



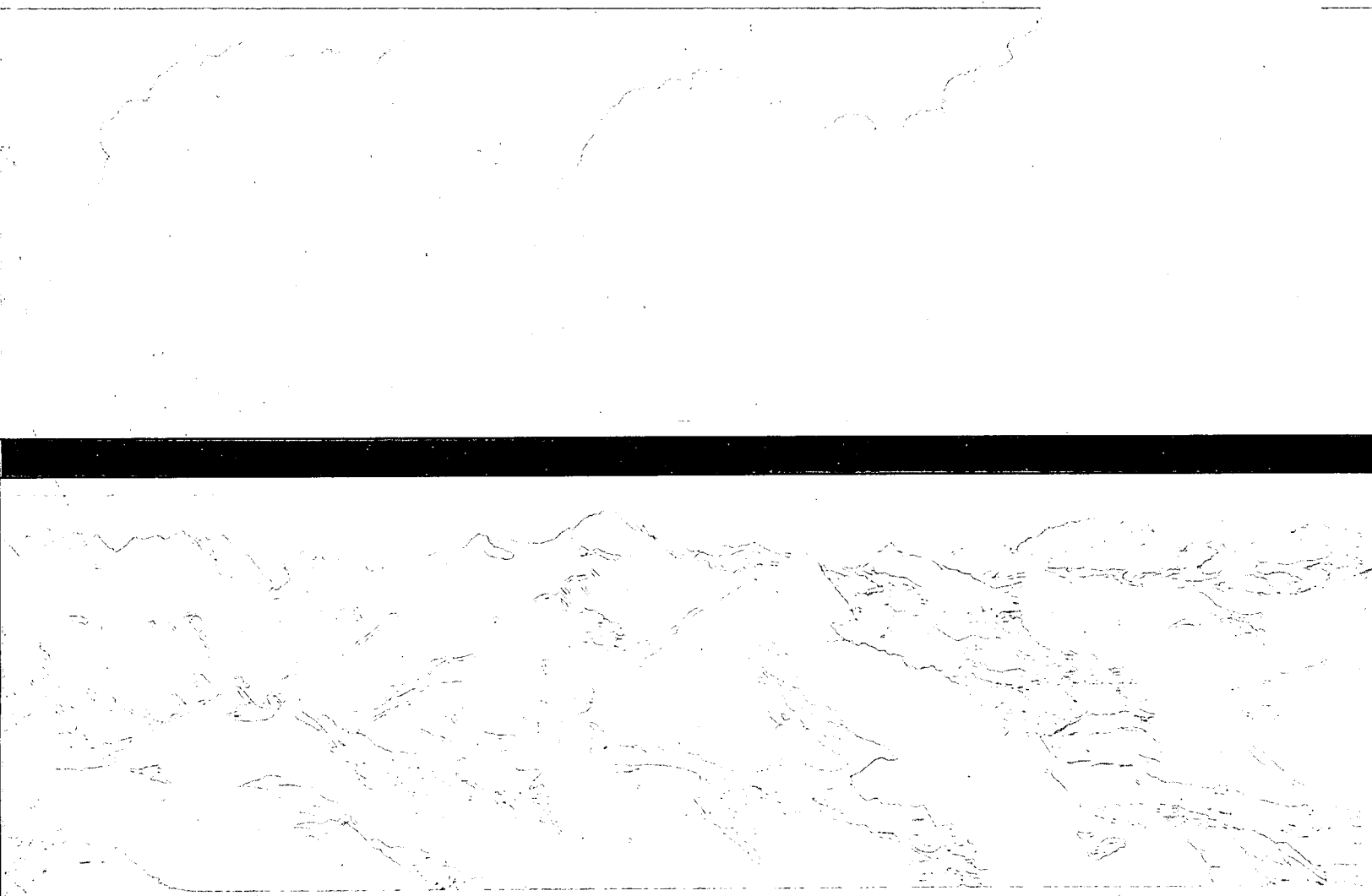
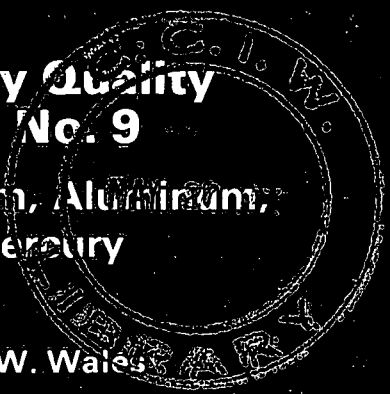
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Interlaboratory Quality Control Study No. 9

