Technical Assistance
HYDROLOGY PROJECT

World Bank & Government of The Netherlands funded

Training module # WQ - 50

Inter-Laboratory AQC Exercise

New Delhi, September 2000

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with
HALCROW, TAHAL, CES, ORG & JPS

Table of contents

Page

1.	**Module context**	**2**
2.	**Module profile**	**3**
3.	**Session plan**	**4**
4.	**Overhead/flipchart master**	**5**
5.	**Evaluation sheets**	**22**
6.	**Handout**	**24**
7.	**Additional handout**	**31**
8.	**Main text**	**33**

1. Module context

This module describes the procedure for setting up an *inter*-laboratory AQC exercise and the conclusions that can be drawn from it.

While designing a training course, the relationship between this module and the others, would be maintained by keeping them close together in the syllabus and place them in a logical sequence. The actual selection of the topics and the depth of training would, of course, depend on the training needs of the participants, i.e. their knowledge level and skills performance upon the start of the course.

Modules in which prior training is required to complete this module successfully are listed in the table below:

No.	Module	Code	Objectives
1.	Basic Statistics	**WQ – 47**	• Understand difference between accuracy and precision • Calculate, descriptors of frequency distribution
2.	Applied Statistics	**WQ – 48**	• Apply common statistical tests for evaluation of the precision of data
3	Quality Assurance and within Laboratory AQC	**WQ – 49**	• Understand the need for QA programme • Set up within laboratory AQC programme

2. Module profile

Title	:	Inter-Laboratory AQC Exercise
Target group	:	HIS function(s): Q2, Q3, Q5, Q6
Duration	:	one session of 60 min
Objectives	:	After the training the participants will be able to*:* • Understand purpose and procedure of an *inter*-laboratory AQC exercise
Key concepts	:	• *inter*-laboratory AQC exercise • reference value • youden plot
Training methods	:	Lecture, exercises
Training tools required	:	Board, flipchart, OHS
Handouts	:	As provided in this module
Further reading and references	:	• Standard Methods: for the Examination of Water and Wastewater, APHA, AWWA, WEF/1995. APHA Publication • Statistical Procedures for analysis of Environmenrtal monitoring Data and Risk Assessment', Edward A. Mc Bean and Frank A. Rovers, Prentice Hall, 1998.

3. Session plan

No	Activities	Time	Tools
1	***Preparations***		
2	***Introduction***: • Ask participants to define: system error, bias, precision, random error and accuracy • Describe objective of the *inter*-laboratory AQC exercise	15 min	OHS
3	***Planning and exercise*** • Coordinating laboratory and its functions • Participating laboratories	10 min	OHS
4	***Analysis of data*** • Reference values, acceptable range • Youden plot	20 min	OHS
5	***Conclusion of exercise***	10 min	OHS
6	***Wrap up***	5 min	

4. Overhead/flipchart master

OHS format guidelines

Type of text	Style	Setting
Headings:	OHS-Title	Arial 30-36, with bottom border line (not: underline)
Text:	OHS-lev1 OHS-lev2	Arial 24-26, maximum two levels
Case:		Sentence case. Avoid full text in UPPERCASE.
Italics:		Use occasionally and in a consistent way
Listings:	OHS-lev1 OHS-lev1-Numbered	Big bullets. Numbers for definite series of steps. Avoid roman numbers and letters.
Colours:		None, as these get lost in photocopying and some colours do not reproduce at all.
Formulas/Equations	OHS-Equation	Use of a table will ease horizontal alignment over more lines (columns) Use equation editor for advanced formatting only

Inter-Laboratory AQC

- Within-laboratory AQC measures precision
- Inter-laboratory AQC
  - *bias*
  - *status of facilities*
  - *basis for interaction*
  - *enhances quality control*

Co-ordinating Laboratory

- Overall responsibility
  - *preparation and distribution of the test samples*
  - *collation and analysis of results*
  - *preparation and distribution of report*
  - *inter-action with individual laboratories*
- Should have time and resources
- Standard or above average facilities

Planning of Exercise (1)

- Test samples
  - *purity of materials*
  - *care in preparation*
  - *stability of samples*
  - *two samples*
- Participating laboratories
  - *familiar with test procedure*
  - *should have completed within-AQC*

Planning of Exercise (2)

- Proposal
  - *clear instructions*
  - *time limit*
  - *reporting format*

Reference Value

- Determined by co-ordinating laboratory
- Nominal concentration of solutions (primary standard)
- Based on pooled data, better acceptability
  - *reject outliers*
  - *calculate* $\bar{x}$ *and* S_R
  - *calculate reference* x_R *as mean of data within* $\bar{x} \pm 2S_R$ *limits*
  - *compare with values based on other two methods*

Acceptable Range

- Values differ due to random variations and systematic errors
- Calculate $S_{adj} = \sqrt{2}\ S_R$
  - *Analysis performed at different times and at different locations*
- Acceptable range
  - $\bar{x}_R \pm 3\ S_{adj}$
- For qualifying, results of both the samples should be within their range

Youden 2 - Sample Plots

- Overall view of performance
- Parameter-wise plots of data of all laboratories
- Values for sample A on x-axis against sample B on y-axis
- One point for each laboratory
- Plot for EC shown in Figure 1

Figure 1

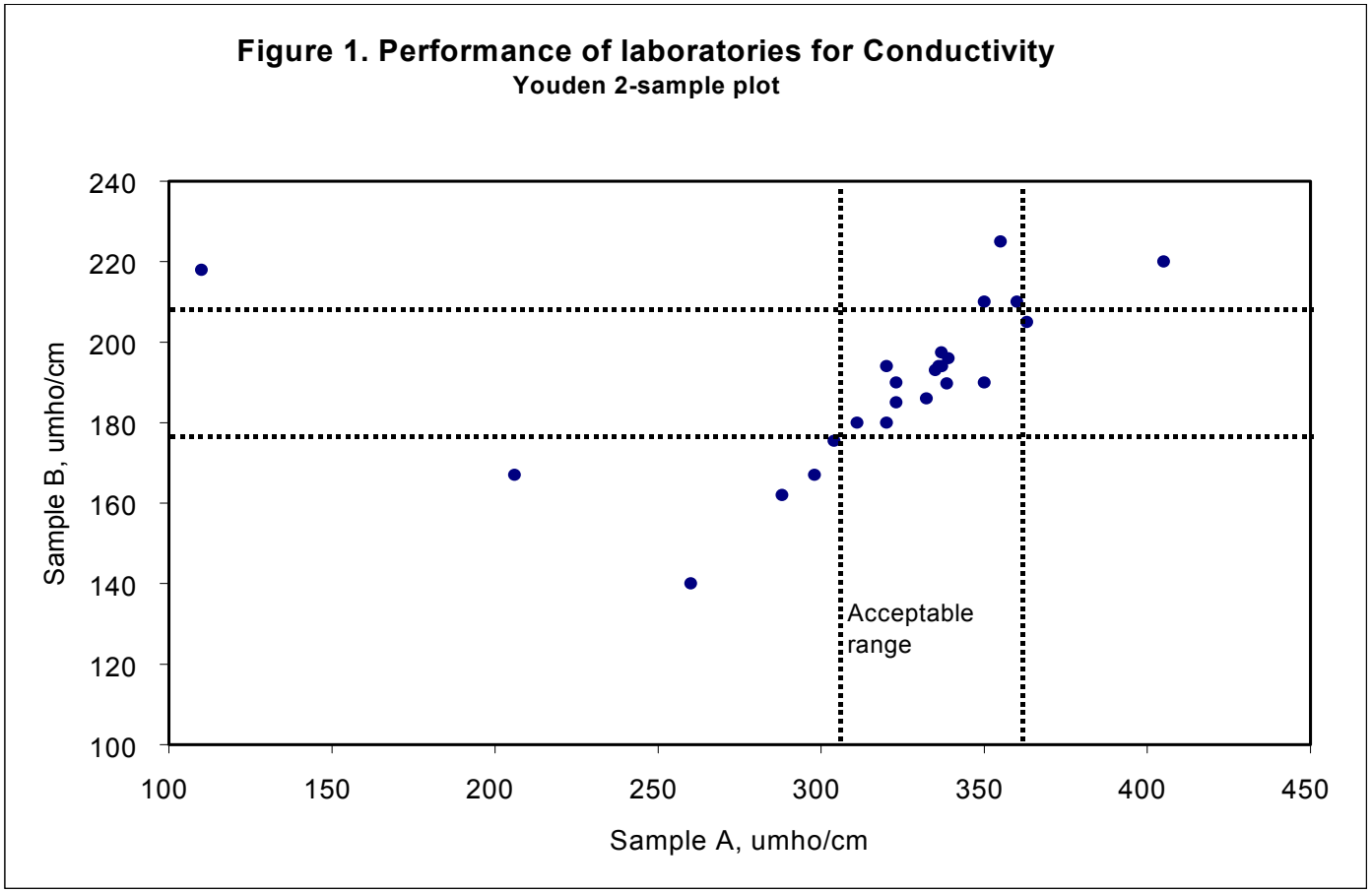


Figure 1. Performance of laboratories for Conductivity
Youden 2-sample plot
240
220
200
180
160
140
120
100
Sample B, umho/cm
100
150
200
250
300
350
400
450
Sample A, umho/cm
Acceptable
range

