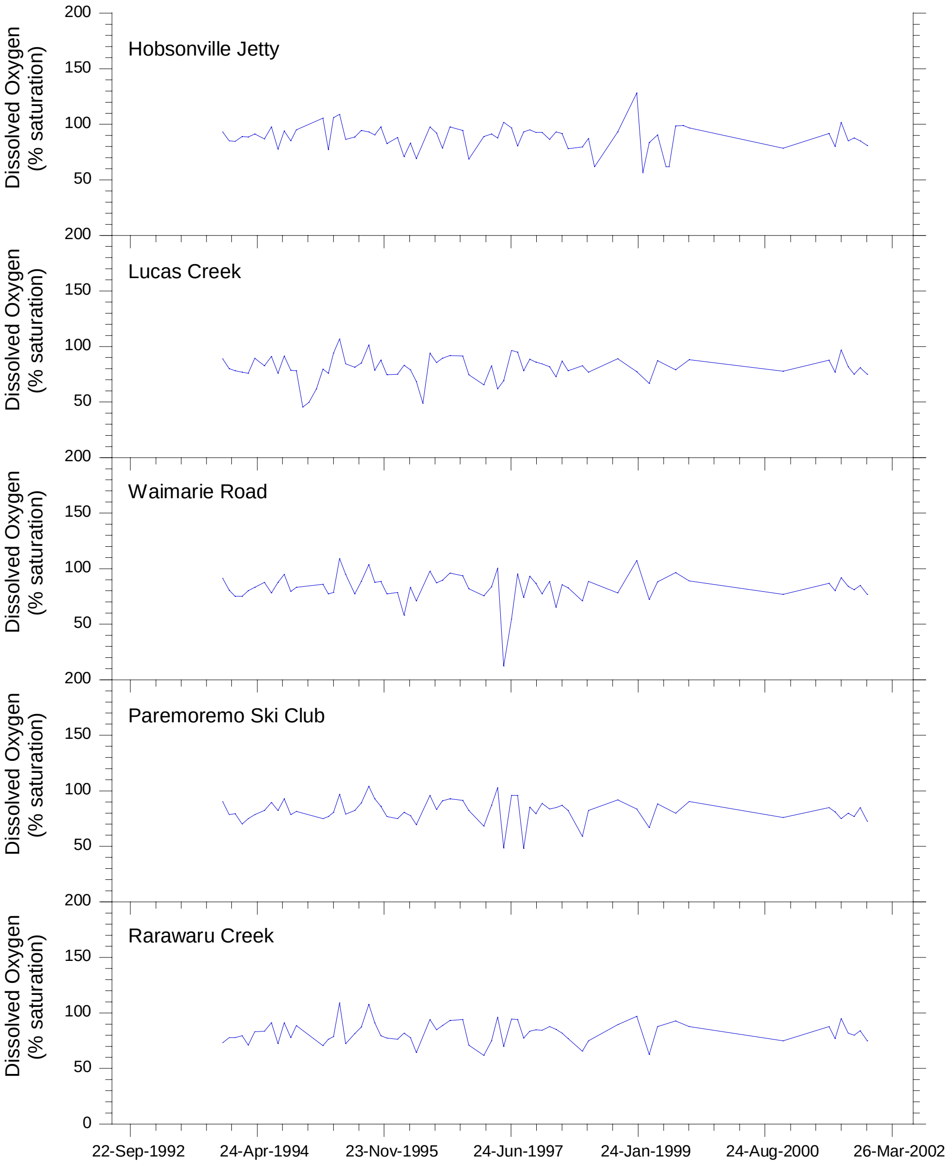
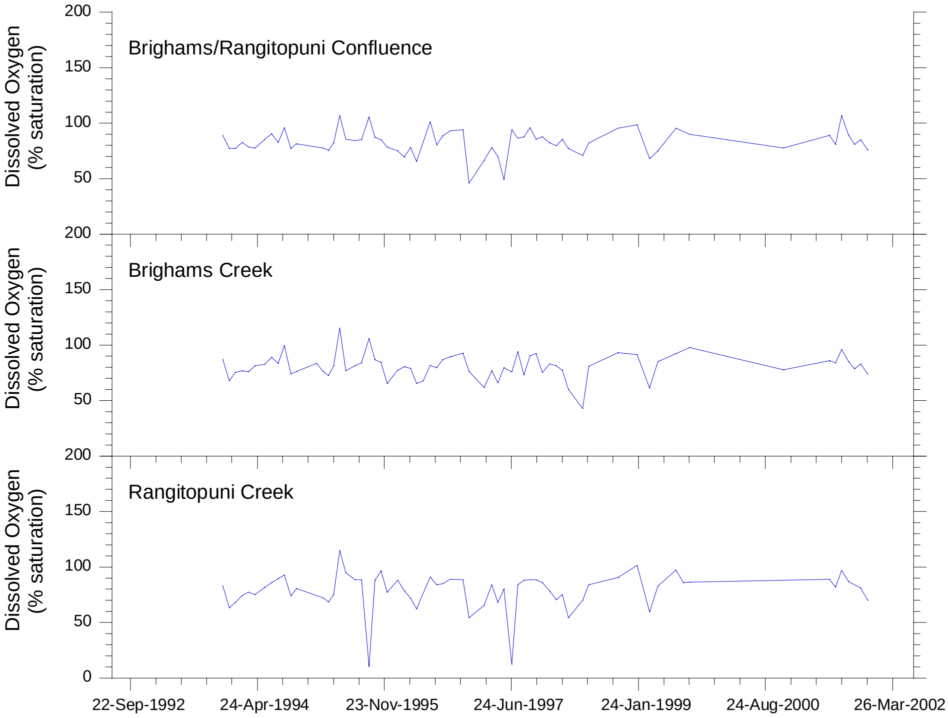

Dissolved Oxygen (% saturation)
Hobsonville Jetty
Lucas Creek
Waimarie Road
Paremoremo Ski Club
Rarawaru Creek
200
150
100
50
0
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002


Brighams/Rangitopuni Confluence
Brighams Creek
Rangitopuni Creek
Dissolved Oxygen (% saturation)
200
150
100
50
0
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002

APPENDIX 52: UPPER WAITEMATA HARBOUR – AMMONIA NITROGEN

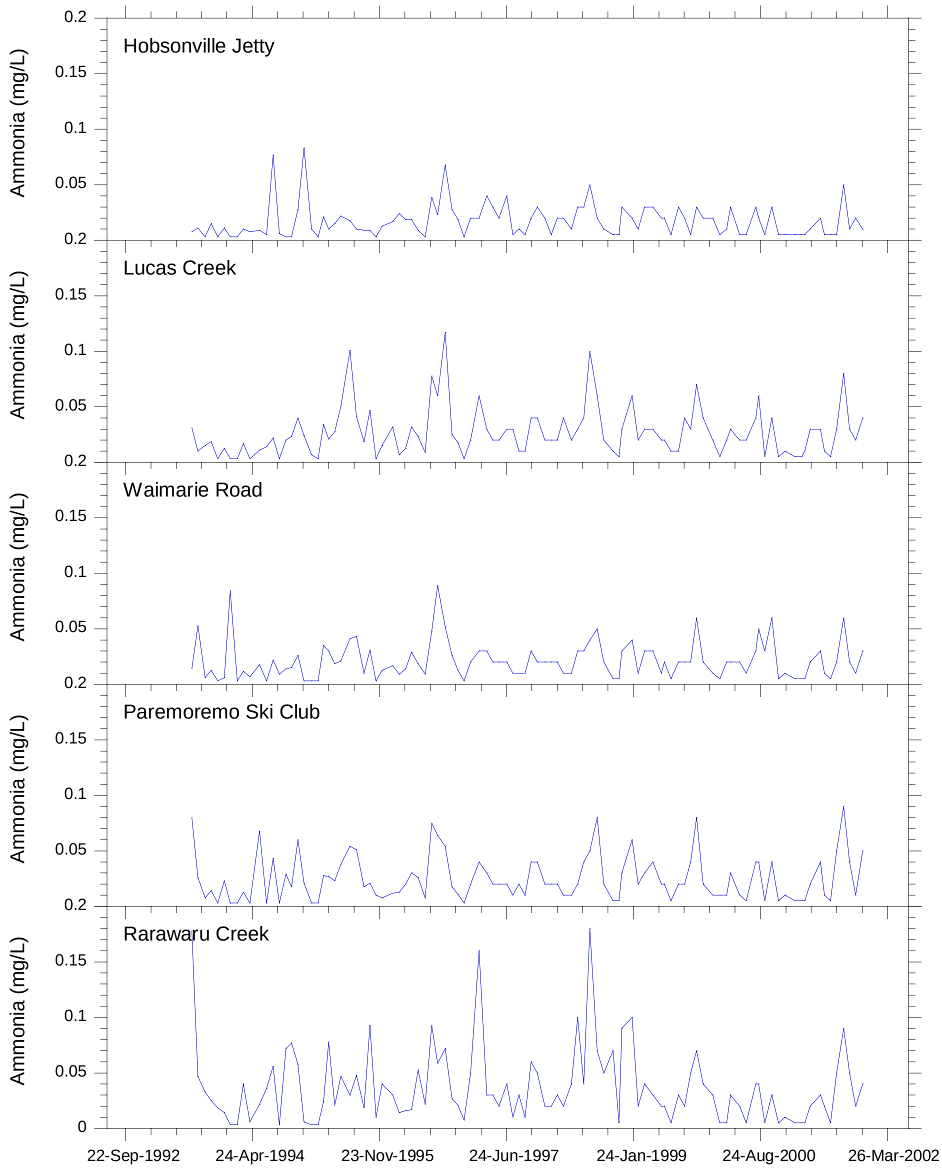
a) Ammonia nitrogen (mg/L) during January 2001 - December 2001