Copper, Cadmium, Aluminum, Strontium and Mercury

D. J. McGirr and R. W. Wales



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**INLAND WATERS DIRECTORATE,
CANADA CENTRE FOR INLAND WATERS,
BURLINGTON, ONTARIO, 1975**



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Abstract

Twenty-six laboratories participated in a quality control study on the determination of copper, cadmium, aluminum, strontium and mercury in water. Copper and cadmium are determined frequently by most participants in this study, and results for these two metals were satisfactory as for a previous study using standard atomic absorption techniques. Precision for aluminum was fair, with a non-zero blank reading, likely picked up from the glassware. Most participants determine aluminum rarely; some had switched methods recently. Satisfactory results for strontium were obtained by seven laboratories using atomic absorption and by five laboratories using flame emission spectroscopy. The automated method used by the Water Quality Branch (WQB) demonstrated greatly improved precision and accuracy for mercury compared to a previous study, whereas the variety of manual methods used produced many outliers.

Résumé

Vingt-six laboratoires ont participé à une étude de contrôle qualitatif en déterminant la teneur en cuivre, cadmium, aluminium, strontium et mercure dans l'eau. Le cuivre et le cadmium sont déterminés fréquemment par la plupart des participants et les résultats obtenus dans cette étude utilisant des techniques d'absorption atomique, et aussi dans le cas d'une étude précédente, ont été satisfaisants. La précision dans le cas de l'aluminium a été passable, la lecture non-zéro du réactif de référence provenant probablement du contenant en verre. La plupart des participants déterminent l'aluminium rarement et plusieurs d'entre eux ont passé à des méthodes différentes récemment. Pour ce qui est du strontium, sept laboratoires utilisant l'absorption atomique et cinq employant la spectroscopie par émission de flamme ont obtenu des résultats satisfaisants. Dans le cas du mercure, la méthode automatisée de la Direction de la qualité de l'eau a démontré un degré de précision grandement amélioré en comparaison avec celui d'une étude précédente, alors que la variété de méthodes manuelles utilisées ont produit plusieurs résultats très inexacts.

Interlaboratory Quality Control Study No. 9 Copper, Cadmium, Aluminum, Strontium and Mercury

D. J. McGirr and R. W. Wales

INTRODUCTION

This is the fourth quality control study on trace metal analysis. It covers three commonly determined metals included in previous studies—copper, cadmium and mercury—and two less commonly determined metals that have never been included in previous studies—aluminum and strontium.

EXPERIMENT DESIGN

The design of the experiment was similar to that of Studies Nos. 3 and 4 in this series. Samples were distributed in concentrated form to participants to be diluted with deionized water before analysis. The metals were then added in the form in which they are usually used to establish standards in the WQB, except mercury, which was added as mercuric chloride (HgCl_2). Samples 1 to 4, which contained copper, cadmium, aluminum and strontium, were to be diluted by a factor of 100. Samples 5 to 7, which contained mercury only, were to be diluted by a factor of 10,000. Participants were to determine the five metals in the diluted samples using their usual analytical techniques.

