Implications of the Proposed Changes to the Monitoring of Lead in Drinking Water

Final Report to the Department of the Environment

DoE/DWI 4264/2
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IMPLICATIONS OF THE PROPOSED CHANGES TO THE MONITORING OF LEAD IN DRINKING WATER

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EXECUTIVE SUMMARY

BACKGROUND

Lead in drinking water arises almost exclusively through contamination from lead pipes or other lead-containing materials. Lead in drinking water can be reduced by water treatment to reduce pick-up of lead, or practically eliminated by replacement of lead pipework and other lead-containing fittings. The concentration of lead in drinking water is strongly influenced by the standing time of water in lead pipework. This means that the method of sampling (e.g. flushed sample, random daytime sample) has a large effect on the measured lead concentration.

The European Commission has proposed a revision of the Drinking Water Directive; for lead it is proposed to reduce the limit from the present 50 µg/l to 25 µg/l for an interim period of 5 years with the ultimate limit of 10 µg/l to be achieved within 15 years of implementation of the Directive. The present standard applies to a flushed sample (the UK standard is numerically the same but is more stringent as it applies to any sample of the first water that issues from the tap). The proposed standards are to apply to "representative" water samples. Whilst the precise form of the proposed standard and monitoring requirements have yet to be determined, pending the outcome of an EC study, it is possible to make estimates of the likely compliance situation based on various assumed scenarios.

OBJECTIVES

The aims of this project are to estimate the likely extent of non-compliance with the interim and final proposed standards of 25 and 10 µg/l for various monitoring methods and interpretations of the standards; to estimate the extent to which further water treatment or pipe replacement would be needed to secure compliance and to calculate the costs of complying with the various scenarios; and to undertake a critical assessment of the various possible sampling regimes.

APPROACH AND METHODOLOGY

Data used for the study included information returns obtained from the Drinking Water Inspectorate, as well as water company responses to a questionnaire dealing with lead pipe occurrence, costs and the results of "special" lead surveys. For each proposed standard, three sample types were considered (random daytime, 30 minute stagnation and composite proportional) with three rules for pass/fail (maximum, percentile, mean). Comparative data on results for different sample types were used to derive relationships between measured random daytime concentrations and the concentrations that would be expected in the other types of sample. The zones which would pass or fail each scenario were then estimated based on the results of statutory monitoring, classification of lead risk for the zone, and the proportion of lead pipes. A simple model of the effects of treatment was used to determine whether treatment would be appropriate (if not already installed and for zones with a reasonable population of lead pipes) or if replacement would be necessary. This information was used together with unit cost data to estimate the costs of compliance for each scenario.

KEY ASSUMPTIONS

In a study of this type it is necessary to make various assumptions; e.g. in assessing the extent of compliance with various scenarios and calculating the costs of remedial measures. The key points to note are:

- statistically determined relationships between lead concentrations in different types of sample, together with compliance sampling data, were used to identify those zones which would pass or fail various scenarios;

- the suitability of water treatment to achieve compliance with each scenario was assessed using a simplified model of the effects of treatment on lead solubility, and various assumptions concerning the ability of treatment to achieve a 10 μg/l limit were included in the cost calculations;

- it was assumed that all lead pipes would be replaced in a zone where water treatment alone would not achieve compliance; and

- pipe replacement was not considered for zones which would pass a lead limit of 10 μg/l, even if these zones contain lead pipes.

The assumptions made are identified in the appropriate section of the report and should be taken into consideration for a full appreciation of the conclusions.

RESULTS

Comparison of results for different sampling techniques showed that concentrations in random daytime samples are in general slightly higher than in 30 minute stagnation samples; composite proportional samples give similar results to 30 minute stagnation; and lead concentrations in flushed samples are sensitive to the details of the procedure.

The overall costs of compliance (rounded figures) for each of the compliance scenarios for the 25 μg/l interim limit are estimated to be:

Summary of costs - England and Wales total - 25 μg/l limit

	Costs £million			
	Random Daytime		30 minute stagnation or composite proportional	
Compliance criterion	Suppliers	Householders	Suppliers	Householders
Maximum	160 - 1900	400 - 5100	60 - 1900	150 - 5100
Mean	30	70	7	20
Percentile	50	100	12	30

To achieve compliance with the final 10 μg/l limit is estimated to incur the following total costs:

Summary of total costs - England and Wales total - 10 μg/l limit

	Costs £million			
	Random Daytime		30 minute stagnation or composite proportional	
Compliance criterion	Suppliers	Householders	Suppliers	Householders
Maximum	1480 - 1900	4790 - 5120	1490 - 1900	4780 - 5120
Mean	700 - 1610	2050 - 4940	390 - 1610	1290 - 4940
Percentile	770 - 1610	2360 - 4940	660 - 1610	2070 - 4940

CONCLUSIONS

There is evidence that random daytime samples are very likely to identify some properties where the "representative" concentration at the tap is high and therefore would be suitable for routine compliance monitoring to determine whether a zone contained properties which were unlikely to comply with the standard. However, for special surveys designed to establish whether or not compliance with the standard has been achieved, the measured concentrations need to be representative and reproducible and 30 minute stagnation or composite proportional samples would be preferable. Flushed samples cannot be considered to be representative of water consumed and therefore would be unsuitable for monitoring unless a correction factor was applied to the results.

The total cost for England and Wales of complying with a 10 µg/l limit is estimated to be in the range £1.7 billion to £7 billion, depending on the assumed monitoring method and compliance criterion. Of this cost, approximately 75% is associated with replacement of lead pipework that is the responsibility of property owners. The wide range in estimated costs is a reflection of the range of water treatment assumptions considered.

The costs are lower than earlier estimates owing to the use of a different approach to costing, and due to reductions in the actual or estimated numbers of lead pipes.

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1. INTRODUCTION

1.1 Background

The European Commission has presented proposals for a revision of the Drinking Water Directive which would replace the existing "Directive concerning the quality of water intended for human consumption" (80/778/EEC). In the case of lead it is proposed to reduce the limit from the present 50 µg/l to 25 µg/l for an interim period of 5 years with an ultimate limit of 10 µg/l to be achieved within 15 years of implementation of the Directive. These limits are to apply to "representative" water samples although the precise form of the standard (e.g. mean, MAC) and monitoring method have yet to be determined, pending a current EC study (reporting in 1998).

Even though the new Directive has yet to be finalised, it is possible to make assumptions and estimates of the likely compliance situation for the UK based on the various possible interpretations of the standards and monitoring requirements. This study estimates the degree of pipe replacement or additional water treatment that would be required in England and Wales to achieve compliance with the possible scenarios. The effectiveness and costs of various sampling regimes are also considered.

1.2 Objectives

- To establish the likely extent of non-compliance with the interim and final proposed standards of 25 and 10 µg/l in terms of estimated number of water supply zones and estimated numbers of properties for various possible interpretations of the standards and monitoring requirements.

- To establish to what extent further water treatment would achieve compliance with the various possible interpretations.

- To establish how much pipe replacement would be needed to secure compliance with the various possible interpretations.

- To critically assess various possible sampling regimes which could be used to obtain a "representative sample drawn from the tap" in terms of their effectiveness and cost and to make recommendations on an appropriate sampling regime.

- To establish the costs to water suppliers (treatment and pipe replacement) and householders (pipe replacement) to comply with the various possible interpretations of the interim and final standards and monitoring requirements and to compare these qualitatively.

1.3 Guide to the report

Section 2 describes the approach taken and identifies the assumptions made regarding water treatment and pipe replacement.

Section 3 describes the methodology, including data collection, estimation of the extent of non-compliance with various compliance scenarios, and cost estimation.

Section 4 presents the main findings of the study, including estimates of the numbers of zones which would fail the various compliance scenarios, numbers of zones suitable for water treatment and properties requiring pipe replacement to achieve compliance, resultant costs for water undertakers and property owners, and costs of the various monitoring regimes.

Section 5 gives the main conclusions, including summarised cost information and discussion of sampling procedures and approaches to lead surveys.

The report necessarily includes several technical terms particular to lead in drinking water; these are explained in the **Glossary** provided in Appendix A.

2. APPROACH

2.1 General

Contamination of drinking water by lead occurs almost exclusively through contact with pipe material or fittings that contain lead. In the UK contamination of drinking water by lead through polluted raw waters is rare since lead concentrations in raw waters are generally low, and conventional water treatment will remove lead present in raw water down to trace quantities.

Although lead pipework is the main source of lead contamination there are other materials which contain lead; these include solders, brasses and galvanised pipes. Thus it is possible that even where there are no lead pipes lead concentrations may exceed 10 µg/l due to the lead in the solders and fittings. There are laboratory data to show these can leach lead but the true extent to which this is a problem in distribution has not been measured. Lead free solders and brasses are now available for drinking water systems. The lead salts used as stabilisers in some uPVCs can also leach lead, but this is only significant for a short period from newly installed pipes.

Lead is largely present in drinking water in the dissolved form. Particulate lead, where small flakes of lead become detached from lead pipes, is also found in a small minority of areas of the UK. Lead can also appear to be particulate but is in fact dissolved lead that has become adsorbed onto other particulate matter such as hydrated oxides of iron and manganese.

The only method which will eliminate lead from drinking water altogether is replacement of all lead containing materials in contact with the water. Water treatment by pH adjustment and orthophosphate dosing can reduce dissolved lead concentrations but will not eliminate the problem completely.

The aim of this study is to estimate, for a number of compliance scenarios, where further water treatment would be effective and where the only method to achieve compliance would be pipe replacement.

2.2 Sampling scenarios

Since lead enters drinking water by leaching from lead pipe work which is in the near vicinity of the sampling point, i.e. the consumer's tap, the concentration of lead in a sample will be markedly affected by the way in which the sample is taken. Essentially there are five types of sample that are used to measure lead, these are described below.

Random daytime sample: A sampler visits the property at a random time during the working day (the choice of property may also be randomised). A single sample (typically 1 litre) is taken from a drinking water tap without flushing any water from the tap beforehand. The stagnation time of water in the pipes before sampling is unknown and depends on when the water was last used.

First draw sample: A sample is taken (normally by the consumer) from the drinking water tap first thing in the morning before water has been used anywhere in the house and without flushing the tap beforehand. The stagnation time of these samples although much longer than random daytime samples, is also usually unknown.

Fully flushed sample: A sample is taken after prolonged flushing of the tap (at least 5 service pipe volumes) at around 4 litres/min.

Fixed stagnation time sample: After prolonged flushing of the tap, water is allowed to stand in the pipework for a defined period (often 30 minutes, although other times have been used) after which a sample is taken without flushing the pipe beforehand.

Composite proportional sample: A consumer-operated device is fitted to the drinking water tap which splits off a small constant proportion (5%) of every volume of water drawn for drinking purposes. The samples are pooled for analysis.

In the UK random daytime samples are used for compliance monitoring. A 1 litre sample is taken at a random time during the working day from a pre-selected random address.

The proposed Directive requires the sampling method for lead to be "representative of the water drawn by the consumer". The precise form of sampling is the subject of an ongoing EU study. None the less it is possible to consider and evaluate the possible sampling methods. The best representation of water drawn by a consumer is provided by the composite proportional sample. Thirty minute stagnation samples could also be a possibility since studies have shown that the average daytime stagnation for a typical household is thirty minutes. Lead concentrations in random daytime samples are considered representative of water drawn at the time of sampling but they may not be representative of the water drawn at other times because they exhibit a wide variability. Flushed samples are not representative of water consumed since in general householders do not run the tap for any length of time before filling the kettle, for example. Fully flushed samples would represent the lowest lead concentration likely at a property. Conversely, first draw samples would give a worst case lead concentration.

Sampling may be done for one of two overall purposes:

- routine checks of water quality,
- specifically designed surveys, for example to establish the risk of exceeding a particular lead concentration or whether water treatment has reduced lead concentrations to acceptable values.

Clearly sampling for the first of these purposes should be from as wide a range of locations as possible. Routine checks are clearly essential as a quality audit, and the current UK requirement for random selection of all properties is appropriate to ensure its effectiveness. In the case of lead, the routine checks have some limited value in confirming what should already be known, and occasionally in bringing to light unsuspected problems.

The second case, where a survey is to be carried out to ascertain a risk or to check the effectiveness of measures to reduce the lead concentration, is different. Such a survey should be confined to properties believed to be served by lead pipes. Failing this, at the time of sampling the sampler should record whether or not the property is served by lead pipes in order to distinguish between two reasons for a low lead concentration - water with low plumbosolvency or no lead pipes.

This study has made estimates for three possible sample types: random daytime (RDT), 30 minute stagnation (30MS) and composite proportional (COMP).

2.3 Statistical scenarios

Three different numerical concentrations are or will be used as the standard for lead:

- 50 μg/l, the current numerical EC and UK standard
- 25 μg/l, the proposed interim EC standard
- 10 μg/l, the WHO recommended limit and the proposed final EC standard.

The sampling procedure, the concentration limit and the interpretation of the limit determine whether *a particular sample* passes or fails the standard. Failure would presumably require action to reduce the lead concentration at the particular property; it might or might not require action that affected the whole zone.

In the UK different rules may be applied to determine whether there is a risk that a zone fails the current UK standard, whether the risk applies to an insignificant part of a zone and therefore whether action is needed to reduce lead concentrations. As indicated above, pass or failure of a zone cannot be judged confidently from limited routine compliance samples, but is judged on the basis of a specific survey.

Zones classified by water undertakers as 1 and 2a according to Schedule 3 from the Water Undertakers (Information) Direction 1992 were assumed to pass the no change scenario, i.e. 50 μg/l regarded as a maximum. There is assumed to be no risk of failing the current UK standard in a zone if all survey samples contain less than 50 μg/l (Class 1, zone passes). There is a risk of failing the current standard in a zone if any of the survey samples exceed 50 μg/l (Class 2, zone fails). But if the proportion of properties failing is less than 2% of all properties on the basis of sample survey or 5% of the population (not more than 1000 people or 400 properties), the risk may be regarded as relating to an insignificant part of the zone and treatment need not be considered (Class 2a, zone passes). The full range of zone lead risk classifications are presented in Appendix A.

The current UK standard concentration of 50 μg/l, is a maximum. The proposed EC directive would require a tightening of the standard. At 25 or 10 μg/l, any of three rules of interpretation might apply, and are considered nominally maximum, mean and percentile. (For the purposes of this study an 80 percentile is used.) However a maximum rule at 10 µg/l would mean that zones without leaded properties would be at risk of failure caused by solders and fittings.

Several different scenarios were identified (Table 2.1).

Table 2.1 Scenarios for the lead standard and its application

Parameter	Options
Concentration	25 or 10 µg/l
Sampling procedure	30 minute stagnation / composite proportional Random daytime Flushed
Rule for zone pass/failure	Maximum 80 Percentile Mean

The data used to estimate the numbers of zones that would pass or fail, given each of these scenarios, were these:

- Summarised results of the 1995 statutory sampling, that included the numbers of measured concentrations by compliance zone in concentration bands, and the water company classification of lead risk by zone. The sampling procedure used in all cases was random daytime sampling.

- Summarised results for 1994 and 1995, that included the maximum measured lead concentrations by zone for each year.

- The proportion of properties with lead pipes, by zone or in some cases by company area or division.

The definitions of pass and failure that were used are these:

- Pass
  Either the zone contains less than both 5% of its population or less than 1000 population (400 properties) supplied through lead pipes, or if it contains more, the results of applying the scenario to a well designed survey would be a pass.

- Failure
  The zone contains at least 5% of its population or more than 1000 population (400 properties) supplied through lead pipes, and the results of applying the scenario to a well designed survey would be a failure.

Application of these definitions was limited by the nature of the data, and it was necessary to make some assumptions. Details of the method used to estimate the numbers of zones that would pass or fail under each scenario are given below.

