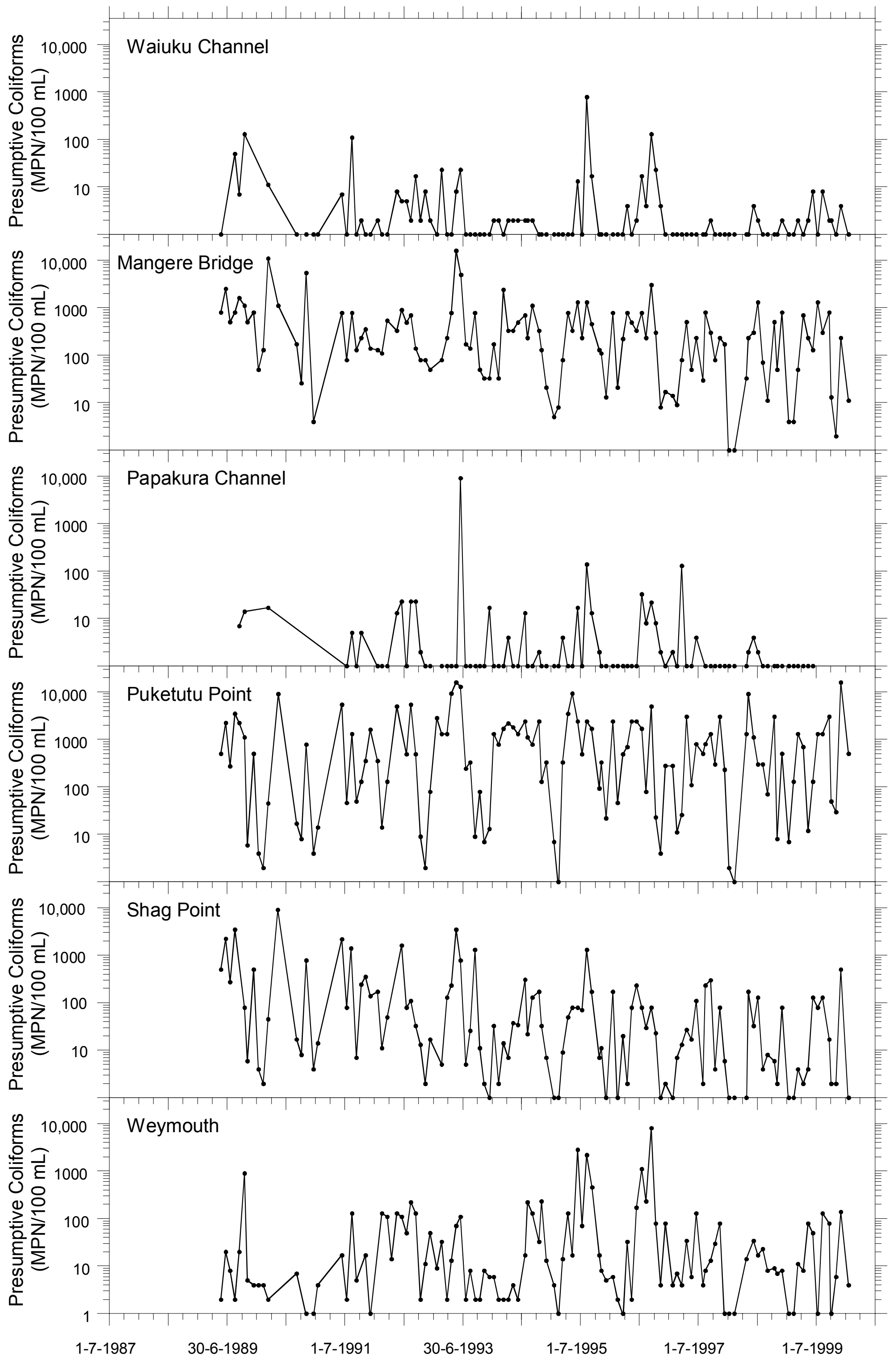

Waiuku Channel
Mangere Bridge
Papakura Channel
Puketutu Point
Shag Point
Weymouth
Presumptive Coliforms (MPN/100 mL)
10,000
1000
100
10
1
1-7-1987
30-6-1989
1-7-1991
30-6-1993
1-7-1995
1-7-1997
1-7-1999

APPENDIX 37: FAECAL COLIFORM – SALINE

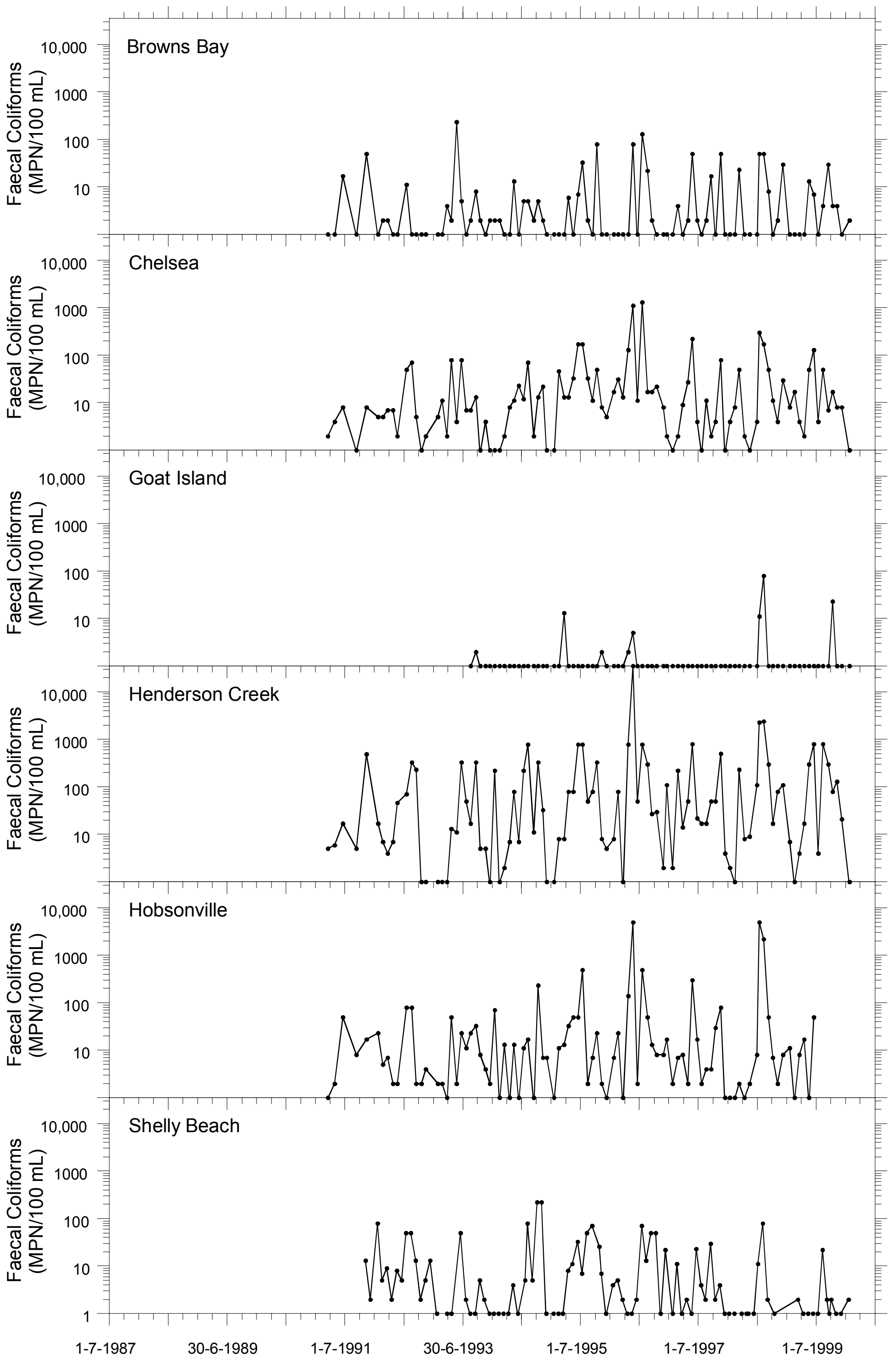
a) Faecal coliform (MPN/100 mL) during January 1999 - December 1999

