

MINISTRY OF ENVIRONMENT AND PARKS  
PROVINCE OF BRITISH COLUMBIA

MICROBIOLOGICAL INDICATORS

- A discussion of the relevance of counts and ratios

P.D. Warrington, Ph.D.  
1990

Resource Quality Section  
Water Management Branch  
Victoria, B. C.



## INTRODUCTION

As a result of the literature surveys required in order to write "Water Quality Criteria for Microbiological Indicators", Warrington - 1988, a number of questions were raised concerning the adequacy and specificity of the current health related monitoring practices carried out in British Columbia. Some data gathering activities were carried out to help answer these questions.

Several good reviews of problems and practices in the field of microbiological contamination of ambient waters, and how to ascertain the significance of the numbers obtained in sampling programs, are available. The following are recommended as an introduction: Hoadley and Dutka - 1977, Pipes - 1982, Berg - 1983, Warrington - 1988, 1988A.

### Sampling and Analysis: Variability and Representativeness

By definition the total coliform/fecal coliform, total coliform/E. coli and fecal coliform/E. coli ratios should all be greater than 1.0. Inspection of Tables 1 and 2 shows that this is not always true, especially for FC/E. coli. This is a reflection of sampling, sub-sampling and analysis activities and establishes how far apart measured values need to be before they are significant. Microbiological data is intrinsically very variable due to the 'clumped' nature of the distribution of the organisms. They tend to be concentrated on particles of organic material rather than evenly dispersed throughout the water. Table 3 gives means and standard deviations for some Kalamalka Lake data which shows how variable the data is; generally the standard deviation is larger than the mean value. The sample sizes for this data are given in Table 4 to show that most samples are quite large and that the variability is intrinsic and not a function of small sample numbers.

Duplicate samples were taken about five minutes apart at a beach on Kalamalka Lake, over a period of three months. There were 47 pairs of duplicates for each of E. coli, fecal coliforms and total coliforms, Table 8, and they show considerable variability. If one calculates what percentage the smaller of a pair of duplicates, is of the larger, for each pair, the range is quite extreme. It varies from a maximum of 100%, for all bacteria, to a minimum of 3% for total coliforms, 7% for fecal coliforms and 6% for E. coli. The mean percent is between 47% and 51% for all three bacterial groups.

With this kind of variability, a great many duplicate samples would be required in order to get an accurate measure of the average concentration in a natural body of water. What is the value of this average to a swimmer who ingests water that is much higher than the average and gets sick, even though the average meets the health criteria for swimming?

Fecal coliforms vs. E. coli

There is currently debate in the literature over whether or not the fecal coliform test should be replaced by an E. coli test, due to the greater specificity of E. coli for indicating fecal contamination. In most situations, almost all the fecal coliforms should be E. coli anyway, but there are exceptions. Where conditions of high organic loading from food, dairy and pulp and paper wastes occur, Klebsiella may be a significant component of the fecal coliform total. If this is so, then fecal coliforms are not good indicators of the risk of contracting a human pathogen, and E. coli should be measured directly. The main reason for the increased proportion of Klebsiella is their ability to grow and replicate in vitro in these organic wastes, while E. coli does not share this ability to the same extent.

Samples were taken from a pulp mill waste settling pond, which had no known input of human waste. One would have expected most fecal coliforms to be Klebsiella and few, if any, to be E. coli. Due to the nature of the samples, analyses for E. coli could not be carried out. The fecal coliform-to-total coliform ratio was 0.026; fecal type organisms were greatly outnumbered and outcompeted in the utilization of this organic nutrient source. Table 5 presents the raw data.

Samples were also taken from a wine and fruit juice waste aeration lagoon. The only fecal inputs to this waste were from visiting waterfowl. The ratio of E. coli to fecal coliforms was 0.28; the remainder was presumed to be Klebsiella. This water met existing recreational criteria based on the E. coli count, but not based on the fecal coliform count. The important question is whether or not there is a health risk at these fecal coliform levels if the E. coli component is relatively small and below fecal coliform criteria limits. This data is given in Table 6.

Kalamalka Lake beach samples gave very consistent ratios of 1.1, fecal coliforms over E. coli, except for one sample at one site with a very high E. coli count. Virtually all these fecal coliforms are E. coli and this is the usual case with animal or human waste contamination of ambient waters. Tables 3 and 4 give this data.

