A question of policy?

'Why have the level of inputs to sewers not been reduced already?'

The first answer to this question must be that they have! Improvement appears to be taking place over a long period of time, sometimes as a result of industrial decline or clearance of old works, in others because of increase in efficiency of material use, or by material substitution, but also by the direct efforts of the RWAs and their predecessors through the consent system.

As shown in this study some increases in effluent metal input to sewers are as a direct result of the river quality programmes;
and/or as a result of categorising rivers;
and/or as a result of central or local political intervention as expedient, particularly at times of recession;
and/or in some locations toleration of relatively high inputs may have

broadened when, as in this study, sewage sludge is disposed to sea, or some other less critical route.

The whole of S.9 has been concerned with seeking answers to the above question, conclusions reached are given in S.9.4.

It is concluded here that particularly when in conjunction with the above circumstances the effects of:

a) the best practical means defences implicit in the consent making and enforcement procedures;

b) the absence of control authorities' statutory right to specify effluent pre-treatment process used, method of use, or use;

c) the weak penalties if any, for contravention;

d) the disincentives for metal reduction, provided by the charging system;

e) the lack of perceived parity with competitors;

f) the resultant trader's perceptions of 'the rules of the game', have in some areas led to increases,or prevented further decrease, of metal inputs to sewers;

g) the failure of successive governments to implement Part II of COPA 74 has been an additional factor.

Implementation now seems to be taking place, even if in rather an oblique way, but this may be due to existing British law "... since there is no legislation empowering water authorities or the Secretary of State to specify water quality objectives or standards, the standards of the Directive exist in Britain only by having been adopted as a matter of administrative practice."[13]

By the device of listing "discharges excepted from exemption granted by the order", 'The control of pollution (Exemption of certain discharges from control) Order 1983' makes it possible for the RWAs to apply the necessary controls to metalliferous trade and

sewage discharges. Control of discharges "...containing free or combined cadmium... lead, copper, nickel, chromium, zinc or arsenic in such quantities as to give rise to pollution within the meaning of article 1.2 of Council Directive No.76/464/EEC on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community."[14]

Similarly the order which came into operation on 31st August 1983 enables RWAs to meet the requirements of Council Directives 78/659/EEC, 75/440/EEC, 79/923/EEC and 76/160/EEC, mentioned in S.1 of this study, and 80/68/EEC 'On the protection of ground water against pollution caused by certain dangerous substances.' It is now important that less polluting effluents should be obtained without transferring extra pollutants to sludge.[15,16.]

Similarly, the setting up of registers of consents available for public inspection is facilitated by The Control of Pollution (Consents for Discharges) (Notices) Regulations 1984 which came into operation on 26th July 1984.[17]

h) Searching for technological solutions to efficient pollution reduction is not a substitute for an efficient politico-economic framework, in which all the rules, explicit and implicit, encourage the required behaviour. Implementation of Part II of COPA 74 and the presences of the EC Directives listed above, together with the proposal for a Directive on the use of Sewage Sludge in Agriculture, where relevant and if agreed, provide the opportunity and much of the incentive required to develop a more positive framework.

j) It would now be timely to include metals in the trade effluent charging formula, as suggested in S.9.4 concl. 2A so that the charging system reinforces, but does not take the place of,

consents in regulating trade effluents discharged to sewers.[18]

k) It is also concluded that the necessary changes to the charging formula could be made in such a way as to not increase, and possibly decrease, charges already made on well controlled trade effluents discharged to sewers. See 9.4 concl. 2C.

l) Similarly, provision of relatively few, conditional, fixed interest low cost loans might now be strategically and economically effective.

10.5.

Marquand defined a pollutant as "... a substance or substances which is in an undesirable condition (in terms of state or location), because it causes more damage, or has potential to cause more damage to a target or targets than it would in some other attainable condition."

On the basis of this definition, it is clear that the best attainable condition is when as little metal as possible becomes waste in the first place, by use of recovery and re-use within the industrial process itself.

The definition also raises questions as to the degree to which metalliferous wastes should be disposed in a relatively small target area rather than receive elaborate dilution in sewage sludge, and then in the 'target' medium, here agricultural land, to which the sludge is disposed.

It is in this decision that the proposed directive has an important role to play. This is particularly so when "A target is damaged when action of the pollutant, ceteris paribus, has caused it to perform the present or future services for which we value it less well than it did before." See S1.4.