DATA EVALUATION

The data were treated in the same way as in previous studies; standard deviation, relative standard deviation, mean error and relative error were calculated for all results after rejection of outliers by the t-test described by Grubbs (1969). Separate statistics were calculated for those results obtained by the procedure for "extractable" metals as defined by Traversy (1971), or an equivalent procedure. Copper, cadmium and aluminum results were considered separately according to whether they were obtained by direct aspiration or solvent extraction (indicated on the report sheet).

For the purpose above, procedures were considered equivalent if they did not differ in some significant respect, such as the use of a different chelating agent, the use of a digestion or concentration step, or the use of such devices as the graphite furnace or the Sampling Boat.

Separate statistics were also calculated for other methods where there were enough data, as the statistics for single methods are more meaningful than "overall" statistics. There was only one instance (strontium) where there were enough data obtained by another method to calculate statistics. Since laboratories used their usual analytical techniques, the data calculated for individual methods (bottom part of Tables I to V) give a good indication of the performance of that method in routine use.

Individual results are tabulated in Tables VI to X. Results used for the calculation of the WQB method ("extractable" metal referred to above) are indicated by a W. In Table IX, results used for the flame emission calculation (bottom part of Table IV) are designated by an E. Results which were rejected as outliers relative to all the results taken together are flagged by an R in Tables VI to X. When parts of the results were selected for the calculation of statistics for individual methods, a separate outlier calculation was done for those selected. Only in a few cases were results rejected for an individual method that were not rejected relative to the overall results.

Laboratory 908 submitted two sets of results, one from procedures similar to the WQB method and the second from concentration by evaporation followed by direct aspiration. The first set of results is tabulated as Laboratory No. 908 and the second set as Laboratory No. 927. The latter was not included in outlier and standard deviation calculations.

There are a number of means of calculating detection limits based on statistical considerations (Ingle, 1974). In many of these, once a confidence level has been selected, the detection limit for a given procedure is calculated simply as the intra-laboratory standard deviation multiplied by a factor which is generally close to 2.

Inter-laboratory standard deviations generally exceed intra-laboratory standard deviations by a factor of about 2 or 3 (Youden, 1969). For purposes of comparison, one standard deviation, calculated for a single test method as in the bottom part of Tables I to V, can be taken as an indication of the detection limit typically obtained for that method. The standard deviation for the lowest sample for

which the calculation was done gives the most reliable indication.

The actual detection limit may vary somewhat from one laboratory to the next. The precision with which a detection limit is known is usually low, regardless of the method of estimation. Normally, detection limits should be expressed to only one significant figure.

RESULTS

Copper

Precision and accuracy for copper were both satisfactory. Mean errors were negligible (Table I) and standard deviations pointed to a detection limit of about 0.001 to 0.002 mg/l, which was in line with the claims (Traversy, 1971).

Standard deviations for the WQB method alone (lower part of Table I) were moderately lower in general than for all laboratories combined (upper part of Table I), which is to be expected when a single method is compared with a mixture of methods. Although sample 1 is an exception, it is not very significant, as the precision of the standard deviation calculated so close to the detection limit is rather low.

Enough laboratories used direct aspiration and solvent extraction for Sample 4 that separate statistics could be calculated for each procedure. Either procedure gives satisfactory precision above 0.050 mg/l.

The 0.75 mg/l sample was included because it is close to the tentative maximum acceptable level of 1.0 mg/l for copper in raw water used for municipal water supplies in Canada (Working Group on Water Quality Criteria, 1972). Surface water samples with copper concentrations at this level are encountered occasionally. There were few analytical problems at this level.

Cadmium

Cadmium in Canadian surface waters almost invariably occurs at levels near or below the detection limit of 0.001 to 0.002 mg/l, which applies to the atomic absorption methods used by most laboratories participating in this study. The level of 0.010 mg/l in sample 3 represents the tentative maximum permissible level of cadmium in raw waters used for Canadian municipal water supplies (Working Group on Water Quality Criteria, 1972).

Analytical results for cadmium were good in this study as in Study No. 4, with reasonable overall precision

throughout the range of interest and very few blank errors. Precision was good for the WQB method, pointing to a detection limit of 0.0005 to 0.001 mg/l, which was in line with the claims (Traversy, 1971).