Fecal coliform to fecal streptococci ratios

Geldreich and Kenner - 1969, reported that ratios of 4.0 or greater were found in human feces and wastewater, for fecal coliforms/fecal streptococci. The ratio was less than 0.7 for animal feces, farm drainage and separate stormwater systems. In addition, the literature indicates that Salmonella levels are generally less than 1% in man and over 10 - 20% in livestock. If consistently true, this information could help to determine the source of fecal contamination of ambient waters.

The ratio for waterfowl found by Hussong et al - 1979, was similar to that found in man. The ratio in the Canada geese and whistling swans appeared to be diet dependent; wild birds had ratios of 3.9 and 9.2 respectively, while fasting or captive birds had ratios of 0.1 and 0.6. The fecal coliform to fecal streptococci ratio for the pulp waste reported in Table 5 averaged 0.51 (2.4 - 0.14) and no animal wastes of any kind were found in this material. Fecal streptococci can, however, multiply in this type of waste. Similarly, the ratio in the wine and juice wastes was 0.24 (4.92 - <0.01), Table 6, and while there were no animal feces in the wastes themselves, birds did visit the aeration pond. Again, fecal streptococci could multiply in this waste which would tend to increase the ratio.

Table 7 from Olivieri et al - 1977, shows how much variability occurs in the ratios, with a large data set from a number of different sites. Human enteric viruses were found in 75 - 100% of the storm samples, indicating human fecal contamination, even though the majority of the ratios indicated animal sources.

It is difficult to take fecal coliform/fecal streptococci ratios seriously in the face of the extreme variability of such ratios; even in fecal matter itself, the ratios vary widely, Table 2, and in natural waters many factors influence the relative abundance of the two bacteria. Such ratios should not be used in isolation to determine the source of contamination in a natural system; field or sanitary surveys are required, Olivieri - 1981. Geldreich and Kenner - 1969, indicate that ratios should be applied and interpreted with some caution. They are most meaningful when

collected at outfalls, before entering the open waters, since various environmental variables and differential die-off rates, will affect the ratios. A maximum travel time downstream of 24 hours is suggested as a limit within which the ratio is of value. In any case, ratios of fecal coliforms/ fecal streptococci between 0.7 and 4.0 are difficult to interpret.

Since it would be of value to be able to distinguish different species or groups of animals as potential sources of pollution in recreational waters, fresh fecal material was analyzed from a number of species which frequent such habitats. Moose, beaver and muskrat would also have been of interest but fecal samples could not be obtained. In the homeothermic animals tested, most of the total coliforms were fecal coliforms, and most of these were E. coli. However, in the poikiothermic fish, the fecal coliforms formed a small proportion of the total coliforms, but most of these fecal coliforms were E. coli. The fecal coliform/fecal streptococci ratios varied quite widely, even for duplicate samples of the same species of animal.

Some data of Reimers et al - 1990, indicates that in storage lagoons in sub-tropical conditions, the coliforms all die-off within about a year, but that there is no reduction in fecal streptococci numbers. Thus the ratio of FC/FS will rapidly get smaller with time. This puts severe restraints on the value of FC/FS ratios for environmental water quality investigations, even if the initial ratios were self-consistent and distinct for different sources.