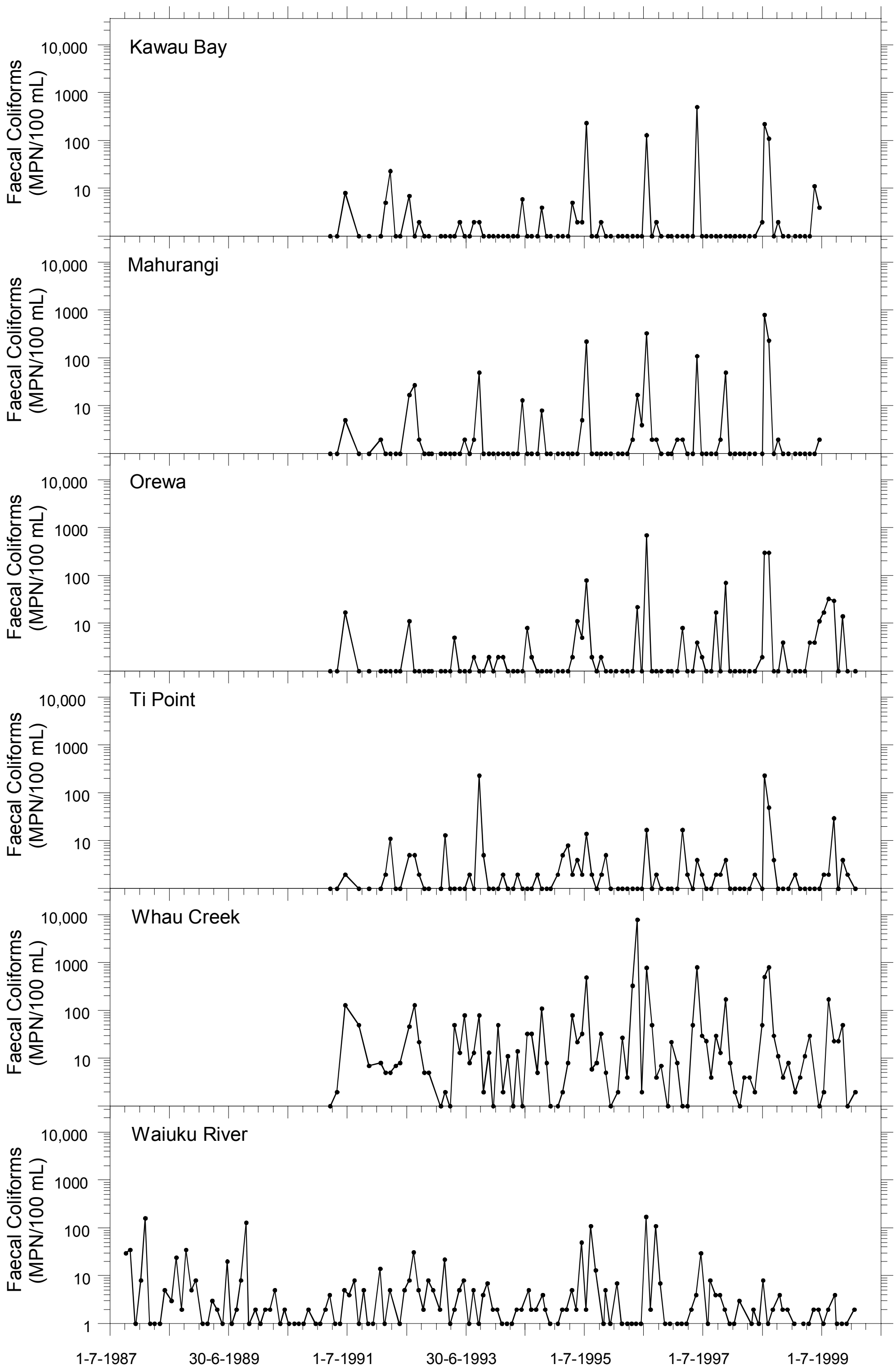
Date	Browns Bay	Chelsea	Goat Island	Henderson	Hobsonville	Shelly Beach	Kawau Bay	Mahurangi	Orewa	Ti Point	Whau	Waiuku River	Waiuku Channel	Mangere Bridge	Papakura Channel	Puketutu Point	Shag Point	Weymouth
Jan-99	1	8	1	7	11		1	1	1	2	2	1	1	4	1	4	1	1
Feb-99	1	17	1	1	1		1	1	1	1	4	0.5	0.5	2	0.5	23	0.5	0.5
Mar-99	1	4	1	4	8	2	1	1	1	1	11	1	1	50	1	220	2	8
Apr-99	1	2	1	17	17	1	1	1	4	1	30	1	1	70	1	300	2	6
May-99	13	50	1	300	1	1	11	1	4	1		2	2	50	1	6	2	30
Jun-99	7	130	1	800	50	1	4	2	11	1	1	2	2	130	1	80	23	30
Jul-99	1	4	1	4		1			17	2	2	1	1	130		800	8	1
Aug-99	4	50	1	800		22			33	2	170	2	1	110		300	14	17
Sep-99	30	7	1	300		1			30	30	23	4	1	70		300	4	50
Oct-99	4	17	23	80		2			1	1	23	1	1	8		17	1	1
Nov-99	4	8	1	130		1			14	4	50	1	1	1		23	1	2
Dec-99	1	8	1	21		1			1	2	1	1	1	13		110	2	23
median	3	8	1	50	10	1	1	1	4	2	11	1	1	50	1	95	2	7
IQR/median (%)	150	240	0	580	130	100	300	0	345	67	220	100	0	150	0	290	200	340

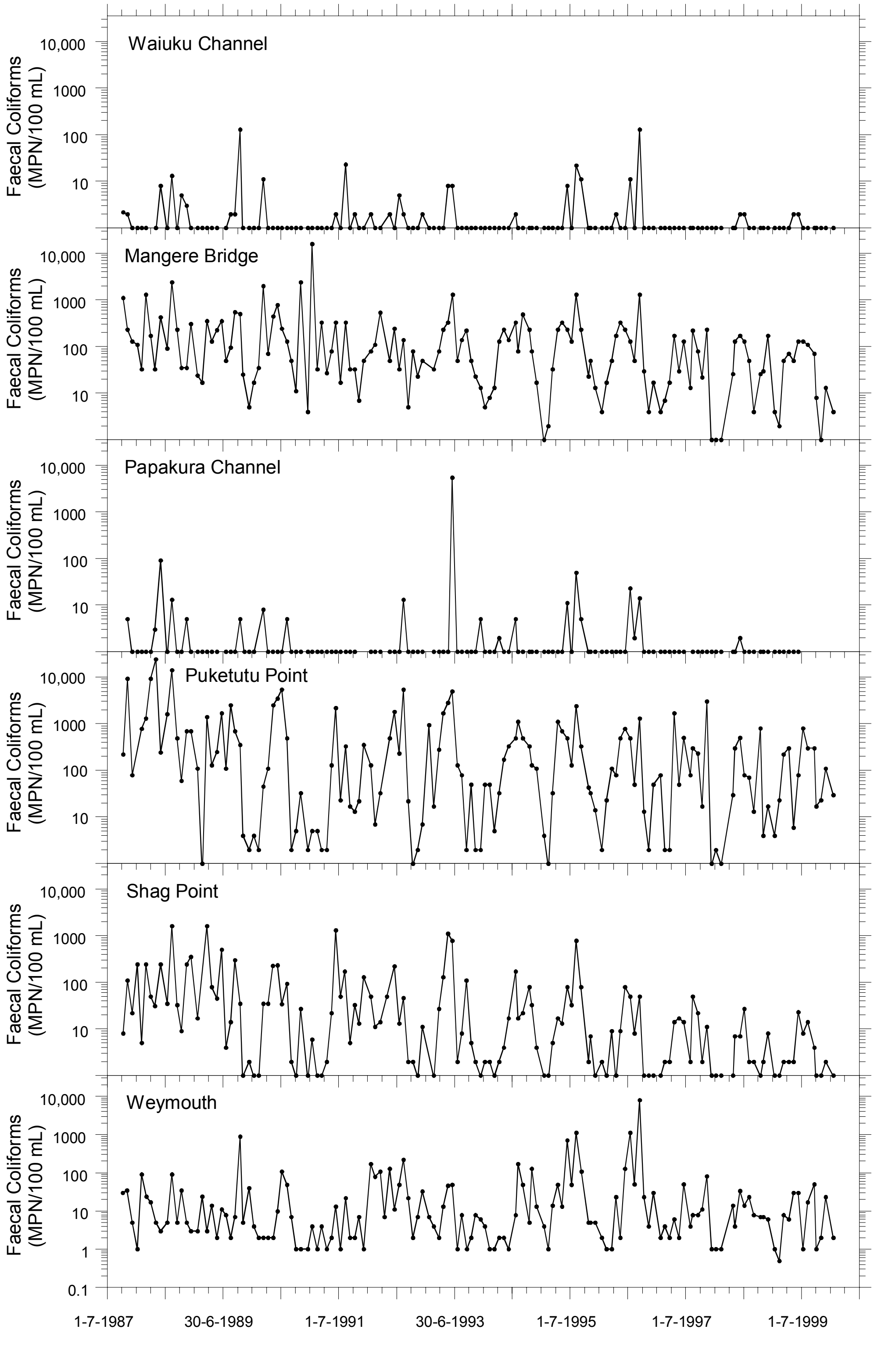
b) Statistical summary for all data to January 2000: Faecal coliform (MPN/100 mL)

Date	Browns Bay	Chelsea	Goat Island	Henderson	Hobsonville	Shelly Beach	Kawau Bay	Mahurangi	Orewa	Ti Point	Whau	Waiuku River	Waiuku Channel	Mangere Bridge	Papakura Channel	Puketutu Point	Shag Point	Weymouth
N	100	100	78	100	93	94	93	94	101	100	99	146	144	145	133	145	144	147
Median	1.5	8.0	1.0	21.5	8.0	2.0	1.0	1.0	1.0	1.0	8.0	2.0	1.0	70.0	1.0	110.0	9.0	7.0
Normality	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Seasonality	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
Trend	NS	95%	NS	95%	NS	95%	NS	NS	95%	NS	NS	80%	95%	95%	95%	95%	95%	NS
Slope	–	0.67	–	1.54	–	-1.95	–	–	0	–	–	0	0	-4.7	0	-4.99	-1.95	–

c) The graphs on the following page show all faecal coliform measurements up to January 2000 (where data are available)


Browns Bay
Chelsea
Goat Island
Henderson Creek
Hobsonville
Shelly Beach
Faecal Coliforms (MPN/100 mL)
10,000
1000
100
10
1
1-7-1987
30-6-1989
1-7-1991
30-6-1993
1-7-1995
1-7-1997
1-7-1999


Kawau Bay
Mahurangi
Orewa
Ti Point
Whau Creek
Waiuku River
Faecal Coliforms (MPN/100 mL)
10,000
1000
100
10
1
1-7-1987
30-6-1989
1-7-1991
30-6-1993
1-7-1995
1-7-1997
1-7-1999


Waiuku Channel
Mangere Bridge
Papakura Channel
Puketutu Point
Shag Point
Weymouth
Faecal Coliforms (MPN/100 mL)
10,000
1000
100
10
1
0.1
1-7-1987
30-6-1989
1-7-1991
30-6-1993
1-7-1995
1-7-1997
1-7-1999

APPENDIX 38: ENTEROCOCCI – SALINE

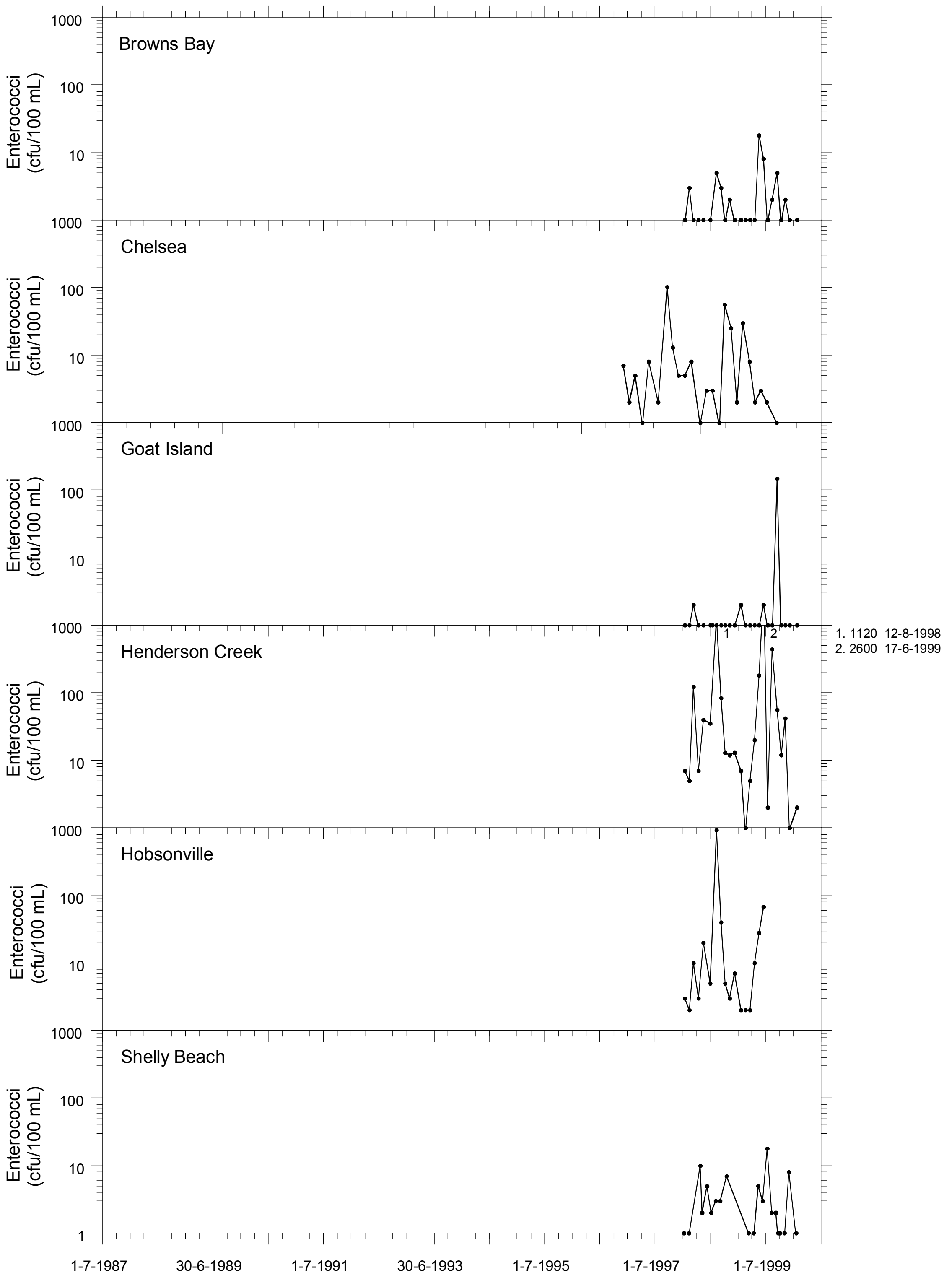
a) Enterococci (cfu/100 mL) during January 1999 - December 1999