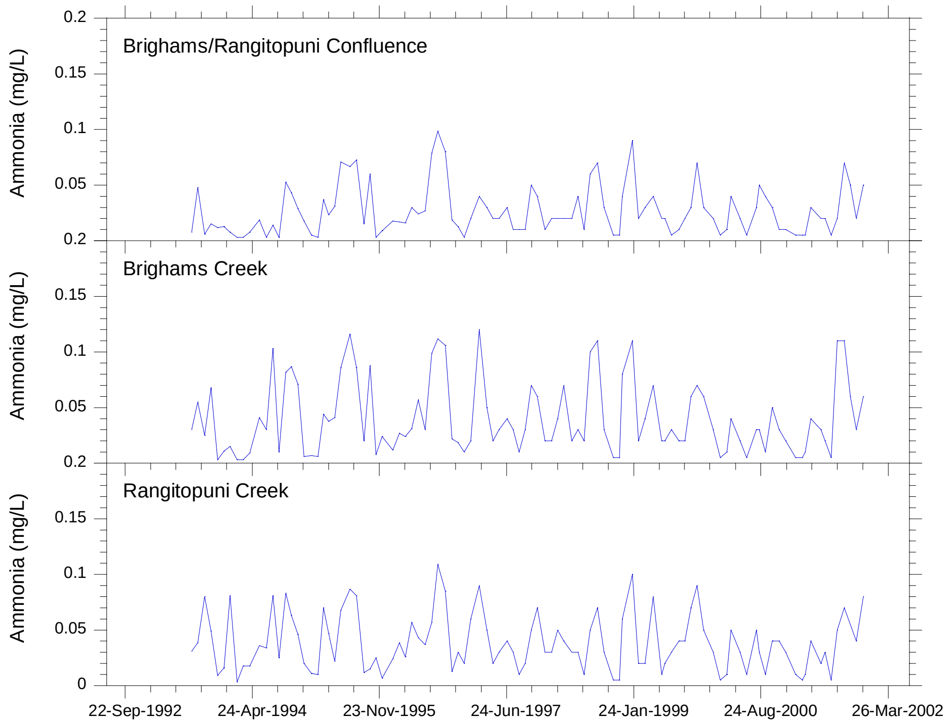
Date	Hobsonville	Lucas	Waimarie	Paremoremo	Rarawaru	Brighams/Rangitopuni	Brighams	Rangitopuni
30-Jan-01	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.010
02-Mar-01	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
14-Mar-01	0.005	0.010	0.005	0.005	0.005	0.005	0.010	0.010
09-Apr-01	0.010	0.030	0.020	0.020	0.020	0.030	0.040	0.040
24-May-01	0.020	0.030	0.030	0.040	0.030	0.020	0.030	0.020
12-Jun-01	0.005	0.010	0.010	0.010	0.020	0.020	0.020	0.030
11-Jul-01	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
08-Aug-01	0.005	0.030	0.020	0.050	0.050	0.020	0.110	0.050
07-Sep-01	0.050	0.080	0.060	0.090	0.090	0.070	0.110	0.070
04-Oct-01	0.010	0.030	0.020	0.040	0.050	0.050	0.060	0.040
02-Nov-01	0.020	0.020	0.010	0.010	0.020	0.020	0.030	
04-Dec-01	0.010	0.040	0.030	0.050	0.040	0.050	0.060	0.080
Median	0.008	0.025	0.015	0.015	0.020	0.020	0.030	0.030
IQR/Median %	100	85	117	250	188	150	171	117

b) Statistical summary for 1992-2001: Ammonia nitrogen (mg/L)

	Hobsonville Jetty	Lucas Creek	Waimarie Road	Paremoremo Ski Club	Rarawaru Creek	Brighams/Rangitopuni confluence	Brighams Creek	Rangitopuni Creek
N	102	102	102	102	102	102	102	101
Median	0.012	0.020	0.020	0.020	0.030	0.020	0.030	0.030
Normality	F	F	F	F	F	F	F	F
Seasonality	N	N	Y	N	Y	Y	Y	N
Trend	NS	NS	NS	NS	NS	NS	NS	NS
Slope	NS	NS	NS	NS	NS	NS	NS	NS

c) The graphs on the following pages show ammonia nitrogen measurements from January 1993 to December 2001 (where data available).


Hobsonville Jetty
Lucas Creek
Waimarie Road
Paremoremo Ski Club
Rarawaru Creek
Ammonia (mg/L)
0.2
0.15
0.1
0.05
0
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002


Brighams/Rangitopuni Confluence
Brighams Creek
Rangitopuni Creek
Ammonia (mg/L)
0.2
0.15
0.1
0.05
0
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002

APPENDIX 53: UPPER WAITEMATA HARBOUR – NITRITE NITROGEN

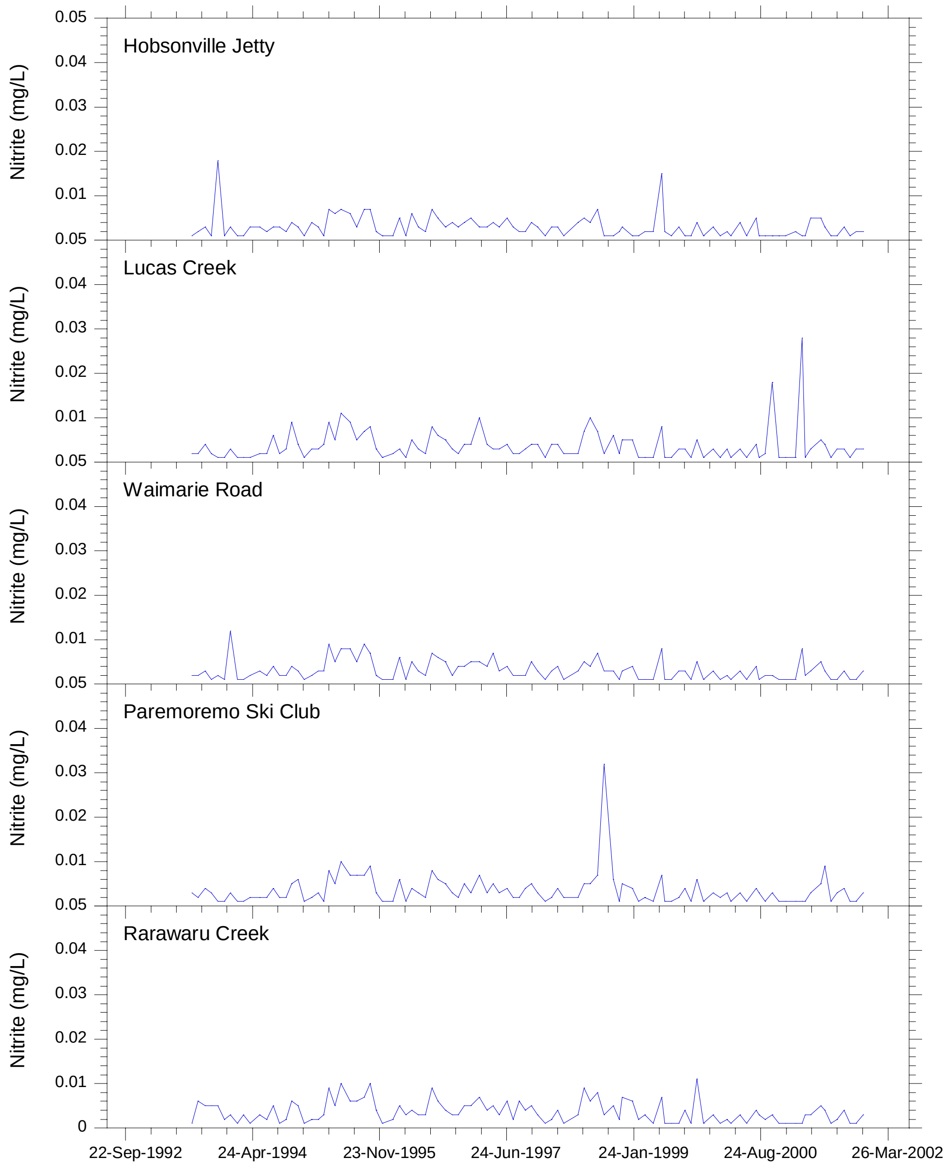
a) Nitrite nitrogen (mg/L) during January 2001 - December 2001