Overall standard deviations were distinctly higher than the standard deviation for the WQB method alone (Table II). This poorer general precision can be attributed to the wide variety of methods used, including Sampling Boat, carbon rod, tantalum crucible, dithizone extraction, pre-concentration by evaporation, evaporation to dryness followed by re-resolution in acid, and one photometric procedure. Too few laboratories used any one method other than the WQB one to permit a statistically valid evaluation.

Aluminum

The WQB method for low levels of aluminum has been changed recently. A simpler oxine-MIBK extraction at pH 8.0 has replaced the older chloroform extraction method (Traversy, 1971), in the revised version of the WQB laboratory manual. Statistics in the bottom part of Table III are based on the revised procedure as no participants used the older method.

A number of participants used only the direct aspiration method and found less than their detection limit in all samples. The "less than" and N.D. (not detected) values were ignored in compiling the statistics in Table III. Values submitted by Laboratories 902 and 919 for sample 2 were rejected by use of the *w/s* statistic (Grubbs, 1969, pp. 7-10).

Although the overall precision for aluminum was comparable to that found for other metals, precision for the WQB method was relatively poor, with many low values. There are several possible explanations for this, including sample size which is very small (four laboratories), so that one or two bad results can have an exaggerated effect. Because participants determine aluminum infrequently and some have changed methods recently, they may not have solved all the problems with the new procedure.

Sample 3 contained the same level of aluminum as sample 1 and as well 0.1 mg/l iron added as FeCl_3 . The iron did not cause any serious problems, either with the WQB method or with the other methods.

Most laboratories that used methods sufficiently sensitive to detect levels in the low microgram per litre range reported readings in the 0.001 to 0.005 mg/l range for sample 4, which was a blank. This blank reading did not likely come from the samples, since they were shipped as

concentrates, but may well have resulted from laboratory glassware. Work carried out in the laboratory (Alkema, 1973) showed that there was a blank result from the glassware in the order of 0.005 to 0.01 mg/l even after rinsing with warm 1:10 nitric acid or chromic acid cleaning solution.

Storage tests done at the same time as this study and later indicated that it is common for aluminum to increase on storage in natural samples, filtered or unfiltered, even in well-cleaned plastic bottles. The problem is now under study, and sample stability is recommended for consideration as an integral part of any future method development work.

The precision of the aluminum determination at low levels can likely be improved with experience and with more attention to blank errors and other sources of random error. Pending further improvements in the routine application of the method, however, the standard deviations, the storage stability and the blank errors all indicate that it is risky to claim a detection limit much below 0.01 mg/l, even though many laboratories can "see" 0.001 mg/l.

Strontium

Most participants determined strontium by direct aspiration with the atomic absorption spectrophotometer, and the precision indicates that the limits claimed of about 0.005 to 0.01 mg/l are realistic. Since strontium concentrations in Canadian surface waters seldom fall much below 0.1 mg/l, this procedure is quite satisfactory for the purposes of most participants.

Five laboratories, designated by E in Table IX, used flame emission spectroscopy, and their results are summarized in the bottom part of Table IV. There was a small overall negative bias in this method, and the precision and sensitivity were not as good.

The precision of the WQB method was satisfactory, particularly in the lower part of the range. Better precision should be achievable at higher levels.

Mercury

Mercury was included in Study No. 4 using a similar experiment design with synthetic samples distributed as concentrates. Results were rather poor, and the WQB method in particular proved unsatisfactory. The report suggested that participants review their test procedures.

The present study shows a slight improvement in overall results and a marked improvement in the results obtained by the WQB automated method. The results obtained by

the WQB method showed better precision and fewer outliers than the overall results (Table V); in Study No. 4 the WQB method had been, if anything, slightly inferior to the other methods.