TABLE 1

MF Counts/gm fecal weight

Coliforms			Fecal Strep.	Sample	
Total	Fecal	<u>E. coli</u>		Animal	#
2.4 x 10 <sup>6</sup>	1.8 x 10 <sup>6</sup>	2.1 x 10 <sup>6</sup>	3.0 x 10 <sup>9</sup>	Horse	1
1.9 x 10 <sup>6</sup>	1.8 x 10 <sup>6</sup>	1.8 x 10 <sup>6</sup>	2.6 x 10 <sup>8</sup>	Dog	2
9.2 x 10 <sup>7</sup>	1.2 x 10 <sup>8</sup>	9.2 x 10 <sup>7</sup>	1.6 x 10 <sup>7</sup>	Man	3
2.4 x 10 <sup>8</sup>	1.5 x 10 <sup>5</sup>	1.4 x 10 <sup>5</sup>	1.5 x 10 <sup>8</sup>	Fish-1	4
1.8 x 10 <sup>8</sup>	3.0 x 10 <sup>3</sup>	3.5 x 10 <sup>3</sup>	1.9 x 10 <sup>7</sup>	Fish-2	5
1.5 x 10 <sup>8</sup>	3.5 x 10 <sup>1</sup>	3.5 x 10 <sup>1</sup>	9.0 x 10 <sup>7</sup>	Fish-3	6
1.9 x 10 <sup>8</sup>	5.1 x 10 <sup>4</sup>	4.8 x 10 <sup>4</sup>	8.6 x 10 <sup>7</sup>	Fish-mean values	
5.2 x 10 <sup>6</sup>	4.4 x 10 <sup>6</sup>	4.2 x 10 <sup>6</sup>	2.6 x 10 <sup>3</sup>	Goose-1	7
1.1 x 10 <sup>8</sup>	8.0 x 10 <sup>5</sup>	8.9 x 10 <sup>5</sup>	2.0 x 10 <sup>7</sup>	Goose-2	8
2.9 x 10 <sup>6</sup>	8.0 x 10 <sup>4</sup>	6.0 x 10 <sup>4</sup>	5.6 x 10 <sup>8</sup>	Goose-3	9
4.3 x 10 <sup>7</sup>	2.5 x 10 <sup>7</sup>	3.0 x 10 <sup>7</sup>	1.1 x 10 <sup>6</sup>	Goose-4	10
3.6 x 10 <sup>8</sup>	2.7 x 10 <sup>8</sup>	2.2 x 10 <sup>8</sup>	1.4 x 10 <sup>6</sup>	Goose-5	11
1.3 x 10 <sup>8</sup>	1.1 x 10 <sup>8</sup>	7.8 x 10 <sup>7</sup>	5.0 x 10 <sup>9</sup>	Goose-6	12
3.5 x 10 <sup>8</sup>	1.3 x 10 <sup>6</sup>	6.5 x 10 <sup>5</sup>	2.6 x 10 <sup>6</sup>	Goose-7	13
8.2 x 10 <sup>7</sup>	2.8 x 10 <sup>7</sup>	3.4 x 10 <sup>7</sup>	3.5 x 10 <sup>5</sup>	Goose-8	14
1.4 x 10 <sup>8</sup>	5.5 x 10 <sup>7</sup>	4.6 x 10 <sup>7</sup>	7.0 x 10 <sup>8</sup>	Goose-mean values	
4.8 x 10 <sup>8</sup>	3.5 x 10 <sup>8</sup>	2.8 x 10 <sup>8</sup>	8.9 x 10 <sup>6</sup>	Duck-1	15
1.1 x 10 <sup>8</sup>	8.3 x 10 <sup>7</sup>	9.0 x 10 <sup>7</sup>	1.3 x 10 <sup>8</sup>	Duck-2	16
9.0 x 10 <sup>7</sup>	7.9 x 10 <sup>7</sup>	6.2 x 10 <sup>7</sup>	4.5 x 10 <sup>7</sup>	Duck-3	17
1.3 x 10 <sup>8</sup>	1.1 x 10 <sup>8</sup>	9.3 x 10 <sup>7</sup>	8.7 x 10 <sup>7</sup>	Duck-4	18
1.1 x 10 <sup>8</sup>	7.5 x 10 <sup>7</sup>	6.2 x 10 <sup>7</sup>	6.1 x 10 <sup>7</sup>	Duck-5	19
1.7 x 10 <sup>8</sup>	1.5 x 10 <sup>8</sup>	1.3 x 10 <sup>8</sup>	1.5 x 10 <sup>8</sup>	Duck-6	20
2.2 x 10 <sup>8</sup>	1.6 x 10 <sup>8</sup>	1.3 x 10 <sup>8</sup>	4.9 x 10 <sup>8</sup>	Duck-7	21
1.9 x 10 <sup>8</sup>	1.4 x 10 <sup>8</sup>	1.2 x 10 <sup>8</sup>	1.4 x 10 <sup>8</sup>	Duck-mean values	
2.9 x 10 <sup>10</sup>	3.9 x 10 <sup>9</sup>	2.2 x 10 <sup>10</sup>	2.7 x 10 <sup>7</sup>	Cow-1, misc.	22
9.7 x 10 <sup>6</sup>	6.9 x 10 <sup>6</sup>	8.1 x 10 <sup>6</sup>	6.4 x 10 <sup>6</sup>	Cow-2, Diet-1, Hay	23
1.7 x 10 <sup>6</sup>	9.8 x 10 <sup>5</sup>	9.8 x 10 <sup>5</sup>	1.3 x 10 <sup>6</sup>	Cow-3, Diet-1, Hay	24
2.7 x 10 <sup>5</sup>	2.2 x 10 <sup>5</sup>	2.1 x 10 <sup>5</sup>	3.0 x 10 <sup>5</sup>	Cow-4, Diet-1, Hay	25
7.7 x 10 <sup>5</sup>	5.8 x 10 <sup>5</sup>	3.2 x 10 <sup>5</sup>	4.0 x 10 <sup>5</sup>	Cow-5, Diet-1, Hay	26
1.2 x 10 <sup>8</sup>	1.0 x 10 <sup>8</sup>	9.3 x 10 <sup>7</sup>	2.8 x 10 <sup>6</sup>	Cow-6, Diet-2, Grain	27
4.6 x 10 <sup>8</sup>	4.4 x 10 <sup>8</sup>	3.2 x 10 <sup>8</sup>	1.6 x 10 <sup>7</sup>	Cow-7, Diet-2, Grain	28
5.9 x 10 <sup>8</sup>	6.1 x 10 <sup>8</sup>	4.9 x 10 <sup>8</sup>	1.8 x 10 <sup>7</sup>	Cow-8, Diet-2, Grain	29
9.6 x 10 <sup>8</sup>	7.1 x 10 <sup>8</sup>	4.7 x 10 <sup>8</sup>	5.9 x 10 <sup>6</sup>	Cow-9, Diet-2, Grain	30
3.2 x 10 <sup>8</sup>	3.2 x 10 <sup>8</sup>	4.1 x 10 <sup>8</sup>	7.6 x 10 <sup>6</sup>	Cow-10, Diet-2, Grain	31
1.8 x 10 <sup>8</sup>	1.0 x 10 <sup>8</sup>	9.7 x 10 <sup>7</sup>	1.1 x 10 <sup>7</sup>	Cow-11, Diet-2, Grain	32
2.9 x 10 <sup>9</sup>	5.6 x 10 <sup>8</sup>	2.2 x 10 <sup>9</sup>	8.8 x 10 <sup>6</sup>	Cow-mean values	