Youden 2 - Sample Plot for EC

- Figure also shows acceptable limits
- Two horizontal lines for value on Y – axis
- Two vertical lines for values of X – axis
- Acceptable values lie in the central rectangle
- Examples for TDS, TH, Fluoride shown in Figure 2 – 4

Figure – 2

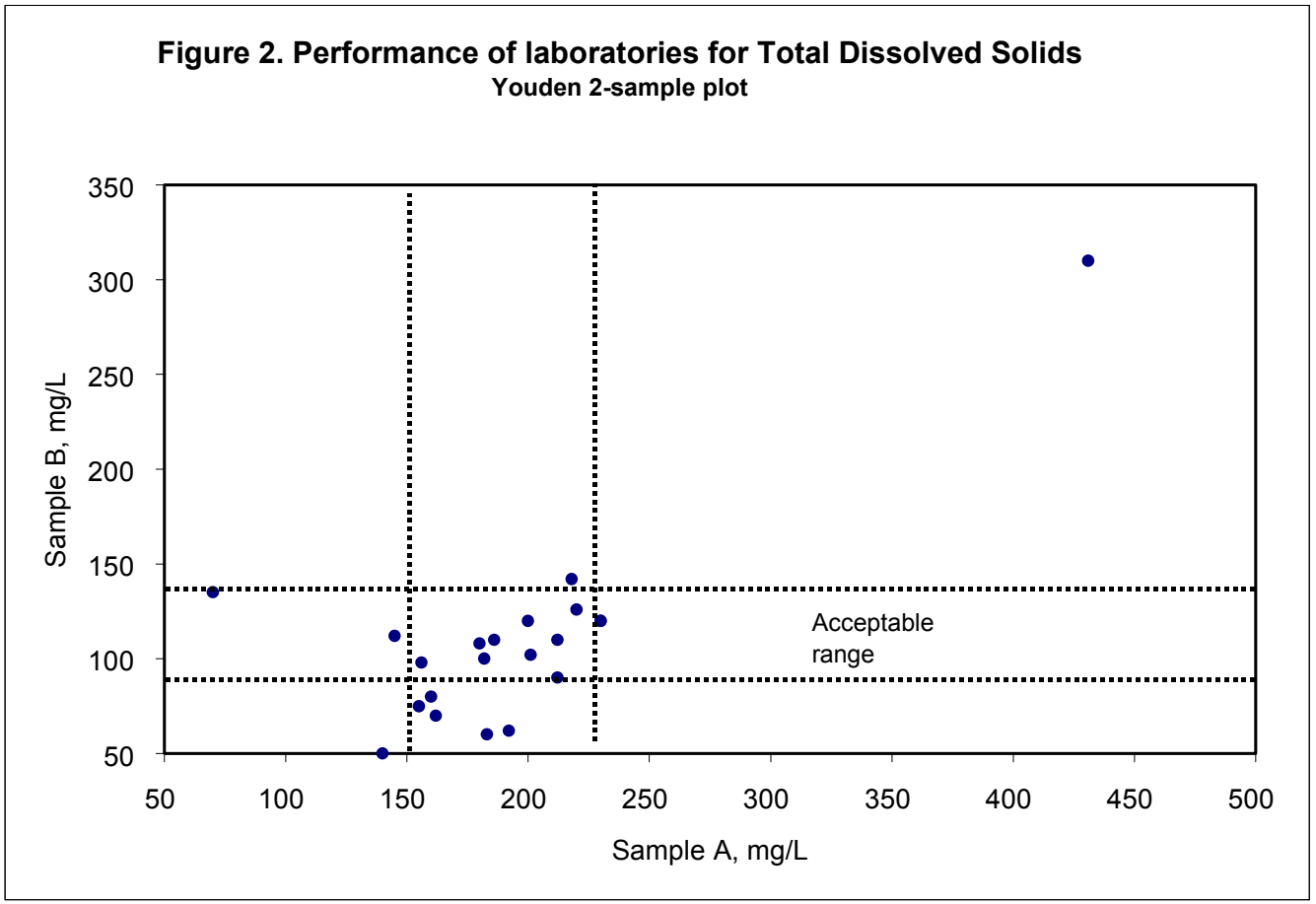
- 
Figure 2. Performance of laboratories for Total Dissolved Solids
Youden 2-sample plot
Sample B, mg/L
350
300
250
200
150
100
50
Acceptable
range
50
100
150
200
250
300
350
400
450
500
Sample A, mg/L

Figure – 3

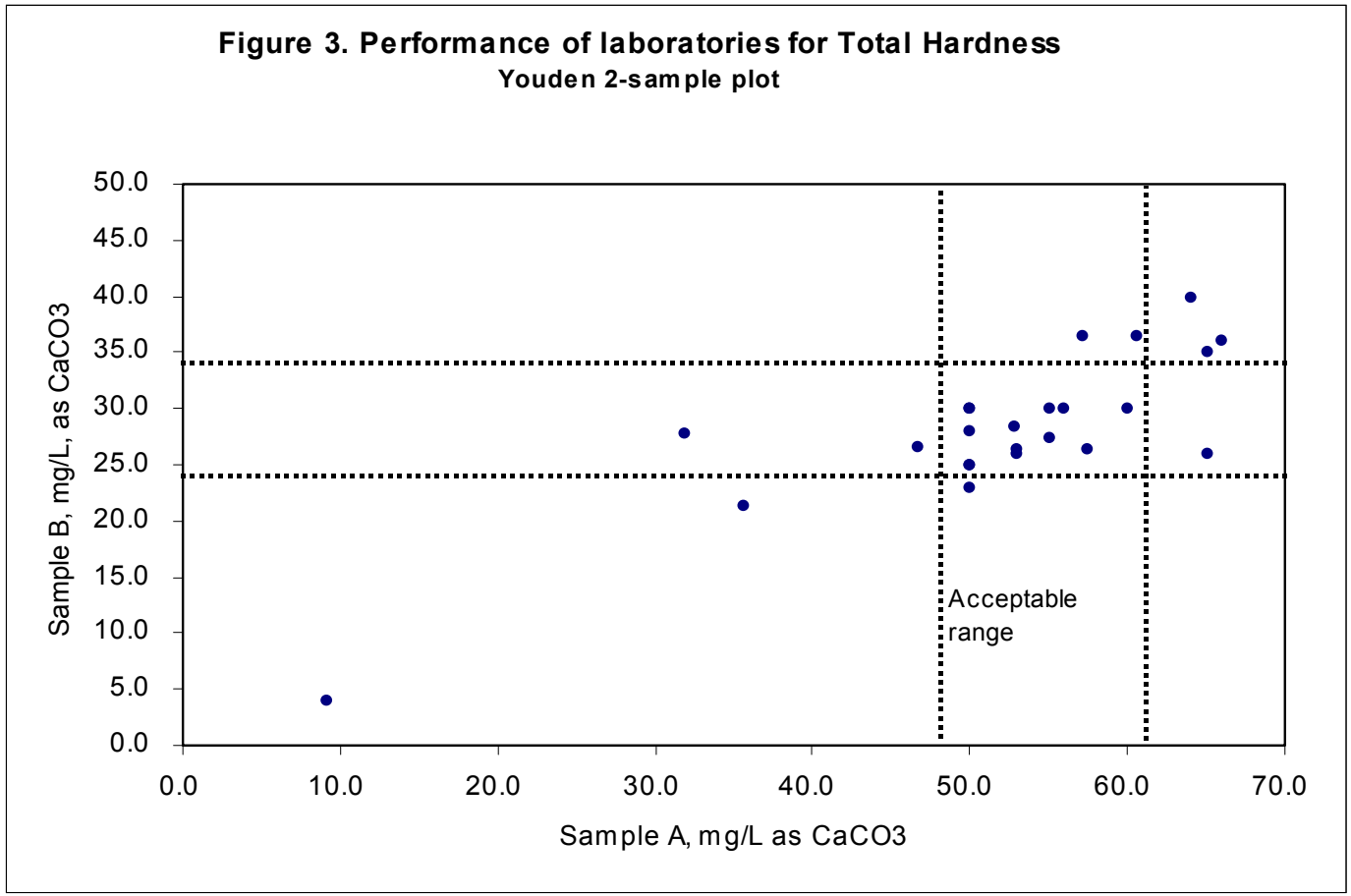


Figure 3. Performance of laboratories for Total Hardness
Youden 2-sample plot
Sample B, mg/L, as CaCO3
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
Sample A, mg/L as CaCO3
Acceptable
range