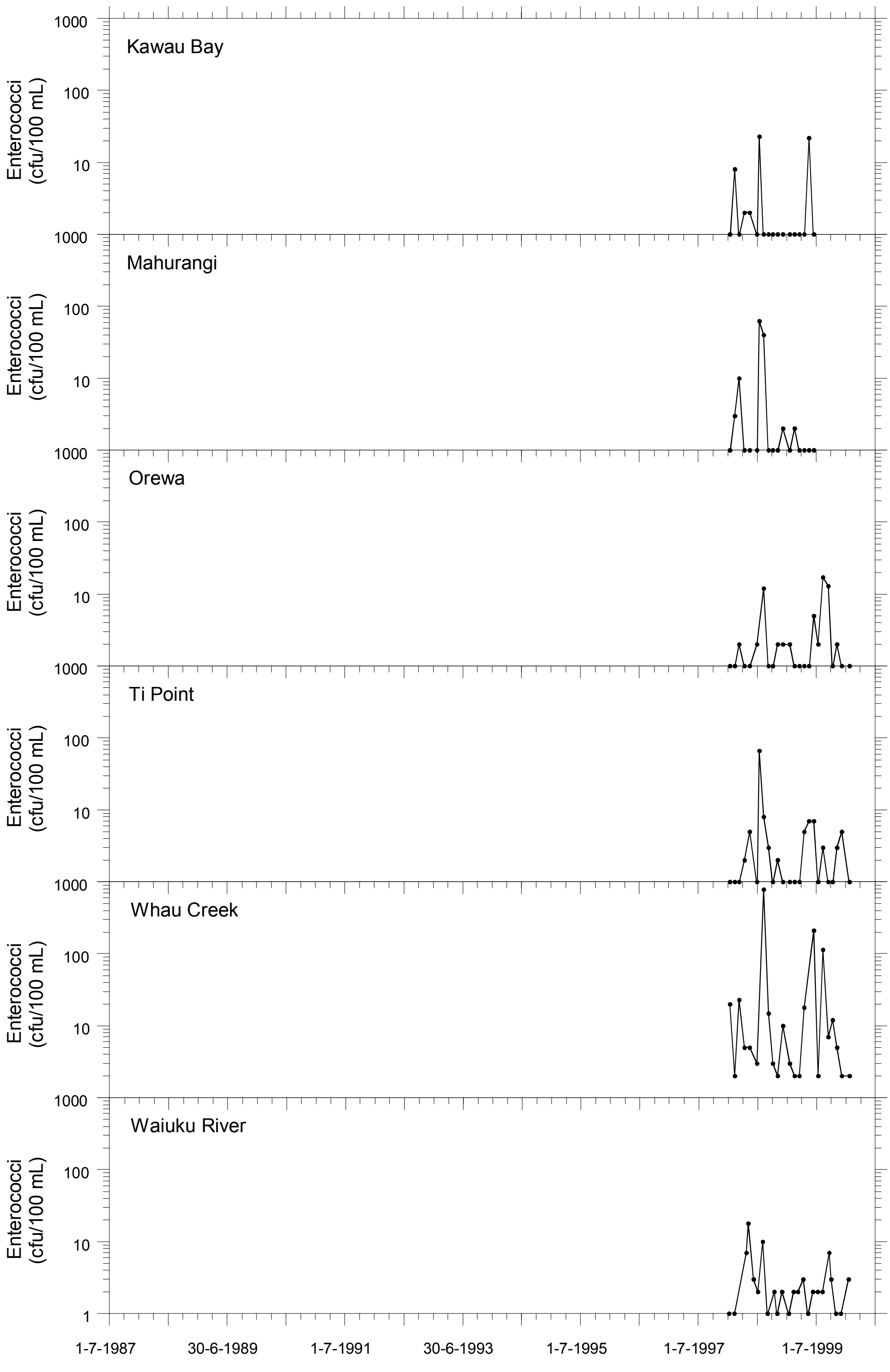
Date	Browns Bay	Chelsea	Goat Island	Henderson	Hobsonville	Shelly Beach	Kawau Bay	Mahurangi	Orewa	Ti Point	Whau	Waiuku River	Waiuku Channel	Mangere Bridge	Papakura Channel	Puketutu Point	Shag Point	Weymouth
Jan-99		1	2	7	2		1	1	2	1	3	1	1	1	1	1	1	2
Feb-99		3	1	1	2		1	2	1	1	2	2	1	2	1	2	1	1
Mar-99		3	1	5	2	1	1	1	1	1	2	2	1	3	1	5	1	7
Apr-99		1	1	20	10	1	1	1	1	5	18	3	1	40	1	2	1	7
May-99		56	1	180	28	5	22	1	1	7		1	1	20	2	3	2	17
Jun-99		25	2	2600	68	3	1	1	5	7	210	2	1	22	2	5	1	10
Jul-99		2	0	2		18			2	0	2	2	2	5		1	1	1
Aug-99		30	1	440		2			17	3	114	2	2	2		5	3	5
Sep-99		8	148	56		2			13	1	7	7	1	13		1	2	1
Oct-99		2	1	12		1			1	1	12	3	1	1		1	1	1
Nov-99		3	1	42		1			2	3	5	1	1	1		2	1	3
Dec-99		2	1	1		8			1	5	2	1	1	5		1	1	7
median	–	3	1	16	6	2	1	1	2	2	5	2	1	4	1	2	1	4
IQR/median (%)	–	340	25	520	360	150	0	0	120	200	260	60	0	325	0	125	25	150

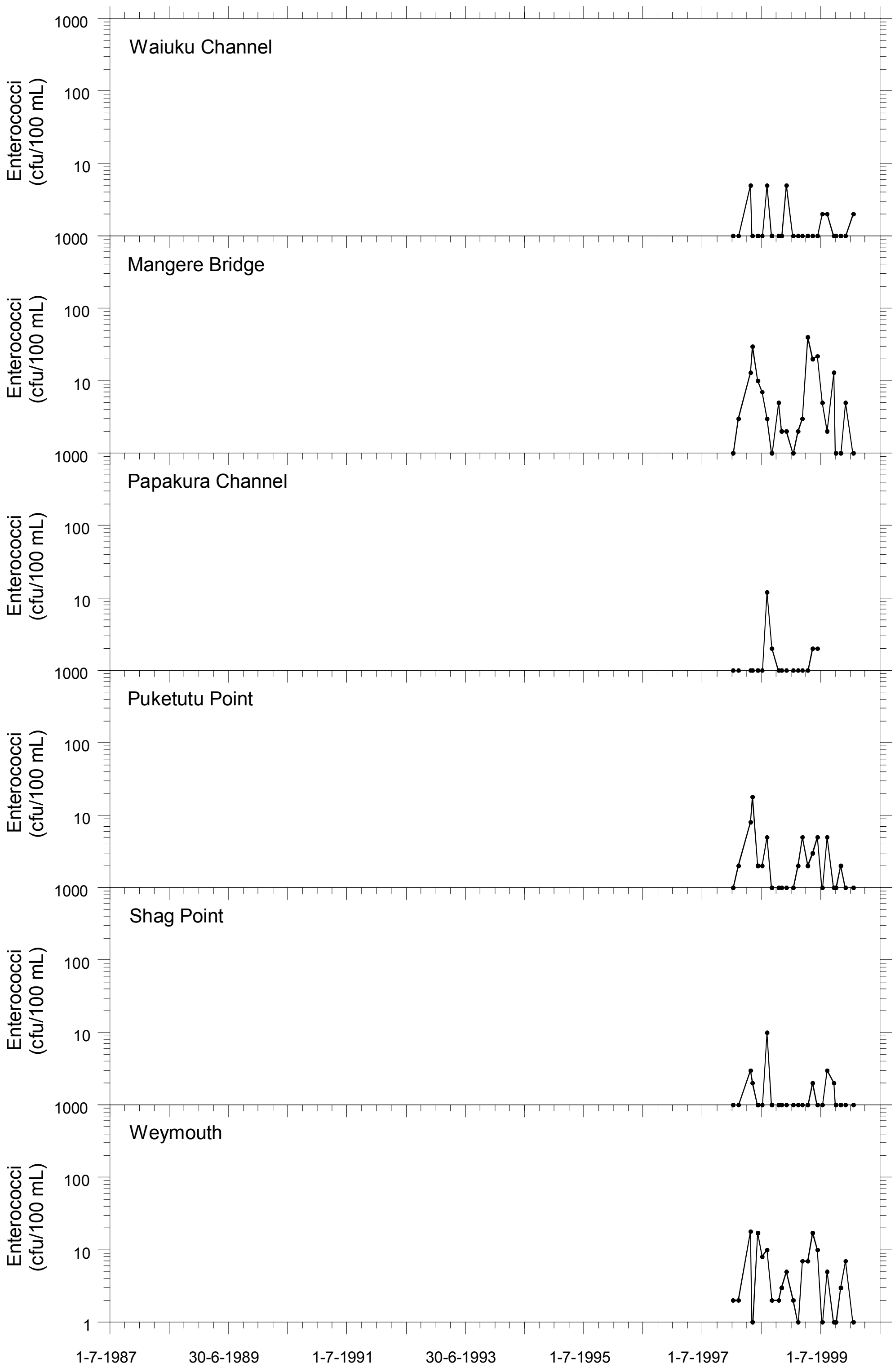
b) Statistical summary for all data to January 2000: Enterococci (cfu/100 mL)