Six laboratories, marked by a W in Table X, used the WQB method. Two (906 and 920) used the Coleman mercury analyzer and the remainder a variety of manual or semi-automated procedures mostly based on the Hatch and Ott procedure (1968). Unfortunately, there are many variations of this method and some participants did not specify their procedures completely so that it was not possible to calculate separate statistics.

The original WQB method (Goulden and Afghan, 1970) has been modified since Study No. 4, and since the publication of the WQB manual (Traversy, 1971), to include potassium persulfate as well as sulfuric acid and permanganate in the oxidation step to ensure complete oxidation of organo-mercury compounds. This change is not likely responsible for the improvement shown in this study as samples were prepared with HgCl_2 only. The improvement is probably due to more experience and to the ironing out of difficulties that affected the method in the first few years of its routine application.

The superiority of the automated method over the other methods as a group is most evident in sample 5, with a true value of 0.00010 mg/l, which is close to the detection limit of most methods, but which is also close to the typical levels encountered in surface water samples. Of 21 laboratories, seven reported a "less than" value, and four reported high outliers having values of 3, 10, 20, and 47 times the true value. Six of the ten remaining laboratories used the WQB method. With such a large number of results excluded for one reason or another, it was considered meaningless to calculate overall statistics for this sample. Statistics for the WQB method are presented in the lower part of Table V and show satisfactory performance at this low level.

Admittedly, some laboratories using manual methods obtained acceptable results; however, the general picture indicates that the manual methods tend to be "outlier-prone" and insensitive, whereas there were few poor results among the data collected by the WQB automated method.

The level of 0.005 mg/l in sample 6 represents the tentative maximum permissible level of mercury in drinking water in both the U.S.A. and the U.S.S.R. (U.S. Public Health Service, 1970). Mercury at this level or higher is encountered in about 3 to 5% of river samples in North America. Precision at this level was not much better than at the intermediate level of 0.00035 in sample 7.

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Tables

Table I. Copper Results
(all concentrations in mg/l)

All Laboratories	Sample Number				
	1	2	3	4	
true value	0.005	0.015	0.750	0.090	
no. of results used	22	25	25	24	
no. of outliers rejected	1	0	0	2	
mean	0.00511	0.0148	0.770	0.0901	
standard deviation	0.00074	0.0023	0.053	0.0081	
relative std. dev.	14%	15%	6.9%	9.0%	
mean error	0.00012	-0.00022	0.020	0.00013	
relative error	2.4%	-1.5%	2.7%	1.4%	
WQB method only	1 ext.	2 ext.	3 direct	4 direct	4 ext.
true value	0.005	0.0150	0.750	0.090	0.090
no. of results used	12	11	15	9	6
no. of outliers rejected	0	0	1	0	1
mean	0.00533	0.0146	0.770	0.0900	0.0905
standard deviation	0.00156	0.00157	0.033	0.0103	0.0066
relative std. dev.	29%	11%	4.2%	11%	7.3%
mean error	0.00033	0.00045	0.020	0.000	0.0005
relative error	6.7%	-3.0%	2.7%	0	0.6%

Ext = statistics based on results obtained by solvent extraction only.
Direct = statistics based on results obtained by direct aspiration only.

Table II. Cadmium Results
(all concentrations in mg/l)

All Laboratories	Sample Number				
	1	2	3	4	
true value	0.005	0.050	0.010	0.000	
no. of results used	22	23	21		
no. of outliers rejected	1	0	2		
mean	0.00589	0.0485	0.0102		
standard deviation	0.00227	0.0123	0.0018		
relative std. dev.	39%	25%	18%		
mean error	0.00089	-0.0015	0.00024		
relative error	18%	-3.1%	2.4%		
WQB method only	1 ext.	2 ext.	2 direct	3 ext.	4
true value	0.005	0.050	0.050	0.010	0.000
no. of results used	9	5	7	9	
no. of outliers rejected	1	2	0	1	
mean	0.00489	0.0446	0.0509	0.0101	
standard deviation	0.00078	0.0049	0.0031	0.00093	
relative std. dev.	16%	11%	6.2%	9.2%	
mean error	-0.00011	-0.0054	0.00086	0.00011	
relative error	-2.2%	-10.8%	1.7%	1.1%	

Ext = statistics based on results obtained by solvent extraction only.
Direct = statistics based on results obtained by direct aspiration only.