Figure – 4

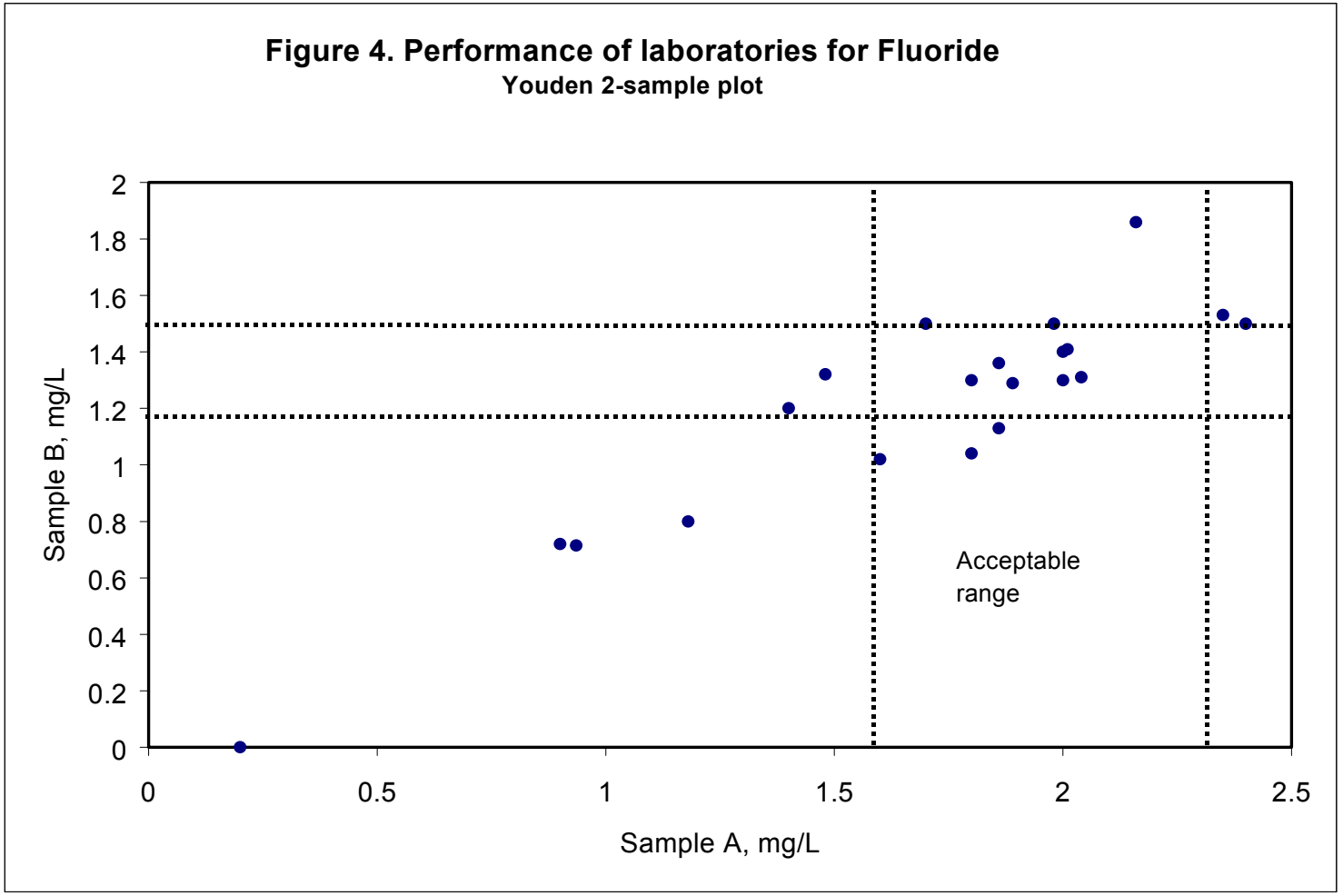


Figure 4. Performance of laboratories for Fluoride
Youden 2-sample plot
Sample B, mg/L
Sample A, mg/L
Acceptable range
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
0.5
1
1.5
2
2.5

Systematic Errors (Bias)

- Youden plot shows most points in the first or the third quadrants, Systematic error is dominant
- Both results either too high (first quadrant) or too low (third quadrant)
- Random errors would distribute points uniformly in the four quadrants

Total Error Components

- Difference between reported and reference value
  - *Random error*
  - *System error*
- Draw perpendicular on line of unit slope passing through reference value point
- Random error/ System error = (Length of perpendicular)/ (Distance of foot of perpendicular to reference value point)

Coefficient of Variations

- Overall accuracy of the laboratories
- Should be comparable to standard values achievable by the methods
- Will decrease with improvement in technique and upgradation of facilities

Conclusion

- Co-ordinating Laboratory
  - *collate and analyse data*
  - *send reports to participating laboratories*
  - *individual letters identifying errors and remedial steps*
- Report should not be delayed

5. Evaluation sheets

6. Handout

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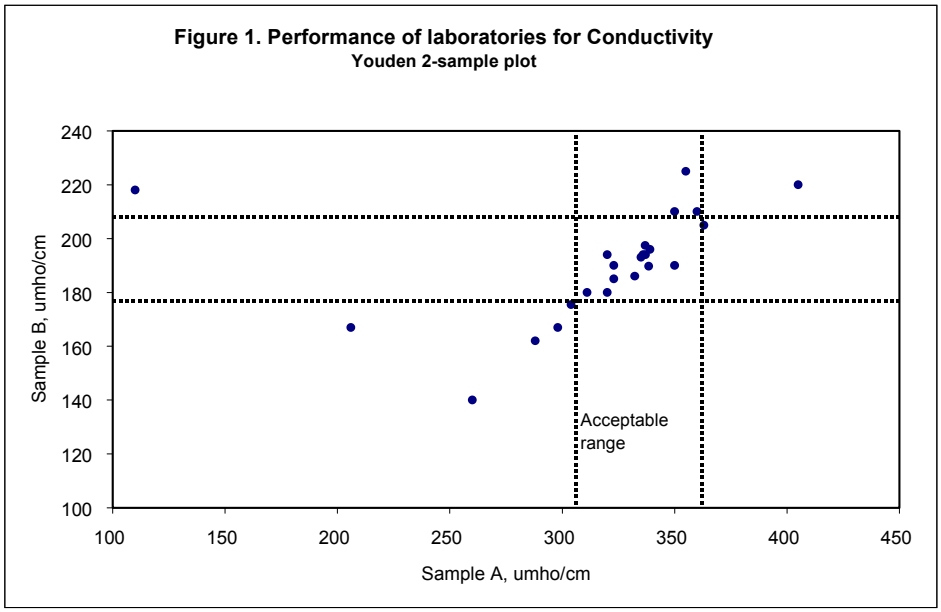

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Figure 2

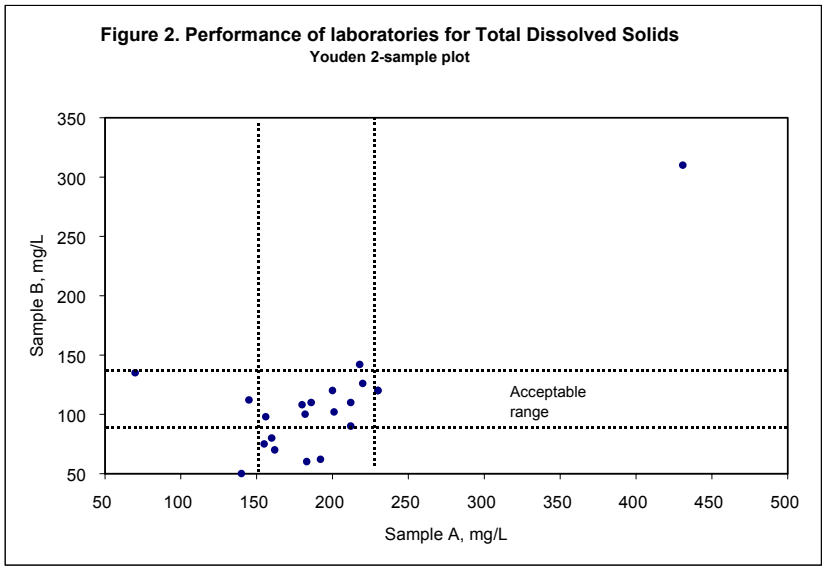


Figure 3

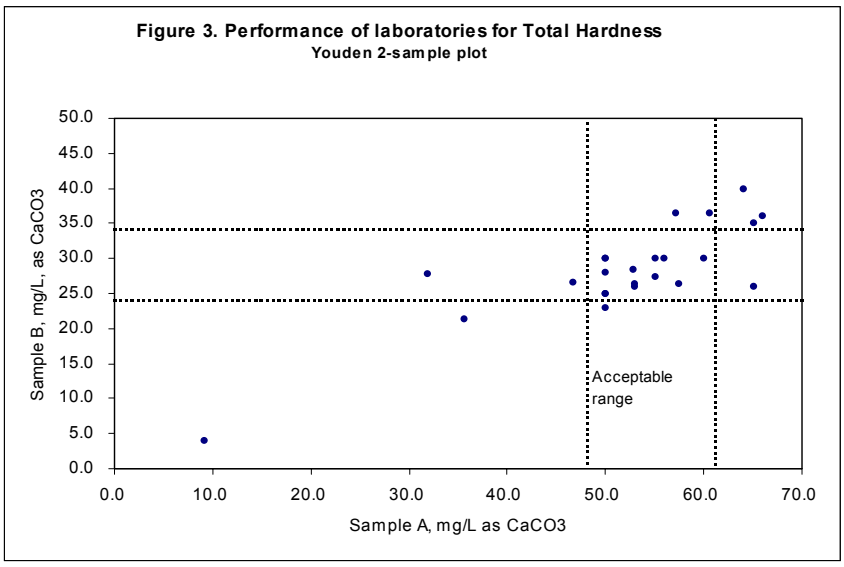
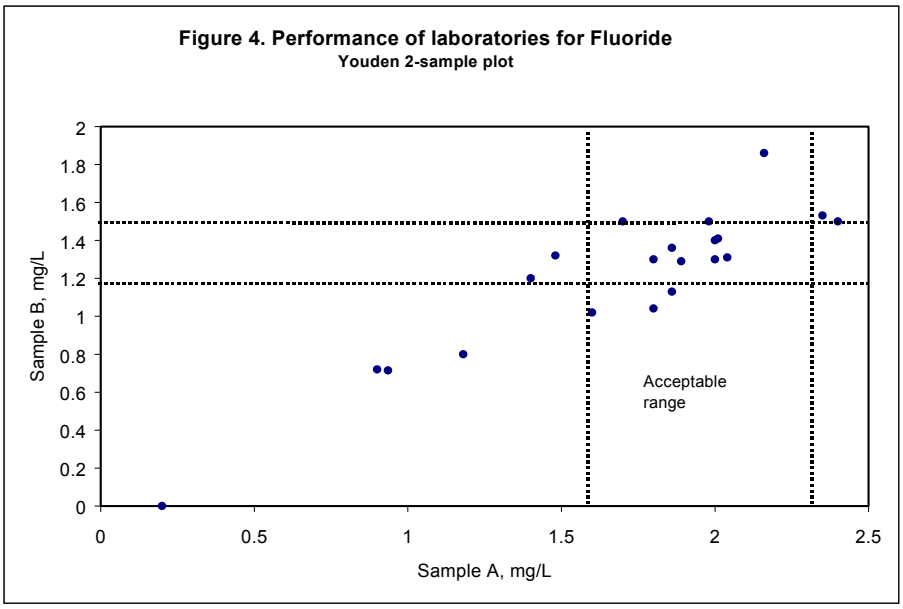