Date	Browns Bay	Chelsea	Goat Island	Henderson	Hobsonville	Shelly Beach	Kawau Bay	Mahurangi	Orewa	Ti Point	Whau	Waiuku River	Waiuku Channel	Mangere Bridge	Papakura Channel	Puketutu Point	Shag Point	Weymouth
N	24	24	25	24	17	21	18	18	24	21	23	24	24	24	17	24	24	24
Median	1	4	1	13	5	2	1	1	1	2	5	2	1	3	1	2	1	3
Normality	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Seasonality	N	N	N	Y	N	N	N	N	Y	N	N	N	N	Y	N	N	N	N
Trend	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Slope	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

c) The graphs on the following page show all enterococci measurements up to January 2000 (where data are available)

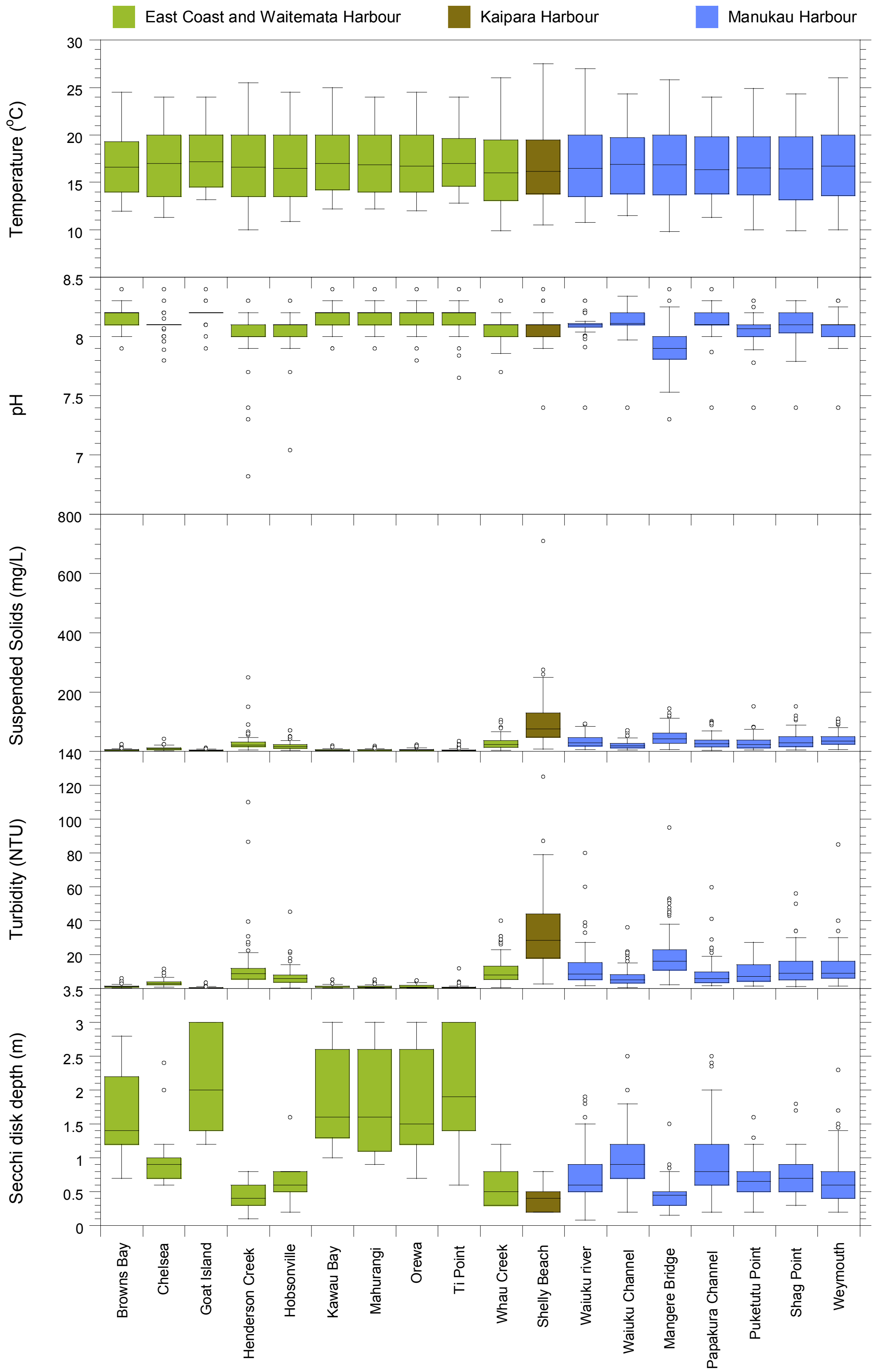

Browns Bay
Chelsea
Goat Island
Henderson Creek
Hobsonville
Shelly Beach
Enterococci (cfu/100 mL)
1000
100
10
1
1. 1120 12-8-1998
2. 2600 17-6-1999
1-7-1987
30-6-1989
1-7-1991
30-6-1993
1-7-1995
1-7-1997
1-7-1999

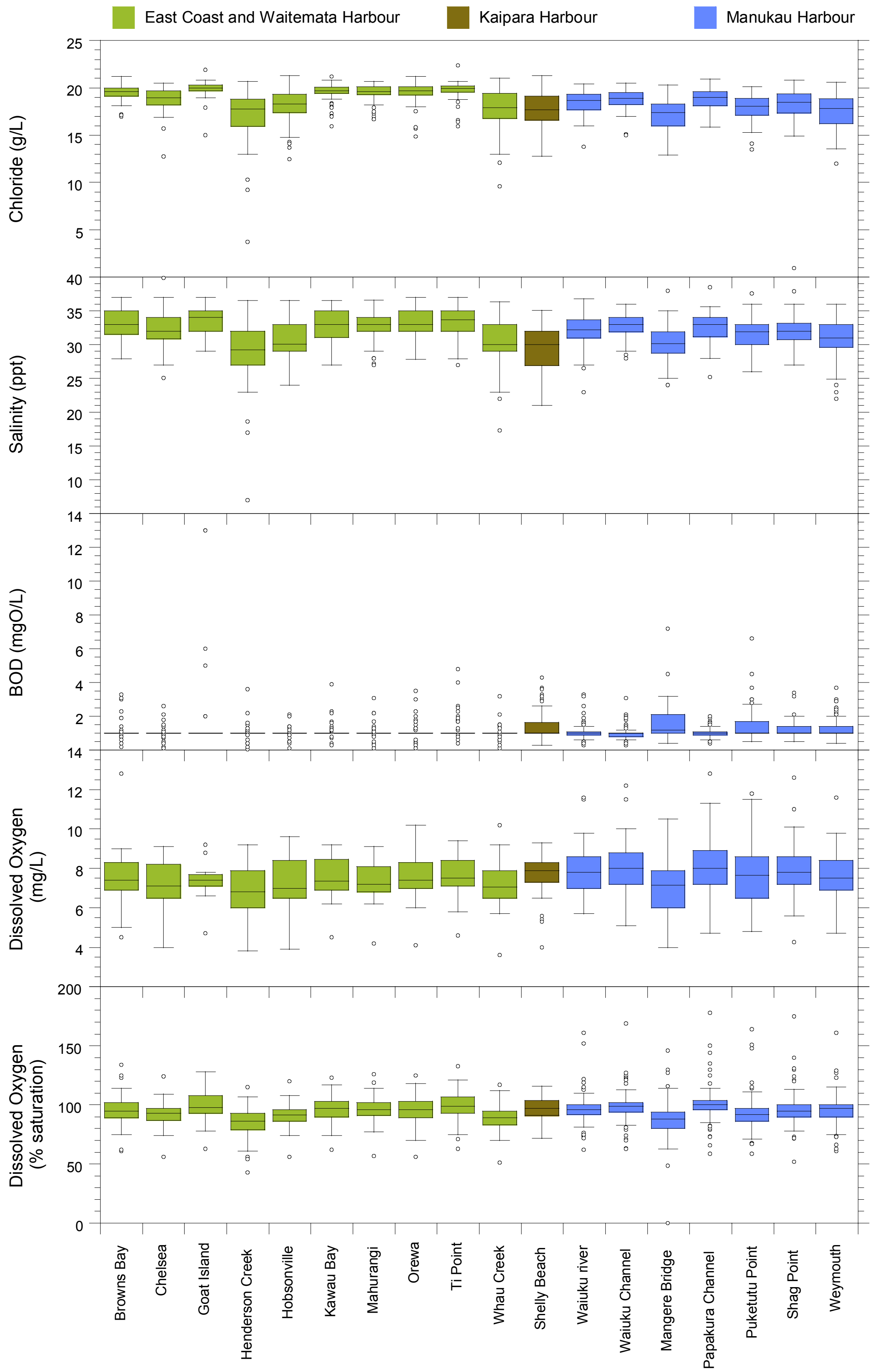

Kawau Bay
Mahurangi
Orewa
Ti Point
Whau Creek
Waiuku River
Enterococci (cfu/100 mL)
1000
100
10
1
1-7-1987
30-6-1989
1-7-1991
30-6-1993
1-7-1995
1-7-1997
1-7-1999