Table III. Aluminum Results
(all concentrations in mg/l)

All Laboratories	Sample Number			
	1	2	3†	4
true value	0.030	0.010	0.030	0.000
no. of results used	11	8	11	6
no. of outliers rejected	0	2	0	
mean	0.0256	0.0100	0.0286	0.003
standard deviation	0.0057	0.0019	0.0065	
relative std. dev.	22%	19%	23%	
mean error	-0.0044	0.0000	-0.0014	
relative error	-14.7%	0	-4.8%	
WQB method* (all extracted)				
true value	0.030	0.010	0.030	0.000
no. of results used	4	3	4	3
no. of outliers rejected	0	0	0	
mean	0.0228	0.0083	0.0268	0.002
standard deviation	0.0071		0.0093	
relative std. dev.	31%		35%	
mean error	-0.007	-0.0017	-0.0033	0.002
relative error	-24%		-11%	

*Extracted with oxine/MIBK; this method has been adopted subsequent to publication of the WQB lab manual.

†Contained 0.1 mg/l Fe as FeCl₃.

Table IV. Strontium Results
(all concentrations in mg/l)

All Laboratories	Sample Number			
	1	2	3	4
true value	0.040	0.150	0.000	0.080
no. of results used	15	15		14
no. of outliers rejected	0	0		1
mean	0.0389	0.1442		0.0793
standard deviation	0.0093	0.0187		0.0064
relative std. dev.	24%	13%		8.0%
mean error	-0.0011	-0.0058		-0.0007
relative error	-2.8%	-3.9%		-0.8%
WQB method (direct only)				
true value	0.040	0.150	0.000	0.080
no. of results used	7	7		7
no. of outliers rejected	0	0		0
mean	0.0421	0.1429		0.0853
standard deviation	0.0037	0.0214		0.0122
relative std. dev.	8.7%	15%		14%
mean error	0.0021	-0.0071		0.0053
relative error	5.4%	-4.8%		6.6%
Flame emission (5 labs)				
mean	0.0316	0.1358		0.0730
standard deviation	0.0134	0.0176		0.0092
relative std. dev.	43%	13%		13%
relative error	-21%	-9.5%		-8.8%

Table V. Mercury Results
(all concentrations in mg/l)

	Sample Number		
	5	6	7
All Laboratories			
true value	0.000100	0.00500	0.00035
no. of results used	10	20	16
no. of outliers rejected	4	1	1
mean	—	0.00509	0.000399
standard deviation	—	0.00124	0.000153
relative std. dev.	—	24%	38%
mean error	—	0.000086	0.000049
relative error	—	1.7%	14%
Automated WQB method only	5	6	7
true value	0.000100	0.00500	0.00035
no. of results used	6	6	6
no. of outliers rejected	0	0	0
mean	0.000103	0.00472	0.000365
standard deviation	0.000010	0.00111	0.000063
relative std. dev.	10%	21%	17%
mean error	0.000003	-0.00028	0.000015
relative error	3.3%	-5.6%	4.3%