2.4 Pipe replacement assumptions

For the purposes of cost estimation it is assumed that all lead pipes would be replaced in a zone where water treatment alone would not achieve compliance.

For zones passing a lead limit of 10 µg/l, no allowance is made for pipe replacement even where these zones contain lead pipes.

2.5 Rules for determining when treatment would be appropriate

For the compliance scenarios considered the following rules were derived to determine which zones would comply if further water treatment were installed.

The concentration of lead in water from lead pipes is governed by the equilibrium solubility of lead in water in contact with lead pipe deposits, and the mass transfer of lead from the deposit surface to the bulk water which in turn depends on the pipe geometry and the stagnation time of water in the pipe. Water treatment to control lead concentrations relies on adjustment of pH and alkalinity to reduce the solubility of existing lead carbonate deposits, and/or dosing of orthophosphate to form and maintain a lead orthophosphate deposit of low solubility. It is assumed that orthophosphate treatment would be necessary to achieve a sufficiently low solubility to meet a 25 µg/l standard. A 10 µg/l limit (as a mean) might be also achievable in some zones, similarly some zones might fail a 25 µg/l limit (as a maximum) after treatment was installed.

In this study a range of cost estimations were made. The most demanding assumes that water treatment will reduce solubility sufficiently to comply with a lead standard of 25 µg/l as a mean or 80 percentile but not with a standard of 25 µg/l as a maximum or 10 µg/l as a maximum, mean or 80 percentile. The least stringent assumes that some zones will pass a lead standard of 25 µg/l as a maximum and 10 µg/l expressed as a mean or 80 percentile solely by orthophosphate dosing for plumbosolvency control and all zones will pass 25 µg/l as a mean or 80 percentile.

Note: high lead concentrations due to "particulate" or "colloidal" lead tend to be rare and to be found in localised areas, often in conjunction with "dirty water" problems. The remedial measures are generally case-specific so it is not possible to derive reliable predictions of occurrence, or cost estimates for dealing with, particulate lead.

The equilibrium solubility (E) of the lead orthophosphate deposit can be calculated from water quality data (including pH, alkalinity, orthophosphate concentration and calcium concentration). The dependence of solubility on these water quality parameters is complex; however, for the purposes of determining whether treatment would be appropriate, the solubility is approximated by the linear function

$$E = 0.22 * Alk$$

where E is the equilibrium solubility (µg/l Pb)

Alk is the alkalinity (mg/l HCO_3)

This equation underestimates the solubility of lead in low alkalinity waters; in order to compensate for this it is assumed that the minimum equilibrium solubility achievable is 20 µg/l.

Theoretical and empirical models exist to predict the mass transfer behaviour of lead. Experience with the use of these models and practical measurements together with the comparative study of current data have resulted in the derivation of solubility values applicable to each scenario. These values were used to predict where water treatment could achieve a 25 µg/l limit for different samples types and compliance criteria.

Data were studied from three companies, eight zones in total, where water treatment to control plumbosolvency has been installed for a number of years. The data show that the numbers of zones passing/failing standards of 10 µg/l as a mean and 25 µg/l as a 95 percentile (near maximum) are similar. See Figure 2.1. In addition to assisting in the derivation of the solubility predictions for the 25 µg/l lead standard as described above, these data illustrate that orthophosphate dosing can also achieve compliance with the 10 µg/l lead standard in some zones. See Table 2.2.

For each zone, an assessment was made of whether treatment would be a feasible (additional) option to meet each scenario on the following basis:

- Significant lead pipe population: at least 5% of population or at least 1000 population (400 properties), whichever is the smaller, supplied through lead pipe have to be present for treatment to be practicable (compared to pipe replacement).

- Treatment is not already installed: it is assumed that any optimisation of existing treatment would incur negligible cost.

- Calculated equilibrium solubility satisfies the criteria discussed above and as summarised in Table 2.3.

Table 2.2 Summary of data from zones that have received water treatment for a number of years

	Mean 10 µg/l			
95 percentile 25 µg/l	Pass	Marginal (1)	Fail	Total
Pass	1	1	0	2
Marginal (1)	1	0	0	1
Fail	0	2	3	5
Total	2	3	3	8

(1) Marginal is defined as within 10% of the limit value, i.e. between 9 and 11 µg/l for a limit of 10 µg/l, or 22.5 and 27.5 µg/l for a limit of 25 µg/l.

Table 2.3 Assessment criteria for water treatment

	Compliance criterion- solubility values (E) µg/l		
Sample Type	Maximum	Mean	80 percentile
25 µg/l, random daytime	<20 - 25	50	50
25 µg/l, 30 minute stagnation or composite proportional	<20 - 25	63	63
10 µg/l, random daytime or 30 minute stagnation or composite proportional	< 10 (1)	< 20 - 25 (2)	< 20 - 25 (2)

(1) i.e. treatment will not achieve compliance with 10 µg/l as a maximum
(2) i.e. similar to 25 µg/l maximum

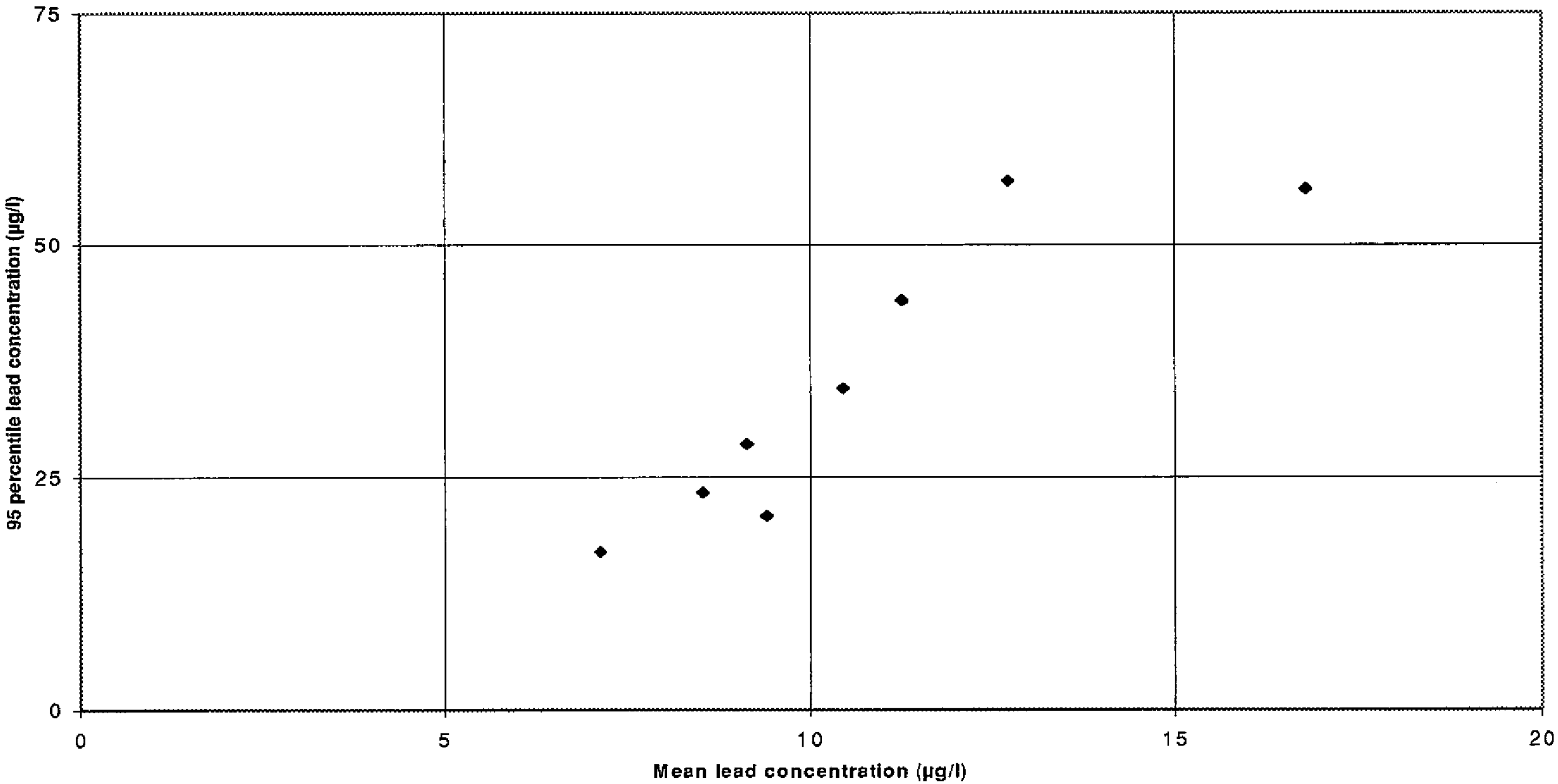

Figure 2.1 95 percentile vs. mean lead concentrations - phosphate dosed water

3. METHODOLOGY

3.1 Data collection

Data were collected from four sources:

- Information Direction returns on lead for 1995, and 1994 and 1995 water quality summary compliance data were provided by DWI.
- The Water Companies in England and Wales were requested to provide data on lead pipe occurrence, special lead sampling surveys and lead rehabilitation costs. This was achieved by a questionnaire, a copy of which is reproduced in Appendix B. Companies were also supplied with data previously supplied to WRc for update.
- Data held by WRc from previous lead studies was used where appropriate and with the originators permission.
- Data from lead surveys undertaken in other parts of the UK and Europe were also gathered.

3.2 Comparison and critical assessment of the possible sampling procedures

The comparison has two main aspects - the ability of the procedures to obtain "representative samples drawn from the tap", and their cost. The first of these is addressed in the next few sections. The cost aspects are recorded in Sections 3.10 and 3.11.

For the first aspect, comparative data on the different procedures were obtained and analysed. The results were used to test a general theoretical understanding of the procedures.

The data comprised:

- Comparative data on random daytime, stagnation and flushed samples, provided by six UK Water Companies;
- Published French data on composite proportional, flushed and stagnation samples;
- Data on lead concentrations at stagnation times between zero and 360 minutes at properties located in several UK water supply regions,

obtained in the 1970s and reported in WRc report TR 243 (Bailey *et al.* 1986);

- Concentrations of lead in repeated 30 minute stagnation samples, selected from a large quantity of data obtained in 1981-82 and held on archive at WRc.

The first two sets of data were used to derive relationships between the concentrations of lead in samples obtained at the same location and time, using different procedures. These relationships have been represented by the median and upper/lower percentile values of the concentration ratios (i.e. concentration using procedure A / concentration using procedure B).

The third set of data was used to confirm the understanding of the increase of lead concentration with stagnation time, represented by a theoretical model, and to indicate the repeatability in practice of concentrations in samples taken after different stagnation times. The fourth set of data was used to confirm the repeatability of 30 minute stagnation samples.

3.3 Estimation of the extent of non-compliance with possible interim and final standards

Summarised statutory sampling results by zone for 1995 were used as the basic data set. The data were modified to represent what might have been measured using different procedures, using ratios obtained from the comparison between sampling procedures. Different concentration limits (25 or 10 µg/l) and pass/fail rules (maximum, mean or 80 percentile) were applied to the modified data sets to predict which zones would pass or fail.

Companies were asked to give their views on the zones that would pass or fail under different scenarios. These were compared with the WRc predictions (see Section 3.9).

3.4 Testing of stagnation curve model using real data

A model which generated stagnation curves given saturation values, pipe diameter and temperature had been constructed previously (Van den Hoven 1987). In order to test this, real data from a previous report, TR 243, were used.

In TR 243, time series of data are given. These are measurements of lead concentrations at a tap after stagnation times varying from zero to 360 minutes. In order to compare the model with the real data, it was necessary to find a figure for the saturation concentration for each site. This was done by taking the mean of the four 360 minute values provided, then using a multiplier to derive the saturation value. The multiplier was derived from the model, and depends on the diameter of the pipe. These numbers are shown in Table 3.1.

The influence of temperature is very small, and a temperature of 12 °C was assumed.

The theoretical stagnation curves are similar to the measured values, except at stagnation times of 20 minutes or less, when the measured values are higher than predicted (Figure 3.1).

A second set of data was taken from a report by Anjou Recherche (Randon 1996). This was a report on extensive laboratory work on dissolution of lead in drinking water. In this case, values up to 14 hours were given, and the mean of the values from 10 to 14 hours was taken as the saturation value. For the Anjou Recherche data there is good overall agreement between measured and predicted, but an apparent tendency for the model to over-predict for stagnation times up to 2 hours (Figure 3.2).