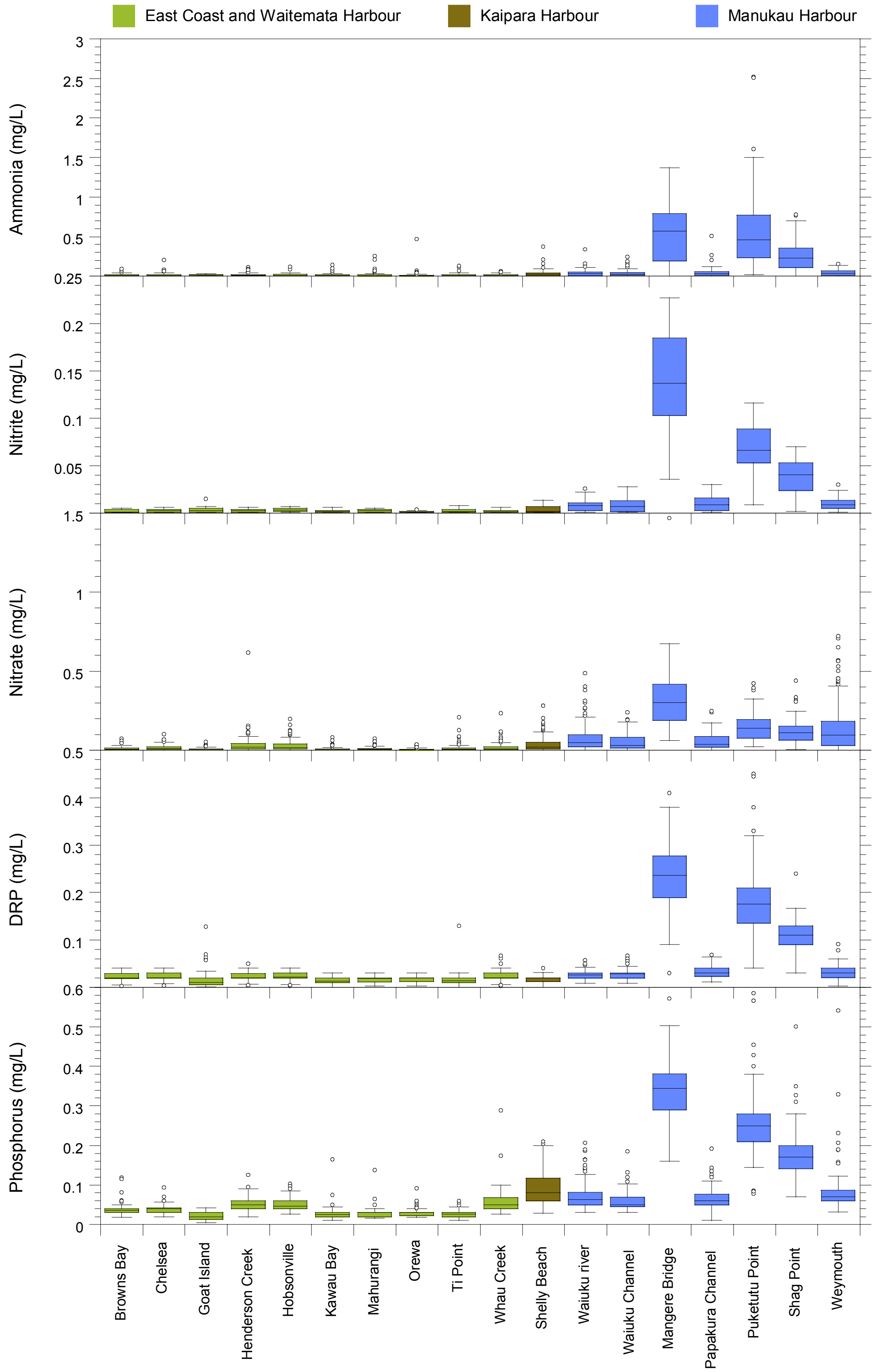


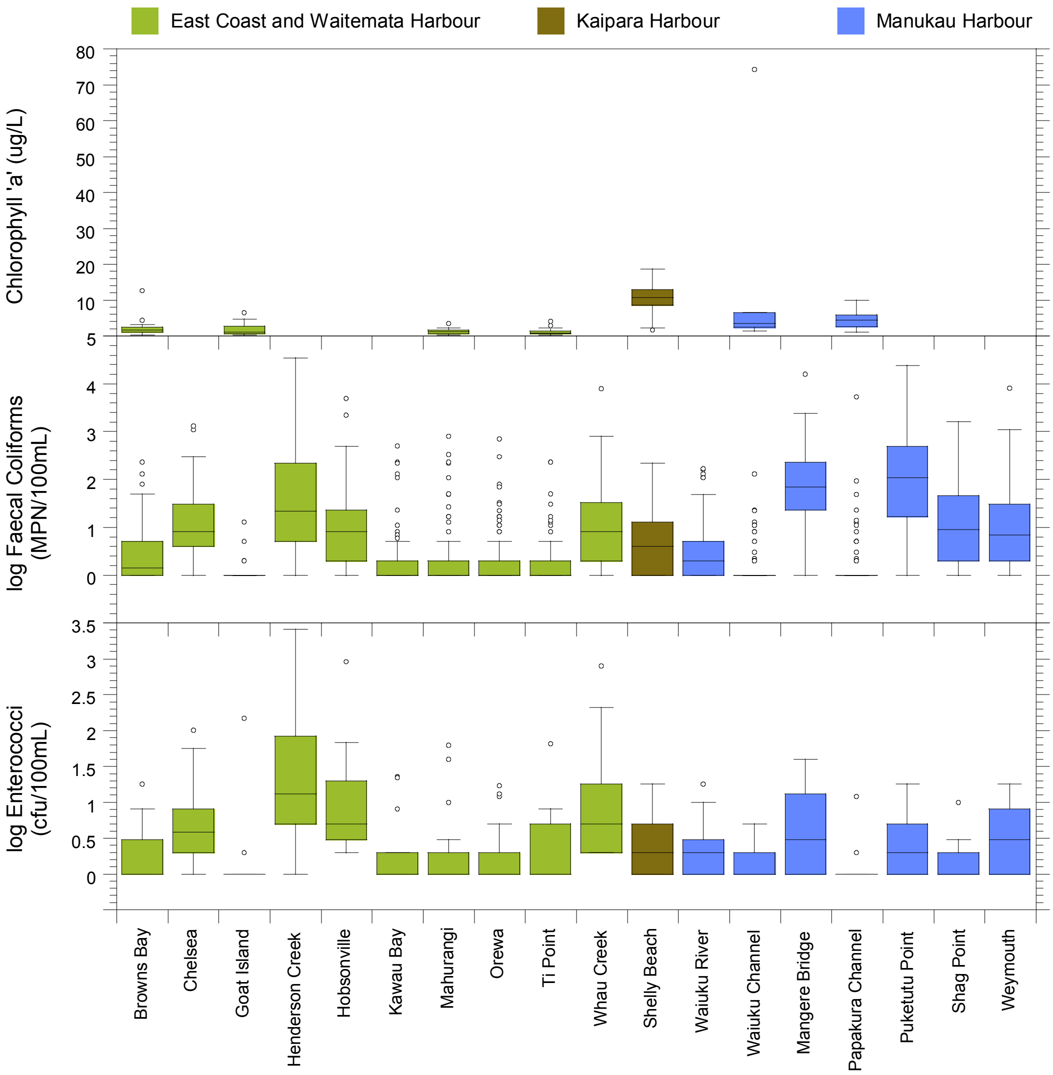
Waiuku Channel
Mangere Bridge
Papakura Channel
Puketutu Point
Shag Point
Weymouth
Enterococci (cfu/100 mL)
1000
100
10
1
1-7-1987
30-6-1989
1-7-1991
30-6-1993
1-7-1995
1-7-1997
1-7-1999

APPENDIX 39: BOX PLOTS OF EACH WATER QUALITY VARIABLE FOR THE SALINE SITES


East Coast and Waitemata Harbour
Kaipara Harbour
Manukau Harbour
Temperature (°C)
pH
Suspended Solids (mg/L)
Turbidity (NTU)
Secchi disk depth (m)
Browns Bay
Chelsea
Goat Island
Henderson Creek
Hobsonville
Kawau Bay
Mahurangi
Orewa
Ti Point
Whau Creek
Shelly Beach
Waiuku river
Waiuku Channel
Mangere Bridge
Papakura Channel
Puketutu Point
Shag Point
Weymouth


East Coast and Waitemata Harbour
Kaipara Harbour
Manukau Harbour
Chloride (g/L)
Salinity (ppt)
BOD (mgO/L)
Dissolved Oxygen (mg/L)
Dissolved Oxygen (% saturation)
Browns Bay
Chelsea
Goat Island
Henderson Creek
Hobsonville
Kawau Bay
Mahurangi
Orewa
Ti Point
Whau Creek
Shelly Beach
Waiuku river
Waiuku Channel
Mangere Bridge
Papakura Channel
Puketutu Point
Shag Point
Weymouth


East Coast and Waitemata Harbour
Kaipara Harbour
Manukau Harbour
Ammonia (mg/L)
Nitrite (mg/L)
Nitrate (mg/L)
DRP (mg/L)
Phosphorus (mg/L)
3
2.5
2
1.5
1
0.5
0.25
0.2
0.15
0.1
0.05
1.5
1
0.5
0.5
0.4
0.3
0.2
0.1
0.6
0.5
0.4
0.3
0.2
0.1
0
Browns Bay
Chelsea
Goat Island
Henderson Creek
Hobsonville
Kawau Bay
Mahurangi
Orewa
Ti Point
Whau Creek
Shelly Beach
Waiuku river
Waiuku Channel
Mangere Bridge
Papakura Channel
Puketutu Point
Shag Point
Weymouth


East Coast and Waitemata Harbour
Kaipara Harbour
Manukau Harbour
Chlorophyll 'a' (ug/L)
log Faecal Coliforms (MPN/100mL)
log Enterococci (cfu/100mL)
Browns Bay
Chelsea
Goat Island
Henderson Creek
Hobsonville
Kawau Bay
Mahurangi
Orewa
Ti Point
Whau Creek
Shelly Beach
Waiuku River
Waiuku Channel
Mangere Bridge
Papakura Channel
Puketutu Point
Shag Point
Weymouth

APPENDIX 40: “LESS THAN”, <, AND “GREATER THAN”, >, VALUES REPORTED IN THE LTB DATA SET FOR SALINE SITES

Site	TP	DRP	NO_3-N	NH_4-N	BOD	Presumptive coliform	Faecal coliform	Chlorophyll a	Enterococci	NO_2-N*	NO_3NO_2*	Secchi disk	Faecal coliform
	<											>	
Browns Bay				38	81	32	49	1	14	12	5		
Chelsea				28	81	3	12		4	6	1		
Goat Island	1	1	29	59	69	66	70	5	20	9	3		
Henderson				23	82	5	13		2	7	4	3	
Hobsonville		1		22	74	8	15			3	4		
Kaipara (Shelly Beach)		2		16	58	28	37		8	10			1
Kawau Bay		5		32	74	53	68		13	6	6		
Mahurangi		2		34	74	51	66	4	12	4	4	2	
Orewa		1		40	80	56	67		13	13	6	1	
Ti Point		5		31	81	45	57	6	12	11	4	2	
Whau		1		32	79	8	15			11	4	5	
Clarks Beach				14	61	29	51		8	2	1		
Grahams Beach				16	61	62	113		18	4	1		
Mangere Bridge				1	51	2	5		6				
Papakura Channel				11	54	61	112		13	2	1		
Puketutu					58	2	4		11				
Titirangi				2	61	13	30		18		1		
Weymouth				12	62	11	23		6	2	3		

APPENDIX 41: DATA SUMMARIES FOR LTB LAKES WATER QUALITY PROGRAMME FOR 1992-1999.