Figure 4



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Conclusion

- Co-ordinating Laboratory
  - *collate and analyse data*
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  - *individual letters identifying errors and remedial steps*

- Report should not be delayed

Add copy of Main text in chapter 8, for all participants.

7. Additional handout

These handouts are distributed during delivery and contain test questions, answers to questions, special worksheets, optional information, and other matters you would not like to be seen in the regular handouts.

It is a good practice to pre-punch these additional handouts, so the participants can easily insert them in the main handout folder.

8. Main text

Contents

1.	Introduction	1
2.	Objectives	1
3.	Planning of exercise	1
4.	Discussion of result	4
5.	Conclusion of the Exercise	6

Inter-Laboratory AQC Exercise

1. Introduction

Analytical Quality Control (AQC) is one of the main components of a Quality Assurance (QA) system, wherein the quality of analytical data being generated in any laboratory is controlled through minimising or controlling errors to achieve a target accuracy. A particular water quality study or any organised water quality monitoring programme involves the collection, comparison and interpretation of analytical data, which leads to a decision for the management and use of the water resource. The correctness of decision or action depends largely upon the accuracy of the analytical results. If the errors of the analytical results are high, the manpower, material and money spent on any monitoring programme or study would be futile and further lead to wrong decision and improper action plans.

The AQC programmes may be categorised as *within*-laboratory or *inter*-laboratory programmes. A within-laboratory exercise was described in module #49. It focuses mainly on precision and whether the system is under statistical control. Only in some cases it may point towards freshly introduced bias, for example, values of individual measurements of a determinand for a standard solution, being consistently on one side of the previously calculated mean. This module describes an *inter*-laboratory exercise.

2. Objectives

The objectives of an *inter*-laboratory AQC programme are:

1 To test for possible bias in measurements in a laboratory.

2 To provide direct evidence of comparability of results among laboratories in a common water quality monitoring programme. Some related objectives and benefits are listed below:

- to assess the status of analytical facilities and capabilities of participating laboratories.
- to identify the serious constraints (random & systematic) in the working environment of laboratories.
- to provide necessary assistance to the concerned laboratories to overcome the short comings in the analytical capabilities.
- to promote the scientific and analytical competence of the concerned laboratories to the level of excellence for better output.
- to enhance the internal and external quality control of the concerned laboratories

3. Planning of exercise

An *inter*-laboratory AQC exercise should be planned carefully with complete instructions for the participating laboratories to avoid confusion and unnecessary correspondence. A co-ordinating laboratory is chosen to assume the overall charge of the exercise. Some aspects of planning are summarised below.

3.1 Co-ordinating Laboratory

The co-ordinating laboratory distributes identical portions of the same standard solution(s) or sample to each participating laboratory, which analyses the portion it receives. Results from the different laboratories are analysed by the co-ordinating laboratory to estimate the bias of results of each laboratory.

Thus, it is essential that a laboratory able to act in this co-ordinating role is available and has sufficient time and resource for the very careful work involved. Such a co-ordinating laboratory should be a member of the working group of the analysts. On satisfactory completion of the exercise, any of the participating laboratories, which qualifies may then also act as a co-ordinating laboratory.

3.2 Test samples

The objective of distributing a solution or sample is that each participating laboratory should receive and analyse a portion containing the same concentration of the determinand. For standard solutions, the co-ordinating laboratory should know this concentration to an accuracy appreciably better than that required of normal analytical results otherwise the results of the exercise will be worthless. The need for great care in the preparation and distribution of solutions cannot, therefore, be over-emphasised. Generally, it will often be desirable for the co-ordinating laboratory alone to make preliminary tests to ensure that its procedures do achieve the above requirement.

3.3 Purity of material used to preparation of standard solutions

The chemicals used to prepare the standard test solutions should be of standard quality whose purity is guaranteed by a written specification; 99.5% or better purity is usually adequate. High purity water (de-ionised or distilled) is generally satisfactory, but absence of the determinand in such water should not be assumed.

Annexure I gives an example of the preparation of standard solutions for the analysis of the following 9 parameters. Note that two samples were prepared, one was 1.5 to 2 times more concentrated than the other in terms of the various determinands.

1 Conductivity (COND)
2 Total dissolved solids (TDS)
3 Total Hardness (TH)
4 Fluoride (F)
5 Sulphate (SO4)
6 Nitrate –N.(NO3-N)
7 Phosphate –P (PO4-P)
8 Sodium (Na)
9 Boron (B)

3.4 Errors in preparing the test solution or samples

In preparing a standard solution, it is useful that two analysts independently calculate the weight of standard material required in making up the desired volume of solution. A second analyst should check the balance readings when the standard material is weighed by the first analysis, and also independently calculate, the weight of material taken.

All apparatus used must be scrupulously clean and in particular, free from traces of the determinand of interest. Great care must be taken to avoid contamination of materials and

apparatus before and during the preparation. Manipulations such as quantitative transfers and diluting solutions to a graduation mark must be conducted with the utmost care.

When the standard solution has been prepared a question arises whether the concentration of the solution should be checked by analysis. The approach recommended is to prepare the solution as a primary standard using all the classical precautions associated with such a preparation. The freshly prepared solution should be analysed for the determinand of interest, a sufficient number of replicates being made for the purposes of stability testing. The estimate of initial concentration also serves as a check for gross errors in the preparation. The true concentration for the collaborative test should, however, be taken as the nominal concentration of the solution as a primary standard and not the analytical result obtained in the concentration check.

3.5 Determinand stability and contamination

When the distribution is carried out, several portion of solution should be retained at the co-ordinating laboratory for stability checks, and for replacements if required. The solution should be stored in containers of the type used in the distribution and under the storage conditions specified to participating laboratories. The concentration of the determinand of interest should be checked at the end of the collaborative exercise and should not have changed significantly from the initial value. For most determinands, this usually means 1% of the nominal concentration, and sufficient replicate analyses should be made to achieve that precision.

It is vitally important that the concentration of the determinand of interest in the samples should be stable throughout the period of the tests, and a preservative may some times be added to ensure this stability. However, some preservatives may cause interference in certain analytical methods, and so the possible effect of any proposed preservative on all methods of analyses must always be investigated carefully before the preservative is used.

The material of which sample bottles are made should neither absorb nor release the determinand, and bottles must be scrupulously cleaned to be free of the determinand of interest. Particular care is necessary for many trace impurities to ensure that bottle stoppers and caps are not a source of contamination.

3.6 Participating laboratories

The participating laboratories should be thoroughly familiar with the recommended analytical procedures for the parameters included in the exercise. They should have satisfactorily completed a within-laboratory exercise for the determinand producing results of acceptable precision.

The participating laboratories can easily assess sources of bias resulting from the use of impure chemicals, poor quality distilled water and sub-standard. If such errors are detected, they should be removed before starting the inter-laboratory exercise.

3.7 Proposal

The exercise is started by sending two samples by courier to the participating laboratories. The laboratories are requested to analyse both samples for various previously decided parameters. Sample of an instruction sheet and the reporting format, which may be sent with the samples is given in Annexure II.

4. Discussion of results

4.1 Reference value and acceptable range for reported values

The 'true' strength of the samples or the 'Reference value' can be determined in three different ways:

i. by the recommended analytical procedure in the reference laboratory

ii. from theoretical considerations assuming that the solutions were made correctly and that the purity of the chemicals used was as displayed on the bottle labels

iii. from the combined results of analysis of the participating laboratories.

It is recommended that the reference value against which the performance of the laboratories are to be judged is determined by the second method. However, to give a better acceptability of the standard reference value among the participating laboratories, the third method may also be adopted. The values obtained from the other two methods may the be used to check that the adopted value is not heavily biased due to the inclusion of some extreme values in the reported results.