Table 2

Ratios of gut bacteria in feces from various sources

TC/FC	FC/ <u>E.c</u>	FC/FS	Sample	
			Animal	#
1.3	0.9	$6.0 \times 10^{-4}$	Horse	1
1.1	1.0	$7.0 \times 10^{-3}$	Dog	2
0.8	1.3	7.5	Men	3
$1.6 \times 10^3$	1.1	$1.0 \times 10^{-3}$	Fish-1	4
$6.0 \times 10^4$	0.9	$1.6 \times 10^{-4}$	Fish-2	5
$4.3 \times 10^6$	1.0	$3.8 \times 10^{-7}$	Fish-3	6
$3.7 \times 10^3$	1.1	$5.9 \times 10^{-4}$	Fish-mean values	
1.2	1.1	$1.7 \times 10^3$	Goose-1	7
$1.4 \times 10^2$	0.9	$4.0 \times 10^{-2}$	Goose-2	8
36	1.3	$1.0 \times 10^{-4}$	Goose-3	9
1.7	0.8	23	Goose-4	10
1.3	1.2	$1.9 \times 10^2$	Goose-5	11
1.2	1.4	2.2	Goose-6	12
$2.7 \times 10^2$	2.0	0.5	Goose-7	13
2.9	0.8	80	Goose-8	14
2.5	1.2	$8.1 \times 10^{-2}$	Goose-mean values	
1.4	1.3	39	Duck-1	15
1.3	0.9	0.6	Duck-2	16
1.1	1.3	1.8	Duck-3	17
1.2	1.2	1.3	Duck-4	18
1.5	1.2	1.2	Duck-5	19
1.1	1.2	1.0	Duck-6	20
1.4	1.2	0.3	Duck-7	21
1.4	1.2	1.0	Duck-mean values	
7.4	0.2	144	Cow-1, ?	22
1.4	0.9	1.1	Cow-2, hay	23
1.7	1.0	0.8	Cow-3, hay	24
1.2	1.0	0.7	Cow-4, hay	25
1.3	1.8	1.5	Cow-5, hay	26
1.2	1.1	35.7	Cow-6, grain	27
1.0	1.4	27.5	Cow-7, grain	28
1.0	1.2	33.9	Cow-8, grain	29
1.4	1.5	120	Cow-9, grain	30
1.0	0.8	42.1	Cow-10, grain	31
1.8	1.0	9.1	Cow-11, grain	32
5.2	0.3	63.6	Cow-mean values	