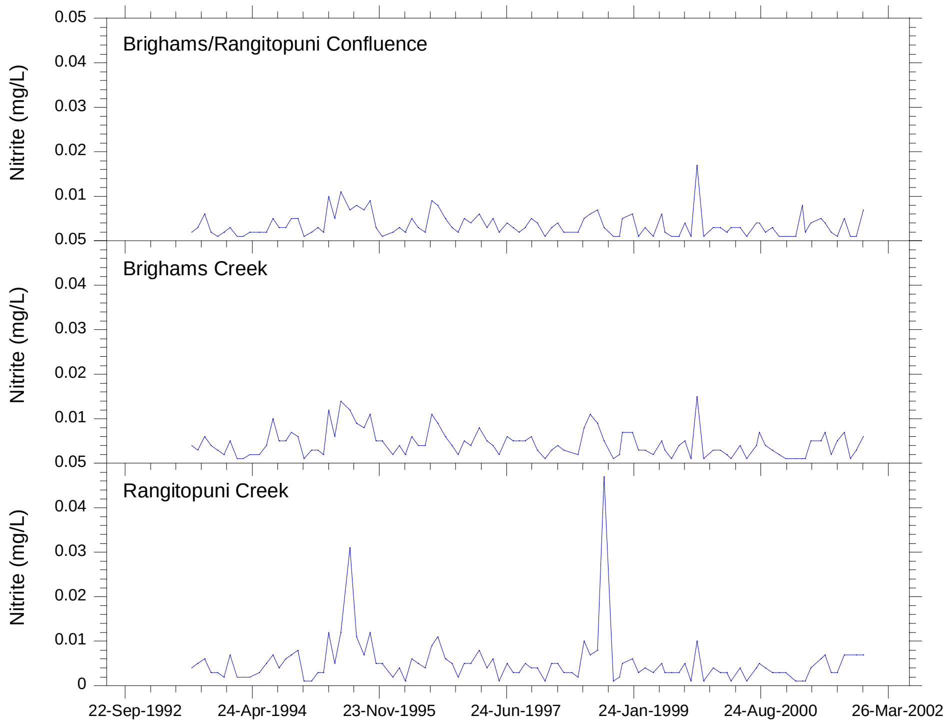
Date	Hobsonville	Lucas	Waimarie	Paremoremo	Rarawaru	Brighams/Rangitopuni	Brighams	Rangitopuni
30-Jan-01	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001
02-Mar-01	0.001	0.028	0.008	0.001	0.001	0.008	0.001	0.001
14-Mar-01	0.001	0.001	0.002	0.001	0.003	0.002	0.001	0.001
09-Apr-01	0.005	0.003	0.003	0.003	0.003	0.004	0.005	0.004
24-May-01	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006
12-Jun-01	0.003	0.004	0.003	0.009	0.004	0.004	0.007	0.007
11-Jul-01	0.001	0.001	0.010	0.001	0.010	0.002	0.002	0.003
08-Aug-01	0.001	0.003	0.001	0.003	0.002	0.001	0.005	0.003
07-Sep-01	0.003	0.003	0.003	0.004	0.004	0.005	0.007	0.007
04-Oct-01	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
02-Nov-01	0.002	0.003	0.001	0.001	0.001	0.001	0.003	0.007
04-Dec-01	0.002	0.003	0.003	0.003	0.003	0.001	0.006	0.007
Median	0.002	0.003	0.003	0.002	0.003	0.002	0.004	0.004
IQR/Median %	100	75	83	113	100	163	106	125

b) Statistical summary for 1992-2001: Nitrite nitrogen (mg/L)

	Hobsonville Jetty	Lucas Creek	Waimarie Road	Paremoremo Ski Club	Rarawaru Creek	Brighams/Rangitopuni confluence	Brighams Creek	Rangitopuni Creek
N	101	101	101	101	101	101	101	101
Median	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.004
Normality	F	F	F	F	F	F	F	F
Seasonality	N	N	N	Y	N	N	Y	Y
Trend	97%	NS	NS	NS	99%	NS	94%	NS
Slope	0	NS	NS	NS	-0.0002	NS	-0.0002	NS

c) The graphs on the following pages show nitrite nitrogen measurements from January 1993 to December 2001 (where data available).


Hobsonville Jetty
Lucas Creek
Waimarie Road
Paremoremo Ski Club
Rarawaru Creek
Nitrite (mg/L)
0.05
0.04
0.03
0.02
0.01
0
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002


Brighams/Rangitopuni Confluence
Brighams Creek
Rangitopuni Creek
Nitrite (mg/L)
0.05
0.04
0.03
0.02
0.01
0
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002

APPENDIX 54: UPPER WAITEMATA HARBOUR – NITRATE NITROGEN

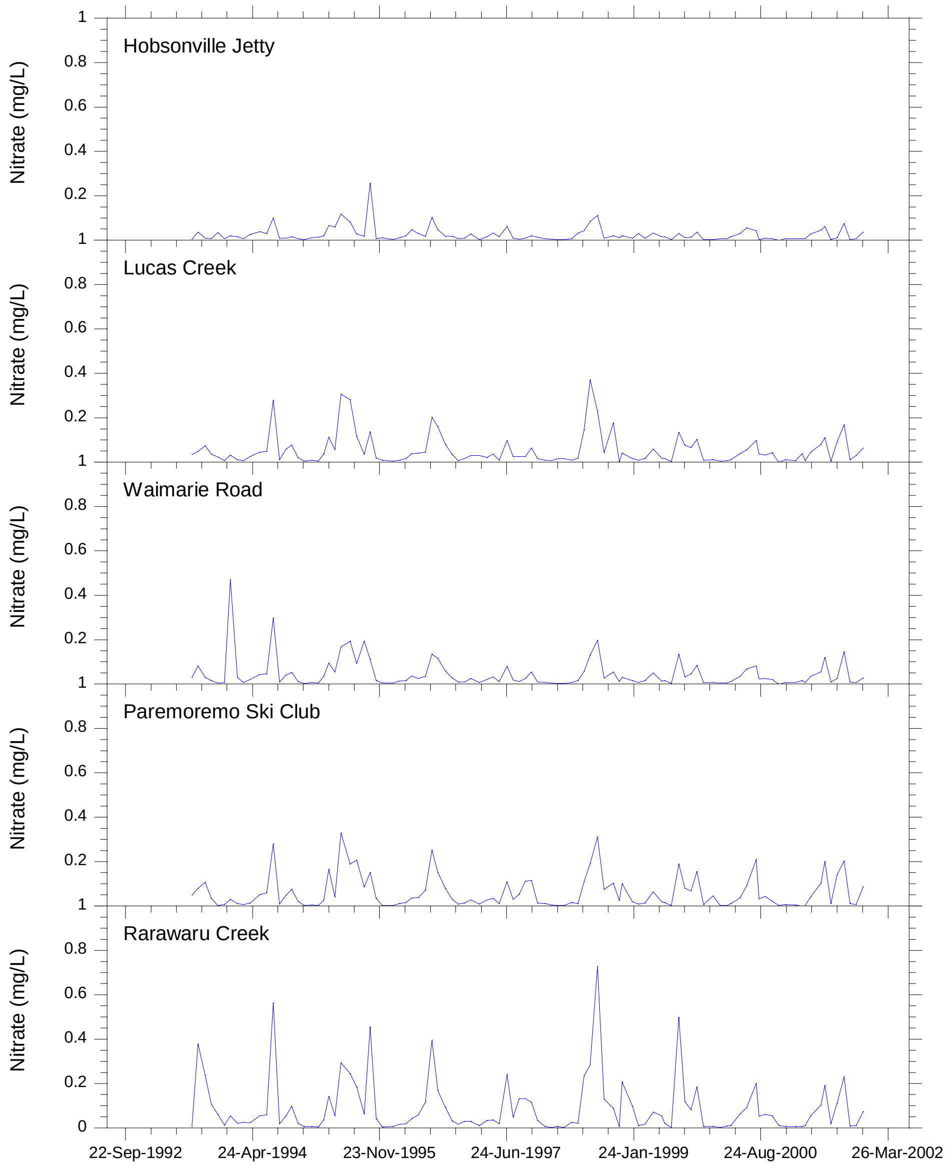
a) Nitrate nitrogen (mg/L) during January 2001 - December 2001