Table 3.1 Multipliers used to derive saturation values

Pipe diameter (mm)	Multiplier
19	1.25
13	1.05

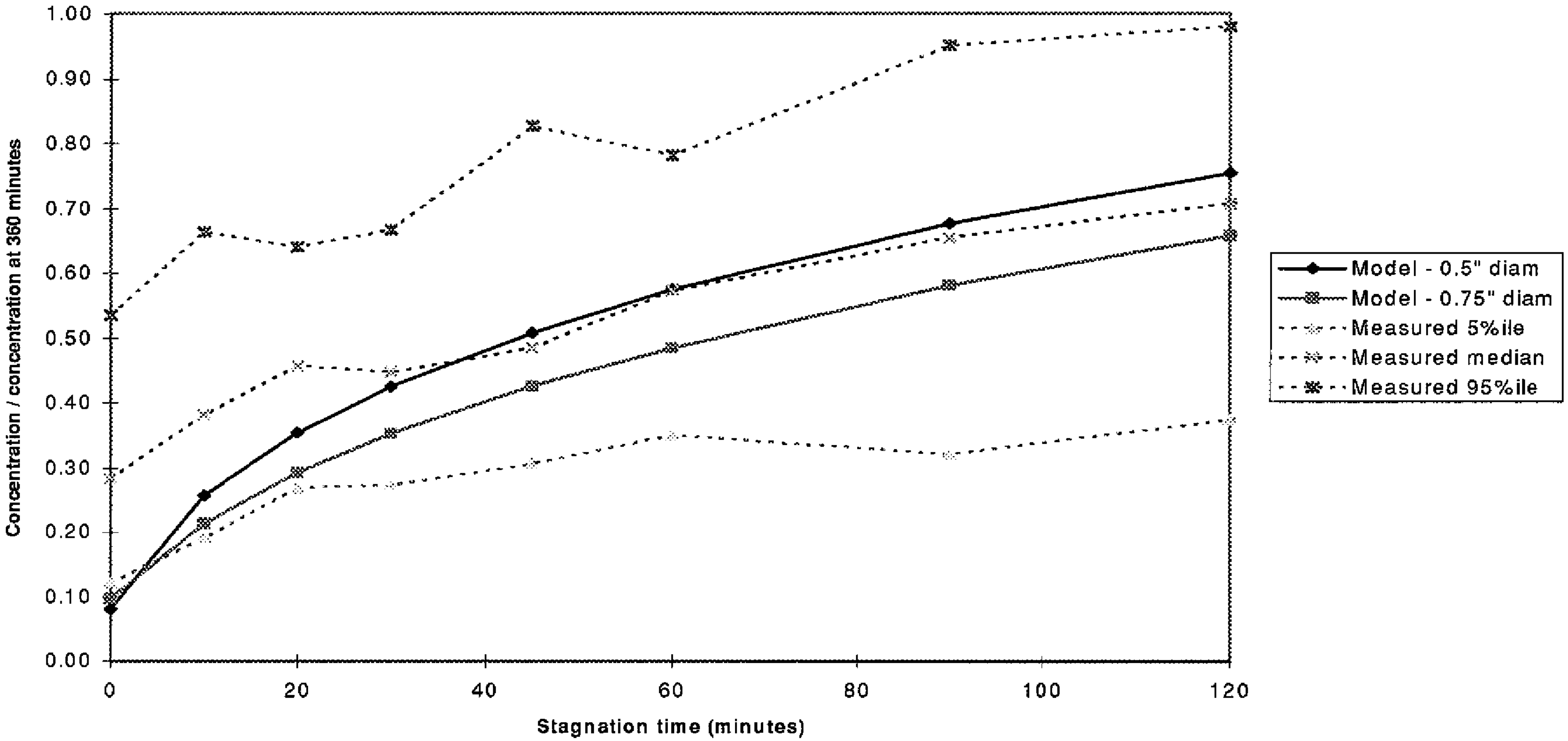

Figure 3.1 **Modelled vs. measured stagnation curves - TR243 data**

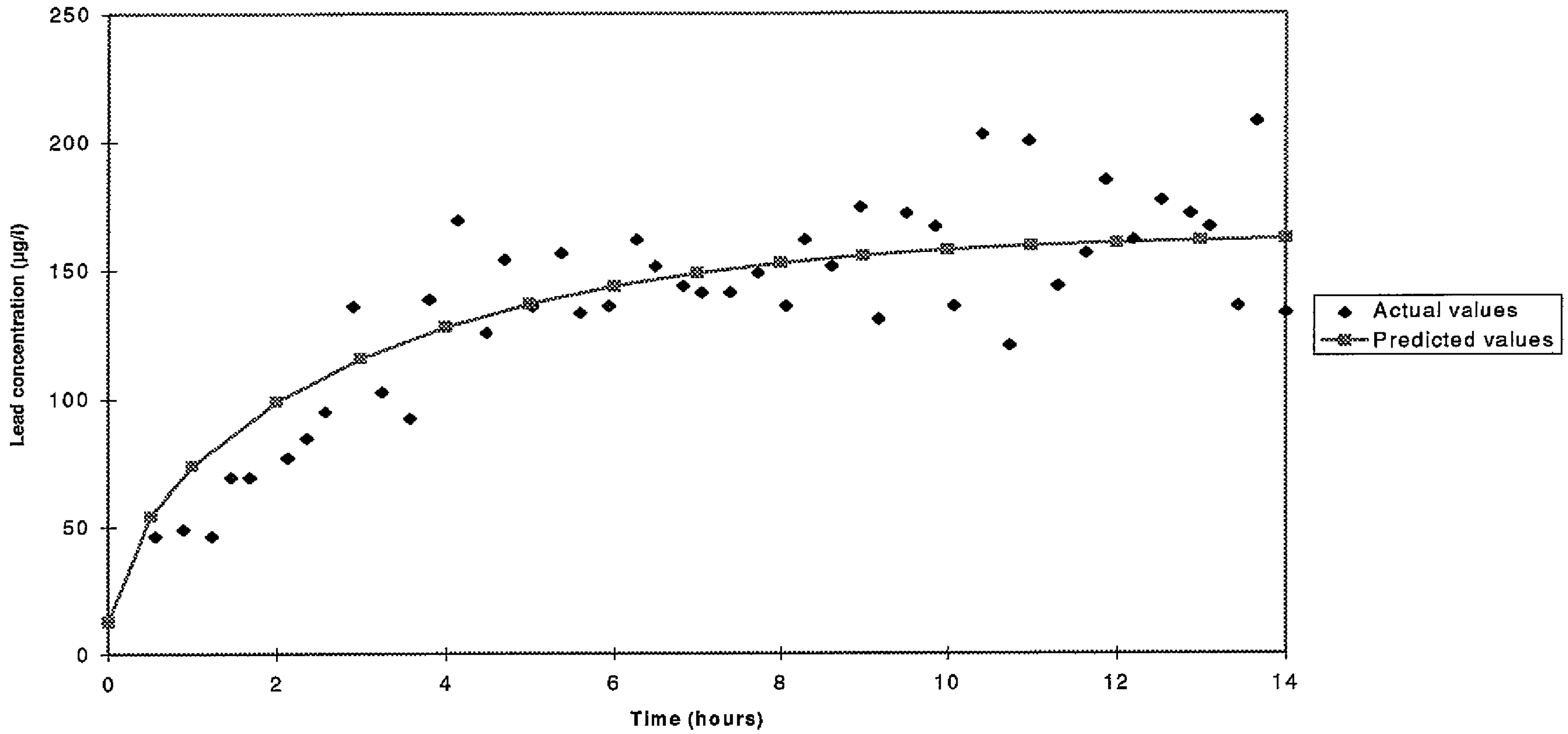

Figure 3.2 Modelled vs. measured stagnation curves - Anjou Recherche data

3.5 Comparing different sampling methods

One objective of the project was to compare the results obtained using different sampling methods, to see if there was a direct relationship between them.

Several water companies provided data which allowed comparisons to be made. These were data from special surveys, where properties had been sampled using more than one method. Most comparisons were between flushed and stagnation samples, but some data for random daytime sampling were also provided. Details are given in Appendix C.

In order to compare two sampling techniques, the values obtained with each were plotted against one another as a scatter graph. One of the objectives of comparing the different sampling techniques was to find out how the technique used affects whether or not a zone is considered as having a lead risk. In other words, do some techniques tend to give higher lead concentrations than others, or show different degrees of variability?

None of the companies was able to provide data on composite proportional sampling.

Company A provided enough data from which to derive ratios linking results obtained by random daytime, 30 minute stagnation and flushed samples. However there must be some doubt over the effectiveness of company A's flushing procedure, as 22 of the 62 flushed sample concentrations were higher than the corresponding stagnation concentrations.

In addition, some work on comparison of sampling techniques has been carried out in France by Anjou Recherche (Randon 1996). According to this research, the ratio of 30 minute stagnation to composite proportional sampling is 0.93:1, and the ratio of fully flushed to 30 minute stagnation sampling is 0.42:1. This is similar to the figure of 0.38 for company B data, but much less than the ratios of 0.83:1 and 0.67:1 for companies A and C. The reason for the differences is not clear. One possibility is that the Anjou Recherche research, by using fully flushed samples, detected lower concentrations than the 2 minute flushes used by company A.

Companies A and F provided data on random daytime and stagnated samples, which were reasonably consistent. Median ratios between the 30 minute stagnation concentration and the corresponding random daytime concentration were 0.89:1 (company A), 0.79:1 (company F source 1) and 0.85:1 (company F source 2).

3.6 Repeatability of sampling

The data from TR 243 was used to study the repeatability of sampling. For each site, the ratio of each value to the 360 minute value was calculated. Because the stagnation curve is the same shape regardless of its height, the ratio of the value of two points in time along the curve should be the same as that for the same two times on any other curve. The mean and standard deviations of these ratios was found. The standard deviation is a measure of the repeatability of the sampling. The results of this analysis are shown in Table 3.2.

Table 3.2 Repeatability of sampling

	Ratio 0/360	Ratio 10/360	Ratio 20/360	Ratio 30/360	Ratio 45/360	Ratio 60/360	Ratio 90/360	Ratio 120/360
Mean	0.30	0.42	0.46	0.47	0.54	0.57	0.63	0.70
SD	0.12	0.23	0.16	0.15	0.17	0.15	0.17	0.20
SD/Mean	0.41	0.54	0.34	0.32	0.32	0.27	0.27	0.28

It can be seen that the SD/mean ratio decreases as the stagnation time increases. From 20 minutes upwards, the rate of decrease is small.

The repeated 30 minute stagnation samples consisted of several sets of three. At a number of locations, samples were taken over several months to a year, clustered so that three samples were taken within a four day period, followed by a gap of a few weeks. The coefficients of variation within each set of three measure the repeatability. At four different locations, median values for the coefficient of variation were found to be 0.23, 0.13, 0.17 and 0.29. The variation *between* (as opposed to *within*) sets of three at the same site was greater, due to variations in water quality and temperature. An example of the data is shown in Figure 3.3.

These results indicate that if a repeat 30 minute stagnation sample is taken within a few days, there is a good probability (2 out of 3 times) that the two concentrations will be within 25%. There is a very high probability (19 out of 20 times) that they will be within 50%.

There is no direct evidence on the repeatability of random daytime samples. However, because of the unknown stagnation time it is likely that bigger differences between repeat samples would be common.

On the other hand, the data from companies A and F suggest that random daytime sampling may be a satisfactory procedure for detecting a problem, if not for quantifying it. Of the total of 494 pairs of results, in only one case was the random daytime concentration less than 10 µg/l with the 30 minute stagnation concentration more than 25 µg/l. (There were 14 cases in which the reverse applied, i.e. the 30 minute stagnation concentration was less than 10 µg/l, while the random daytime concentration was more than 25 µg/l).

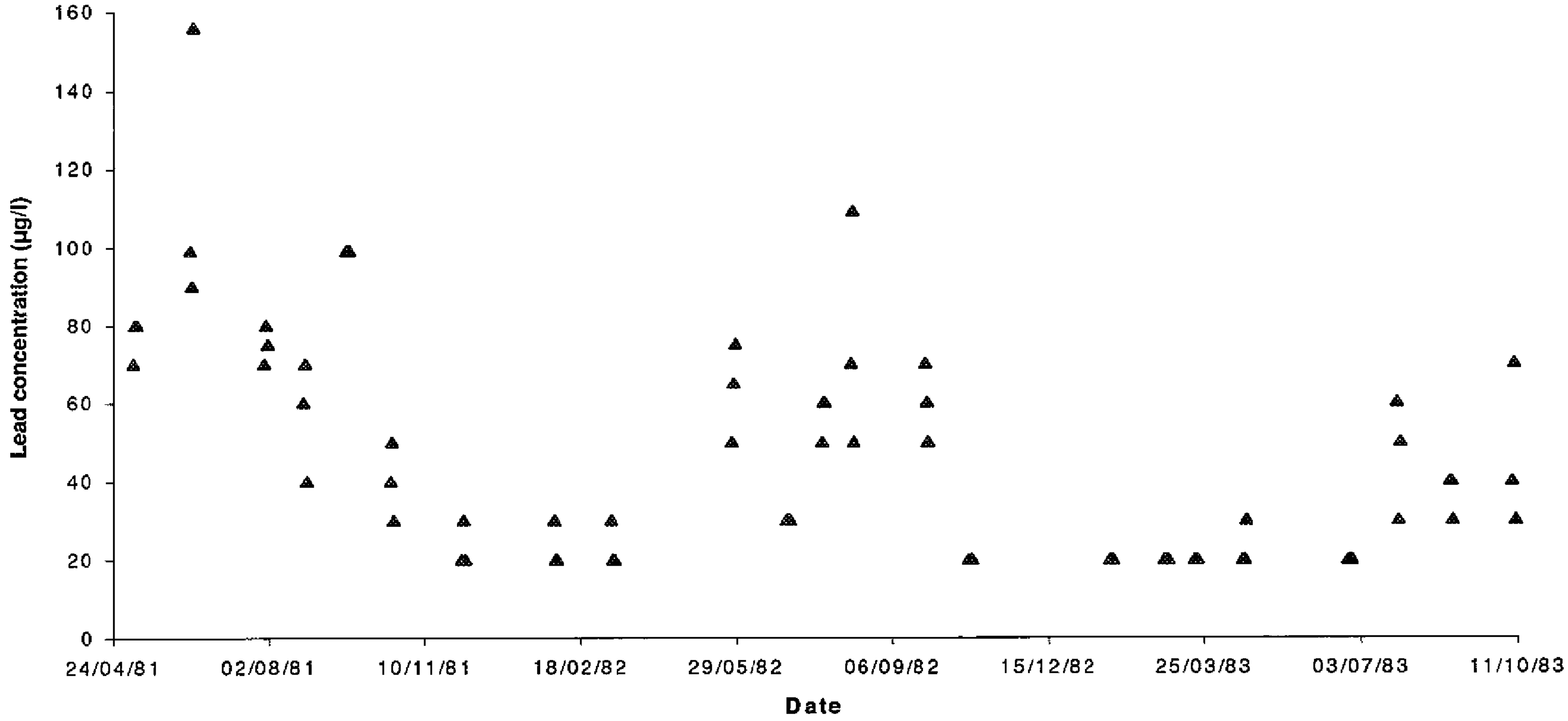

Figure 3.3 30 minute stagnation repeat sampling example

3.7 Compliance with the lead standard in 1995

The DWI lead returns were analysed as follows:

- A matrix was set up with lead concentration horizontally and lead risk vertically.
- The returns were examined, and each zone was categorised according to the maximum concentration measured for that zone, and its lead risk.
- This built up a matrix which showed, for each concentration band and lead risk, how many zones fell into that category.
- The matrixes for all the different companies were aggregated into one, which is shown below as Table 3.3. The definitions of zone lead risk classes are given in Appendix A.

Table 3.3 Summary of 1995 lead returns for England and Wales

	No. of zones with 1995 results in maximum concentration (µg/l)							
Lead risk	0-10	>10 - 20	>20 - 30	>30 - 40	>40 - 50	>50 - 100	>100	Total
1	881	137	57	32	23	16	8	1154
2a	77	29	14	11	11	50	29	221
2b	8	5	1	2	1	10	3	30
2c	18	9	4	2	1	4	2	40
2d	64	51	47	43	33	116	109	463
2e	27	14	10	6	5	17	11	90
2f	15	16	22	15	14	55	21	158
2g	56	20	7	8	5	15	15	126
2h	13	2	2	3	2	0	1	23
3	0	0	0	0	0	0	0	0
Total	1159	283	164	122	95	283	199	2305

3.8 Estimating likely non-compliance by zone for future standards

Step 1 Initial grouping of zones

The 1995 results and the company lead risk classification were used to divide the zones into three groups:

Group I) zones in class 1 with the maximum measured lead concentration ≤10 µg/l.

For these zones there is no evidence of any problem. However data from a specially designed survey or from other years might contain measured concentrations over 10 µg/l, and a proportion of the zones would therefore be expected to fail under some scenarios. This was allowed for as described in step 7.

Group II) zones in classes 2b to 2h.

Surveys in or around 1989 indicated that action was judged to be required in these zones on the basis of the 50 µg/l standard. Since the new lead standard is intended to be tighter, it is almost certain that action would have been required under any scenario. Treatment to reduce lead concentrations has now been installed in many zones, and hence this has not been included in the cost calculations.

Group III) zones in class 1 with a maximum concentration over 10 µg/l, and zones in class 2a (problem restricted to an insignificant part of the zone).

Zones in this group might pass or fail, depending on the scenario, and steps 2 to 6 were applied to this group only.

Step 2 Allowing for samples from properties without lead pipes

For each zone, a proportion of the measured lead concentrations were removed from the 1995 results, corresponding to the proportion of properties stated by the water company not to have lead pipes. In all zones the lowest measured concentrations were removed first. In most but not all cases this meant removing measured concentrations ≤10 µg/l. This does not influence the maximum concentration, but has the effect of raising the percentile and mean values.

Step 3 Adjusting the concentrations for different sampling procedures

Relationships between the concentrations measured using different sampling procedures were derived from data provided (see Section 3.5), which was analysed on a zone by zone basis. The median values of "correction factors" are shown in Table 3.4. Wide variation between zones was found.

Table 3.4 Correction factors to convert random daytime sample results to 30 minute stagnation / composite proportional sampling

	Random daytime	
	Mean	Maximum
30 minute stagnation / composite proportional	0.89	0.74

A ratio was not derived for the 80 percentile values. It would lie between the values for the mean and maximum.

Step 4 Applying the pass/fail rules

For each zone, the maximum, mean and 80 percentile values were estimated. Because the data were provided in ranges, actual measured concentrations were estimated as the mid point of the range.

These values were then compared to the appropriate limit - 10 or 25 µg/l.