Table VI. Copper Analytical Results in mg/l

Lab. No.	Sample Number			
	1	2	3	4
901 W	0.005	0.015	0.780	0.092
902	0.0046	0.0144	0.700	0.140 R
903 W	0.0049	0.0045 R	0.84	0.09
904 W	<0.01	0.01	0.80	0.08
905 W	0.004	0.015	0.70	0.09
906 W	0.006	0.015	0.743	0.085
907 W	0.005	0.015	0.75	0.093
908 W	0.005	0.014	0.790	0.090
909 W	0.010 R	0.014	0.750	0.100
910	0.007	0.015	0.750	0.090
911	0.0050	0.0103	0.76	0.0840
912 W	0.004	0.015	0.75	0.09
913 W	<0.01	0.02	0.80	0.09
914	0.005	0.015	0.80	0.100
915 W	0.005	0.016	0.78	0.09
916	0.007	0.019	0.92	0.079
917	0.005	0.015	0.75	0.085
918 W	0.005	0.015	0.8	0.1
919 W	0.005	0.015	0.660	0.080
920	0.005	0.016	0.86	0.10
921 W	<0.01	0.015	0.74	0.075
922 W	0.005	0.015	0.74	0.088
923 W	0.005	0.01	0.83	0.11
924	0.005	0.010	0.78	0.062
925	0.005	0.016	0.78	0.092
926	0.005	0.015	0.740	0.090
927	0.004	0.015	0.798	0.144
true value	0.005	0.015	0.750	0.090

W = used for the calculation of the WQB method.
R = rejected as outliers relative to all the results.

Table VII. Cadmium Analytical Results in mg/l

Lab. No.	Sample Number			
	1	2	3	4
901 W	0.004	0.050	0.009	0.001
902	0.005	0.067	0.014	<0.00004
904 W	0.01	0.05	0.01	<0.01
905 W	0.004	0.04	0.010	<0.001
906 W	0.011	0.079	0.020 R	<0.002
907 W	0.005	0.05	0.01	<0.001
908 W	0.005	0.051	0.010	<0.001
909 W	0.008	0.055	0.011	0.001
911	0.0031	0.0418	0.0136	<0.0010
912 W	0.0050	0.045	0.0100	<0.0001
914	0.005	0.050	0.010	<0.005
915 W	0.005	0.05	0.009	<0.001
916	0.008	0.041	0.005	0.000
917	0.006	0.048	0.011	<0.001
918 W	0.006	0.019	0.011	0.001
919 W	0.005	0.041	0.010	0
920	0.020 R	0.061	0.023 R	0.010
921 W	0.01	0.052	0.01	<0.01
922 W	0.006	0.053	0.012	<0.001
923	0.0046	0.03	0.01	<0.001
924	0.005	0.060	0.011	N.D.
925 W	0.004	0.042	0.010	0.000
926	0.004	0.050	0.010	<0.001
927	0.005	0.052	0.010	<0.001
true value	0.005	0.050	0.010	0.000

W = used for the calculation of the WQB method.
R = rejected as outliers relative to all the results.
N.D. = not detectable.

Table VIII. Aluminum Analytical Results in mg/l

Lab. No.	Sample Number			
	1	2	3	4
901	<0.06	<0.06	<0.06	<0.06
902	0.025	0.014 R	0.030	<0.0025
905 W	0.03	0.011	0.03	0.001
906	0.025	0.010	0.020	0.005
908 W	0.023	0.009	0.037	0.004
912	0.03	0.01	0.03	<0.01
913	<0.1	<0.1	<0.1	<0.1
914	0.02	0.01	0.03	<0.01
916	<0.1	<0.1	<0.1	<0.1
917	<0.05	<0.05	<0.05	<0.05
918	0.03	0.01	0.03	N.D.
919 W	0.013	0.006 R	0.015	0.003
920	0.030	0.010	0.037	N.D.
921	<0.1	<0.1	<0.1	<0.1
922	<0.10	<0.10	<0.10	<0.10
924 W	0.025	N.D.	0.025	N.D.
925	0.030	0.010	0.030	0.000
926	<0.060	<0.060	<0.060	<0.060
927	0.028	0.013	0.033	0.006
true value	0.030	0.010	0.030	0.000

W = used for the calculation of the WQB method.
R = rejected as outliers relative to all the results.
N.D. = not detectable.