It could be argued that much of the disposal carried out in the

past and some carried out today does not question what the final target is, so much so that the word target, without this definition, would be misleading.[19]

There are those who might suggest that Cd and Pb limits specified in annexes 1A, 1B and 1C of the proposal for a directive, are too severe when agricultural land is the general target. But, as shown in table 10.4, on land receiving sewage sludge average annual input was 100.2 and 2172.4 gms.ha.y^{-1} of Cd and Pb of which 92.5 and 87.74 percent respectively are from the sludge. Total annual inputs being approximately for Cd 66.6 and 60.1 percent and for Pb 14.5 and 6.5 percent respectively of Maximum annual application rates allowed by the proposal for a Directive and the DOE/NW Guidelines. See table 6.2.

The contribution of average sewage sludge application is apparent.

But at the time of decision effects on some specific targets will not be understood. For instance, investigations carried out at Rothamstead compared effects of treatment with inorganic fertilizers and high and low applications of farmyard manure and sewage sludge on sandy loam plots between the years 1942-1967. Recently these plots have been assessed for health of soil microbial population.

Results indicate that 16 years after the last sewage sludge application, sludged plots have far higher metal concentrations than other plots treated, Zn, Cu, Ni and Cd soil concentrations being 75, 65, 36 and 71-217 percent of maximum concentrations allowed by the Guidelines. Now 16 years after the last application - 41 years after the first application of sludge to these plots, they appear to have a relatively low biomass, soil fungi count and nitrogen fixing capacity. It must be concluded that as since 1967 they have received the same regime as the other treatment plots, the polluting effect of sludge, previously applied, on specific targets affect the general target and "... has caused it to

perform the present or future services for which we value it less well than it did before." The implications of this recent finding for future sewage sludge disposals are not yet known.[20]

If the opportunity of disposing of sewage sludge by use on agricultural land is to be kept open it is important that constraints specified in any agreed directive are not regarded as fixed limits. For if the necessary confidence of the farming community is to be retained, any required amendment to controls should take place quickly to take account of new scientific findings. For why should farmers accept the risks unless they can be assured of this safeguard?

Such changes if and when necessary might be, for instance, adjustment of maximum soil metal concentrations. Article 12 of the proposal allowing "Where conditions so demand the Member States may take more stringent measures than those provided for in this directive." While Article 15 makes provision for adaption to 'technical progress'. Such provisions are seen here as necessary requirements if agricultural land is to be used for disposal, and are in keeping with the House of Lords Select Committee's opinion that "The criterion of what is a socially unacceptable level of pollution has changed dramatically over the last fifty years, and is likely to continue to change. Therefore a policy for the control of pollution should include a built-in mechanism to improve the quality of the environment beyond the standards acceptable at the present."[21,22].

As this built-in mechanism is already inherent in the proposal for a Directive it is finally concluded that:

In addition to providing mandatory and firmly recommended constraints 'on the use of sewage sludge in agriculture', the proposal also provides opportunities, many of which have been discussed in this study.

It now remains to be seen to what extent the government, the state departments, the RWAs and 'traders' themselves will perceive, foster and/or make use of those opportunities to provide greater parity and a more technologically innovative, efficient and less wasteful tomorrow, and to continue 'the fight against pollution'.

It was suggested in the 1970 White Paper that four factors were necessary for effective pollution control.

- First, scientific and technological knowledge.
- Second, the right framework of economic analysis and economic priorities.
- Thirdly, we need the right legal and administrative framework to translate priorities and decisions into action, and "There is also a fourth, and that is the will to do the job." [23]

It is hoped that in a very small way this research may have contributed to an appraisal of factors 1-3. It is concluded that, in the type of context studied, the proposal for a directive, as amended if and when agreed, may contribute to the fourth, 'the will'.

TABLE 10.1

SIMPLE COMPLIANCE

Required percent reduction of Zn, Cu, Ni, Cd and Pb mean concentrations in unstabilised, simulated digested and lime treated sludges in order to achieve simple compliance with Mandatory sludge concentration limits specified in Annex 1A of a proposal for an EC directive. (a).

Column	1	2	3	4
Symbols	M	O-M/O	rO-M/rO	
Parameter	Mandatory Limits	Required reduction in sludge concentration		
Sludge Type		Unstabilised	Sim.digested	Sim.Lime Treated
Units	$mgkg^{-1}$ DS.	per cent		
Metal				
Zn	3000	0	0	0
Cu	1500	0	0	0
Ni	400	8.82	32.66̇	0
Cd	40	12.59	35.44	0.35
Pb	1000	5.105	29.915	0
Data Source	a.	Table 8.6	Table 8.8	Table 8.8

Notes: a. OJC 264 p.6, 8.10.1982.