Step 5 No change scenario

Under this scenario, 50 µg/l and a maximum rule, the original water company classifications were applied and all zones in classes 1 and 2a were assumed to pass.

Step 6 10 µg/l maximum scenario

All zones were regarded as at risk of failure. However the data are not sufficient to indicate the proportion of zones that would fail.

Step 7 Zones in class 1 with the maximum measured lead concentration ≤10 µg/l

The maximum concentrations by zone in 1994 and 1995 were compared, in order to gain some understanding of the proportion of group I zones that might have been found to fail by a comprehensive survey. The findings are summarised in Table 3.5.

Table 3.5 Comparison of 1994 and 1995 maximum concentrations µg/l by zone

Number of zones	1994 maximum ≤10	1994 maximum >10	Total
1995 maximum ≤10	889	325	1214
1995 maximum >10	249	876	1125
Total	1138	1201	2339

The degree of overlap between the 1994 and 1995 results indicates that, if other years' results were also included, the "core" of zones for which the maximum concentrations were consistently below 10 µg/l might number nearly 800. These can reasonably be assumed to be contained within the class 1 zones, for nearly 900 of which the 1995 maximum concentration was ≤10 µg/l. Therefore there are probably nearly 100 zones in group I that might be judged to fail under the more demanding scenarios.

A summary of the compliance predictions is given in Table 3.6.

Flushed samples

There is evidence that, as would be expected, the concentration of lead in a flushed sample is sensitive to the flushing procedure. In a fully flushed sample it may be around 40% of the concentration in a 30 minute stagnation sample. However there is evidence that this percentage may be as high as 80% if flushing is not complete.

The proposed new EC Directive refers to a "representative sample drawn from the tap". It seems clear that a fully flushed sample cannot be taken as representative. Therefore if flushing were to be adopted as a standard procedure, a factor (of 2.5?) would have to be applied to estimate a representative concentration and bring the value into line with composite proportional or stagnation sampling.

If this adjustment to make flushed samples "representative" were not done then a rule of thumb would be:

- Flushed sampling without correction and a limit of 10 (or 25) µg/l would be equivalent to composite proportional / 30 minute stagnation sampling and a limit of 25 (or 50) µg/l.

Table 3.6 Numbers of zones predicted to pass or fail under different scenarios

Scenario			Group I zones		Group II zones		Group III zones		All zones +	
Limit (µg/l)	Rule	Sampling procedure	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail
50	Maximum	RDT	881	0	0	930	530	0	1411	930
25	Maximum	RDT	881	0	0	930	367	163	1248	1093
25	Maximum	COMP/ 30MS	881	0	0	930	367	163	1248	1093
25	Maximum	Flush	881	0	0	930	see discussion below			
25	Percentile	RDT	881	0	0	930	427	103	1308	1033
25	Mean	RDT	881	0	0	930	480	50	1361	980
25	Mean	COMP/ 30MS	881	0	0	930	485	45	1366	975
25	Mean	Flush	881	0	0	930	see discussion below			
10	Maximum	RDT	881 -?	?	0	930	125	405	1006 -?	1335 +?
10	Percentile	RDT	881	0	0	930	196	334	1077	1264
10	Mean	COMP/ 30MS	881	0	0	930	308	222	1189	1152

+ the sum of all zones here differs slightly from the total number of zones in Table 3.5, this is because of differing zone numbers from 1994 to 1995.
? see discussion in Section 3.9.

3.9 Data audit

Part of the questionnaire which was sent out as part of this project asked the utilities to assess whether or not each zone would comply with several possible new scenarios for lead concentration. Of the ten water and sewerage companies, six returned their assessments and four did not.

WRc also estimated which zones would comply under various scenarios (see Section 3.3). An audit was carried out to find out how the WRc estimates compared with the utilities' estimates. To do this, six utilities were chosen: four of the larger companies and two of the smaller companies. Four scenarios were chosen:

- 25 µg/l, maximum, 30 minute stagnation samples
- 25 µg/l, maximum, random daytime samples
- 10 µg/l, mean, 30 minute stagnation samples
- 10 µg/l, maximum, random daytime samples

For these scenarios, a check for consistency was made.

- 25 µg/l limit is less demanding than 10 µg/l
- A maximum rule is more demanding than an mean rule.
- Random daytime sampling is (marginally) more demanding than composite proportional or 30 minute stagnation sampling.

Five out of the six companies followed these rules in their assessments. Several companies stated that they had no experience of composite proportional sampling; some made estimates only for random daytime sampling.

The basis of their assessments is summarised in Table 3.7.

Table 3.7 Basis of companies' assessments of zones passing or failing

Company	Basis
B	Not stated
C	Estimates based on 1990-96 compliance data and special survey data. As no information was available on composite sampling, this was taken to be the most pessimistic of the scenarios.
G	All estimates based on 1995 compliance data.
H	Estimates for RDT are based on 1995 compliance data, except where treatment has been added in 1996. Estimates for stagnation are based on test rig work.
I	Probably based on 1996 compliance data.
J	Estimates based on sampling carried out between January 1995 and September 1996.

WRc's estimates were compared with the companies' estimates. For the smaller companies, all zones were compared whereas for the larger companies, a selection of the zones were sampled. The results are shown in detail in Appendix D.

These conclusions were drawn from the audit.

- Companies generally applied reasonable rules to their data when making assessments.
- For the first 3 scenarios, WRc's estimates agree well with those of the companies, the main difference being that companies allocated a significant number to the "marginal" category, while WRc simply applied a pass/fail rule.
- For the fourth scenario, WRc's estimates were more optimistic than those of three companies (B, C and I). In all, WRc estimated that 71 zones out of 177 audited would pass, while the 6 companies together estimated that 29 would pass, 15 would be at risk of failure and 133 would definitely fail.

The differences are probably due to the companies' access to the full data, while WRc was able to use only 1995 compliance data.

The results suggest that for all but the fourth scenario - 10 µg/l limit on the maximum, random daytime sampling - the numbers of zones estimated by WRc to pass or fail do not need to be modified. However for this scenario, a large proportion of the zones that pass the WRc rules, i.e. in risk class 1 and for which the maximum concentration measured in the 1995 compliance data is less than 10 µg/l, are probably at risk of failing under this scenario.

3.10 Cost estimation

In this study a range of cost estimations are presented. The most demanding assumes that water treatment will reduce solubility sufficiently to comply with a lead standard of 25 µg/l as a mean or 80 percentile but not with a standard of 25 µg/l as a maximum or 10 µg/l as a maximum, mean or 80 percentile. The least stringent assumes that some zones will pass a lead standard of 25 µg/l as a maximum and 10 µg/l expressed as a mean or 80 percentile solely by orthophosphate dosing for plumbosolvency control and all zones will pass 25 µg/l as a mean or 80 percentile.

The following assumptions were also made when estimating the cost of compliance with each scenario.

At a lead standard of 25 µg/l:

- For class 2d to 2f zones there would be no additional costs since treatment has already been installed in these zones and hence zones are assumed to pass.
- For class 2b and 2c zones treatment is not an option so there will be a replacement cost where lead concentrations are above 25 µg/l.
- For class 1 and 2a zones (that exceed 25 µg/l) for some zones additional water treatment will achieve compliance for which there will be a cost. For

the remaining class 1 and 2a zones (that exceed 25 µg/l) there will be replacement costs.

At a lead standard of 10 µg/l:

- For class 1 zones where lead concentrations are less than 10 µg/l there will be no additional costs.

- For zones where replacement was performed to meet 25 µg/l there will be no extra costs.

- For some zones water treatment will achieve compliance at 10 µg/l as a mean or 80 percentile. For class 1 and 2a zones an operational treatment cost has been included. For 2d to 2f treatment costs are not included.

- For all other zones there will be replacement costs.

General:

- All estimates are made assuming zero discount rates.

- Treatment costs are estimated assuming the capital cost is incurred in year 1 plus operational costs for year 2 onwards. Costs are estimated on a per capita basis.

- When calculating the cost of replacement it is assumed that the current replacement rate continues regardless of other replacement initiatives. Therefore, for replacements to meet 25 µg/l, 5 years of current replacement rates are deducted and for replacements to meet 10 µg/l, 15 years of current replacement rates are deducted from current pipe occurrences.

- The number of properties with lead communication pipes, supply pipes and plumbing requiring replacement will be similar.

- Unit cost data for pipe replacement and water treatment were supplied by the water companies and supplemented by data previously collected by WRc. Data are summarised in Appendix E.

3.11 Comparison of the cost of sampling

As part of the questionnaire the water companies were asked to estimate the cost associated with their current compliance sampling for lead together with the additional costs that would be incurred if sampling were targeted solely at lead piped properties and if 30 minute stagnation or composite proportional sampling were used.

4. RESULTS

A summary of the number of zones that are estimated to fail the various compliance scenarios is given in Table 4.1. Table 4.2 shows the number of zones for which water treatment is predicted to be necessary to achieve compliance at 25 µg/l. Table 4.3 shows the numbers of properties for which water treatment would not be effective and pipe replacement is required to meet 25 µg/l. (All property counts are rounded to the nearest 1000.)

Tables 4.4 to 4.7 show the estimated costs (£million) to meet compliance in these zones for the various scenarios. (All costs are rounded.)

A summary of the additional costs of sampling estimated for each sample type is given at the end of this section.

In all tables in this section the ranges presented represent the possible variation due to the effect of water treatment. The most demanding assumes that water treatment will reduce solubility sufficiently to comply with a lead standard of 25 µg/l as a mean or 80 percentile but not with a standard of 25 µg/l as a maximum or 10 µg/l as a maximum, mean or 80 percentile. The least stringent assumes that some zones will pass a lead standard of 25 µg/l as a maximum and 10 µg/l expressed as a mean or 80 percentile solely by orthophosphate dosing for plumbosolvency control and all zones will pass 25 µg/l as a mean or 80 percentile.

Table 4.1 Summary of number of zones and properties with lead pipes estimated to fail the various compliance scenarios

Limit value		Compliance scenarios					
		Random daytime			30 minute stagnation		
		Maximum	Zone mean	80 percentile	Maximum	Zone mean	80 percentile
25μg/l	zones	231 - 1445	68	85	127 - 1445	35	53
	properties (millions)	0.86 - 9.8	0.18	0.24	0.46 - 9.8	0.07	0.15
10μg/l	zones	1320 - 1445	613 - 1445	699 - 1445	1320 - 1445	457 - 1445	646 - 1445
	properties (millions)	5.5 - 9.8	2.3 - 9.8	2.6 - 9.8	5.5 - 9.8	1.5 - 9.8	2.3 - 9.8

Some figures are presented as ranges to represent the possible variation in effect of water treatment to control plumbosolvency

Table 4.2 Number of zones predicted to be suitable for additional water treatment to achieve compliance at 25 μg/l

Compliance scenarios					
Random daytime			30 minute stagnation		
Maximum	Zone mean	80 percentile	Maximum	Zone mean	80 percentile
0 - 114	30	36	0 - 77	19	31

Some figures are presented as ranges to represent the possible variation in effect of water treatment to control plumbosolvency

Table 4.3 Number of properties (millions) requiring lead pipe replacement to achieve compliance at 25 µg/l

Compliance scenarios					
	Random daytime			30 minute stagnation	
Maximum	Zone mean	80 percentile	Maximum	Zone mean	80 percentile
0.42 - 9.8	0.07	0.11	0.13 - 9.8	0.02	0.03

Some figures are presented as ranges to represent the possible variation in effect of water treatment to control plumbosolvency

Table 4.4 Estimated cost (£million) to water suppliers to comply with a lead standard of 25 μg/l after 5 years

Region	Compliance scenarios for a lead standard of 25 μg/l					
	Random daytime			30 minute stagnation or composite proportional		
	Maximum	Zone mean	80 percentile	Maximum	Zone mean	80 percentile
Central/Eastern	34.18 - 542.9	0.391	1.662	16.83 - 542.9	0.275	1.608
Northern	19.41 - 759.7	1.834	2.133	9.697 - 759.7	0.582	1.100
South East	97.35 - 461.5	23.97	38.62	27.26 - 461.5	3.803	6.143
Wales/South West	7.422 - 139.7	4.190	4.197	4.746 - 139.7	2.565	2.703
TOTAL	158.4 - 1907	30.38	46.62	58.53 - 1904	7.224	11.56

Some figures are presented as ranges to represent the possible variation in effect of water treatment to control plumbosolvency

Table 4.5 Estimated cost (£million) to water suppliers to comply with a lead standard of 10 µg/l after 15 years (in addition to costs incurred to meet 25 µg/l)

Region	Compliance scenarios for a lead standard of 10 µg/l					
		Random daytime		30 minute stagnation or composite proportional		
	Maximum	Zone mean	80 percentile	Maximum	Zone mean	80 percentile
Central/Eastern	0 - 432.8	203.3 - 464.6	204.0 - 463.7	0 - 449.1	130.5 - 464.6	141.5 - 463.7
Northern	0 - 469.5	111.3 - 605.6	155.0 - 605.5	0 - 502.2	93.79 - 606.4	152.2 - 606.3
South East	0 - 307.1	331.4 - 387.8	334.4 - 374.3	0 - 370.7	147.5 - 405.6	328.9 - 404.1
Wales/South West	0 - 108.8	26.81 - 123.4	28.40 - 123.4	0 - 115.2	14.43 - 124.0	22.17 - 123.9
TOTAL	0 - 1318	672.9 - 1581	721.9 - 1567	0 - 1433	386.2 - 1601	644.8 - 1598

Some figures are presented as ranges to represent the possible variation in effect of water treatment to control plumbosolvency.
The range for the maximum standard starts from zero since in the worst case scenario all rehabilitation necessary will have been performed to meet the 25 µg/l standard.

Table 4.6 Estimated cost (£million) to householders to meet a lead standard of 25 µg/l after 5 years

Region	Compliance scenarios for a lead standard of 25 µg/l					
		Random daytime		30 minute stagnation or composite proportional		
	Maximum	Zone mean	80 percentile	Maximum	Zone mean	80 percentile
Central/Eastern	158.2 - 1775	0.263	5.031	59.27 - 1775	0.263	5.031
Northern	40.87 - 2056	3.014	3.140	18.57 - 2056	0.249	0.410
South East	178.4 - 869.5	47.39	71.29	53.08 - 869.5	8.171	14.51
Wales/South West	26.99 - 422.4	16.07	16.09	18.01 - 422.4	9.830	10.12
TOTAL	404.5 - 5123	66.73	95.55	148.9 - 5123	18.51	30.07

Some figures are presented as ranges to represent the possible variation in effect of water treatment to control plumbosolvency

Table 4.7 Estimated cost (£million) to householders to meet a lead standard of 10 µg/l after 15 year (in addition to costs estimated to meet 25 µg/l)

Region	Compliance scenarios for a lead standard of 10 µg/l					
	Random daytime			30 minute stagnation or composite proportional		
	Maximum	Zone mean	80 percentile	Maximum	Zone mean	80 percentile
Central/Eastern	0 - 1544	737.2 - 1713	848.8 - 1708	0 - 1640	525.1 - 1713	708.2 - 1708
Northern	0 - 1838	440.1 - 1976	590.0 - 1976	0 - 1860	355.6 - 1979	574.9 - 1978
South East	0 - 642.9	675.0 - 796.3	691.3 - 773.2	0 - 764.5	321.9 - 834.2	654.5 - 828.0
Wales/South West	0 - 357.1	125.7 - 391.7	132.2 - 391.6	0 - 365.7	71.36 - 397.7	103.2 - 397.4
TOTAL	0 - 4383	1978 - 4877	2262 - 4849	0 - 4630	1274 - 4923	2041 - 4912

Some figures are presented as ranges to represent the possible variation in effect of water treatment to control plumbosolvency.
The range for the maximum standard starts from zero since in the worst case scenario all rehabilitation necessary will have been performed to meet the 25 µg/l standard.