Table 3

Means and Standard Deviations for Kalamalka Lake Bacteriological Data

Site	<u>E. coli</u>		Fecal Col.		Total Col.		Fecal Strep.	
	Mean	Stnd.	Mean	Stnd.	Mean	Stnd.	Mean	Stnd.
K-1, E208077	55.8	131.2	62.8	140.6	89.8	180.1	190.3	595.5
K-2, E208078	431.1	1326.9	464.2	1353.6	791.1	1516.1	574.1	1992.7
K-3, E208079	1120.0	7769.5	391.3	1287.2	1406.7	6156.8	316.3	643.9
K-4, E208080	125.3	299.8	131.2	310.8	248.0	525.5	202.6	618.0
K-5, E208081	38.4	55.3	55.6	74.9	114.9	152.2	119.4	284.0
VC-1, 0500089	28.6	83.7	31.0	86.7	64.7	175.0	71.7	219.0
CS-1, E208076	117.6	169.8	133.6	186.3	212.6	324.2	146.2	132.7
CS-2, E208075	198.7	186.5	204.4	181.2	519.2	462.6	951.6	2549.9
CS-3, E208091	1956.1	3268.6	2108.6	3760.8	5819.1	8627.5	7270.4	8429.3
CS-4, E208090	168.9	287.0	182.4	281.1	1431.6	3269.4	1298.3	2816.3
CS-5, E208089	82.7	54.4	87.4	50.1	390.9	412.1	329	240.3
CS-6, E208088	18.6	11.3	20.9	13.3	51.8	58.4	159.9	275.5

Table 4

Sample Sizes and Fecal Coliforms/Fecal Streptococci Ratios  
Kalamalka Lake Study Data

Site	<u>E. coli</u>	FC	TC	FS	FC/FS	FC/ <u>E.c</u>
K-1	81	81	80	81	0.3	1.1
K-2	81	81	81	81	0.8	1.1
K-3	84	84	84	84	1.2	0.3
K-4	131	131	131	84	0.6	1.0
K-5	37	37	36	84	0.5	1.4
VC-1	56	56	56	56	0.4	1.1
CS-1	56	56	55	56	0.9	1.1
CS-2	49	50	50	50	0.2	1.0
CS-3	19	19	19	19	0.3	1.1
CS-4	19	19	19	19	0.1	1.1
CS-5	17	17	17	17	0.3	1.1
CS-6	18	18	16	19	0.1	1.1

Table 5

Prince George Pulp and Intercon Pulp Outfall (PE 0390001)  
Settling Pond E104898

COLIFORMS			FECAL STREPT.	FECAL COLIFORM/ FECAL STREPT. RATIO
TOTAL	FECAL	<u>E. COLI</u> *		
4000	40	-	30	1.33
540	9	-	33	0.27
240	9	-	22	0.41
3500	5	-	2	2.50
5400	7	-	49	0.14
2736	14	-	27.2	0.51 **

\* membrane filtration not suitable due to viscosity and overgrowth of non coliforms on selective media, no method for E. coli using MPN available.

\*\* means

Table 6

Kelowna Wine and Juice Waste Aeration Pond E207857

COLIFORMS			FECAL STREP.	FC/FS	<u>E.c</u> /FC	
TOTAL	FECAL	<u>E. COLI</u>				
28900	145	45	7950	0.02	0.006	
11800	26	12	735	0.04	0.016	
1400	10	6	50	0.02	0.120	
10200	91	71	7200	0.01	0.010	
3050	2	2	1340	0.00	0.001	
7750	2	< 2	3650	0.00	0.000	
390000	5070	1350	1030	4.92	1.311	
30700	25	10	1750	0.01	0.006	
28800	375	-	90	4.17		
-	8	27	-			
-	4	10	-			
512600	5758	1535	23795			Totals
56955.6	523.5	153.5	2643.9	0.24	0.06	Means

Table 7

Frequency of Occurrence of the FC/FS Ratio  
at each Sample Station

Station	Ratio FC/FS		
	< 1.0	1.0 - 4.0	> 4.0
<u>Background Samples</u>			
Raw Sewage	12	27	61
Herring Run	46	34	20
Jones Falls	27	31	42
Gwynns Falls	33	45	22
<u>Storm Event Samples</u>			
Stoney Run	82	12	6
Glen Avenue	87	5	6
Howard Park	41	41	18
Jones Falls Drain	76	12	12
Bush Street	81	13	6
Northwood	92	0	8