TABLE 10.2

95% PROBABILITY OF COMPLIANCE

Required percent reduction of mean metal concentrations in unstabilised, simulated digested and lime treated sewage sludges, when SD:$\bar{X}$ ratio is held constant, to achieve 95% probability of compliance with Mandatory limits specified in Annex 1A of the proposal for an EC directive. a.

Column	1	2	3	4
Symbols	M	O-M/O	rO-M/rO	
Parameter	Mandatory	Required reduction in sludge concentrations		
Sludge Type		Unstabilised	Sim.digested	Sim.Lime Treated
Units	$mgkg^{-1}$ DS.		per cent	
Metal				
Zn	3000	0	23.04	0
Cu	1500	17.78	39.27	6.27
Ni	400	46.07	60.17	38.52
Cd	40	49.2	62.98	42.09
Pb	1000	68.3	76.57 e	51.05
Data Source	a.	Table 8.20	Table 8.22	Table 8.24

Notes:

a. OJC 246 p.6, 8.10.1982.

b. Using the probability formula $\bar{X}$ + 1.645 SD=M limit, distribution of metal concentration cases in sewage sludge being treated as normal.

c. Calculated from data shown in table 8.22.

TABLE 10.3

Percent reduction of annual mean and standard deviation of metal concentrations in unstabilised sludge, when 0, 1 or 2 highest concentration cases of Zn, Cu or Pb are omitted or replaced. (e).

Column	1	2	3	4	5	6
Parameter	Mean	Standard Deviation	Percent reduction of Mean and SD		Percent reduction of Mean and SD	
Cases in $\bar{X}$	30	30	29a	29a	28b	28b
Unit	mgkg DS in SS		%	%	%	%
Metals						
Zn	1568.08		6.71		11.67	
Zn		796.89		29.73		52.485
Cu	753.443		12.75		21.63	
Cu		651.03		40.09		76.595
Cases in $\bar{X}$	9	9	9ac	9ac	9bd	9bd
Pb	1053.8		36.145		55.48	
Pb		1277.21		55.26		85.26

Notes:

a. omitting highest concentration case on which annual mean was based.

b. omitting 2 highest concentration cases on which annual mean was based.

c. adding in the new, 8 case, mean concentration.

d. adding in 2 new, 7 case, mean concentrations.

e. calculated on the basis of results shown in table 8.13.

TABLE 10.4

Average inputs of Cd and Pb to UK agricultural land receiving sewage sludge. e.

Element	Cd		Pb	
Units	gms.ha.$^{-1}$y.$^{-1}$	%	gms.ha.$^{-1}$y.$^{-1}$	%
Input route				
Atmospheric deposition	3 a	3	250 a	11.51
Inorganic fertiliser	4.5b	4.5	16.3c	0.75
Sewage sludge	92.7d	92.5	1906.1d	87.74
Totals	100.2	100.0	2172.4	100.00

Notes:

a. Ex Critchley R.F. An assessment of trace element inputs and pathways to the marine and terrestrial environments. in Int. Cont. on heavy metals in the environment, Heidelberg Sept. 83, table 3.

b. Ex supplementary submission by MAFF to HLSC. H. Lords Session 83-84 1st report p.155 final paragraph.

c. Input mass derived from Critchley table 2 (see note a) and 9.2m.ha. of agric. land (i.e. 1/2 total given by Critchley).

d. Based on 475.08 x 10^3 tonnes of sewage sludge of mean Cd and Pb concentration of 16 and 329 mg.kg^{-1} respectively. DOE/NWC Sewage Sludge Survey 1980 data August 1983.

e. Spread on approximately 82000 ha. land. Critchley R.F. private communication.

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London, HMSO, reprinted 1972. See for instance paras. 87, 89, 100 and p.28.

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12. Mess, H. op.cit. p.324.

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b. 14.8.1978. OJL 222 pp.1-10.
c. 25.7.1975. OJL 194 pp.26-31, and
29.10.1979. OJL 271.
d. 10.11.1979. OJL 281. p.51.
e. 5.2.1976 OJL 31 p.7.
f. 25.7.1975. OJL 194 pp.5-13 particularly p.12.

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