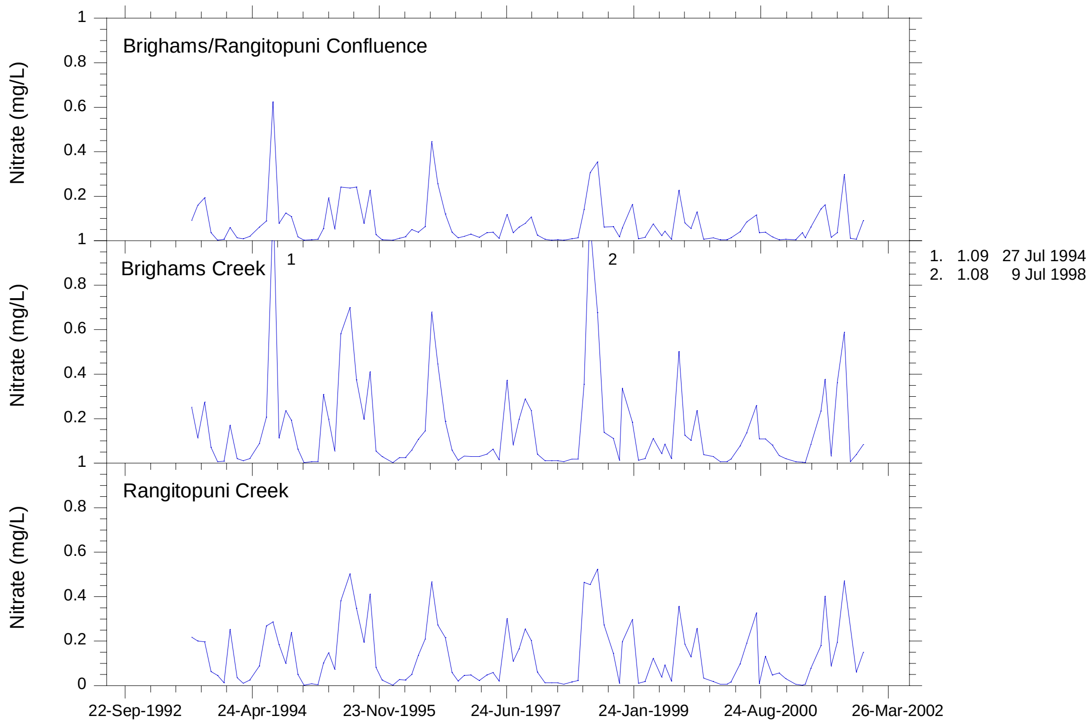
Date	Hobsonville	Lucas	Waimarie	Paremoremo	Rarawaru	Brighams/Rangitopuni	Brighams	Rangitopuni
30-Jan-01	0.006	0.004	0.005	0.003	0.005	0.003	0.004	0.004
02-Mar-01	0.006	0.011	0.008	0.000	0.005	0.029	0.003	0.001
14-Mar-01	0.004	0.004	0.006	0.002	0.008	0.012	0.002	0.004
09-Apr-01	0.023	0.042	0.031	0.039	0.053	0.058	0.079	0.074
24-May-01	0.042	0.075	0.051	0.099	0.099	0.139	0.230	0.174
12-Jun-01	0.058	0.105	0.117	0.192	0.188	0.157	0.371	0.397
11-Jul-01	0.001	0.003	0.008	0.011	0.017	0.015	0.030	0.085
08-Aug-01	0.011	0.088	0.022	0.138	0.111	0.035	0.357	0.193
07-Sep-01	0.073	0.165	0.143	0.200	0.226	0.294	0.581	0.463
04-Oct-01	0.000	0.010	0.008	0.010	0.008	0.009	0.006	
02-Nov-01	0.006	0.026	0.006	0.006	0.010	0.006	0.036	0.054
04-Dec-01	0.034	0.060	0.025	0.084	0.069	0.085	0.078	0.143
Median	0.009	0.034	0.015	0.025	0.035	0.032	0.057	0.085
IQR/Median %	359	205	190	414	269	273	450	182

b) Statistical summary for 1992-2001: Nitrate nitrogen (mg/L)

	Hobsonville Jetty	Lucas Creek	Waimarie Road	Paremoremo Ski Club	Rarawaru Creek	Brighams/Rangitopuni confluence	Brighams Creek	Rangitopuni Creek
N	102	102	102	102	102	102	102	101
Median	0.012	0.026	0.020	0.029	0.047	0.036	0.075	0.076
Normality	F	F	F	F	F	F	F	F
Seasonality	Y	Y	Y	Y	Y	Y	Y	Y
Trend	NS	NS	NS	NS	NS	NS	NS	NS
Slope	NS	NS	NS	NS	NS	NS	NS	NS

c) The graphs on the following pages show nitrate nitrogen measurements from January 1993 to December 2001 (where data available).


Hobsonville Jetty
Lucas Creek
Waimarie Road
Paremoremo Ski Club
Rarawaru Creek
Nitrate (mg/L)
1
0.8
0.6
0.4
0.2
0
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002


Brighams/Rangitopuni Confluence
Brighams Creek
Rangitopuni Creek
Nitrate (mg/L)
1. 1.09 27 Jul 1994
2. 1.08 9 Jul 1998
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002

APPENDIX 55: UPPER WAITEMATA HARBOUR – DISSOLVED REACTIVE PHOSPHORUS

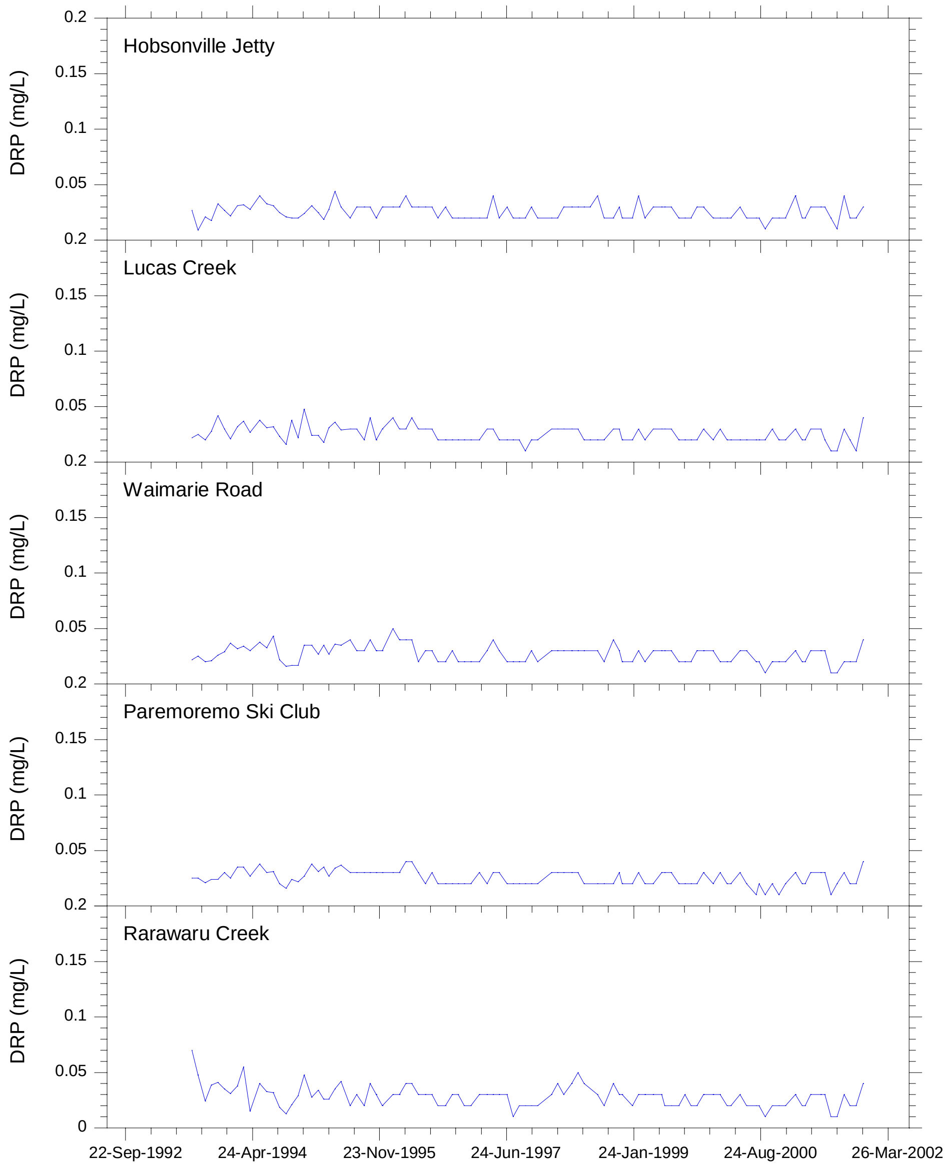
a) Dissolved reactive phosphorus (mg/L) during January 2001 - December 2001

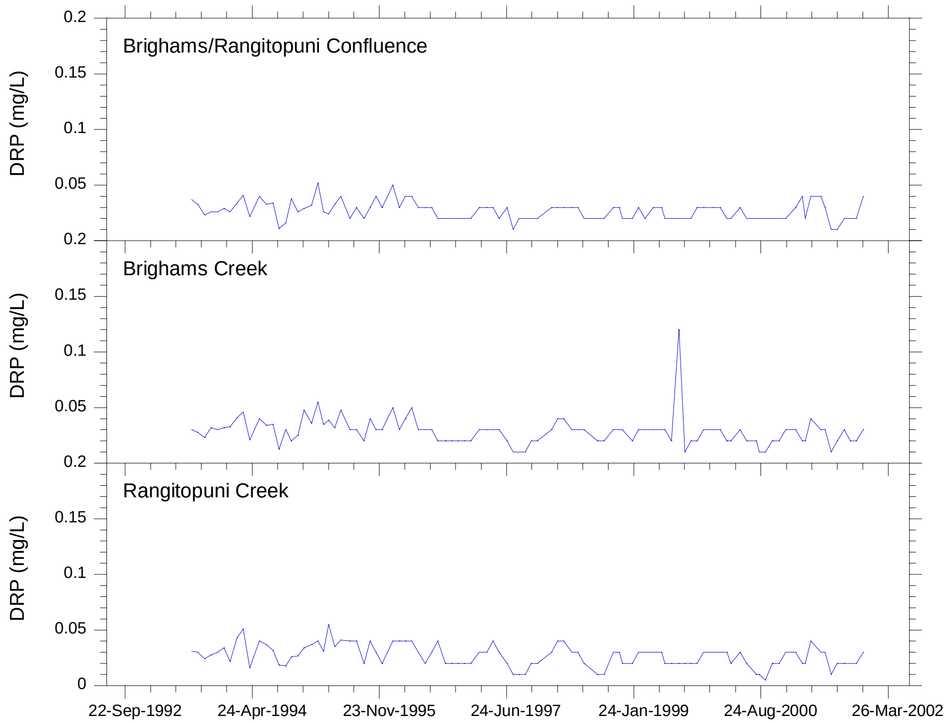
Date	Hobsonville	Lucas	Waimarie	Paremoremo	Rarawaru	Brighams/Rangitopuni	Brighams	Rangitopuni
30-Jan-01	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03
02-Mar-01	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02
14-Mar-01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
09-Apr-01	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04
24-May-01	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03
12-Jun-01	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03
11-Jul-01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
08-Aug-01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02
07-Sep-01	0.04	0.03	0.02	0.03	0.03	0.02	0.03	0.02
04-Oct-01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
02-Nov-01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02
04-Dec-01	0.03	0.04	0.04	0.04	0.04	0.04	0.03	0.03
Median	0.025	0.020	0.020	0.025	0.025	0.025	0.025	0.020
IQR/Median %	40	63	50	40	40	80	40	50

b) Statistical summary for 1992-2001: Dissolved reactive phosphorus (mg/L)