Example 1 illustrates the procedure for calculating the reference value from the combined analysis results of the participating laboratories and the acceptable range.

Example 1

Annexe III gives conductivity values of two standard samples A and B, reported by the participating laboratories in an AQC exercise and the procedure for calculating the reference mean and the acceptable range. The theoretical conductivity and that determined by a reference laboratory for the two solutions were:

Solution	**Conductivity, micro mho/cm**	
	Theoretical	Reference laboratory
A	335	340
B	190	198

The data were first subjectively scrutinised for removal of outliers. This was followed by calculating the mean, X and S of the remaining data and the 95 % confidence limits for the mean ($\bar{x} \pm .96S$). The data values within the 95 % confidence limits were filtered out for calculating the reference mean, X_R. The conductivity values for the solutions in this manner were determined to be:

Solution	**Conductivity, micro mho/cm**
A	333
B	192

It is seen that these values are comparable to the theoretical values and those reported by the reference laboratory. These are therefore are acceptable.

In order to determine the acceptable range for the reported values, the standard deviation, S_R, of the filtered data set after rejecting the outliers is multiplied by $\sqrt{2}$ to adjust the, 'Within

Run Precision' to 'Between Day Precision', to obtain S_{adj}. This is done to account for the fact that the analyses were performed at different times at different locations. The acceptable range is then calculated as $X_R \pm 3S_{adj}$. The ranges were determined as:

Solution	Conductivity acceptable range, micro mho/cm
A	306 – 360
B	178 - 207

Values which do not fall in the calculated ranges are not acceptable. A laboratory which reports values for *both* the samples within the acceptable ranges is considered to qualify in the exercise.

4.2 Youden 2-Sample Plots

An over all view of the performance of laboratories for each parameter can be obtained from Youden 2-sample plots. Figures 1 to 4 give the plots for 4 parameters covered under an exercise. For each parameter, the plot shows the value for sample A against that for sample B reported by a laboratory. Thus there is one data point for each laboratory for the two samples.
The acceptable limits for the two samples are also drawn on the plot as two parallel horizontal lines for the sample values plotted on the Y-axis and two parallel vertical lines for the sample values plotted on the X- axis.

The centre of the rectangular block created by the two sets of parallel lines is the reference value for the parameter. Results close to this point are considered to represent a high degree of accuracy.

The figure can be divided in 4 quadrants by drawing a vertical and a horizontal line through the reference value. If only random errors influence the determinations, the points would be expected to be randomly distributed in all the four quadrants. This is rarely seen. The points tend to concentrate in the first (++) or the third (--) quadrant, indicating that the laboratories tend to get, for both the samples, either high values or low values. This points to the dominant role of systematic error. If a point lies on a line of unit slope passing through the reference value, then the determination has only systematic error.

An estimate of the random error and systematic error components of the total error (reported value minus reference value) for the result of a laboratory can be obtained by drawing a perpendicular from its data point on the line of unit slope passing through the reference value point. The ratio of random error to the systematic error is equal to the ratio of the length of the perpendicular to the distance of the foot of the perpendicular to the reference value measured along the unit slope line.

It is advisable not to reveal the identity of the laboratories on the plot. Each laboratory, however, can recognise its own result in the plot.

4.3 Coefficient of Variation

The coefficient of variation of reported results, after excluding the outliers, gives an overview of the accuracy of the participating laboratories. It is expected that as the laboratories acquire better facilities and improve their technique, the coefficient of variation would decrease.

For the data of Example 1, the coefficient of variation for the conductivity values was calculated as 5.98 and 8.54, for samples A and B, respectively. It may be noted that it was higher for the more dilute solution.

5. Conclusion of the Exercise

It is the responsibility of the co-ordinating laboratory to collate and analyse the data as early as possible, preferably within one week of the last date decided for the receipt results. The last date should be realistic and sufficient allowance should be given for procedural delays. Often some participating laboratories would not respond in time. There is indeed no need to wait for their results. Probably they would not have analysed the samples.

A copy of the combined report should be sent to each laboratory, giving the reference values, number of laboratories qualifying, parameter-wise, in the exercise and the coefficient of variation for each determination. Along with the report, a separate letter should be addressed to each of the laboratories, individually, identifying probable sources of their errors and remedial steps.

Annex: I Composition of standard samples

INGREDIENT OF SOLUTIONS, Hydrology Project, December 1998

S.No.	Name of Chemical	Weight in gm.	Final Volume	Concentration
1.	MAGNESIUM SULPHATE ($MgSO_4$, $7H_2O$)	16.4	2 litres	800 ppm Mg and 3200 ppm SO_4
2.	CALCIUM CHLORIDE ($CaCl_2$, $2H_2O$)	14.7	2 litres	2000 ppm Ca 3500 ppm Cl
3.	SODIUM FLUORIDE (NaF)	2.21	1 litre	1000 ppm F
4.	POTASSIUM NITRATE (KNO_3)	7.214	1 litre	1000 ppm NO_3-N
5.	BORIC ACID (H_3BO_3)	5.716	1 litre	1000 ppm B
6	SODIUM CHLORIDE (NaCl)	12.717	1 litre	5000 ppm Na
7	POTASSIUM DIHYDROGEN PHOSPHATE (KH_2PO_4)	0.439	1 litre	100 ppm PO_4-P

PREPARATION OF SAMPLE – A

300 ml $MgSO_4$.$7H_2O$ + 200 ml $CaCl_2$.$2H_2O$ + 80 ml NaF + 160 ml KNO_3 + 60 ml H_3BO_3 + 200 ml KH_2PO_4 + 240 ml NaCl C $\longrightarrow$ Final Volume 40 litres

PREPARATION OF SAMPLE – B

165 ml $MgSO_4$.$7H_2O$ + 100 ml $CaCl_2$.$2H_2O$ + 56 ml NaF + 100 ml KNO_3 + 30 ml H_3BO_3 + 120 ml KH_2PO_4 + 140 ml NaCl $\longrightarrow$ Final Volume 40 litres

Annex II: Communication with the despatch of samples

CENTRAL REFERNCE LABORATORY

ANALYTICAL QUALITY CONTOL, (AQC/WATER) EXERCISE – DEC.,2000 FOR THE LABORATORIES OF SURFACE AND GROUND WATER DEPARTMENTS

GENERAL INSTRUCTIONS:

Note: Please read the following instructions carefully before starting analysis of samples
Two nos. of synthetic water samples (A & B) of one lit. each labelled with lab code are provided for analysing Conductivity, Total solids, Total Hardness, Sodium, Fluoride, Sulphate, Nitrate-N, Phosphate-P and Boron.

Both samples (A & B) are to be analysed separately for all 9 parameters as shown below.

S.No.	Parameter	Unit
01	Conductivity at 25°C	μ mhos/cm
02	Total Solids	mg/l
03	Total hardness as ca CO_3	mg/l
04	Sodium	mg/l
05	Fluoride as F	mg/l
06	Sulphate as SO_4	mg/l
07	Nitrate – N	mg/l
08	Phosphate – P	mg/l
09	Boron	mg/l

Note: Choose appropriate sample volume for each parameter for single run so that analysis can be done within the provided sample volume.

ANALYTICAL METHODS:

1. You may choose any relevant method being followed in your laboratory for various parameters. However, the method is to be mentioned into the data report format.
2. In case of spectrophotometric analysis method the standard graph and the factor used for calculation is to be submitted along with the data sheet.
3. Brief outline of the procedures for each analytical parameter is to be provided as annexure along with the data sheets.

Please note the following points:
All the samples are to be analysed most preferably during 07th to 11th December' 00 for better comparison purpose of data obtained from various laboratories.

- **Report the analysis result in the enclosed Data Format Sheet only. Kindly avoid using separate typed data sheet.**
- Be sure that Lab code & sample code numbers are mentioned in the Data format sheet while sending the report.
- Be sure that all the units of various parameters are properly taken care while reporting data.
- Analysis report should be sent directly to the following address positively latest **by 25th December 2000, without fail.**

Dr. S. D. Bewtra, Additional Director Labs
3, Central Reference Laboratory
Olof Palme Marg, Delhi-110032, Fax: (011) 2320844, 2317079

AQC/WATER	DEC. 2000

LAB CODE	

ANALYTICAL QUALITY CONTROL (AQC/WATER) EXERCISE – DEC.'2000 FOR THE LABORATORY OF SURFACE AND GROUND WATER DEPARTMENTS OF CENTRAL AND STATE AGENCIES

01	**Name of the organisation**	
02	**Address of the Laboratory with PIN code, Phone & Fax**	**PIN:**
		Phone: **Fax:**
03	**Samples analysed by: (Name & designation)**	**1.** **2.**
04	**Date of receipt of samples**	

RESULT

S. No.	*Parameter*	**Sample Code**		**Method Adopted**	**Instrument Used**	**Calibration graph attached Yes/No**	**Date of Analysis**
		A	**B**				
01	Conductivity at 25°(μ mhos/cm)					--	
02	Total Solids (mg/l)					--	
03	Total Hardness as $CaCo_3$ (mg/l)					--	
04	Sodium (mg/l)						
05	Fluoride as F (mg/l)						
06	Sulphate (mg/l)						
07	Nitrate – N (mg/l)						
08	Phosphate – P (mg/l)						
09	Boron (mg/l)						