Table 4.8 Summary of costs associated with different sampling regimes

Sample type	Estimated cost (£) per sample		
	mean	max.	min
Current compliance sampling		marginal	
Random daytime targeting lead piped properties	16	35	4
30 minute stagnation targeting lead piped properties	23	45	8
Composite proportional targeting lead piped properties		see text below	

Composite proportional sampling has not been used by water companies in England and Wales and thus no cost estimations were supplied. However it could be expected to be in excess of twice the cost of stagnation sampling since two visits to the property would be required. The first to install the sampling device and the second to collect the water sample and remove the device.

Using these unit costs an example of comparative costs can be calculated. If it is assumed, for example, that there are 2305 water compliance zones, and in 1375 (class 1 and 2a) four samples per year are required and in 930 (remaining risk classes) twelve samples per year are required, the annual costs associated with each sample type are given in Table 4.7.

Table 4.9 Example of costs of sampling

Sample type	Example annual cost £K for all England and Wales
Random daytime targeting lead piped properties	267
30 minute stagnation targeting lead piped properties	383
Composite proportional	766 minimum

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Estimated non-compliance with possible interpretations of the new lead standard

- Between 2 and 10% of zones would fail a lead standard of 25 µg/l depending on the sampling scenario adopted.

- Of these zones between 39 and 58% would require pipe replacement to achieve compliance and in 42 to 61% compliance could be achieved with additional water treatment.

- At a standard of 10 µg/l between 20 and 63% of zones (including those failing at 25 µg/l) would fail depending on the sampling scenario adopted.

Thus it is concluded that the water treatment measures currently installed in England and Wales to comply with the current lead standard (50 µg/l) are adequate in all but the minority of zones to achieve compliance with a proposed interim standard (25 µg/l). But to achieve compliance with the proposed final standard (10 µg/l) as a maximum would require some considerable effort. Pipe replacement would be necessary at between 5.5 to 9.8 million properties. It should also be noted that this would not remove all the lead pipework in England and Wales since the available data suggest that a further 39% of zones that are believed by water companies to contain lead pipework would achieve compliance at 10 µg/l. If the proposed final standard (10 µg/l) is expressed as a mean the cost estimates are more uncertain. Some zones would achieve compliance from water treatment alone but others would require pipe replacement.

5.2 Sampling procedures

Data were obtained from six UK companies and from a published summary of French research that could be used to relate the concentrations of lead obtained by various sampling procedures at the same time and location. These helped to confirm a theoretical understanding of stagnation curves.

- Concentrations in random daytime samples are on average slightly higher than in 30 minute stagnation samples. However there is wide scatter in this relationship.

- There is evidence that random daytime samples are very likely to identify some properties where the "representative" concentration at the tap is high, i.e. genuine problems are unlikely to be missed. The procedure may therefore be acceptable for routine monitoring to determine whether a zone contains properties which were unlikely to comply with the standard, even if it is not acceptable for special lead surveys because of its lack of repeatability.

- Concentrations in 30 minute stagnation samples are similar to those in composite proportional samples.
- Concentrations in flushed samples are sensitive to the details of the procedure, i.e. flushing time and rate.
- Composite proportional, 30 minute stagnation and random daytime samples (less so) can all be argued to represent water drawn by the user for drinking. This cannot be argued for flushed samples, and therefore a correction factor (of around 2.5) should be applied, should this procedure be adopted by the EC.

Two purposes for measuring lead concentrations need to be distinguished - routine sampling carried out as a check on water quality, and special surveys designed to confirm (or not) compliance with the standard. For the first of these purposes, the sampling procedure should not miss genuine problems in a zone, and a case could be argued for using any convenient procedure, such as random daytime sampling, to do this. For the second purpose, it is a requirement that measured concentrations be representative and reproducible; there is evidence that stagnation and composite proportional sampling meet this requirement.

5.3 An approach to lead surveys and their interpretation

The intention of the new limit appears to be to ensure as far as possible that the average concentration of lead in water consumed at any single property is (eventually) below 10 μg/l.

"Audit" (compliance) sampling that is carried out routinely cannot be relied on to provide a clear picture of lead concentrations in a zone, because (i) there are not enough samples, and (ii) any property in the zone can be chosen for sampling, whether or not there is lead in the pipes or joints that serve it. Such sampling has a useful but limited rôle - to flag up problems. Therefore any exceedance should be investigated further, but is not by itself sufficient evidence that the zone "fails". Special lead surveys are therefore necessary.

The words "pass" and "failure" are sometimes used without a definition of their meaning. For individual samples, failure can be identified with exceedance. Compliance zones have been divided into two groups, on the basis of the number or proportion of properties at which the limit is exceeded. If this is small (<5% or 400 properties), no action on a zone wide basis would be required; if it is larger, some action such as water treatment or a lead pipe replacement programme would be needed.

It is therefore important to define two things:

- What is the criterion for an *exceedance at a single property* during "audit" sampling? What action should be taken if an exceedance is confirmed?

- What form should a special lead survey take? What rules should be applied to determine whether or not *exceedances are confined to a small proportion/number of properties*?

Audit sampling

Definition of an exceedance

Given the variability in measured lead concentrations at a single property, confirmation of a single high (definition of high?) measured concentration would seem to be necessary, by (i) taking a repeat sample at the same property, and (ii) looking for the cause of the high concentration. An exceedance would be confirmed if (?) the average of the two concentrations exceeded the limit. If the two measured concentrations were widely different, a third sample could be taken.

Action to follow a confirmed exceedance

What action is necessary will depend on whether the exceedance is unexpected. If it simply confirms a known problem which is being addressed, no further action would be necessary. If it is a surprise, further investigation possibly starting with similar properties in the zone would be needed.

Special lead surveys

What form should a survey take?

- Identify the properties likely to be served by lead pipes (including if appropriate lead solders and pipes containing some lead);

- Choose 50 of these properties (streets?) at random;

- Take 30 minute stagnation samples at these properties;

- While at the property note what can be learned about the pipework through which water is supplied.

What criterion should be used to judge whether the lead problem is confined to an insignificant part of the zone?

Since the intention is to identify the proportion of properties where lead exceedances are likely, a percentile criterion would seem to be appropriate. For example a 95 percentile would ensure that, in the long run, exceedances would be confined to 5% of properties surveyed.

However the data summarised above suggest some relationships that help to understand what different formulations of the criterion would mean in practice.

- For samples taken using any standard procedure from properties within a single zone, the following are roughly equivalent: a mean over properties for which lead was detected of 10 µg/l, a 95%ile over properties for which lead was detected of 25 µg/l, and a 98%ile over all properties of 25 µg/l.
- Orthophosphate dosing appears to be able to achieve these standards in some zones, but cannot be relied on to do so everywhere.
- The distinction between surveys restricted to properties with some lead pipes, and those covering all properties, is important. Clearly the value of any parameter (such as the mean) will be less for surveys covering all properties. The precise relationship will depend on the proportion of properties with lead pipes.
- A zonal mean of 10 µg/l (or a 95%ile of 25 µg/l) applied to properties with lead pipes would ensure that individual concentrations at nearly 80% of such properties were below 10 µg/l.

5.4 Cost estimates

The costs of compliance estimated for each scenario for a limit of 25 µg/l are summarised in Table 5.1, whilst Table 5.2 shows the total costs that would be incurred in achieving a 10 µg/l limit. It can be seen that approximately 75% of the costs are associated with the removal of lead supply pipe and plumbing which are the responsibility of the property owners. The range of costs for the maximum at 25 µg/l and all 10 µg/l scenarios reflect the possible range of effectiveness of water treatment under these scenarios.

Table 5.1 Summary of costs - England and Wales total - 25 µg/l limit

	Costs £million			
	Random Daytime		30 minute stagnation or composite proportional	
Compliance criterion	Suppliers	Householders	Suppliers	Householders
Maximum	160 - 1900	400 - 5100	60 - 1900	150 - 5100
Mean	30	70	7	20
Percentile	50	100	12	30

Table 5.2 Summary of total costs - England and Wales total - 10 μg/l limit

	Costs £million			
	Random Daytime		30 minute stagnation or composite proportional	
Compliance criterion	Suppliers	Householders	Suppliers	Householders
Maximum	1480 - 1900	4790 - 5120	1490 - 1900	4780 - 5120
Mean	700 - 1610	2050 - 4940	390 - 1610	1290 - 4940
Percentile	770 - 1610	2360 - 4940	660 - 1610	2070 - 4940

The costs estimated in this report are lower than the costs estimated previously in studies undertaken by WRc for the European Commission. This is because of the following factors:

- The previous studies included the replacement of all lead pipework. This study does not include zones where lead pipework is thought to exist but where data suggests they would comply.
- Some lead pipes have been replaced since the previous studies.
- The current annual replacement rate has increased.
- Where companies have revised their estimates of lead pipe occurrence these have decreased.

The cost of actually undertaking the compliance sampling will differ for different monitoring methods but, compared to the overall cost of achieving compliance, is quite small at less than 0.5% of the annual pipe replacement expenditure that would be required. The cost of 30 minute stagnation sampling is about 1.5 times higher than random daytime sampling, although with current compliance sampling the cost for lead samples is marginal since samples for several other parameters are taken during the same visit, whereas stagnation sampling would be solely for lead. Composite proportional sampling has not been used in the UK but it is estimated that its cost would be at least three times that of random daytime sampling since two visits to each property are required per sample.

REFERENCES

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Randon, G. (1996). Synthese du travail collectif realise par l'AGHTM sur le plomb dans l'eau de distribution. techniques, Sciences methodes 91 (7-8) 530-535.

Van den Hoven, T.J.J. (1987) A new method to determine and control lead levels in tap water. *Aqua* No. 6, 315-327.

APPENDIX A GLOSSARY

A1 DEFINITION OF TERMS

Lead risk - zone classification

In their annual returns of information on lead in drinking water supplies, water undertakers are required to provide an assessment of the risk that the lead concentration would cease to comply with the standard on leaving the undertaker's pipes. The risk codes used are as follows:

Risk	Definition
1	No risk
2a	The risk relates to an insignificant part of the zone
2b	treatment is not reasonably practicable
2c	treatment will not achieve a significant reduction in lead concentration
2d	treatment to be installed or optimised
2e	the significance of the risk and/or the effectiveness of the treatment has yet to be assessed
2f	treatment installed and/or optimised; effectiveness not yet evaluated
2g	treatment installed and/or optimised, but risk not eliminated. Further treatment not reasonably practicable
2h	treatment installed and/or optimised risk eliminated
3	assessment of risk still being made

Types of sample

Random daytime sample: A sampler visits the property at a random time during the working day (the choice of property may also be randomised). A single sample (typically 1 litre) is taken from a drinking water tap without flushing any water from the tap beforehand. The stagnation time of water in the pipes before sampling is unknown and depends on when the water was last used.

First draw sample: A sample is taken (normally by the consumer) from the drinking water tap first thing in the morning before water has been used anywhere in the house and without flushing the tap beforehand. The stagnation time of these samples although much longer than daytime samples, is also usually unknown.

Fully flushed sample: A sample is taken after prolonged flushing of the tap (at least 5 service pipe volumes) at around 4 litres/min.

Fixed stagnation time sample: After prolonged flushing of the tap, water is allowed to stand in the pipework for a defined period (often 30 minutes, although other times have been used) after which a sample is taken without flushing the pipe beforehand.

Composite proportional sample: A consumer-operated device is fitted to the drinking water tap which splits off a small constant proportion (5%) of every volume of water drawn for drinking purposes. The samples are pooled for analysis.

Compliance sampling

Sampling used to establish whether or not the lead concentrations from a property or water supply zone conform to the prescribed limit.

Statutory sampling: Compliance sampling, according to the present Regulations, as described below.

Zone (water supply zone): Supply systems are divided into Zones supplying a population no greater than 50 000 for the purposes of statutory monitoring. The zones are based on defined water quality characteristics supplied from one or more specified sources.

Sampling frequency: The standard sampling frequency for lead is 4 per year which has to be increased to 12 (zone population up to 35 000) or 24 (zone population 35 001-50 000) per year, if the lead concentration in any sample exceeds the standard (50 µg/l). If all sample results for 3 years are <25 µg/l the sampling frequency may be reduced to 1 per year.

Statutory sample type: Statutory sampling for lead is based on one litre random daytime samples, collected without prior flushing, from consumers' taps (usually the kitchen tap) in randomly selected properties (with or without lead pipes) at random times during the working day.

Compliance scenarios

In the present study, three statistical scenarios for compliance were considered:

Maximum: interpretation of the standard as an absolute maximum; a zone would fail if any one sample from the zone exceeded the standard.

Mean: (or average) interpretation of the standard as applying to the mean results from a zone; a zone would comply provided the mean of the lead concentrations in all samples taken from the zone was within the standard.

Percentile: interpretation of the standard as applying to the 80 percentile (80 %ile) of results from a zone; a zone would comply provided the 80 %ile of the lead concentrations in all samples taken from the zone was within the standard. The 80 %ile is the lead concentration below which 80 % of the results lie.

Pipework definitions and responsibilities

Service pipe: The pipe connecting the mains to a property, consisting of:

- **Communication pipe** from the main to the curtilage of the property, the responsibility of the water undertaker, and

- **Supply pipe** from the curtilage of the property to the stopcock inside the property, the responsibility of the property owner.

Plumbing

Internal pipework, the responsibility of the property owner.

Miscellaneous terms

Stagnation curve: the pattern of build-up of lead concentration in water inside a lead pipe over time.

Dissolved lead: or "soluble" lead - lead in water that is in true solution.

Particulate lead: lead in water in the form of particles of lead compounds or lead adsorbed on other particles.

A2 ABBREVIATIONS

Abbreviation	Meaning
RDT	Random daytime sample
30MS	30 minute stagnation sample
COMP	Composite proportional sample
Flush	Flushed sample
SD	Standard deviation

APPENDIX B WATER COMPANY QUESTIONNAIRE

DRINKING WATER INSPECTORATE

Room B148B
Romney House
43 Marsham Street
London SW1P 3PY
Direct Line : 0171-276 8213
Enquiries : 0171-276 8808/8666
Facsimile : 0171-276 8405

To whom it may concern

30 September 1996

Dear Sir/Madam

REVISION OF DRINKING WATER DIRECTIVE: STUDY ON LEAD IN WATER

The European Commission has published proposals for a revision of its Directive concerning the quality of water intended for human consumption (80/778/EEC) ("The Directive"). In the case of lead it is proposed to reduce the limit from the present 50µg/l to 25µg/l for an interim period, with an ultimate limit of 10µg/l in a representative sample of water drawn from the consumer's tap to be achieved within 15 years of implementation of the Directive. The precise form of the standard (e.g. maximum, average) and monitoring method have not yet been determined.

Whilst early agreement to a revised Directive is unlikely , it is important for the UK's negotiating strategy to understand the extent of non-compliance and how much further water treatment and pipe replacement might be needed to achieve compliance with various possible interpretations of the standards and monitoring requirements; and the cost of these measures and the effectiveness and costs of various monitoring regimes. The Drinking Water Inspectorate (DWI) has placed a contract with WRc for a study into lead in drinking water with the following objectives:

1) to establish the likely event of non-compliance with the proposed interim and ultimate standards in terms of numbers of water supply zones and numbers of properties for various possible interpretations of the standards and monitoring requirements;

2) to establish to what extent further water treatment would achieve compliance, and how much pipe replacement would be needed to secure compliance, with the various possible interpreations;

3) to critically assess various possible sampling regimes which could be used to obtain a "representative sample drawn from the tap" in terms of their effectiveness and cost and to make recommendations on an appropriate sampling regime; and

4) to establish the costs to water supplier (treatment and pipe replacement) and householders (pipe replacement) to comply with the various interpretations of the standards and monitoring requirements and to compare these qualitatively.