	Hobsonville Jetty	Lucas Creek	Waimarie Road	Paremoremo Ski Club	Rarawaru Creek	Brighams/Rangitopuni confluence	Brighams Creek	Rangitopuni Creek
N	101	101	100	100	100	100	100	99
Median	0.025	0.023	0.030	0.025	0.030	0.028	0.030	0.030
Normality	F	F	F	F	F	F	F	F
Seasonality	Y	Y	Y	Y	Y	Y	Y	Y
Trend	98%	100%	100%	100%	100%	100%	100%	100%
Slope	0	-0.00020	-0.00026	-0.00014	-0.00071	0	-0.00061	-0.00117

c) The graphs on the following pages show dissolved reactive phosphorus measurements from January 1993 to December 2001 (where data available).


Hobsonville Jetty
Lucas Creek
Waimarie Road
Paremoremo Ski Club
Rarawaru Creek
DRP (mg/L)
0.2
0.15
0.1
0.05
0
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002


Brighams/Rangitopuni Confluence
Brighams Creek
Rangitopuni Creek
DRP (mg/L)
0.2
0.15
0.1
0.05
0
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002

APPENDIX 56: UPPER WAITEMATA HARBOUR – TOTAL PHOSPHORUS

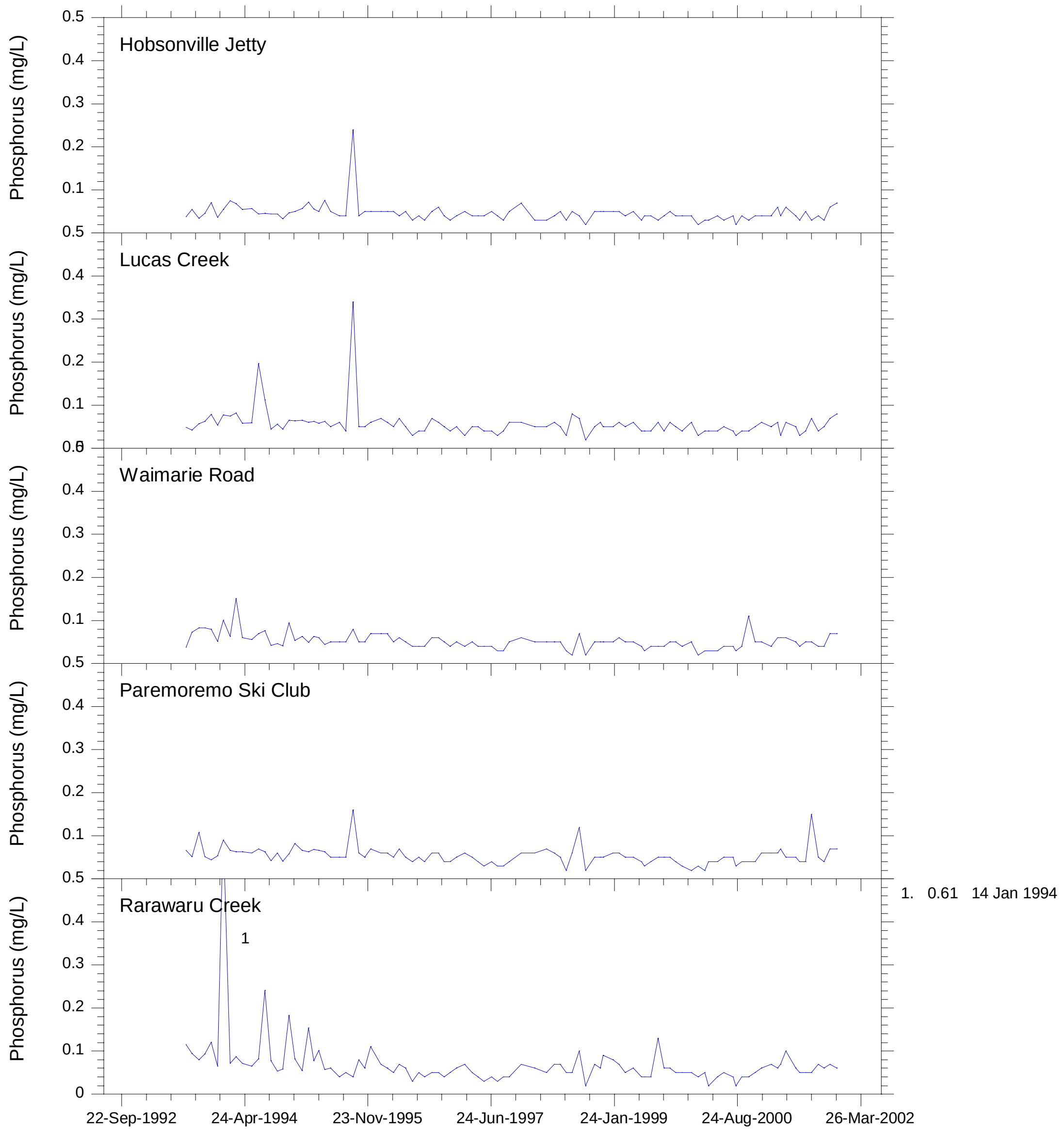
a) Total phosphorus (mg/L) during January 2001 - December 2001

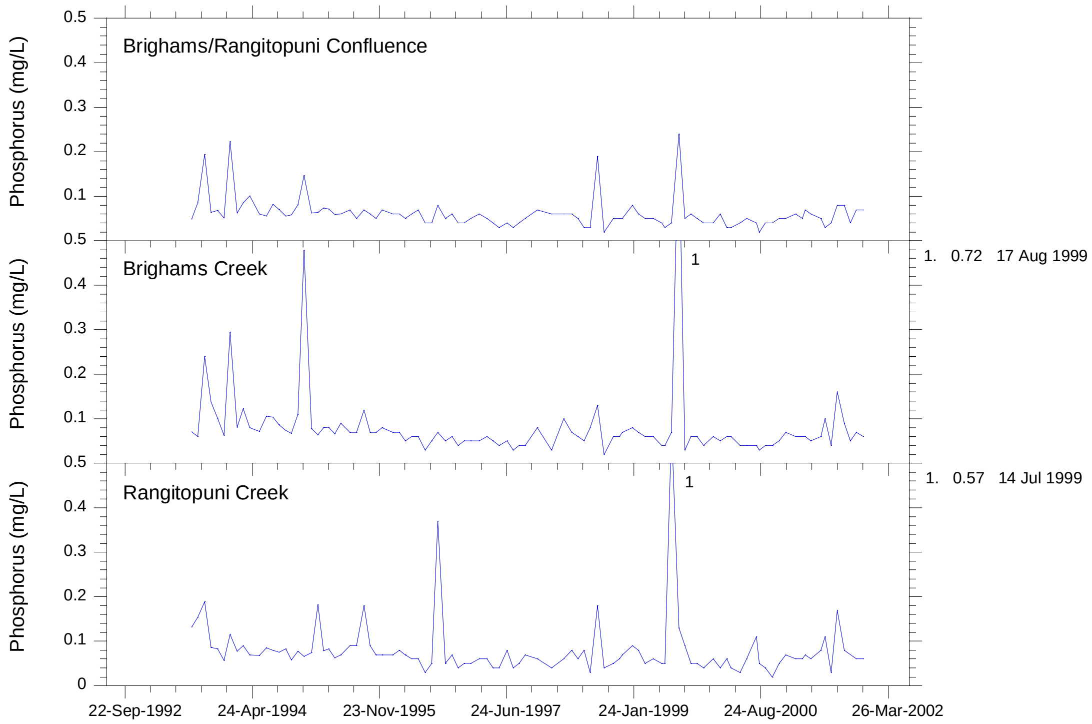
Date	Hobsonville	Lucas	Waimarie	Paremoremo	Rarawaru	Brighams/Rangitopuni	Brighams	Rangitopuni
30-Jan-01	0.04	0.05	0.04	0.06	0.07	0.06	0.06	0.06
02-Mar-01	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06
14-Mar-01	0.04	0.03	0.06	0.07	0.07	0.07	0.06	0.07
09-Apr-01	0.06	0.06	0.06	0.05	0.10	0.06	0.05	0.06
24-May-01	0.04	0.05	0.05	0.05	0.06	0.05	0.06	0.08
12-Jun-01	0.03	0.03	0.04	0.04	0.05	0.03	0.10	0.11
11-Jul-01	0.05	0.04	0.05	0.04	0.05	0.04	0.04	0.03
08-Aug-01	0.03	0.07	0.05	0.15	0.05	0.08	0.16	0.17
07-Sep-01	0.04	0.04	0.04	0.05	0.07	0.08	0.09	0.08
04-Oct-01	0.03	0.05	0.04	0.04	0.06	0.04	0.05	
02-Nov-01	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.06
04-Dec-01	0.07	0.08	0.07	0.07	0.06	0.07	0.06	0.06
Median	0.040	0.050	0.050	0.055	0.060	0.060	0.060	0.060
IQR/Median %	56	45	40	41	21	38	29	33

b) Statistical summary for 1992-2001: Total phosphorus (mg/L)