Note: A copy of the standard Calibration graph wherever applicable as to be attached in annexure

Dated: Signature of Lab incharge

Annex III: Estimation of reference value and acceptable range for conductivity measurement for samples A and B

	COND-A0	COND-A1	COND-A2	COND-B0	COND-B1	COND-B2
	110.000			140.000		
	206.000			162.000	162.000	
	260.000			167.000	167.000	
	288.000	288.000		167.000	167.000	
	298.000	298.000		175.500	175.500	
	304.000	304.000		180.000	180.000	
	311.000	311.000		180.000	180.000	
	320.000	320.000		185.000	185.000	
	320.000	320.000		186.000	186.000	186.000
	323.000	323.000	323.000	189.700	189.700	189.700
	323.000	323.000	323.000	190.000	190.000	190.000
	332.300	332.300	332.300	190.000	190.000	190.000
	335.000	335.000	335.000	193.000	193.000	193.000
	336.000	336.000	336.000	194.000	194.000	194.000
	336.900	336.900	336.900	194.000	194.000	194.000
	337.000	337.000	337.000	194.000	194.000	194.000
	338.500	338.500	338.500	196.000	196.000	196.000
	339.000	339.000	339.000	197.400	197.400	197.400
	350.000	350.000		205.000	205.000	
	350.000	350.000		210.000	210.000	
	355.000	355.000		210.000	210.000	
	360.000	360.000		218.000	218.000	
	363.000	363.000		220.000	220.000	
	405.000			225.000	225.000	
Mean, X **Mean, X_R**	316.696	330.985	 **333.411**	190.358	192.548	 **192.410**
Std Dev, SD X+1.96SD/√N X –1.96SD/√N	56.974	19.791 339.658 322.311		19.227	16.453 199.272 185.823	
SD_R			6.333			3.449
$SD_{adj} = \sqrt{2}SD_R$			8.955			4.878
Lower limit = $X_R - 3SD_{adj}$ **Upper limit = $X_R + 3SD_{adj}$**			**306.545**			**177.777**
			360.277			**207.043**