The success of this study depends very much on the quality and comprehensiveness of data to be collected from water undertakers. Therefore we would be very much obliged if you would assist WRc in their work by providing relevant data and other information which are available. The data will be provided in a non-attributable form in the project report.

If you feel that you need more information about the study please contact Sheila Millar (01793 511711) or Peter Jackson (01491 571531) at WRc or myself at DWI.

I hope that it will be possible to give priority to this request for information from WRc, made on DWI's behalf. Thank you in advance for your co-operation.

Yours sincerley

Owen Hydes

O D HYDES
Deputy Chief Inspector

LEAD IN DRINKING WATER - QUESTIONNAIRE FOR DWI STUDY

Response requested before 31 October 1996

Company ....

Contact name ....

Address ....

Telephone .... ***Fax*** ....

The purpose of this questionnaire is to gather information which will be used to estimate the extent of compliance with the lead standard proposed for a revised EC Directive concerning the quality of water intended for human consumption. The proposed revision of the Directive includes a reduction in the lead standard from the current value of $50\ \mu g l^{-1}$ to $25\ \mu g l^{-1}$ for an interim period and an ultimate limit of $10\ \mu g l^{-1}$ in a representative sample of water drawn from the consumer's tap to be achieved within 15 years of the implementation of the revised Directive. The method for taking samples and assessing compliance has yet to be defined (pending an EC study); consequently we will be investigating a number of possible options. In addition to the data and information requested below the DWI will provide WRc with the annual returns for lead and related water quality data.

CONFIDENTIALITY: All data will be treated in confidence by WRc and the results of the study will be presented non-attributably in the final report to DWI.

1. EC lead data

WRc has data provided by your company in 1994 when we undertook a lead economics study for the European Commission. These data are attached. Please study the data and make any updates required. In particular the lead pipe replacement rate data and cost data are crucial to our estimations. Our estimations will cover the next 15 to 20 years, consequently any information you have on anticipated changes in replacement rates for example, should be described.

2. Data from special surveys

We would be especially interested in data you have from sampling surveys from consumers' taps that are not part of the statutory monitoring. Relevant data would be samples from properties where the materials of the water company's service pipe and the consumer's supply pipe and internal plumbing are known. Also since a large quantity of random daytime sample data already exists, studies involving other sample methods (e.g. stagnation samples) are of particular interest. For all studies the following is required:

- a description of the sampling method
- sample point (e.g. first tap in consumer's premises)
- pipe materials (company's and consumer's, supply and plumbing)
- lead concentration data

- water temperature
- data to illustrate water type e.g. hardness, alkalinity, pH
- date and time of sample

NB. If random daytime samples and 'other' samples e.g. stagnation samples, were taken at the same properties during the same sampling exercise please provide both sets of results.

3. Compliance with proposed EC Directive

As part of the study we will be considering possible scenarios for implementation of the proposed EC Directive. We will be using statistical models to examine compliance but we would like to have independent estimates of likely compliance as a check on these models.

We are considering the following combinations of compliance scenarios and sample types:

Scenario 1. All samples from the zone must be below given **maximum** lead concentration (as current Directive)

Scenario 2. The **mean** of all samples from a zone will be below given lead concentration

Scenario 3. A **90% proportion** of samples from a zone will be below given lead concentration

Sample types:

1. **Random day time (RDT)**. Where the first litre of water from the tap is sampled without first flushing the tap.

2. **30 minute stagnation**. Where the tap is first flushed at a low flow rate to ensure fresh mains water is in the water company's and consumer's pipework. No water is then drawn for 30 minutes. After which the stagnation sample is collected.

3. **Composite**. Where a device that takes a small proportion of all water drawn is temporarily fitted to a consumer's tap. Samples are collected typically over a period of a week, thus giving an 'exposure value' for the people in that household for that week.

For each combination of scenario and sample type please indicate whether you think each of your zones would Pass, Fail or be Marginal/borderline by placing a tick in the appropriate box.

Please assume all samples are collected from the first tap in the consumer's premises and base your estimates on current numbers of lead pipes and current water treatment. Please indicate if additional treatment is planned to be installed.

Zone number ______

Indicate your ***estimates*** of compliance by ticking the appropriate boxes below

For a lead concentration of **25 µgl^{-1}**									
Sample type/Scenario	Maximum			Mean			Proportion		
	P	F	M	P	F	M	P	F	M
RDT									
Stagnation									
Composite									

For a lead concentration of **10 µgl^{-1}**									
Sample type/Scenario	Maximum			Mean			Proportion		
	P	F	M	P	F	M	P	F	M
RDT									
Stagnation									
Composite									

4. Cost of sampling

In order to compare the sampling scenarios effectively we need to make allowance for the differing costs associated with each method. It is recognised that some of the sample methods below are not frequently used, but we would like your estimates of the additional costs associated with their use.

Please include costs such as man-hours, transport and selection of sample sites but exclude analytical costs.

Sampling method	Number of properties per day per sampler	£ per property
Current practice - random day time coincident with compliance sampling for other parameters		
Random daytime samples from selected lead piped properties		
30 minute stagnation sample from selected lead piped properties		
Installation of composite sample devices at selected lead piped properties		
Collection of samples from composite sample device at selected lead piped properties		

5. Other data

Finally, we understand that you have already provided some other lead data to WRc for a current UKWIR research project. Although the objectives and methods of this DWI study are different from those of the UKWIR study some of the data is of use to both projects. Therefore we would like your permission to use some of the data provided for the UKWIR study (attached) for this study.

PLEASE RETURN QUESTIONNAIRES TO MRS SHEILA MILLER, WRc SWINDON, FRANKLAND ROAD, BLAGROVE, SWINDON, SN5 8YF.

By End October 1996

PLEASE ALSO PHONE SHEILA WITH ANY ENQUIRIES ON 01793 511711(FAX 01793 511712)

IF YOU ARE UNSURE - PLEASE ASK!

APPENDIX C COMPARATIVE DATA ON SAMPLING PROCEDURES

C1 DATA SOURCES

Data were provided by six companies, enabling a comparison of concentrations measured using three different sampling procedures - random daytime sampling, flushed sampling and stagnation sampling. No companies were able to provide data on composite proportional sampling.

Table C1 Summary of data from special surveys

Company	Sampling procedure			No. of data pairs	
	Random daytime	Flushed (1)	Stagnation	Stagnation vs. Flushed	Random daytime vs. Stagnation
A	Yes	Yes (2 mins)	Yes (30 mins)	273	61
B	No	Yes (? mins)	Yes (30 mins)	55	-
C	No	Yes (? mins)	Yes (30 mins)	177	-
D	Yes	Yes (2 mins)	Yes (30 mins)	16	16
E	No	Yes (? mins)	Yes (2 hours)	67	-
F	Yes	No	Yes (30 mins)	-	321 (source 1)
				-	113 (source 2)

(1) The flushing procedures varied, and in no case was a flushing rate specified. In all cases the intention was to get mains water that had not been standing in the lead pipes.

C2 COMPARISONS BETWEEN SAMPLING PROCEDURES

Random daytime and stagnation samples

Lead concentrations in random daytime samples tend to be slightly (typically 20% but with wide scatter) higher than those in 30 minute stagnation samples. There is also considerable variability in the ratio, but no clear difference between companies (Figures C.1 to C.4).