	Hobsonville Jetty	Lucas Creek	Waimarie Road	Paremoremo Ski Club	Rarawaru Creek	Brighams/Rangitopuni confluence	Brighams Creek	Rangitopuni Creek
N	99	99	99	99	99	99	99	98
Median	0.040	0.050	0.050	0.050	0.060	0.056	0.060	0.068
Normality	F	F	F	F	F	F	F	F
Seasonality	N	Y	Y	N	Y	Y	N	N
Trend	100%	100%	100%	100%	100%	100%	100%	100%
Slope	-0.00163	-0.00167	-0.00208	-0.00195	-0.00330	-0.00300	-0.00390	-0.00339

c) The graphs on the following pages show total phosphorus measurements from January 1993 to December 2001 (where data available).


Hobsonville Jetty
Lucas Creek
Waimarie Road
Paremoremo Ski Club
Rarawaru Creek
Phosphorus (mg/L)
0.5
0.4
0.3
0.2
0.1
0
1
1. 0.61 14 Jan 1994
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002


Brighams/Rangitopuni Confluence
Brighams Creek
Rangitopuni Creek
Phosphorus (mg/L)
0.5
0.4
0.3
0.2
0.1
0
1
1. 0.72 17 Aug 1999
1. 0.57 14 Jul 1999
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002

APPENDIX 57: UPPER WAITEMATA HARBOUR – CHLOROPHYLL *a*

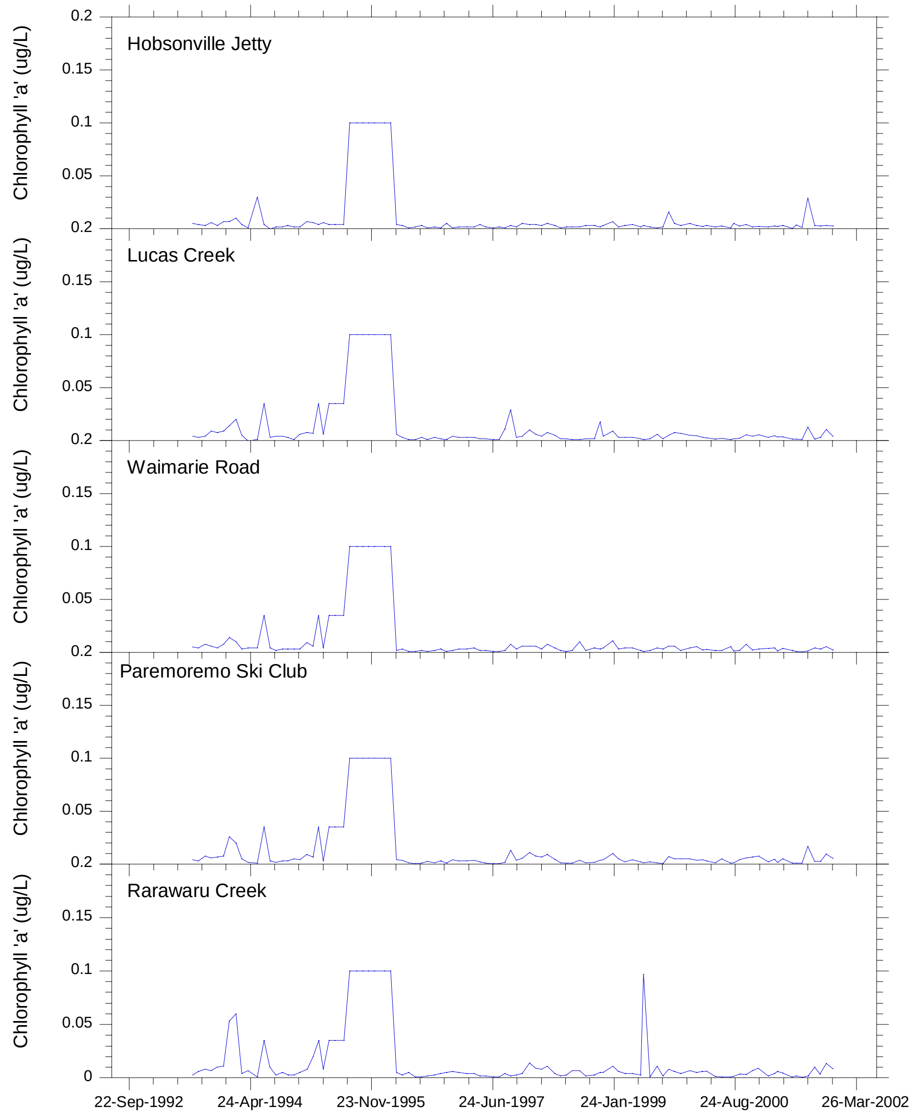
a) Chlorophyll *a* (mg/L) during January 2001 - December 2001

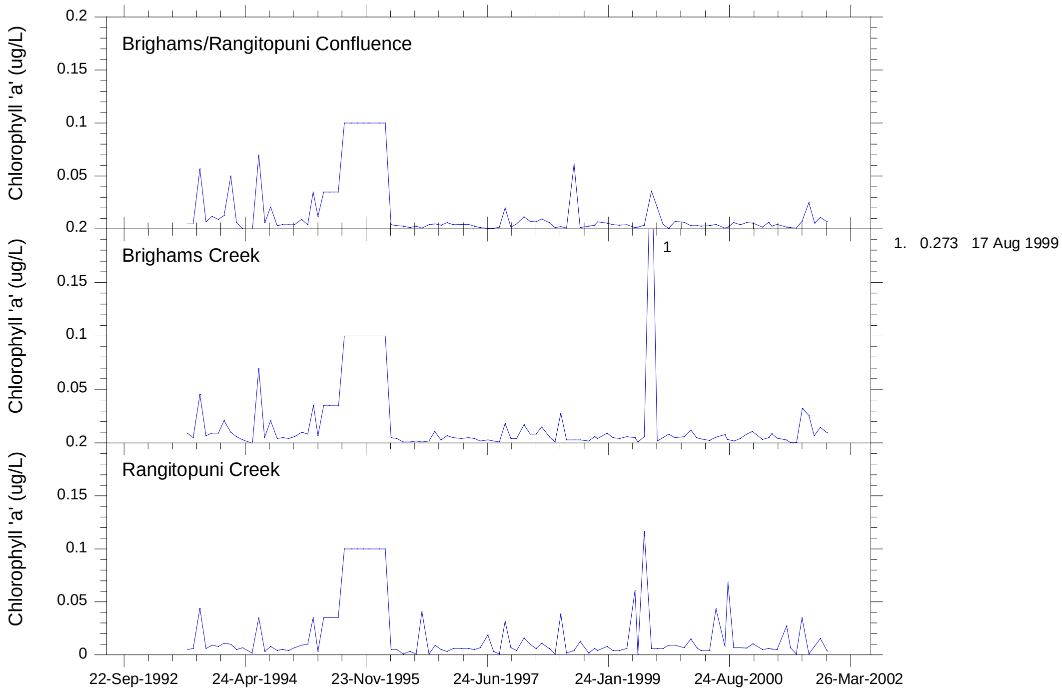
Date	Hobsonville	Lucas	Waimarie	Paremoremo	Rarawaru	Brighams/Rangitopuni	Brighams	Rangitopuni
30-Jan-01	0.0021	0.0030	0.0038	0.0026	0.0021	0.0021	0.0033	0.0051
02-Mar-01	0.0027	0.0045	0.0042	0.0047	0.004	0.0063	0.0052	0.0061
14-Mar-01	0.0024	0.0036	0.0015	0.0021	0.0059	0.0028	0.0088	0.0057
09-Apr-01	0.0031	0.0036	0.0039	0.0052	0.0047	0.0046	0.0047	0.0049
24-May-01	0.0008	0.0015	0.0018	0.0003	0.0003	0.0018	0.0029	0.0274
12-Jun-01	0.0037	0.0015	0.0009	0.0009	0.0021	0.0013	0.0003	0.0068
11-Jul-01	0.0014	0.0003	0.0003	0.0003	0.0007	0.0003	0.0003	0.0003
08-Aug-01	0.0290	0.0129	0.0014	0.0171	0.0021	0.0076	0.0326	0.0352
07-Sep-01	0.0031	0.0016	0.0042	0.0028	0.0101	0.0251	0.0258	0.0011
04-Oct-01	0.0028	0.0034	0.0033	0.0028	0.0039	0.0056	0.0070	
02-Nov-01	0.0032	0.0106	0.0055	0.0096	0.0134	0.0112	0.0144	0.0155
04-Dec-01	0.0029	0.0041	0.0026	0.0055	0.0087	0.0068	0.0094	0.0035
Median	0.003	0.004	0.003	0.003	0.004	0.005	0.006	0.006
IQR/Median %	28	75	85	124	114	98	122	122

b) Statistical summary for 1992-2001: Chlorophyll *a* (mg/L)

	Hobsonville Jetty	Lucas Creek	Waimarie Road	Paremoremo Ski Club	Rarawaru Creek	Brighams/Rangitopuni confluence	Brighams Creek	Rangitopuni Creek
N	102	102	102	102	102	102	102	101
Median	0.003	0.006	0.003	0.005	0.008	0.007	0.008	0.009
Normality	F	F	F	F	F	F	F	F
Seasonality	Y	N	Y	Y	N	N	N	N
Trend	99%	100%	99%	100%	100%	100%	100%	100%
Slope	-0.00020	-0.00187	-0.00026	0.00144	0.00298	0.00314	0.00324	0.00567

c) The graphs on the following pages show chlorophyll *a* measurements from January 1993 to December 2001 (where data available).