Table 8

## Analyses of Duplicate Samples of Bacteria

Ste E208080, K-4, Kalamalka Lake, July 19 to October 18, 1989

Date	Escherichia coli		Fecal Coliforms		Total Coliforms	
	S-1	S-2	S-1	S-2	S-1	S-2
7/6	2	5	2	5	8	8
7/6	11	6	9	8	14	11
7/6	26	10	28	12	32	13
7/12	14	9	5	7	20	12
7/12	6	7	11	6	17	12
7/12	19	9	32	8	57	7
7/16	10	11	15	8	21	10
7/16	16	8	16	4	29	21
7/16	154	319	139	326	324	345
7/19	16	8	8	6	26	10
7/19	13	9	20	8	26	22
7/19	57	16	51	18	107	41
7/23	2	2	3	2	7	14
7/23	3	2	2	2	11	9
7/23	43	29	49	32	153	79
7/26	8	3	11	2	23	8
7/26	5	2	7	4	13	2
7/26	118	52	138	73	212	111
8/2	55	48	67	42	188	129
8/2	76	65	82	53	227	113
8/2	537	52	650	56	1300	167
8/7	24	12	24	10	58	22
8/7	34	15	32	17	70	56
8/7	40	40	48	60	55	71
8/9	24	14	14	16	28	52
8/9	21	26	24	21	34	45
8/9	20	16	74	28	93	46
9/20	23	360	29	345	52	405
9/20	23	276	34	306	42	530
9/20	5	4	8	7	9	23
10/1	30	12	37	19	37	20
10/1	110	88	99	100	136	118
10/4	25	29	29	54	27	36
10/4	87	26	82	14	120	24
10/4	26	127	14	124	24	130
10/9	729	64	681	87	964	220
10/9	1550	229	1850	230	2930	890
10/9	2250	660	2390	600	3370	1660
10/11	629	310	777	278	1650	940
10/11	793	526	850	536	1680	1410
10/11	45	265	63	259	144	755
10/16	14	15	22	12	60	37
10/16	9	25	13	24	29	40
10/16	169	121	156	178	345	155
10/18	1080	89	825	95	1440	156
10/18	1240	134	1000	141	1670	207
10/18	170	17	216	16	1140	35

Bibliography

- Berg, G. Editor. 1983. Viral Pollution of the Environment. CRC Press, Florida.
- Geldreich, E.E. and B.A. Kenner. 1969. Concepts of Fecal Streptococci in Stream Pollution. J. Water Pollut. Cont. Fed. 41:336.
- Hoadley, A.W. and B.J. Dutka. Editors. 1977. Bacterial Indicators/Health Hazards Associated with water. ASTM, STP 635, Phil.
- Hussong, D., J.M. Damare, R.J. Limpert, W.J.L. Sladen, R.M. Weiner and R.R. Colwell. 1979. Microbial Impact of Canada Geese (Branta canadensis and Whistling Swans (Cygnus columbiana) on Aquatic Ecosystems. J. Bact. 88:965.
- Olivieri, V.P. 1982. Bacterial Indicators of Pollution. Chapter 2. In: Pipes, W.O. Editor. 1982. Bacterial Indicators of Pollution. CRC Press, Florida.
- Olivieri, V.P., C.W. Kruse, K. Kawata and J.E. Smith. 1977. Microorganisms in Urban Stormwater. EPA-600/2-77-087. U.S., EPA., Wash. D.C.
- Pipes, W.O. Editor. 1982. Bacterial Indicators of Pollution. CRC Press, Florida.
- Warrington, P.D. 1988. Water Quality Criteria for Microbiological Indicators. Tech. Append. M.O.E., Province of B.C.
- Warrington, P.D. 1988(A). Review Paper. Transferable Drug Resistance in Bacteria. M.O.E., Province of B.C.
- Reiners, R.S., M.D. Lettle, T.G. Akers, W.D. Henriques, R.C. Badeaux, D.B. McDonnell and K.K. Mbela. 1990. Persistence of Pathogens in Lagoon - Stored Sludge. U.S. EPA. 600/S2-89/015 Jan. 1990. Project Summary Report.