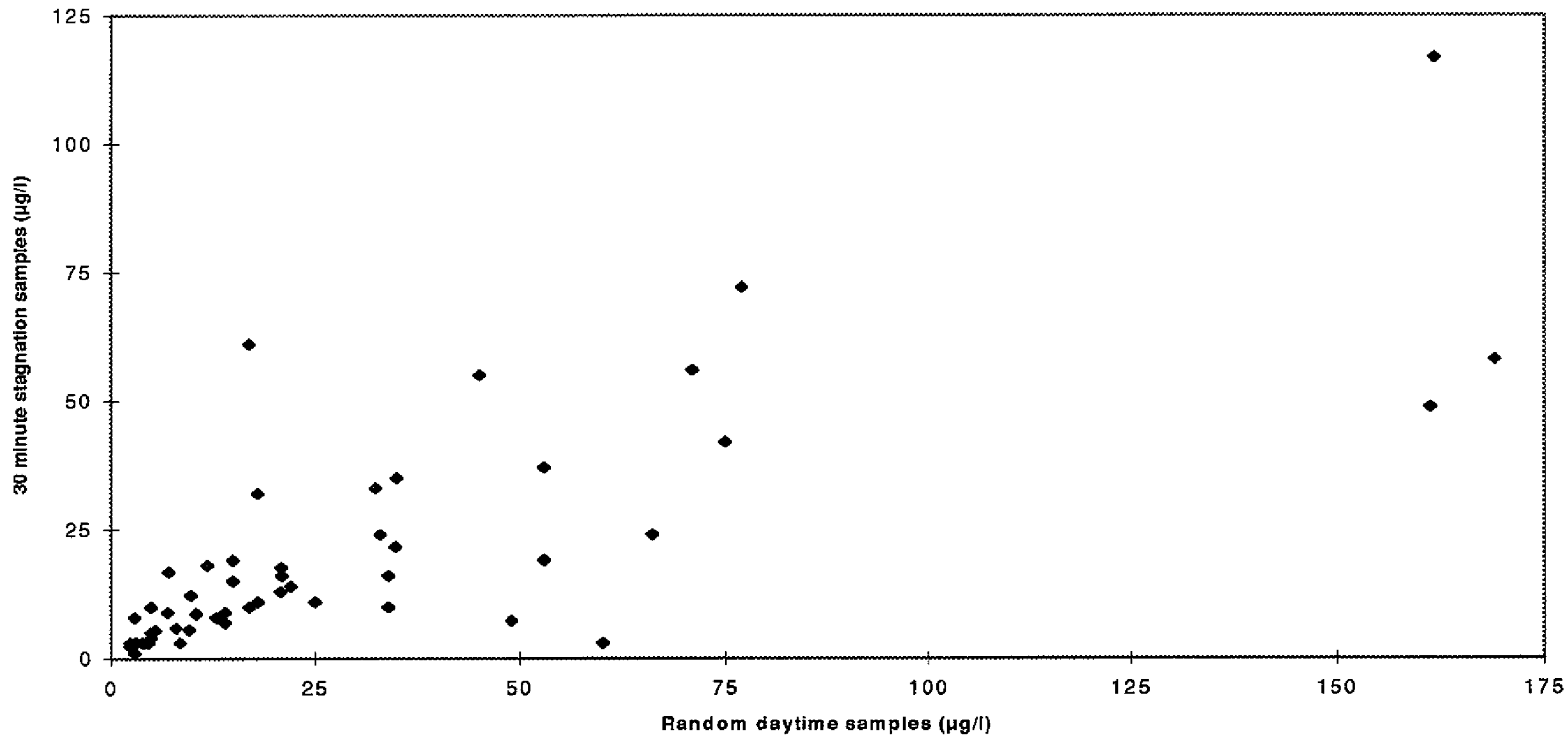

Figure C1 Company A - 30 minute stagnation vs. random daytime samples

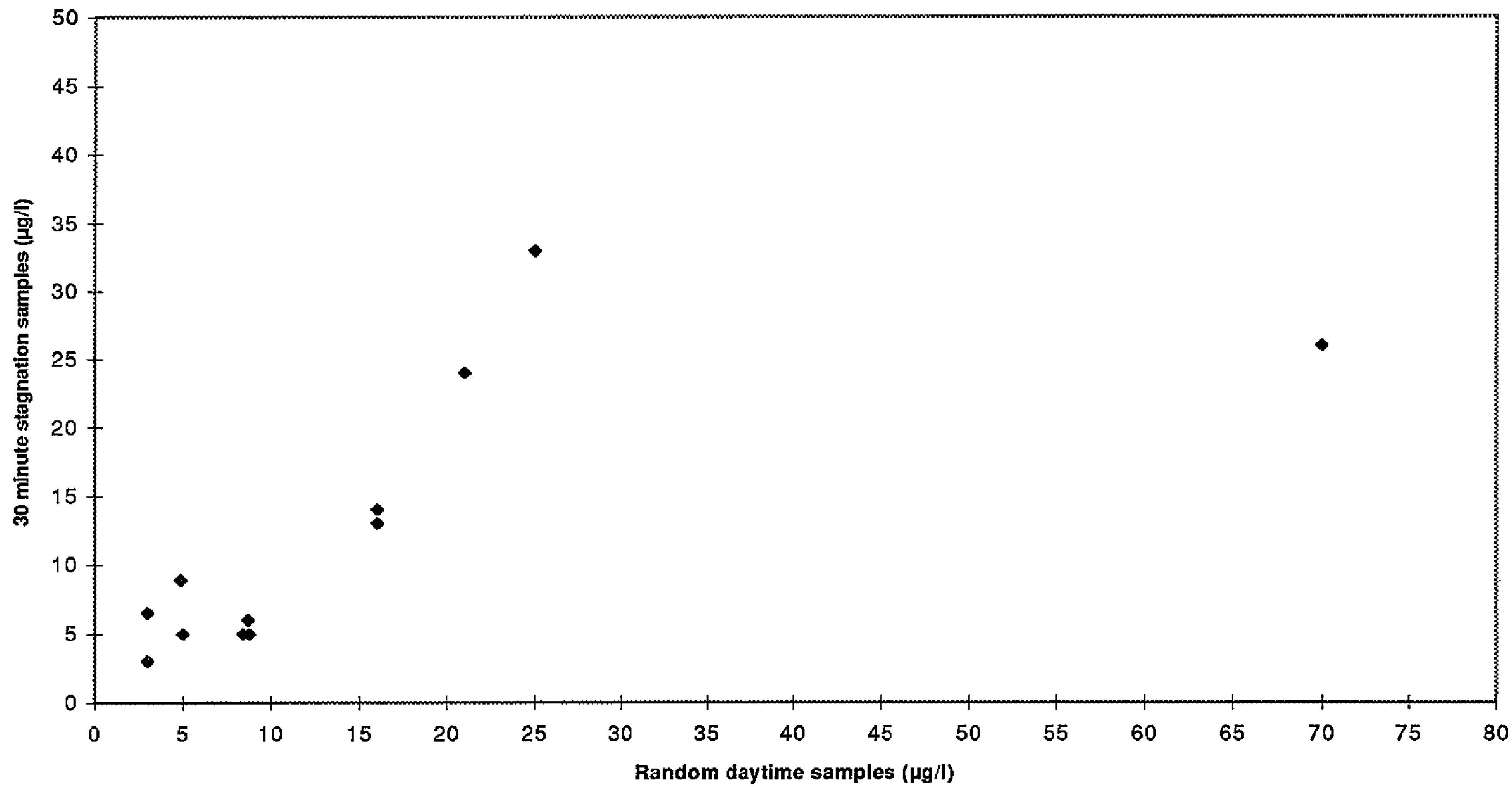

Figure C2 Company D - 30 minute stagnation vs. random daytime samples

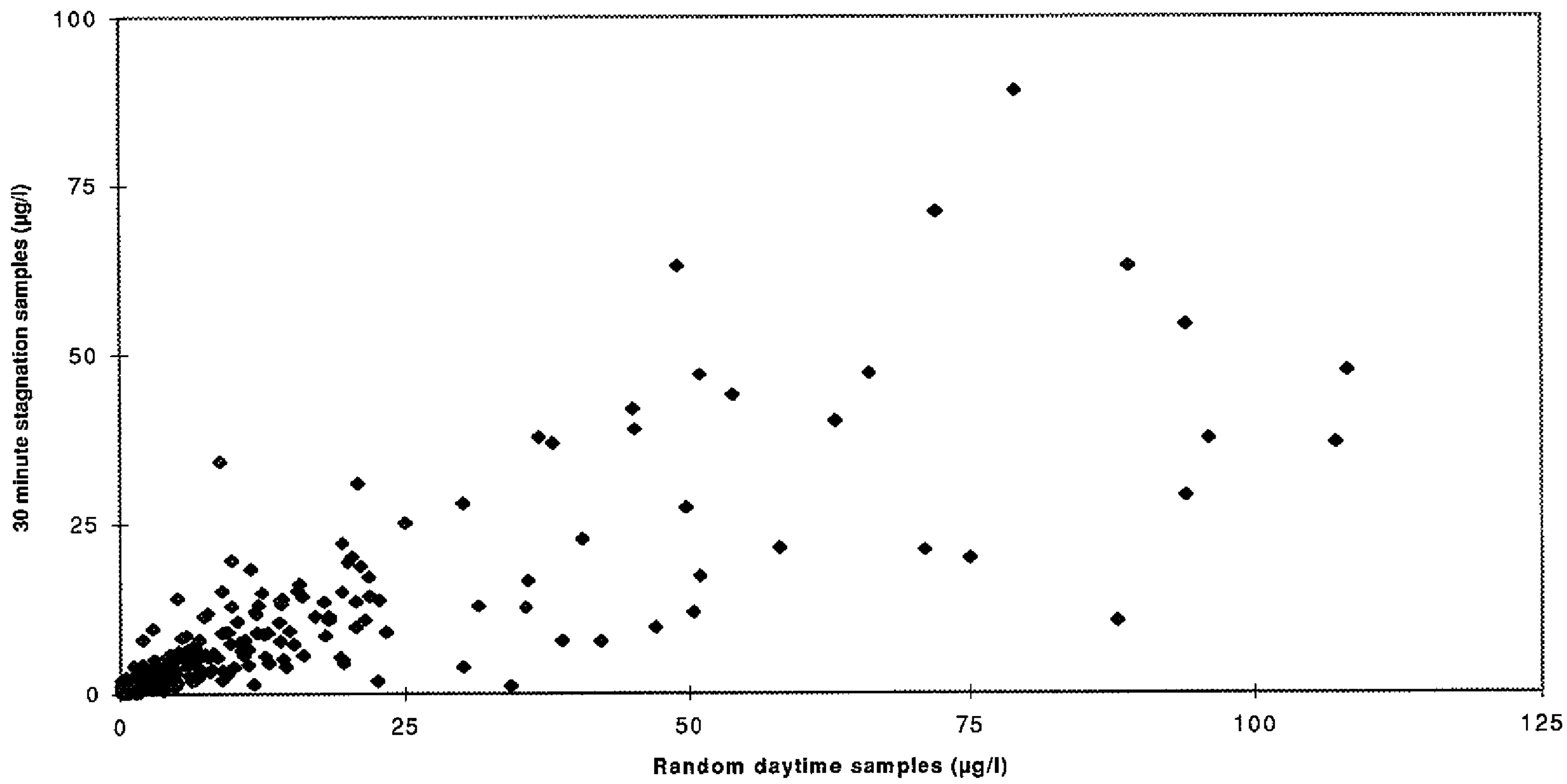

Figure C3 Company F, source 1 - 30 minute stagnation vs. random daytime samples

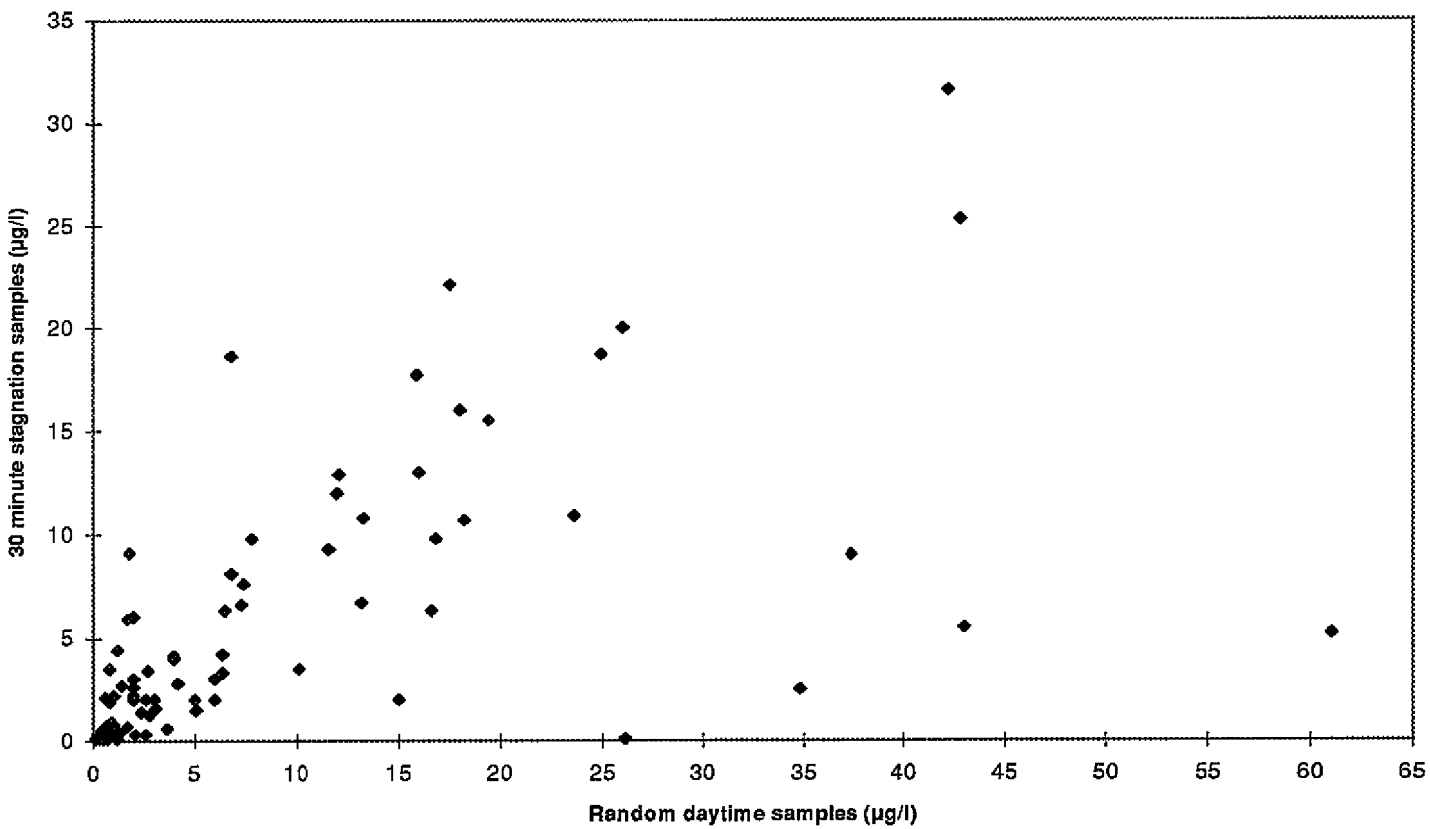

Figure C4 Company F, source(s) 2 - 30 minute stagnation vs. random daytime samples

There appears to be a small proportion of locations where the stagnation sample contained a low lead concentration (<10 µg/l) but the random daytime sample contained a fairly high concentration (>25 µg/l) - 4 out of 61 in company A and 5 out of 319 in company F (source 1). There is only one example of a corresponding difference in the opposite direction, in company F. The reasons for this are not clear.

Flushed samples

One would expect concentrations measured in flushed samples to be generally lower than those measured using stagnated or random daytime samples, and this is confirmed by the data. However there are differences between companies, as well as wide variability within each company (Table C.1). The between company differences may be explained by differences in flushing rates and times.

Table C2 Comparison of flushed sample concentrations with other sampling procedures

Company	Ratio	5 percentile	Median	95 percentile
A	Flushed / 30 minute stagnation	0.29	0.83	2.33
B	Flushed / 30 minute stagnation	0.13	0.38	1.02
C	Flushed / 30 minute stagnation	0.19	0.68	1.53
E	Flushed / 2 hour stagnation	0.14	0.44	1.15
A	Flushed / Random daytime	0.18	0.78	1.77