Lake Pupuke 1992-1999

Depth		5 m			25 m			50 m		
	units	mean	max	min	mean	max	min	mean	max	min
BOD	mg/l	2.0	2.8	1.3	0.4	0.4	0.4	1.8	3.1	0.4
Chlorophyll *a*	ug/l	10.6	43.9	0.0	7.6	54.8	0.3	8.9	60.0	0.6
Chloride	mg/l	37.4	39.6	34.4	37.3	38.4	34.5	37.3	38.7	35.0
Conductivity	mS/m @25oC	27.6	31.1	26.0	27.9	32.7	25.6	28.3	33.3	25.6
Faecal coliform	/100ml	12.3	130.0	1.0	3.2	17.0	1.0	8.2	50.0	1.0
Presumptive coliform	/100ml	20.7	130.0	1.0	9.7	50.0	1.0	14.1	79.0	1.0
NH3NH4	ug/l	10.8	54.0	2.5	20.4	277.0	2.5	232.7	1300.0	2.5
NO2	ug/l	3.4	35.0	0.5	4.1	35.0	0.5	5.5	45.0	1.0
NO3NO2	ug/l	11.8	63.0	2.5	19.7	57.0	2.5	31.8	127.0	2.0
NO3WATER	ug/l	12.1	61.0	0.0	19.4	122.0	0.0	12.4	77.0	0.0
P(m/f)	ug/l	9.4	20.0	2.0	8.8	20.0	2.0	18.8	110.0	2.0
P(total)	ug/l	22.3	45.0	10.0	19.8	60.0	8.0	52.1	180.0	10.0
pH	pH	8.5	9.4	7.5	7.6	8.1	7.2	7.4	7.9	7.1
Suspended solids	mg/l	2.2	3.9	1.0	1.5	9.9	0.1	4.4	29.0	0.1
TKN	mg/l	0.4	1.2	0.1	0.3	0.9	0.1	0.5	1.4	0.2
Turbidity	NTU	0.6	1.1	0.4	0.7	3.9	0.2	2.6	14.0	0.3

Lake Tomarata 1992 - 1999

Depth		0 m			5 m		
	units	mean	max	min	mean	max	min
BOD	mg/l	1.9	2.0	1.8	2.4	3.0	1.3
Chlorophyll *a*	ug/l	11.6	30.0	2.3	12.1	36.0	0.3
Chloride	mg/l	36.1	46.7	21.5	37.9	49.0	21.5
Conductivity	mS/m @25oC	17.1	22.7	15.1	17.9	22.8	15.4
Faecal coliform	/100ml	59	1300	1	25	230	1
Presumptive coliform	/100ml	84	1300	1	51	240	1
NH3NH4	ug/l	12.1	46.0	2.5	17.5	90.0	2.5
NO2	ug/l	1.9	7.0	0.5	2.1	5.0	0.5
NO3NO2	ug/l	14.2	142.0	2.5	9.7	45.0	2.5
NO3WATER	ug/l	13.2	135.0	2.0	7.9	41.0	1.0
P(m/f)	ug/l	9.5	20.0	2.0	9.2	20.0	5.0
P(total)	ug/l	25.3	100.0	8.0	22.5	40.0	10.0
pH	pH	7.3	8.1	6.9	7.2	7.7	6.5
Suspended solids	mg/l	3.2	11.0	1.4	4.3	10.0	1.5
TKN	mg/l	0.5	1.3	0.1	0.6	1.6	0.1
Turbidity	NTU	2.3	5.1	1.1	2.7	5.3	1.4

Lake Spectacle 1992-1999

Depth		0 m			5 m		
	units	mean	max	min	mean	max	min
BOD	mg/l	3.7	8.4	1.6	4.4	8.0	1.7
Chlorophyll *a*	ug/l	98.1	298.2	0.0	103.2	264.1	2.9
Chloride	mg/l	37.1	45.6	17.7	37.6	43.8	17.7
Conductivity	mS/m @25oC	28.2	32.8	20.3	28.8	34.0	24.4
Faecal coliform	/100ml	182	2400	2	61	540	2
Presumptive coliform	/100ml	299	3500	0	281	5000	8
NH3NH4	ug/l	34.5	290.0	2.5	30.7	231.0	2.5
NO2	ug/l	6.2	50.0	0.5	5.5	23.0	0.5
NO3NO2	ug/l	49.2	441.0	2.5	42.2	329.0	2.0
NO3WATER	ug/l	47.6	391.0	0.0	38.1	306.0	1.0
P(m/f)	ug/l	12.7	30.0	2.0	13.8	40.0	5.0
P(total)	ug/l	98.4	394.0	33.0	105.0	170.0	42.0
pH	pH	7.6	9.1	6.4	7.5	8.3	7.2
Suspended solids	mg/l	15.7	34.0	6.0	20.3	41.0	9.3
TKN	mg/l	1.0	1.8	0.3	1.2	2.3	0.3
Turbidity	NTU	11.4	41.0	4.4	14.1	31.4	4.9

Lake Ototoa 1992-1999

Depth		0 m			10 m			20 m		
	units	mean	max	min	mean	max	min	mean	max	min
BOD	mg/l	0.4	0.5	0.2	0.3*	0.3*	0.3*	3.2*	3.2*	3.2*
Chlorophyll *a*	ug/l	4.2	12.0	0.0	4.2	8.8	0.3	6.4	19.3	0.0
Chloride	mg/l	38.6	41.3	19.4	39.8	47.4	19.4	39.2	49.0	20.2
Conductivity	mS/m @25oC	20.6	21.9	19.4	20.9	22.4	19.4	21.3	24.1	19.4
Faecal coliform	/100ml	3	11	1	4	33	1	4	49	1
Presumptive coliform	/100ml	16	230	1	10	110	1	9	110	1
NH3NH4	ug/l	8.7	50.0	2.5	9.5	50.0	2.5	64.4	630.0	2.5
NO2	ug/l	1.5	6.0	0.5	1.6	4.0	0.5	2.3	6.0	0.5
NO3NO2	ug/l	20.7	354.0	2.5	8.6	40.0	1.0	8.2	24.0	2.5
NO3WATER	ug/l	18.9	348.0	1.0	6.8	36.0	0.0	6.1	20.0	0.0
P(m/f)	ug/l	7.1	20.0	2.0	6.7	10.0	2.5	8.2	20.0	5.0
P(total)	ug/l	16.1	30.0	6.0	16.0	30.0	3.0	31.0	320.0	3.0
pH	pH	7.8	8.3	7.1	7.8	8.2	7.4	7.3	7.9	6.6
Suspended solids	mg/l	1.1	3.9	0.2	1.2	2.7	0.3	6.6	58.9	0.5
TKN	mg/l	0.3	0.9	0.0	0.4	1.1	0.1	0.5	1.3	0.1
Turbidity	NTU	0.8	3.5	0.3	0.7	2.7	0.4	2.6	15.0	0.4

*only one value above dectection limit recorded

Lake Kuwakatai 1992-1999

Depth		surface			bottom		
	units	mean	max	min	mean	max	min
BOD	mg/l	3.7	6.4	2.0	3.6	6.1	2.1
Chlorophyll *a*	ug/l	57.8	240.5	2.0	47.7	234.0	0.8
Chloride	mg/l	40.6	47.4	21.9	40.9	47.0	22.7
Conductivity	mS/m @25oC	23.9	25.7	21.8	24.2	25.9	21.8
Faecal coliform	/100ml	52	350	5	19	110	1
Presumptive coliform	/100ml	71	350	5	36	230	2
NH3NH4	ug/l	30.0	210.0	2.5	76.6	370.0	2.5
NO2	ug/l	3.8	17.0	0.5	4.1	13.0	0.5
NO3NO2	ug/l	31.7	217.0	1.0	33.9	249.0	2.5
NO3WATER	ug/l	31.0	200.0	0.0	31.0	241.0	1.0
P(m/f)	ug/l	9.4	20.0	2.5	12.4	30.0	2.5
P(total)	ug/l	71.8	910.0	20.0	45.4	101.0	20.0
pH	pH	8.2	9.1	7.2	7.7	8.6	7.0
Suspended solids	mg/l	6.1	24.0	2.2	6.1	26.0	1.0
TKN	mg/l	0.9	2.2	0.1	0.8	1.7	0.2
Turbidity	NTU	2.8	9.5	1.0	2.1	4.1	1.1

Lake Kereta 1992-1999

Depth		0 m		
	units	mean	max	min
BOD	mg/l	2.7	3.3	1.6
Chlorophyll *a*	ug/l	17.0	60.2	5.0
Chloride	mg/l	42.2	61.1	23.5
Conductivity	mS/m @25oC	26.0	34.5	21.4
Faecal coliform	/100ml	619	5400	4
Presumptive coliform	/100ml	967	9000	49
NH3NH4	ug/l	21.8	140.0	2.5
NO2	ug/l	2.2	4.0	0.5
NO3NO2	ug/l	5.8	15.0	0.0
NO3WATER	ug/l	5.0	12.0	0.0
P(m/f)	ug/l	11.0	30.0	5.0
P(total)	ug/l	50.9	120.0	10.0
pH	pH	8.5	9.8	6.6
Suspended solids	mg/l	10.2	31.0	0.9
TKN	mg/l	0.9	2.0	0.2
Turbidity	NTU	6.4	16.0	1.3

Lake Wainamu 1992-1999

Depth		0 m			5 m		
	units	mean	max	min	mean	max	min
BOD	mg/l	2.8	6.7	0.8	0.4	0.4	0.4
Chlorophyll *a*	ug/l	12.6	45.0	0.0	9.4	64.0	0.3
Chloride	mg/l	41.4	49.4	22.2	40.7	47.9	21.9
Conductivity	mS/m @25oC	21.6	34.7	17.7	21.2	22.6	19.0
Faecal coliform	/100ml	28	220	2	13	79	2
Presumptive coliform	/100ml	96	800	2	30	79	2
NH3NH4	ug/l	10.2	46.0	2.5	16.9	90.0	2.5
NO2	ug/l	2.9	8.0	0.5	4.0	23.0	0.5
NO3NO2	ug/l	25.4	120.0	2.0	29.5	144.0	2.5
NO3WATER	ug/l	24.6	114.0	0.0	26.3	141.0	0.0
P(m/f)	ug/l	11.5	30.0	2.0	13.6	30.0	5.0
P(total)	ug/l	38.2	74.0	14.0	64.2	510.0	16.0
pH	pH	7.6	8.3	7.0	7.3	7.8	6.8
Suspended solids	mg/l	4.0	10.3	1.1	4.6	9.4	2.3
TKN	mg/l	0.4	1.0	0.1	0.4	1.2	0.0
Turbidity	NTU	9.8	26.0	1.2	12.1	27.0	1.4

APPENDIX 42: DESCRIPTION OF WATER QUALITY VARIABLES

INTRODUCTION

The following section provides a summary of general information about the variables used in the LTB surveys including; what they measure, and relevance to water suitability for various uses. Where there are clear differences between freshwater, saline and lake resources each has been discussed separately.

Water Temperature

Water bodies generally show seasonal patterns in temperature that are correlated with air temperature. Heat transfer between the atmosphere and water surface primarily influences water temperatures of large water masses

Stream temperatures, in the absence of industrial discharges of heated water, are primarily regulated by the extent of riparian vegetation shading of the waterway. In catchments developed for urban uses or intensive agriculture, riparian vegetation has generally been removed to ameliorate flooding problems or maximise land use and as a result stream temperatures tend to be elevated.