Table IX. Strontium Analytical Results in mg/l

Lab. No.	Sample Number			
	1	2	3	4
901	0.045	0.160	<0.010	0.080
905 W	0.04	0.17	<0.01	0.08
906 W	0.05	0.11	<0.05	0.11 R
907 W	0.043	0.12	<0.020	0.072
912 W	0.04	0.15	<0.02	0.09
914 E	0.020	0.120	<0.005	0.075
915	0.04	0.16	<0.02	0.08
917 E	0.034	0.121	<0.001	0.062
918 E	0.048	0.13	N.D.	0.065
919 W	0.042	0.150	0.011	0.085
920 E	0.016	0.16	N.D.	0.083
921 E	0.040	0.148	<0.003	0.080
922 W	0.04	0.14	<0.01	0.08
924 W	0.04	0.16	<0.01	0.08
926	0.045	0.156	0.002	0.082
true value	0.040	0.150	0.000	0.080

W = used for the calculation of the WQB method.

R = rejected as outliers relative to all the results.

N.D. = not detectable.

E = used for the flame emission calculation.

Table X. Mercury Analytical Results in mg/l

Lab. No.	Sample Number		
	5	6	7
901	<0.0001	0.0041	0.0003
902	0.000108	0.00504	0.00030
903	<0.0002	0.006	0.0005
904	<0.0002	0.003	0.0002
905 W	0.00010	0.0050	0.00038
906	0.001 R	0.004	<0.001
907 W	0.00012	0.0032	0.00027
909	<0.001	0.0065	<0.001
910	<0.001	0.0055	<0.001
912 W	0.00011	0.00520	0.00032
914	0.00010	0.0048	0.00035
915 W	0.00010	0.0055	0.00037
916	<0.0002	0.0045	<0.0002
917	0.000094	0.00458	0.000307
920	0.002 R	0.005	0.0006
921	0.0047 R	0.0085	0.0058 R
922 W	0.00009	0.0059	0.00045
923	0.0003 R	0.005	0.0008
924 W	0.0001	0.0035	0.0004
925	0.00010	0.0048	0.00034
926	<0.0001	0.0006 R	0.0004
true value	0.000100	0.00500	0.00035

W = used for the calculation of the WQB method.

R = rejected as outliers relative to all the results.

Appendix A

APPENDIX A

LIST OF PARTICIPANTS

Environment Canada, Water Quality Laboratories

Pacific Region (Vancouver)
Western Region (Calgary)
Ontario Region, Inorganic Laboratory (Burlington)
Ontario Region, Ship Support Laboratory (Burlington)
Atlantic Region (Moncton)

Environment Canada, Environmental Protection Service

Technology Development and Demonstration Division
(Burlington)
Water Pollution Control Directorate (Ottawa)
Quebec Region (Montreal)
Atlantic Region (Halifax)

Environment Canada, Fisheries and Marine Service

Fisheries Laboratory (Vancouver)

Provincial Governments

B.C. Water Resources Service (Vancouver)
Alberta Department of the Environment (Edmonton)

Manitoba Department of Mines, Resources and
Environmental Management (Winnipeg)
Ontario Ministry of the Environment (Toronto)
Ministère des Affaires Sociales (Laval-des-Rapides)
Ministère des Richesses Naturelles (Québec)
New Brunswick Department of Fisheries and
Environment (Fredericton)
P.E.I. Department of Agriculture (Charlottetown)
Nova Scotia Department of Public Health (Halifax)

Municipal Governments

City of Winnipeg Waterworks and Waste Disposal
(Winnipeg)
City of Montreal Filtration Plant (Verdun)

Industrial and Consulting Laboratories

B.H. Levelton and Associates (Vancouver)
Chemex Labs Ltd. (North Vancouver)
Cominco Ltd. (Trail, B.C.)
Chemex Labs Ltd. (Calgary)
Bondar – Clegg & Co. Ltd. (Ottawa)

Environment Canada Library, Burlington



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