Figure 1: Performance of laboratories for Conductivity

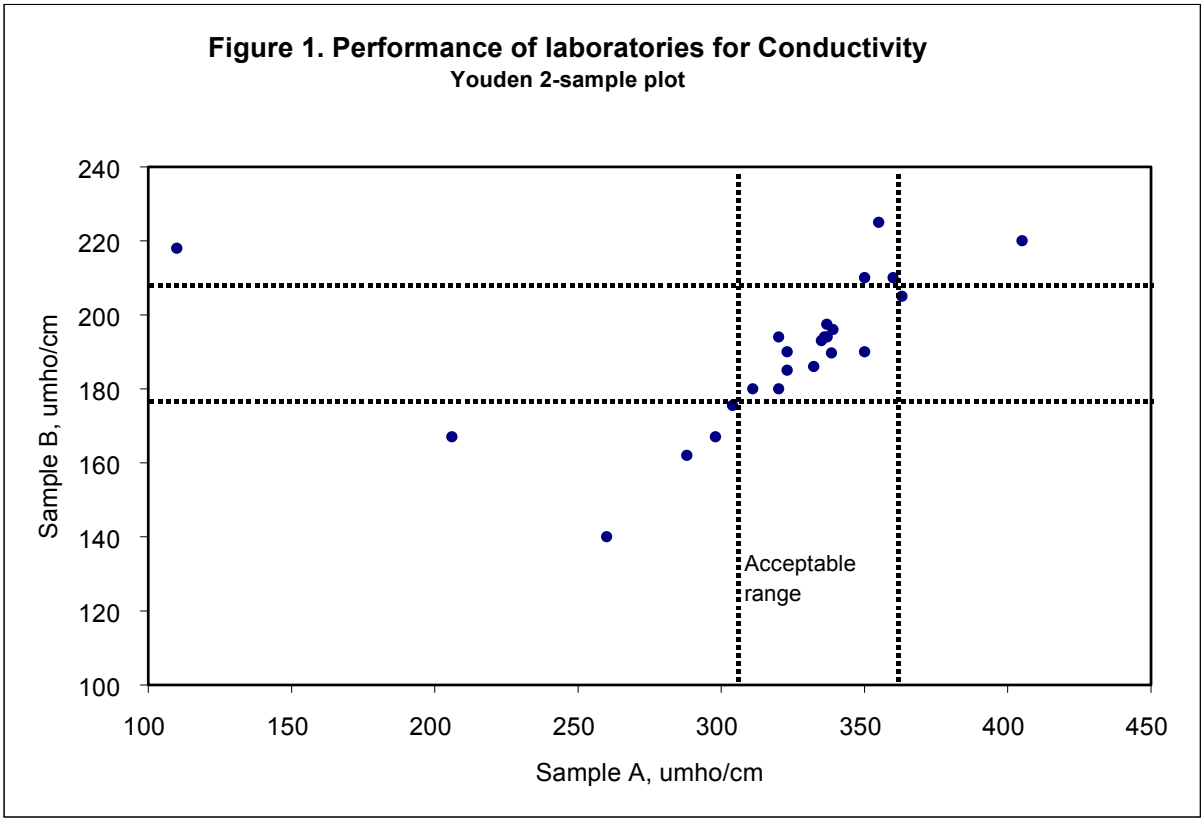

Figure 2: Performance of laboratories for Total Dissolved Solids

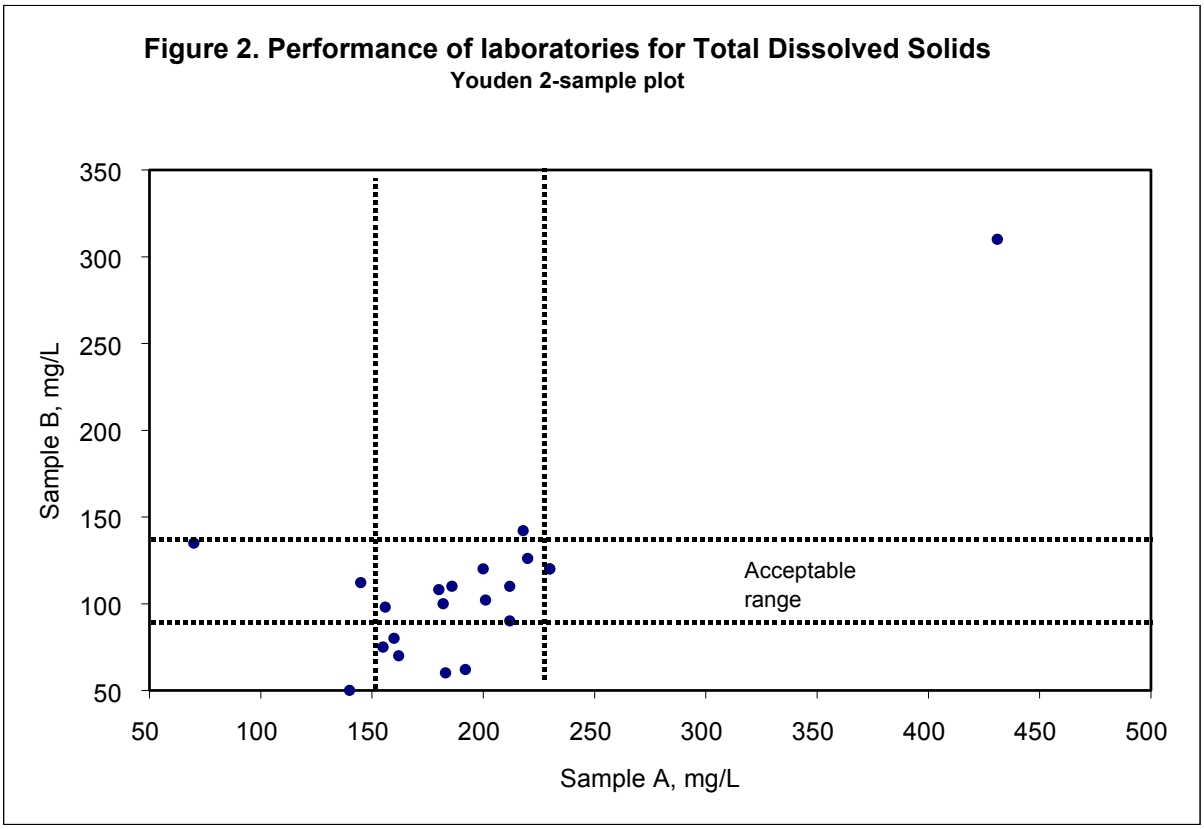

Figure 3: Performance of laboratories for Total Hardness

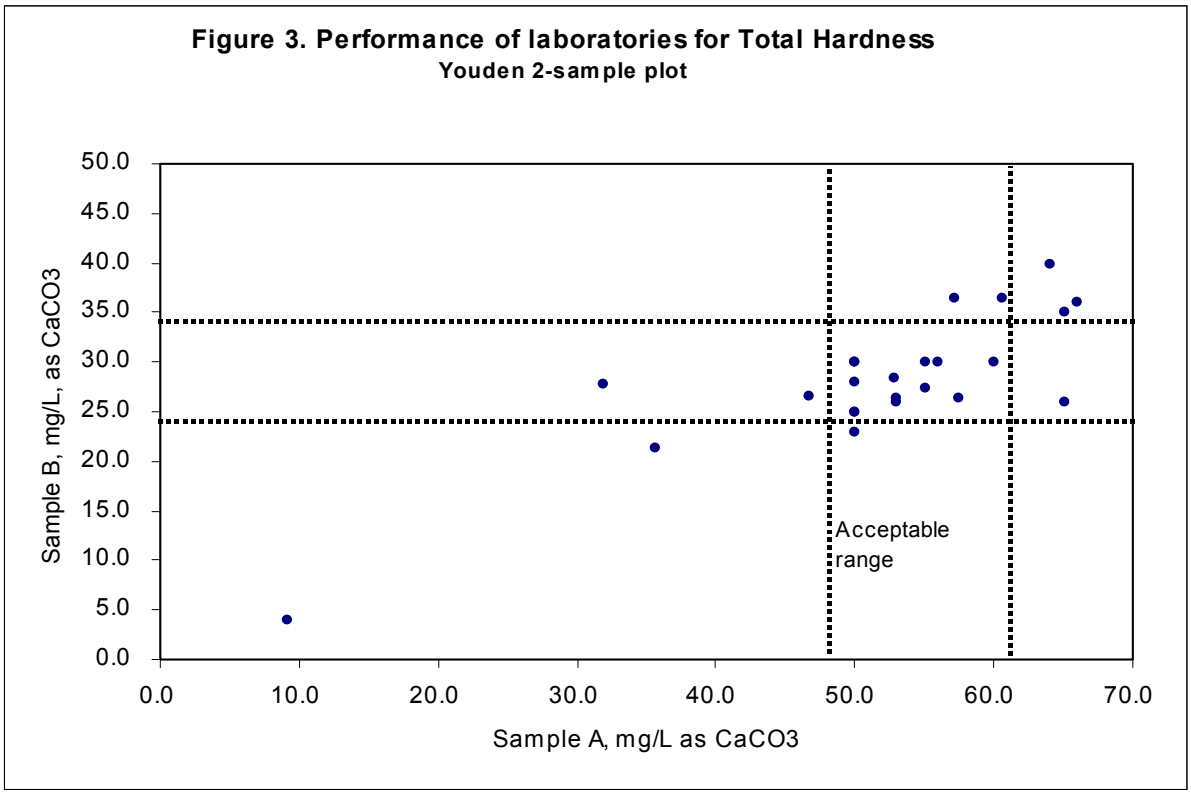

Figure 4: Performance of laboratories for Fluoride

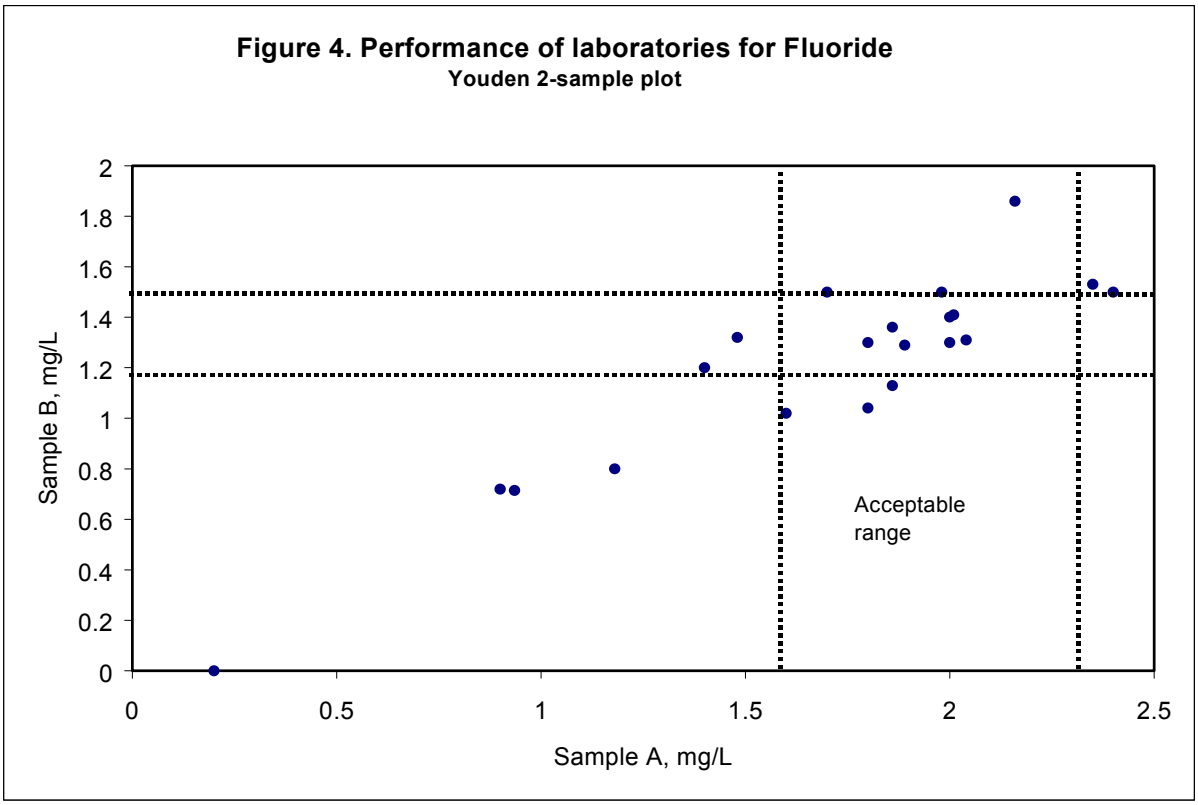