Shallow coastal saline water temperatures are most commonly influenced by water passage on incoming tides over intertidal sediments that have been warmed by the sun, resulting in an increase in water temperature.

Lake watercolour can influence water temperature, because incident radiation is absorbed to a greater extent by darker water bodies resulting in an increase in water temperature.

Elevated water temperature can influence aquatic biota in the following ways:

(i) Community structure in compromised waterways dominated by thermotolerant species that can survive fluctuations in temperature, particularly those experienced in summer.

(ii) An increase in water temperature results in a reduction in the dissolved oxygen carrying capacity of the water. This may be critical for sensitive organisms particularly where saturation levels are already reduced (see next section).

Dissolved Oxygen Saturation

Dissolved oxygen saturation (DO (sat)) gives a direct measure for the assessment of a waterway's ability to support aquatic life and is therefore one of the more important water quality parameters measured in our surveys. However where low saturation levels occur there is often a multiplicity of possible causes.

DO (sat) levels show natural fluctuations both diurnally (throughout the day) and seasonally. Diurnal changes are caused predominantly by the respiratory activities of aquatic biota, particularly plants. Seasonal variations are mainly follow changes in temperature, which is inversely related to oxygen solubility.

Dissolved oxygen levels around 5 mg/L are known to be stressful to sensitive aquatic biota. This concentration equates to a DO (sat) of 40%-60% at the range of temperatures commonly found in Auckland waterways. If low DO (sat) levels persist for any extended period of time some organisms that cannot move away may die. Ultimately the diversity of aquatic biota may be reduced to those species tolerant of low DO (sat).

Amelioration of low DO (sat) levels can be achieved by a reduction of point and non-point source runoff by the modification of land use practices. Riparian vegetation has a role to play in filtering out diffuse sources of oxygen-demanding substances in rural and urban runoff, reducing temperatures and restricting in-stream plant growth by shading. Urbanised areas have the potential to reduce the input of oxygen demanding substances by utilising various stormwater treatment initiatives. In terms of point source inputs, ARC rural and industrial pollution abatement activities are designed to eliminate unauthorised discharges and control authorised discharges of contaminants to a level that can be assimilated by the water body concerned.

In catchments with agricultural development, substantial volumes of stream water are abstracted for irrigation purposes as, under current policy, up to 70% of the one in five year low flow is allocated in the Auckland Region. Consequently DO (sat) levels may be further compromised by discharges of pollutants during the summer when the stream assimilation capacity is reduced by such abstractions.

Supersaturation of water is not unusual where aquatic plants in the form of macrophytes, periphyton or free-floating algae are abundant. During the hours of daylight the release of oxygen during photosynthesis augments the transfer of oxygen through the surface of the waterbody by diffusion. The negative side to the presence of these plants is the consumption of oxygen at night (i.e. by respiration), which can lead to serious oxygen depletion and subsequent effects on other biota. Depression in DO (sat) levels caused by this phenomenon is usually greatest in the early hours of the morning.

Dissolved Oxygen/Temperature Profiles

In lake surveys dissolved oxygen (DO)/temperature profiles are used to determine if there is thermal stratification. A boundary zone exists where temperature decreases by 1 degree Celsius per vertical metre of water depth. Profiles are measured *in situ* using a dissolved oxygen meter and probe lowered from a boat. Stratification occurs during the summer months when calm and warm weather causes the formation of a warm, less dense, water layer on the surface. This layer, the epilimnion, floats on the colder denser water, the hypolimnion, and is separated by the thermocline, where temperature, density and oxygen levels change rapidly with depth (often termed the metalimnion). Low DO levels can have a profound influence on the distribution of organisms in the lake.

Stratification effectively seals off the deeper regions from oxygen replenishment via the lake surface. Hypolimnetic oxygen consumption, resulting from respiration of various microorganisms during the degradation of oxygen-demanding substances in the bottom waters of the lake, can cause DO levels to drop to near zero. A consequence of the low DO levels can be release of nutrients that were formerly bound up in the sediments, into a biologically available form.

In the early autumn when weather patterns become less stable, with cooler temperatures and more wind, sufficient energy in the form of turbulence, convection and advection are provided to effect the mixing of the various stratified layers, a process termed the "turn-over". Turnover results in the transport of bioavailable nutrients from the hypolimnion to the epilimnion and, depending on lake water clarity, potentially into the photic zone where they are accessible to phytoplankton. If turnover occurs during the mid-summer period the nutrient liberation can lead to nuisance algal growth.

Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of the amount of oxygen required to break down the organic matter in a set volume of water in a five-day period at 20 degrees Celsius. High BOD levels in water bodies indicate the presence of organic matter, which may exert an oxygen demand resulting in a reduced dissolved oxygen concentration and therefore a reduction of water quality. A yardstick for comparison is that waters with a BOD greater than 5 mg/I are considered polluted.

Measures available to reduce BOD input have been canvassed in the section on DO (sat).

Conductivity

Conductivity is used to estimate the total dissolved solids (soluble salts) content of the water. The soluble salts concentration is an important consideration in relation to abstraction of water for horticultural use and in extreme situations the suitability of water for stock use.

Chloride

The major natural source of chloride is from groundwater, which in the Auckland Region ranges from 17-40 mg/L depending on the geology concerned. High chloride levels are present in wind blown spray in coastal environments and in rural and urban wastewater. Thus, high chloride levels are often used to indicate the presence of other contaminants in freshwater aquatic systems. Chloride is particularly mobile in groundwater being weakly adsorbed onto soil particles and readily leached by infiltration rainfall.

High chloride levels in freshwaters have the potential to compromise water use for irrigation of crops or for potable supply. Guidelines for crop watering by foliar application recommend maximum levels of less than 100 mg/L (ARWB TP 411987). New Zealand Health Department guidelines (1984) for human consumption give a taste threshold of 200-300 mg/L.

pH

The pH is a measure of the hydrogen ion concentration and therefore indicates the acid or alkaline nature of the water. The pH range is from 0-14 and each unit represents a ten-fold change in hydrogen ion concentration. Natural freshwaters have a pH of around 7 although 6-9 is considered within the normal range. By comparison seawater is strongly buffered and even small pH changes are significant. The normal saline range is considerably narrower than freshwater from pH 7.8 to 8.3.

In the absence of contaminant discharges the major influence on pH levels is likely to be the photosynthetic activity of aquatic plants. This occurs when carbon dioxide is absorbed upsetting the carbon dioxide-bicarbonate equilibrium of the stream waters and elevating pH. This problem is most likely to occur in waterways with high nutrient levels and little overhanging vegetation to limit light levels and thereby in-stream plant growth.

pH does not have a directly toxic effect on aquatic biota although many species are not tolerant to wide fluctuations in pH. The principal influence of pH is on the toxicity or mobility of other contaminants present in the water column or sediments. In urbanised situations receiving water sediments may contain large amounts of heavy metals such as zinc, copper and lead from road stormwater runoff. Decreases in pH would tend to mobilise some of these bound contaminants. The toxicity of other contaminants such as ammonia, which is elevated in some rural waste discharges, generally increases with higher pH and temperature.

Chlorophyll *a*

Chlorophyll *a* level is a measure of the biomass in terms of photosynthetic algae (phytoplankton) abundance. Phytoplankton are microscopic plants which drift freely in the currents of lakes and saline waters. They can determine the suitability of natural waters for a variety of uses. The Lake Managers Handbook (MWD 1987) states that in high concentrations phytoplankton can:

- decrease water clarity;
- alter the colour of the water;
- be toxic to stock and wildlife;
- form unsightly surface scums;
- produce unpleasant tastes and odours;
- alter the water pH;
- deplete oxygen through respiration and decay;
- clog water intake filters; and
- disrupt flocculation and chlorination processes in water treatment plants

Chlorophyll *a* level is used in conjunction with total nitrogen and total phosphorus levels, to assess the trophic status of water bodies, particularly lakes.

The Lake Managers' Handbook (MWD 1987) defines lake trophic status in terms of average annual chlorophyll *a* level and annual maximum chlorophyll a level as follows:

Average annual (μg/L)	Maximum annual (μg/L)	Trophic status
<2	<5	Ultra-oligotrophic (ultra low enrichment)
2-5	5-15	Oligotrophic (very low enrichment)
5-15	15-40	Mesotrophic (medium enrichment)
>15	>40	Eutrophic (highly enriched)

Water Clarity

Public perception of water quality is often based on their observation of water quality or clarity, in that poor water clarity is aesthetically unpleasing, regardless of other water quality parameters. In the ARC baseline water quality monitoring programmes water clarity is expressed by measurements of turbidity, black disk transparency and Secchi disk depth. The critical measures of acceptable water clarity are: for recreational waters clarity greater than 1.6 metres as measured by the black disk technique, and for aesthetic purposes no significant change. A significant change is considered to be a 20% change in black disk reading.

Turbidity

Turbidity is a measure of the passage of the degree to which light is scattered in water by suspended particles and colloidal materials. Samples are analysed in the laboratory using a meter and the results are given as nephelometric turbidity units (NTU).

When turbidity levels are high light penetration is reduced, thereby limiting the ability of aquatic plants (algae and macrophytes) to photosynthesise (i.e. a reduction in the so-called euphotic depth). Organisms that are visually oriented may have difficulty locating and catching prey in turbid water and the fine suspended material that is characteristic of turbid water may detrimentally affect gill structures of aquatic organisms.

Black Disk Transparency

Black disk transparency is a measure of horizontal water clarity. The black disk reflects very little light and black disk transparency is the distance at which it becomes visible to an observer (using an underwater viewer). It is a good estimate of the distance that sighted animals can see horizontally under water.

Secchi Sisk Depth

Secchi depth is a measurement of vertical optical water clarity, usually applied in deeper water bodies such as lakes, which is a function of light penetration. This defines the depth to where photosynthetic plants can survive and is known as the "euphotic depth". As a rough guide, the euphotic depth is taken as 2.5 times the Secchi depth. – The depth at which a quartered 200 mm diameter black and white disk becomes visible to an observer as it is raised through the water column.

Suspended Solids (also called non-filterable residue)

Suspended solids (SS) is a measurement of the suspended material in the water column, including plankton, non-living organic material, silica, clay and silt. High SS levels reduce light penetration and provide media for pollutants to attach to, resulting in a reduction in water quality for a variety of uses, such as horticulture, irrigation, stock water supply, and recreational and ecological functions. Under the appropriate conditions the suspended material can settle out as sediment thereby causing further problems, such as smothering of biota.

SS burdens to waterways can be reduced in a variety of ways depending on the type of land use concerned:

In rural catchments riparian zone management provided an effective filter for diffuse sources of SS and reduces streambed and bank scouring by dissipating the energy of floodwaters. Preventing stock access to stream beds and banks is a useful mitigation tool for reducing excessive SS.

In urban and industrial areas SS can be reduced through the implementation of storm water control measures. The period when land is being urbanised has the greatest potential to mobilise sediments to waterways. ARC Environment has produced urban earthworks guidelines to minimise SS runoff from exposed erodible soils.