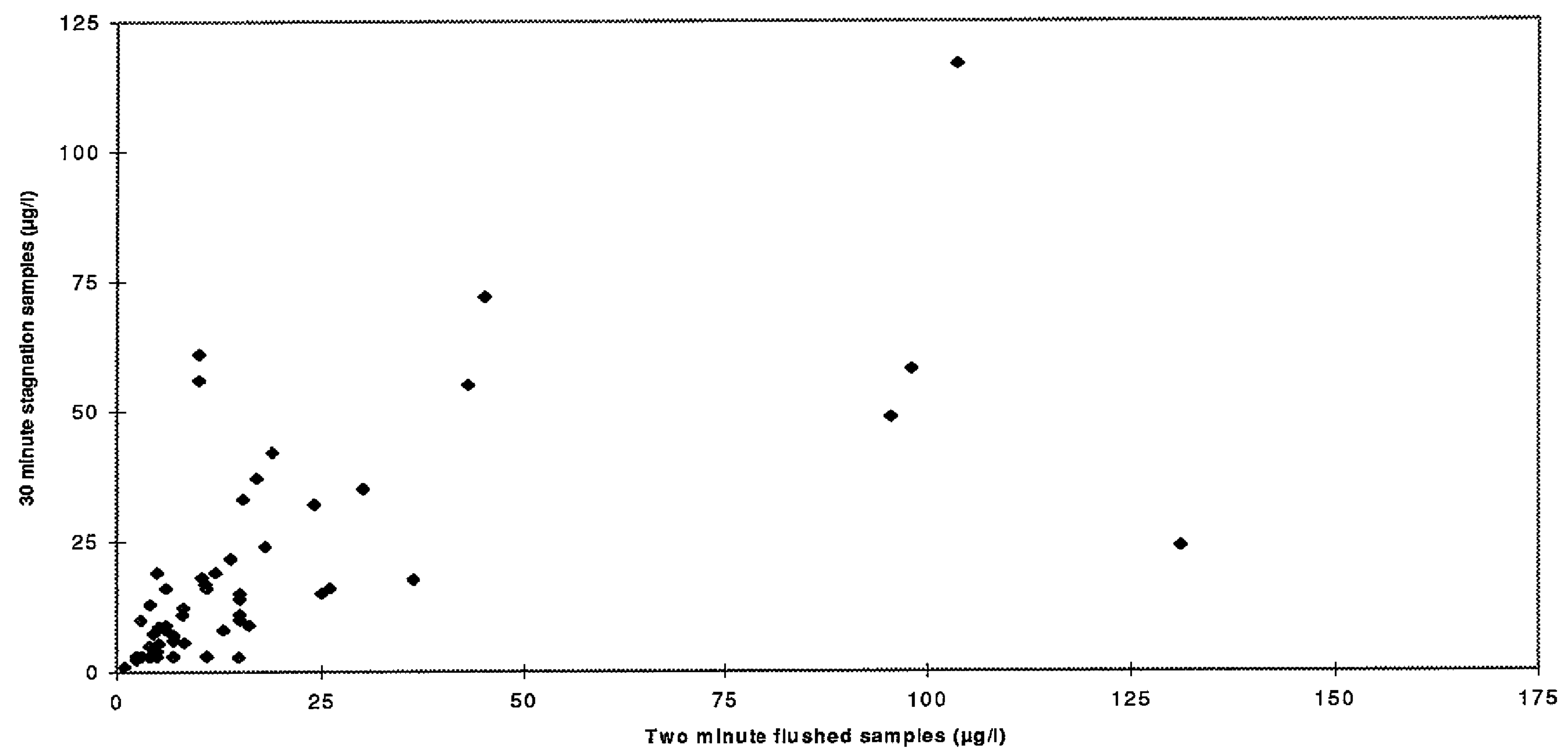

Figure C5 Company A - 30 minute stagnation vs. flushed samples

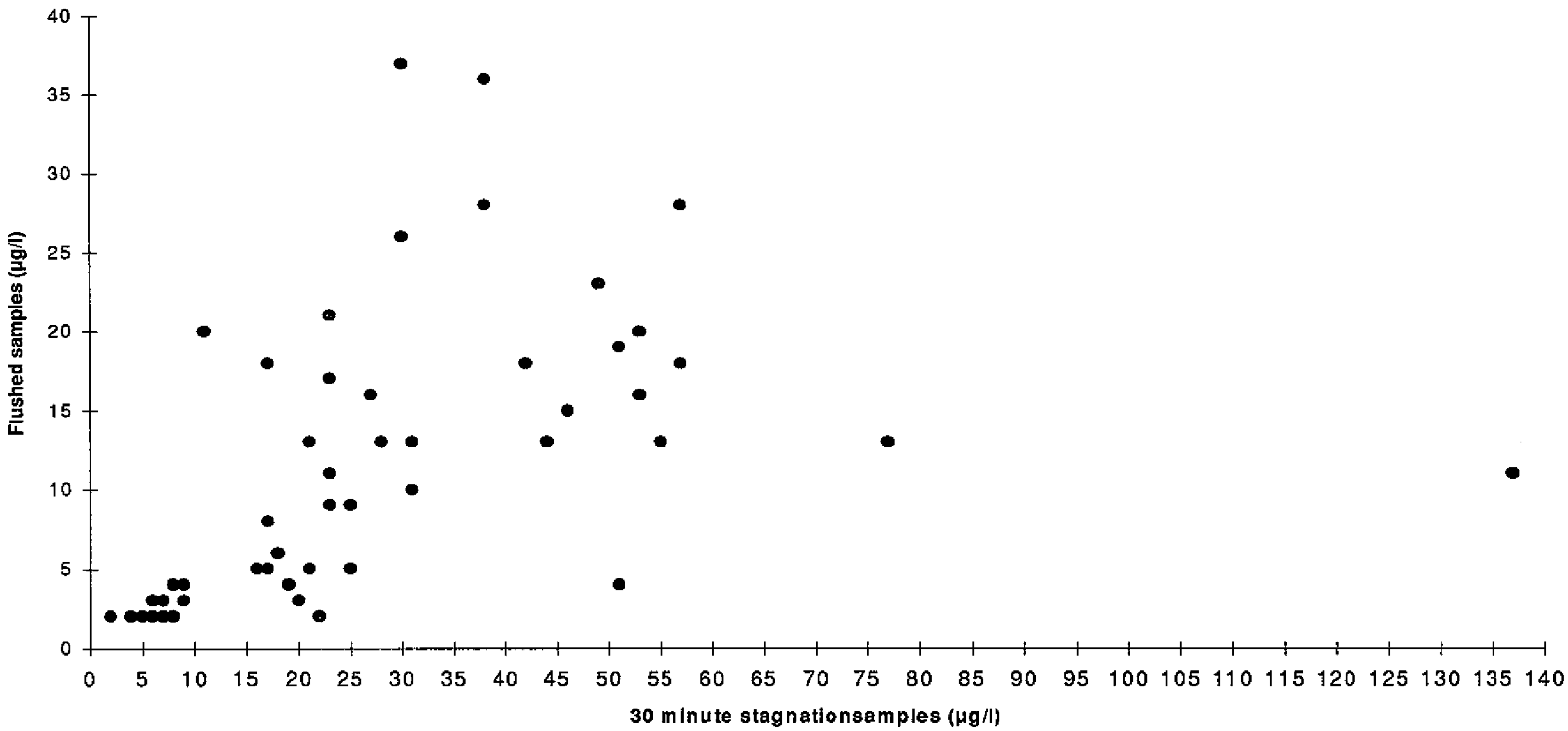

Figure C6 **Company B - Flushed vs. 30 minute stagnation samples**

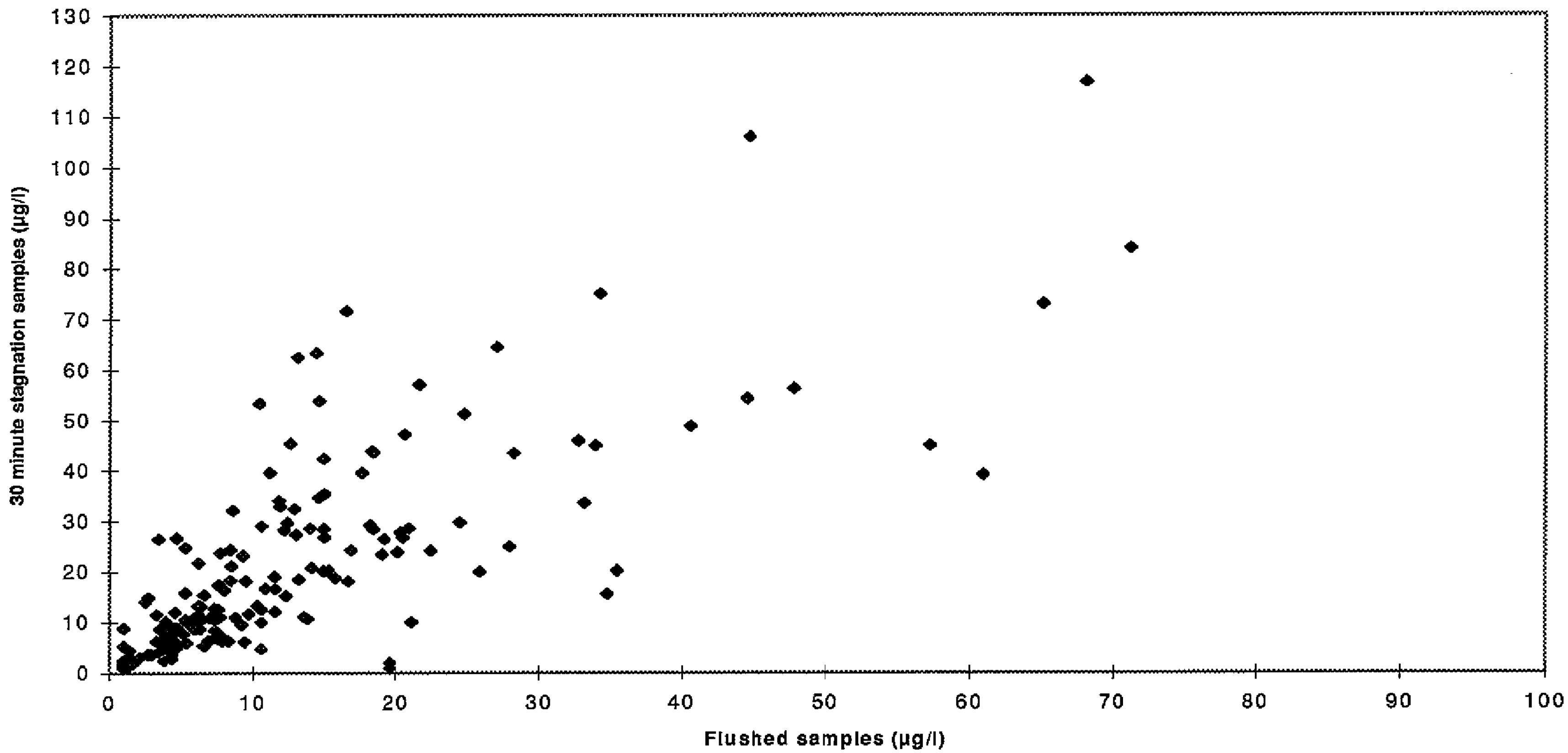

Figure C7 Company C - 30 minute stagnation vs. flushed samples

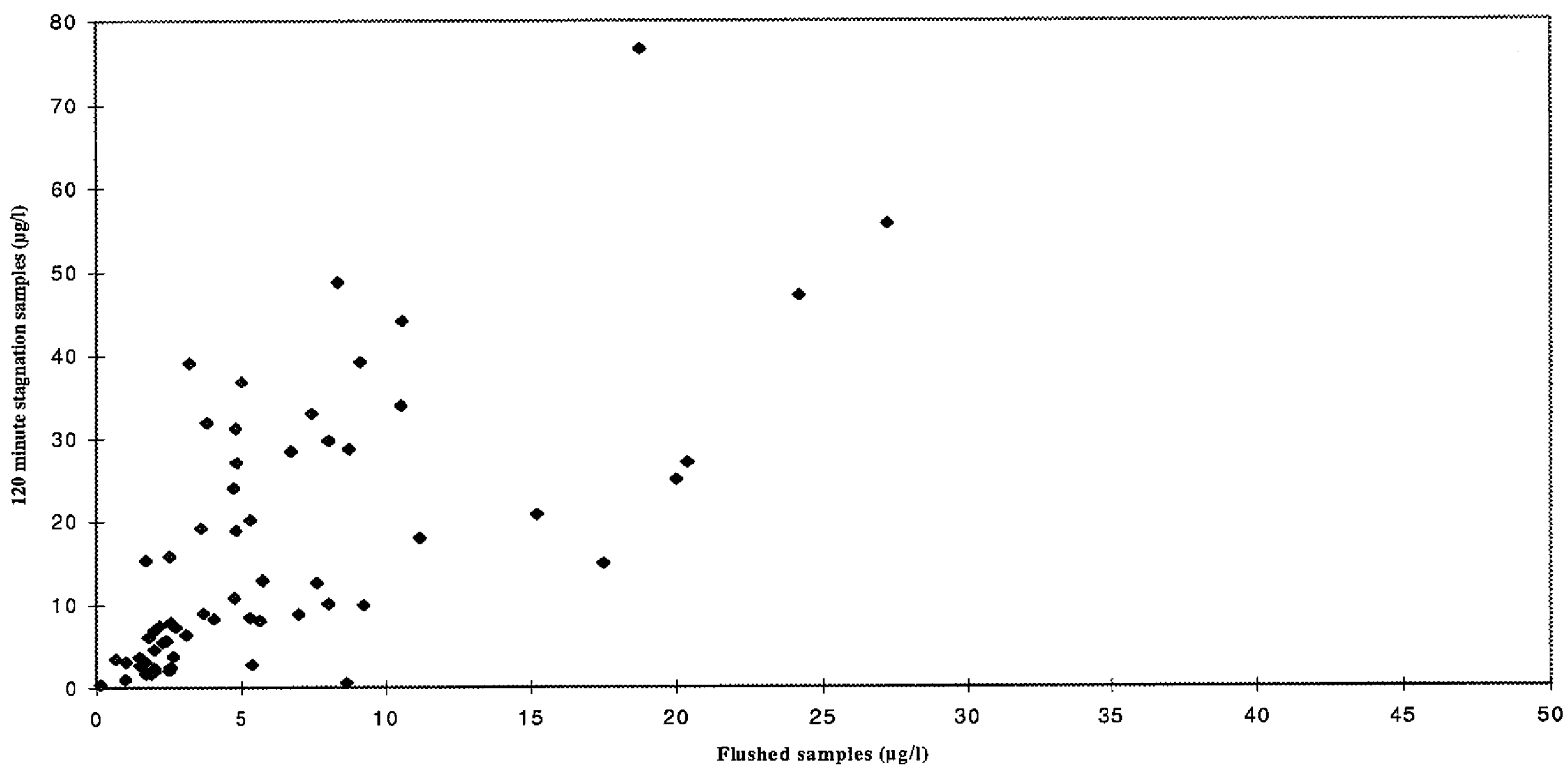

Figure C8 Company E - 120 minute stagnation vs. flushed samples

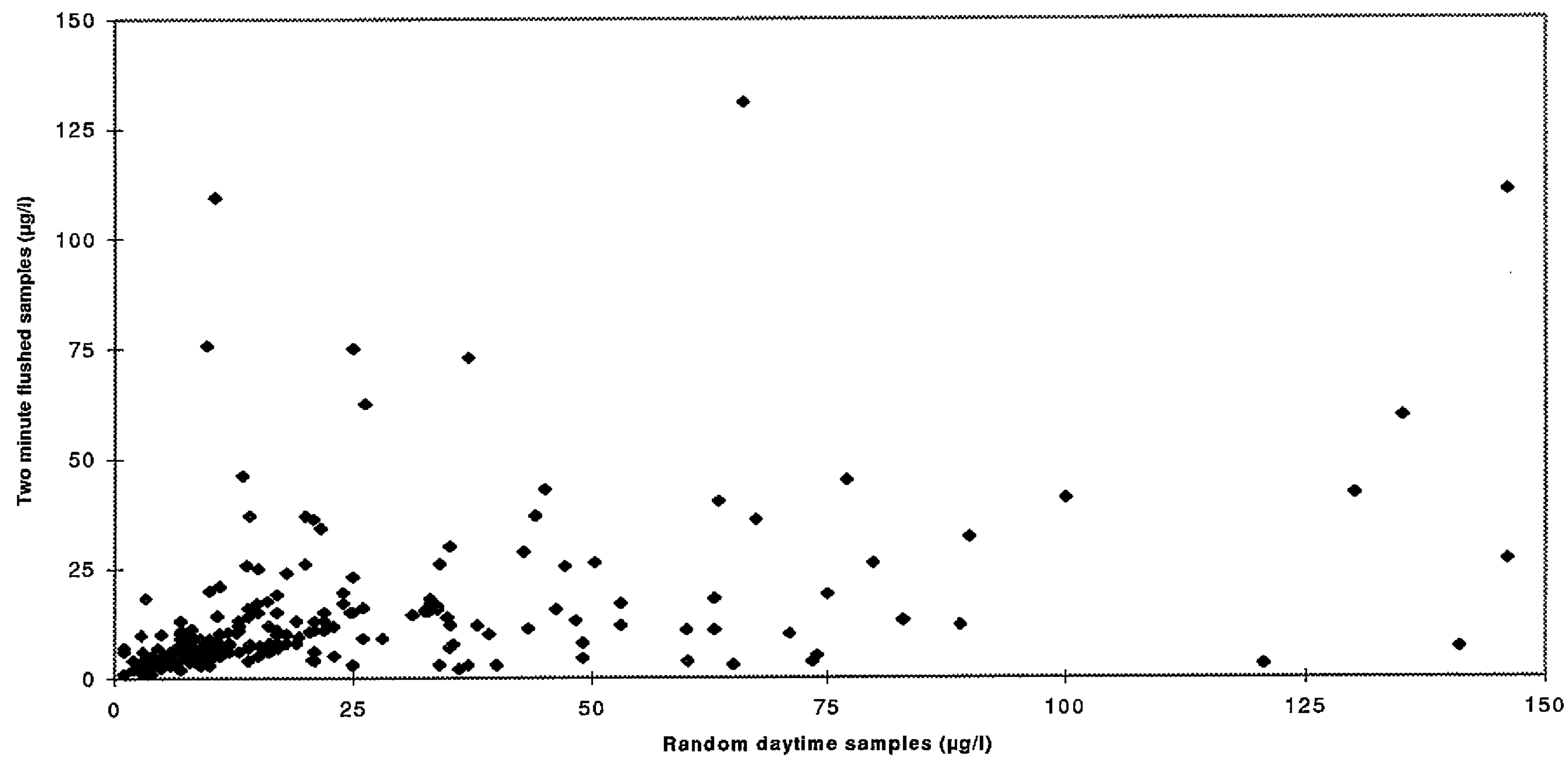

Figure C9 **Company A - Flushed vs. random daytime samples**

APPENDIX D DATA AUDITING TABLES

Table D1 Comparison of WRc and Company B estimates

25 µg/l max, 30MS Company estimate

		Pass	Fail	Marginal	Total
WRc	Pass	15	1	4	20
	Fail	0	1	1	2
	Marginal	0	0	1	1
	Total	15	2	6	23

25 µg/l max, RDT Company estimate

		Pass	Fail	Marginal	Total
WRc	Pass	14	2	4	20
	Fail	0	2	0	2
	Marginal	0	0	1	1
	Total	14	4	5	23

10 µg/l mean, 30MS Company estimate

		Pass	Fail	Marginal	Total
WRc	Pass	12	1	4	17
	Fail	1	1	1	3
	Marginal	3	0	0	3
	Total	16	2	5	23

10 µg/l max, RDT Company estimate

		Pass	Fail	Marginal	Total
WRc	Pass	3	10	0	13
	Fail	0	10	0	10
	Marginal	0	0	0	0
	Total	3	20	0	23

Table D2 Comparison of WRc and Company C estimates

25 µg/l max, 30MS		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	6	14	0	20
	Fail	1	17	0	18
	Marginal	0	0	0	0
	Total	7	31	0	38

25 µg/l max, RDT		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	3	16	1	20
	Fail	0	18	0	18
	Marginal	0	0	0	0
	Total	3	34	1	38

10 µg/l mean, 30MS		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	0	15	0	15
	Fail	1	19	1	21
	Marginal	0	2	0	2
	Total	1	36	1	38

10 µg/l max, RDT		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	0	9	0	9
	Fail	0	29	0	29
	Marginal	0	0	0	0
	Total	0	38	0	38

Table D3 Comparison of WRc and Company G estimates

25 µg/l max, RDT		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	1	0	3	4
	Fail	0	23	6	29
	Marginal	0	0	0	0
	Total	1	23	9	33

10 µg/l max, RDT		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	1	0	0	1
	Fail	0	30	2	32
	Marginal	0	0	0	0
	Total	1	30	2	33

Table D4　Comparison of WRc and Company H estimates

25 µg/l max, 30MS		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	0	1	0	1
	Fail	0	6	0	6
	Marginal	0	0	0	0
	Total	0	7	0	7

25 µg/l max, RDT		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	6	1	0	7
	Fail	4	3	5	12
	Marginal	0	0	0	0
	Total	10	4	5	19

10 µg/l mean, 30MS		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	0	1	0	1
	Fail	0	6	0	6
	Marginal	0	0	0	0
	Total	0	7	0	7

10 µg/l max, RDT		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	4	0	1	5
	Fail	1	9	3	13
	Marginal	1	0	0	1
	Total	6	9	4	19

Table D5 **Comparison of WRc and Company I estimates**

25 µg/l max, 30MS		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	10	3	11	24
	Fail	0	3	7	10
	Marginal	0	0	0	0
	Total	10	6	18	34

25 µg/l max, RDT		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	10	3	11	24
	Fail	0	3	7	10
	Marginal	0	0	0	0
	Total	10	6	18	34

10 µg/l mean, 30MS		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	12	1	8	21
	Fail	8	1	4	13
	Marginal	0	0	0	0
	Total	20	2	12	34

10 µg/l max, RDT		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	0	15	6	21
	Fail	0	11	2	13
	Marginal	0	0	0	0
	Total	0	26	8	34

Table D6 Comparison of WRc and Company J estimates

25 μg/l max, RDT		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	23	1	0	24
	Fail	1	5	0	6
	Marginal	0	0	0	0
	Total	24	6	0	30

10 μg/l max, RDT		Company estimate			
		Pass	Fail	Marginal	Total
WRc	Pass	19	2	1	22
	Fail	0	8	0	8
	Marginal	0	0	0	0
	Total	19	10	1	30

APPENDIX E UNIT COSTS

Pipe	Mean unit cost	Maximum	Minimum
Communication	£393	£754	£203
Supply	£483	Not appropriate due to small data set	
Plumbing	£442	Not appropriate due to small data set	

Water Treatment		
Capital cost		£45,000 per zone
Operating cost		£2.50 per M litre
		Assuming 500 litre per property per day