Figure 5: Performance of laboratories for Sulphate

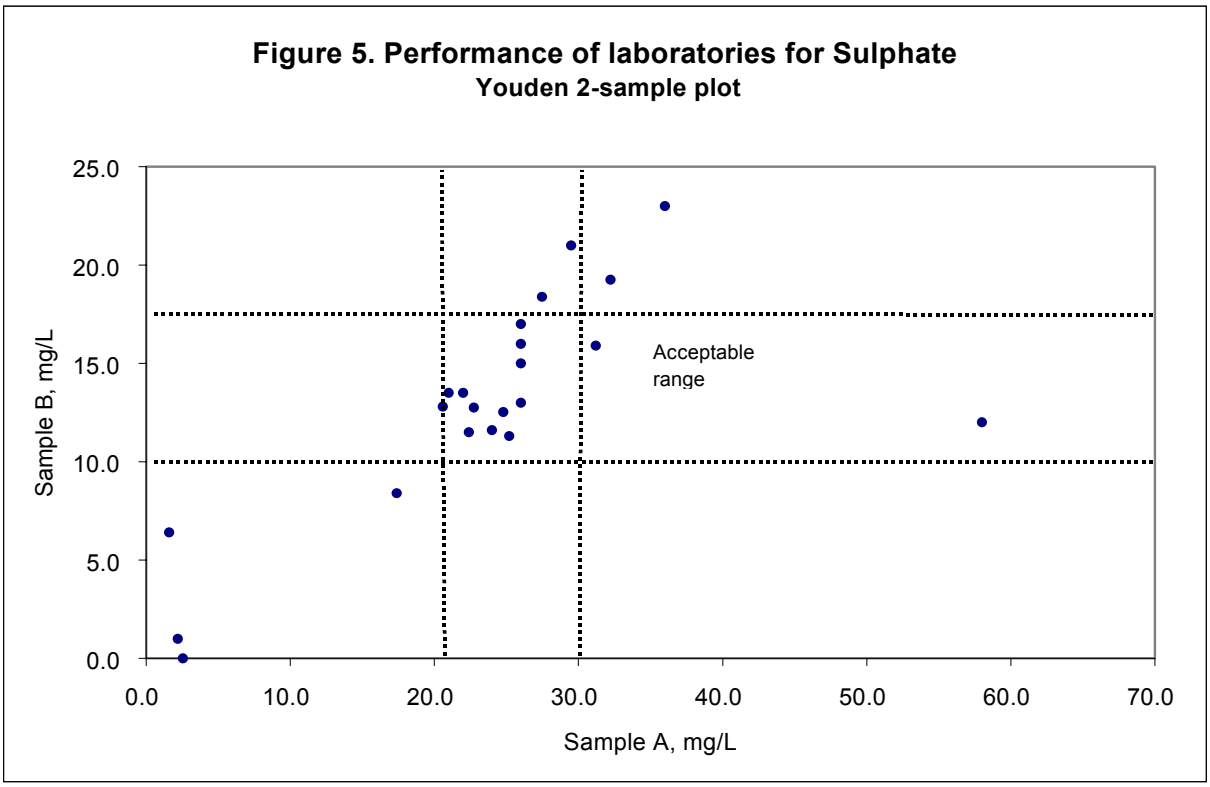

Figure 6: Performance of laboratories for Nitrate

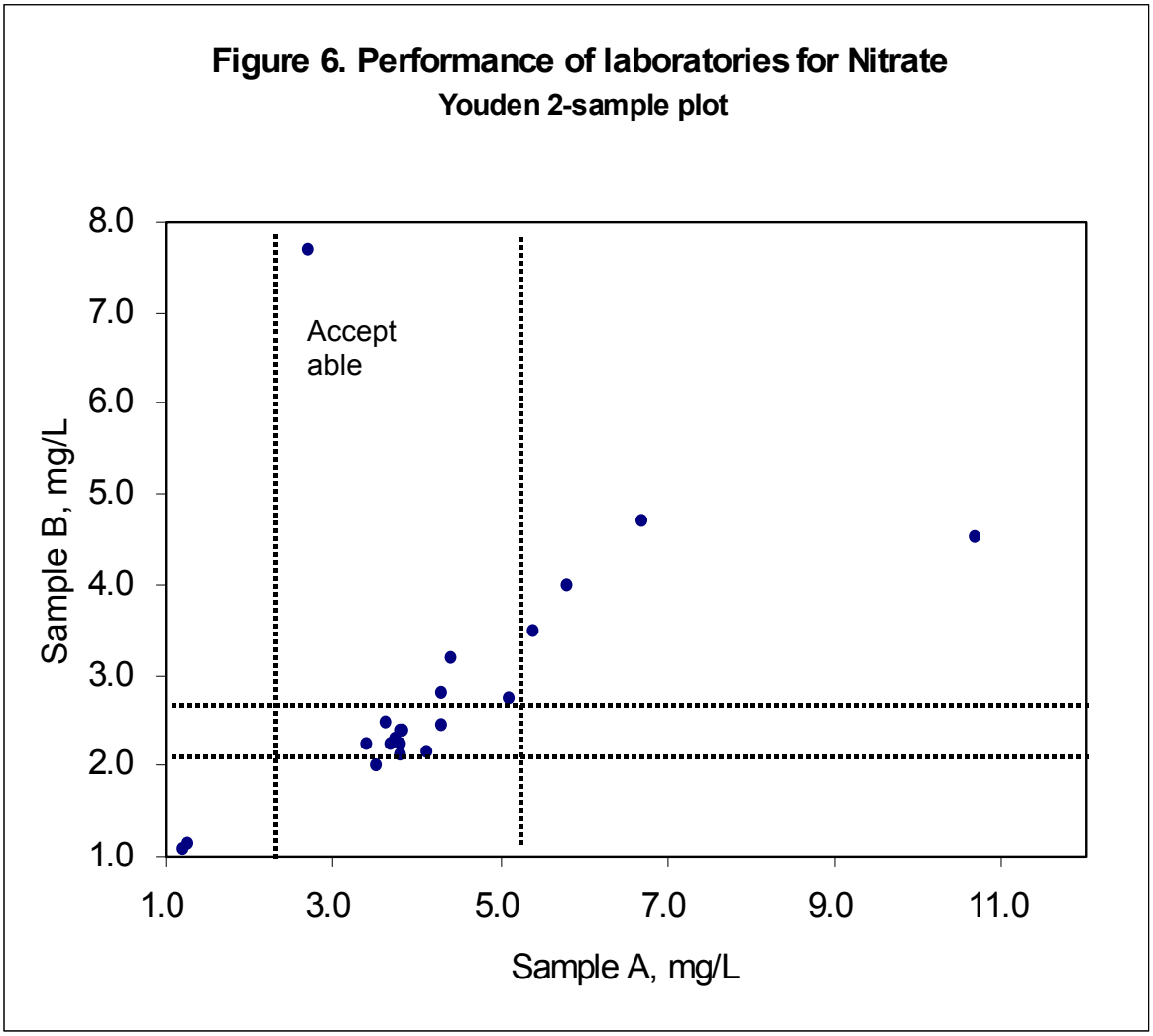

Figure 7: Performance of laboratories for Phosphate

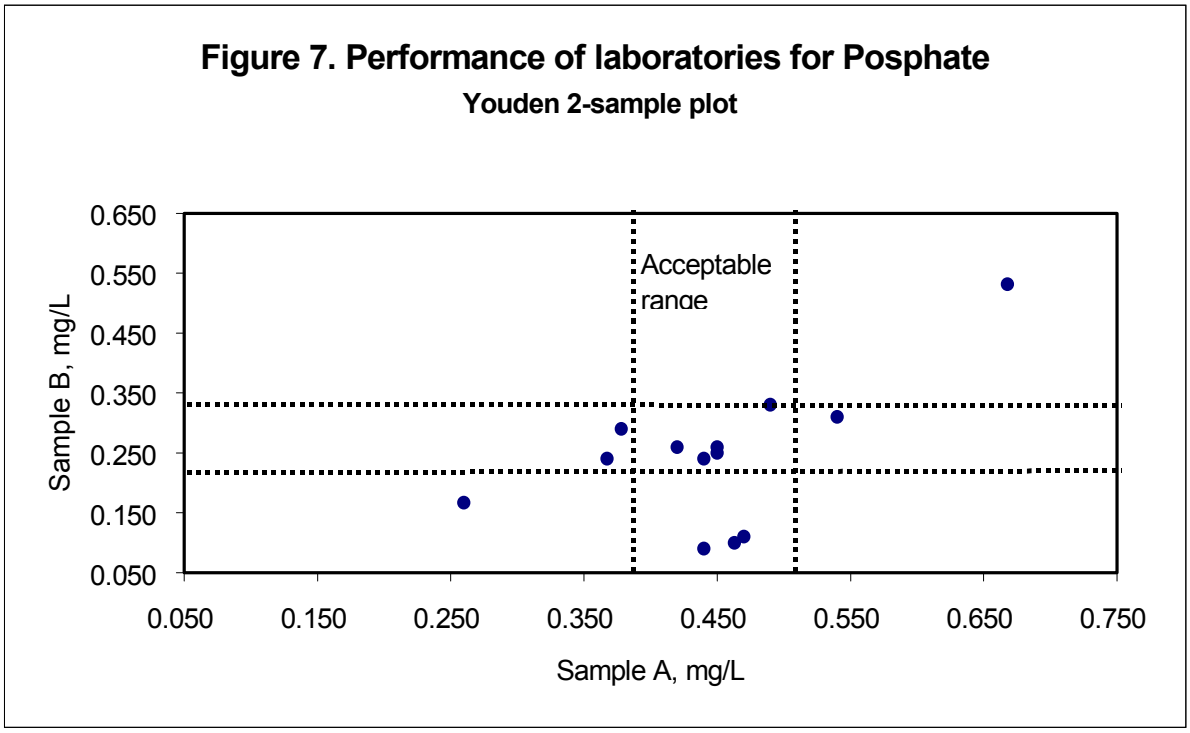

Figure 8: Performance of laboratories for Sodium

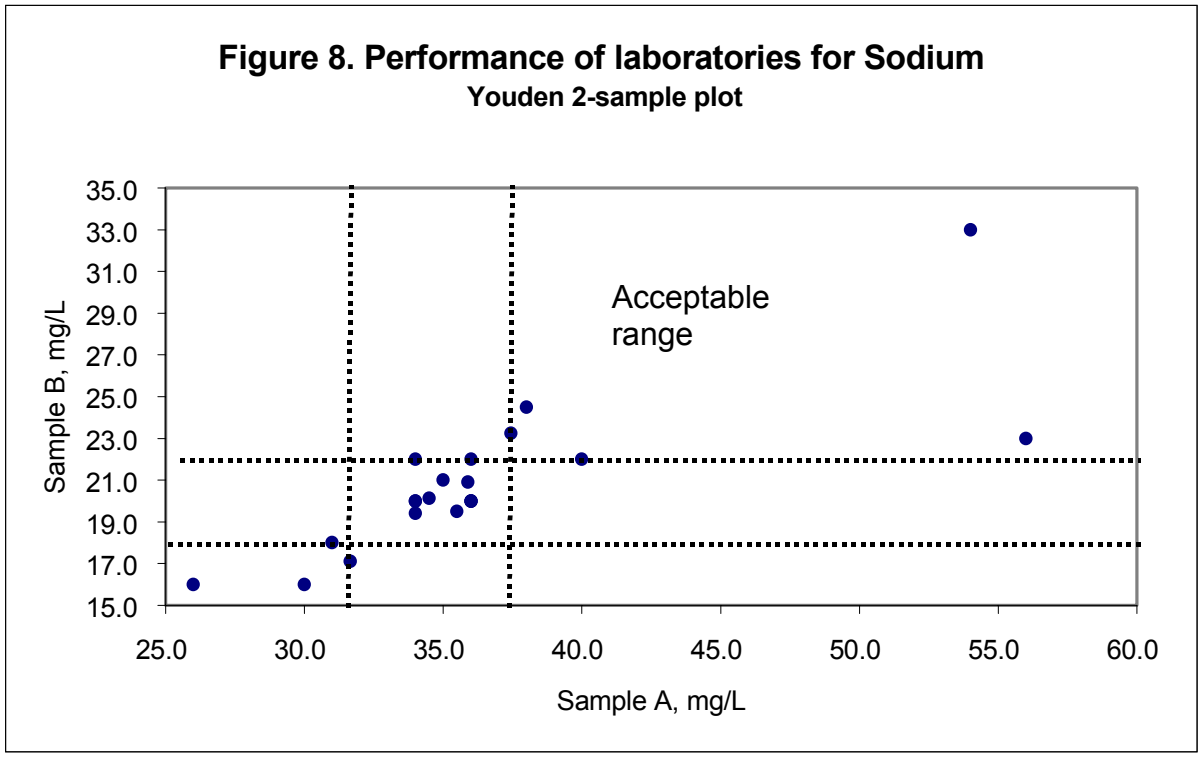

Figure 9: Performance of laboratories for Boron