Microbial Indicators

Microbial indicator organisms are typically used in water quality monitoring to provide a measure of faecal contamination and hence the sanitary quality of water resources. A number of different indicator organisms and monitoring strategies can be used depending on whether the purpose of sampling is simply to detect and quantify the level of contamination, or whether some measure or index of public health risk is required.

The indicator organisms used for water quality monitoring are generally bacteria that are present as normal inhabitants in the gut of healthy warm-blooded animals, including humans, and are shed in large numbers in faecal matter (at a rate of 10^6 – 10^9 per gram). They are not usually considered to present a risk to public health when present in natural waters (i.e. they are not generally disease causing or pathogenic when contacted through this route), but their presence is taken to indicate faecal contamination and hence the possibility that pathogenic microorganisms that are found in the gut may also be present.

It is necessary to use indicator organisms for routine monitoring purposes because there is such a wide variety of pathogens that may be present in faecal matter, that it is impossible to test for all of them at once. Detection of some pathogens, particularly viruses, is also expensive and time consuming. Also, the infective doses for many pathogens, particularly of viruses, are so low as to make routine measurement impracticable.

In New Zealand three bacterial indicator groups have been routinely used for water quality monitoring. These are the presumptive coliform, faecal coliform, and enterococci groups.

Coliforms or Presumptive Coliforms

The term coliform is used to describe a heterogeneous group of bacteria belonging to the family *Enterobacteriaceae*, which are characterised by their ability to ferment lactose with the productopn of acid and gas at 35°C. Included within this definition are members of the *Escherichia*, *Klebsiella*, *Enterobacter*, *Serratia*, and *Citrobacter* genera. While members of all of these genera are typically found in faecal material, only one, *Escherichia coli*, is truly faecal specific.

The results of coliform or presumptive coliform tests are often highly variable and do not necessarily indicate the degree of faecal contamination present in a waterway. This is because members of the coliform group are also found as natural inhabitants of soil and decaying vegetation, and therefore elevated levels in waters may be due to naturally occurring organisms. Nevertheless, the presumptive coliform test may provide useful information on the level and nature of contamination when used in association with other analyses such as the faecal coliform test.

Faecal Coliforms

Faecal coliforms represent a subset of the coliform group that are differentiated by their ability to ferment lactose with the production of acid and gas at the elevated temperature of 44.5°C. This group are more specific indicators of faecal contamination than the coliform group, although the functional definition still includes some organisms that are natural inhabitants of soil and decaying vegetation. The use of the term faecal" in the group description is therefore somewhat misleading, and has lead to the use of the term "thermotolerant coliforms" as an alternative group name.

Faecal coliforms have historically been the indicator of choice for assessment of the sanitary quality of natural waters and have formed the basis of the previous microbiological guidelines for recreation and shellfish growing waters. However, studies undertaken on behalf of the United States Environmental Protection Agency

(USEPA) comparing indicator levels with health effects have indicated that enterococci (see later) provide a much better index of health risk than faecal coliforms. The USEPA have subsequently developed enterococci guidelines for health risk monitoring of recreational water quality in the USA. These guidelines have been used to form the basis of New Zealand's provisional guidelines for recreational water quality monitoring. For further information on this topic refer to the “Recreational Water Quality Guidelines” published by Ministry for the Environment and Ministry of Health, Wellington, November 1999.

However despite this the faecal coliform group is still considered appropriate for qualitative monitoring of faecal contamination in natural waters, and for assessment of long terms trends in water quality over time. It is in this context that the indicators are used in the baseline water quality studies. The only major impediment to this use is the inability to discriminate between contamination of human and non-human origin. Such assessments must be made on the basis of subjective evaluation of likely sources and routes of contamination within the catchment.

Enterococci

Members of the genus *Enterococcus* comprise another group of bacteria that are found in the gut of warm blooded animals and are commonly used as a health related indicators of saline recreational water quality. Enterococci analysis is typically carried out by the membrane filtration method using mE and EIA media (see APHA 1992). This method is selective for two species, *Ent. faecalils* and *Ent. faecium,* which are prominent in human faecal matter, although other faecal and non-faecal associated enterococci may also be detected using this method. Interpretation of results and assessment of public health risk therefore requires that consideration be given to the likely sources contaminants.

Nutrients

Nutrients are chemical compounds that are necessary for normal plant growth and are divided loosely into macro and micro-nutrients. Routine water quality monitoring records two groups of essential macro-nutrients.

The availability of readily assimilated forms of the nutrients nitrogen and phosphorus are commonly accepted as factors limiting aquatic plant growth. Anthropogenic activities increase the nutrient loading through the discharge of waste products, fertilisers and general storm-water runoff. Nutrient enrichment can result in a proliferation of algae and macrophytes in waterways, which potentially has a number of detrimental effects including:

(i) Choking waterways leading to reduced drainage capacity,

(ii) Loss of amenity values,

(iii) Physical habitat reduction,

(iv) Excessive fluctuations in dissolved oxygen and pH,

(v) Reduced suitability for stock watering or horticultural irrigation.

The adverse effects of elevated nitrate levels can be mitigated by the provision of riparian vegetation providing sufficient shading to preclude or minimise in-stream plant growth. Riparian vegetation also provides a mechanism for intercepting contaminants by filtering direct runoff and uptake of nitrate from the soil at the ground water interface. The proactive approach is to prevent or minimise the discharge of nutrient rich discharges into waterways. Nutrient levels entering waterways can be reduced by a number of land management options including;

(i) Limiting concentrations from point sources by consent conditions,

(ii) Requiring land application of wastes in a way that minimises subsequent input to streams,

(iii) Implementing land management techniques such as riparian zone protection to reduce diffuse input.

Ammonia

Ammoniacal nitrogen is a macro-nutrient but is considered in general water quality evaluations in terms of its toxicity to many aquatic animals.

Ammonia occurs in a number of waste products, which if discharged to the environment can result in elevated ammonia levels. Ammonia is reported as a combination of un-ionised ammonia (NH_3) and the ammonium ion (NH_4^+), at normal pH values the latter form predominates. Un-ionised ammonia is the more toxic form to aquatic life. The toxicity of ammonia is very dependent on water temperature, salinity and pH (USEPA, 1985). Regulatory agencies, such as the ARC Environment, have tended to rely on overseas criteria such as those promulgated by the USEPA. The ARC has commissioned studies on Auckland freshwater biota, which corroborate that USEPA criteria are appropriate – ARC Environment and Planning Division TP23 (1992).

Ammonia toxicity for given pH and temperature combination can be calculated using a mathematical equation. As a generalisation a chronic or long term exposure limit of 0.77 mg/L is appropriate for sensitive freshwater organisms under ambient conditions. In saline waters ammonia toxicity is influenced by salinity in addition to pH and temperature. The chronic exposure limit for sensitive saline organisms under ambient conditions is 2.3 mg/L.

Long term or chronic effects on biota include the limitation of species that can survive in the waterway to those tolerant of ammonia. In addition sublethal effects, such as disruption of feeding patterns and removal of food sources, reduction of reproductive viability and restricted recruitment of juvenile organisms in response to long term exposure to ammonia, has been documented by the USEPA.

In catchments with intensive farming practices ammonia rich wastewaters can come from several sources. Potential causes of diffuse input include, rainfall on areas adjacent to waterways that have been grazed recently, spray irrigated with wastewater or had fertilisers such as ammonia urea applied to them recently. Rural point sources include race runoff, oxidation pond discharges, silage leachate, or raw wastes when disposal systems break down or are not used as intended.

Nitrite

Nitrite is the intermediate step in the conversion of ammonia to nitrate. It is usually short lived in the aquatic environment in the presence of oxygen and is therefore indicative of a source of nitrogenous waste in the immediate vicinity of the sampling site. It is intermediate in toxicity to ammonia and nitrate (USEPA, 1986).

Nitrate

Nitrate is the end product of the breakdown (oxidation) of ammonia through the intermediate step of nitrite by microbial decomposition. It is not particularly toxic to aquatic life (USEPA, 1986). Water for use as potable supply is limited to 10 mg/L on public health grounds. In terms of crop irrigation water requirements higher nitrate levels could be seen as an advantage saving on fertiliser costs. For stock drinking water requirements the recommended limit is 100 mg/L.

Sources of nitrate in aquatic systems are similar to those discussed for ammonia. Nitrate is poorly bound to the soil and is therefore highly mobile. It is readily leached into local groundwater systems, particularly under high rainfall events. In winter when ground conditions become saturated the capacity of the soil to assimilate waste is reduced, resulting in elevated nitrate levels in runoff.

Nitrate is an important plant nutrient (which is generally non-limiting), which in conjunction with sufficient available phosphorus can lead to proliferation of aquatic plants (algae and macrophytes). Respiration of aquatic plants at night can lead to reductions in dissolved oxygen to the point that other aquatic organisms may become stressed or killed. Photosynthetic activity of aquatic plants also leads to elevated stream pH, which has an effect on the toxicity of other contaminants in the water such as ammonia.

Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen (TKN) is a measure of the organic nitrogen plus ammonia concentration of a water sample. It includes such natural materials as proteins and peptides, nucleic acids and urea and numerous synthetic organic materials. It is used in this report to calculate the total nitrogen content of water samples.

Total Nitrogen

Total nitrogen is the combination of nitrate, nitrite and TKN, it is to estimate the "bioavailable" fraction of nitrogen in waterways. It is also used in conjunction with total phosphorus and chlorophyll a levels, to assess the trophic status of water bodies, particularly lakes.

The Lake Managers Handbook (MWD 1987) defines lake trophic status in terms of average annual total nitrogen level as follows:

Total Nitrogen (mg/L)	Trophic status
<0.2	Ultra-oligotrophic (ultra-low enrichment)
0.2- 0.3	Oligotrophic (very low enrichment)
0.3- 0.5	Mesotrophic (medium enrichment)
>0.5	Eutrophic (highly enriched)

Total Phosphorus

Total phosphorus is a measure of all the phosphorus present in the sample and includes the soluble (bioavailable) fraction that is adsorbed onto sediment particles and present in the form of algae and other organic matter.

The Lake Managers Handbook (MWD 1987) defined lake trophic status in terms of average annual total phosphorus level as follows:

Total Phosphorus (mg/L)	Trophic status
<0.01	Ultra-oligotrophic (ultra-low enrichment)
0.01-0.02	Oligotrophic (very low enrichment)

0.02-0.05	Mesotrophic (medium enrichment_
>0.05	Eutrophic (highly enriched)

Dissolved Reactive Phosphorus (soluble reactive phosphorus)

Dissolved reactive phosphorus (DRP) is considered to be the bioavailable fraction of phosphorus and is an important as an indicator of water quality. It is frequently cited as the nutrient limiting the proliferation of algae and other aquatic plants in New Zealand waterways. Levels required to stimulate instream plant growth are reportedly as low as 0.01 mg/L (Hickey et al 1989).