Hobsonville Jetty
Lucas Creek
Waimarie Road
Paremoremo Ski Club
Rarawaru Creek
Chlorophyll 'a' (ug/L)
0.2
0.15
0.1
0.05
0
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002


Brighams/Rangitopuni Confluence
Brighams Creek
Rangitopuni Creek
Chlorophyll 'a' (ug/L)
0.2
0.15
0.1
0.05
0
1
1. 0.273 17 Aug 1999
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002

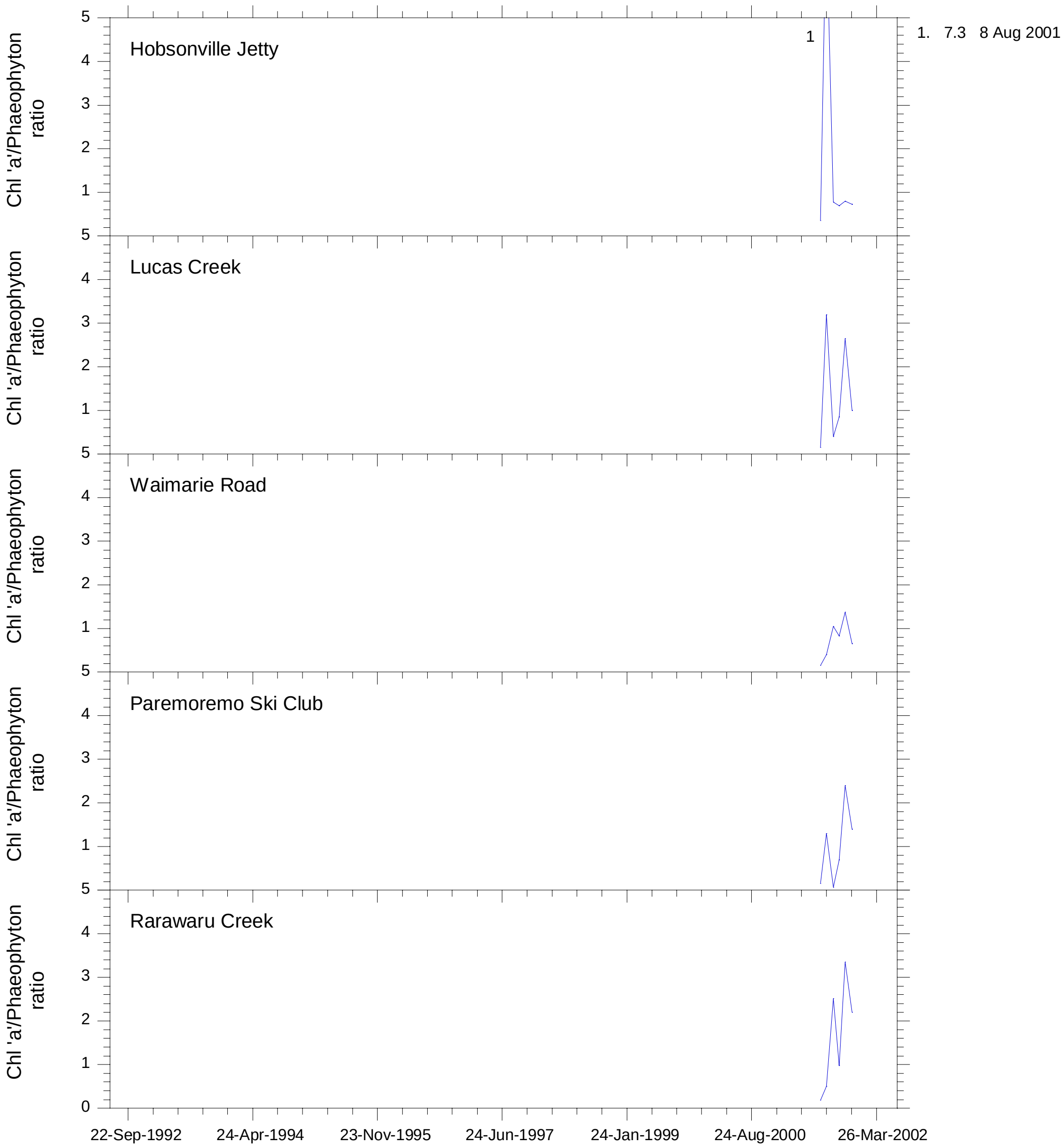
APPENDIX 58: UPPER WAITEMATA HARBOUR – CHLOROPHYLL/PHAEOPHYTON RATIO

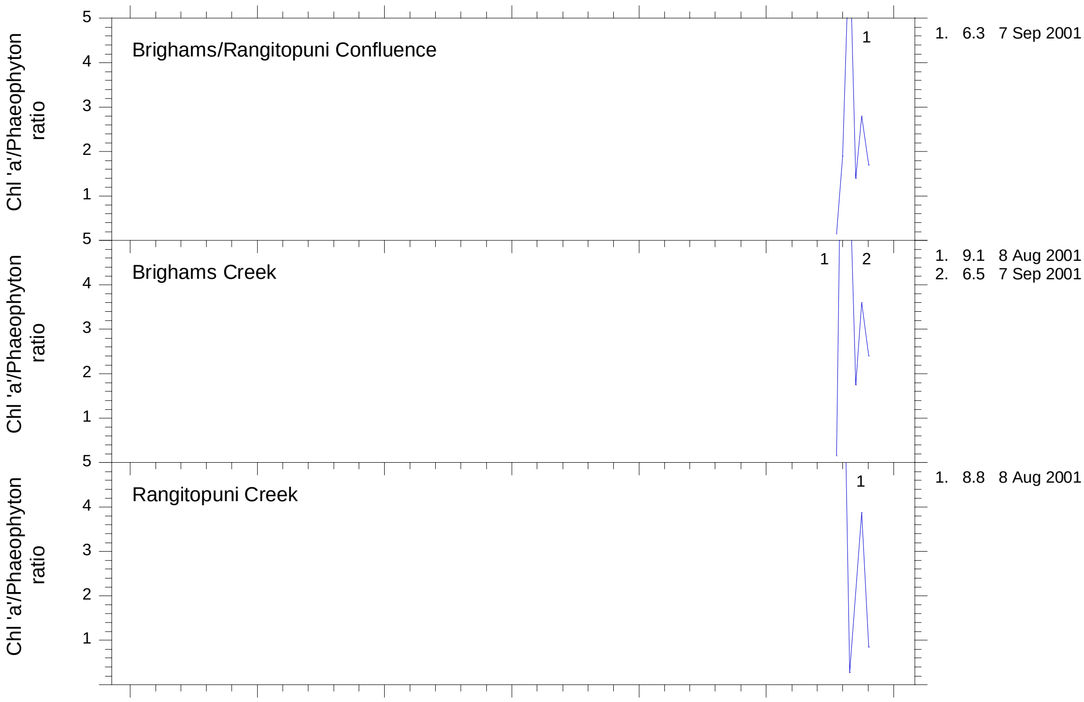
a) Chlorophyll/phaeophyton ratio during January 2001 - December 2001

Date	Hobsonville	Lucas	Waimarie	Paremoremo	Rarawaru	Brighams/Rangitopuni	Brighams	Rangitopuni
30-Jan-01								
02-Mar-01								
14-Mar-01								
09-Apr-01								
24-May-01								
12-Jun-01								
11-Jul-01	>0.35	>0.15	>0.15	>0.15	>0.18	>0.15	>0.15	>0.15
08-Aug-01	>7.30	>3.20	>0.40	>4.30	>0.50	>1.90	>9.10	>8.80
07-Sep-01	>0.78	>0.40	>1.05	>0.07	>2.52	>6.28	>6.45	>0.28
04-Oct-01	<0.70	<0.85	<0.83	<0.70	<0.98	<1.40	<1.75	
02-Nov-01	>0.80	>2.65	>1.38	>2.40	>3.35	>2.80	>3.60	>3.88
04-Dec-01	>0.73	>1.00	>0.65	>1.40	>2.20	>1.70	>2.40	>0.85
Median	0.76	0.71	0.54	0.88	1.35	1.80	3.00	0.85
IQR/Median %	46	258	102	223	144	90	149	424

Insufficient data for statistical summaries.

c) The graphs on the following pages show chlorophyll/phaeophyton ratio measurements from January 1993 to December 2001 (where data available).


Hobsonville Jetty
1
1. 7.3 8 Aug 2001
Lucas Creek
Waimarie Road
Paremoremo Ski Club
Rarawaru Creek
Chl 'a'/Phaeophyton ratio
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002


Brighams/Rangitopuni Confluence
Brighams Creek
Rangitopuni Creek
Chl 'a'/Phaeophyton ratio
1. 6.3 7 Sep 2001
1. 9.1 8 Aug 2001
2. 6.5 7 Sep 2001
1. 8.8 8 Aug 2001

APPENDIX 59: UPPER WAITEMATA HARBOUR – PRESUMPTIVE COLIFORM

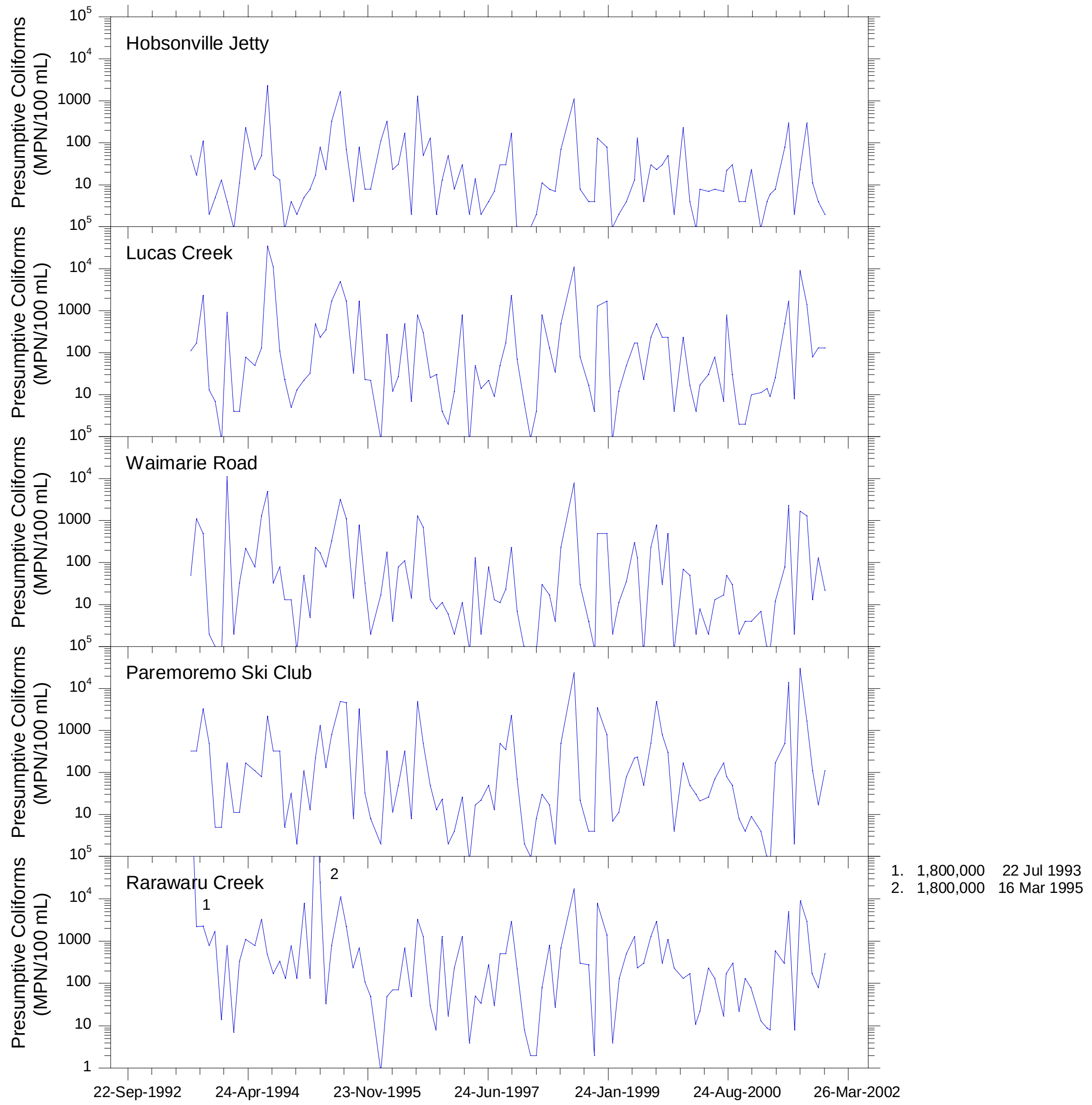
a) Presumptive coliform (MPN/100 mL) during January 2001 - December 2001

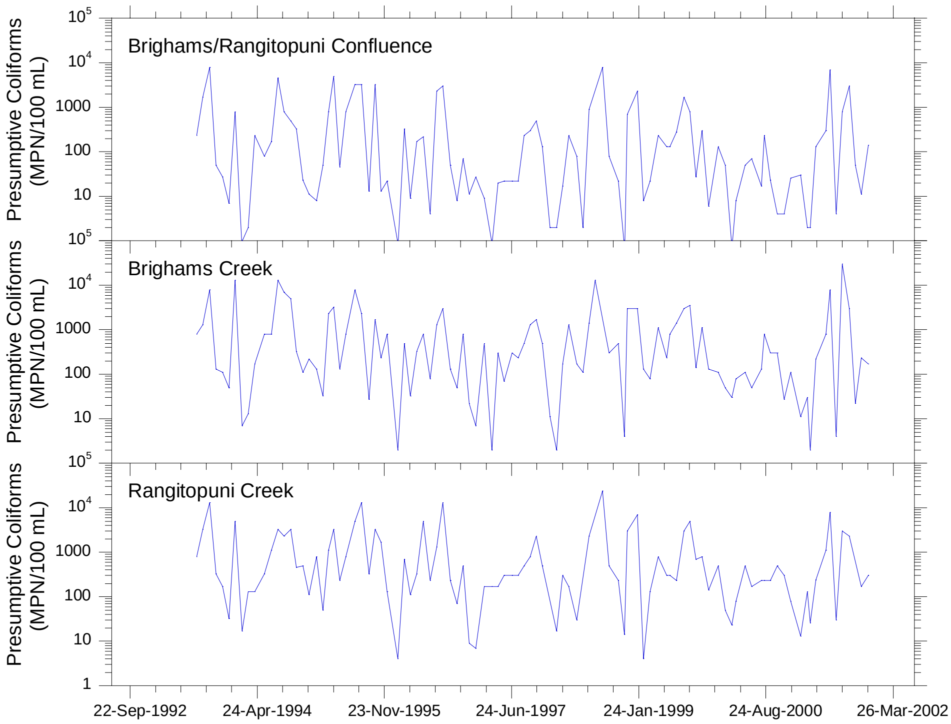
Date	Hobsonville	Lucas	Waimarie	Paremoremo	Rarawaru	Brighams/Rangitopuni	Brighams	Rangitopuni
30-Jan-01	1	11	7	4	13	30	11	13
02-Mar-01	4	14	1	1	9	2	30	130
14-Mar-01	6	9	1	1	8	2	2	26
09-Apr-01	8	26	12	170	600	130	220	240
24-May-01	80	500	80	500	300	300	800	1100
12-Jun-01	300	1700	2300	14000	5000	7000	8000	8000
11-Jul-01	2	8	2	2	8	4	4	30
08-Aug-01	23	9000	1700	30000	9000	800	30000	3000
07-Sep-01	300	1400	1300	1700	3000	3000	3000	2300
04-Oct-01	11	80	13	110	170	50	22	
02-Nov-01	4	130	130	17	80	11	230	170
04-Dec-01	2	130	22	110	500	140	170	300
Median	7	105	18	110	235	90	195	240
IQR/Median %	482	678	2381	724	506	462	682	675

b) Statistical summary for 1992-2001: Presumptive coliform (MPN/100 mL)

	Hobsonville Jetty	Lucas Creek	Waimarie Road	Paremoremo Ski Club	Rarawaru Creek	Brighams/Rangitopuni confluence	Brighams Creek	Rangitopuni Creek
N	101	101	101	101	101	101	101	98
Median	11	49	23	50	230	50	230	300
Normality	F	F	F	F	F	F	F	F
Seasonality	Y	Y	Y	Y	Y	Y	Y	Y
Trend	NS	NS	NS	NS	96%	NS	NS	92%
Slope	NS	NS	NS	NS	-23	NS	NS	-18

c) The graphs on the following pages show presumptive coliform measurements from January 1993 to December 2001 (where data available).


Hobsonville Jetty
Lucas Creek
Waimarie Road
Paremoremo Ski Club
Rarawaru Creek
Presumptive Coliforms (MPN/100 mL)
1
10
100
1000
10^4
10^5
1
2
1. 1,800,000 22 Jul 1993
2. 1,800,000 16 Mar 1995
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002


Presumptive Coliforms (MPN/100 mL)
Brighams/Rangitopuni Confluence
Brighams Creek
Rangitopuni Creek
10^5
10^4
1000
100
10
1
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002

APPENDIX 60: UPPER WAITEMATA HARBOUR – FAECAL COLIFORM

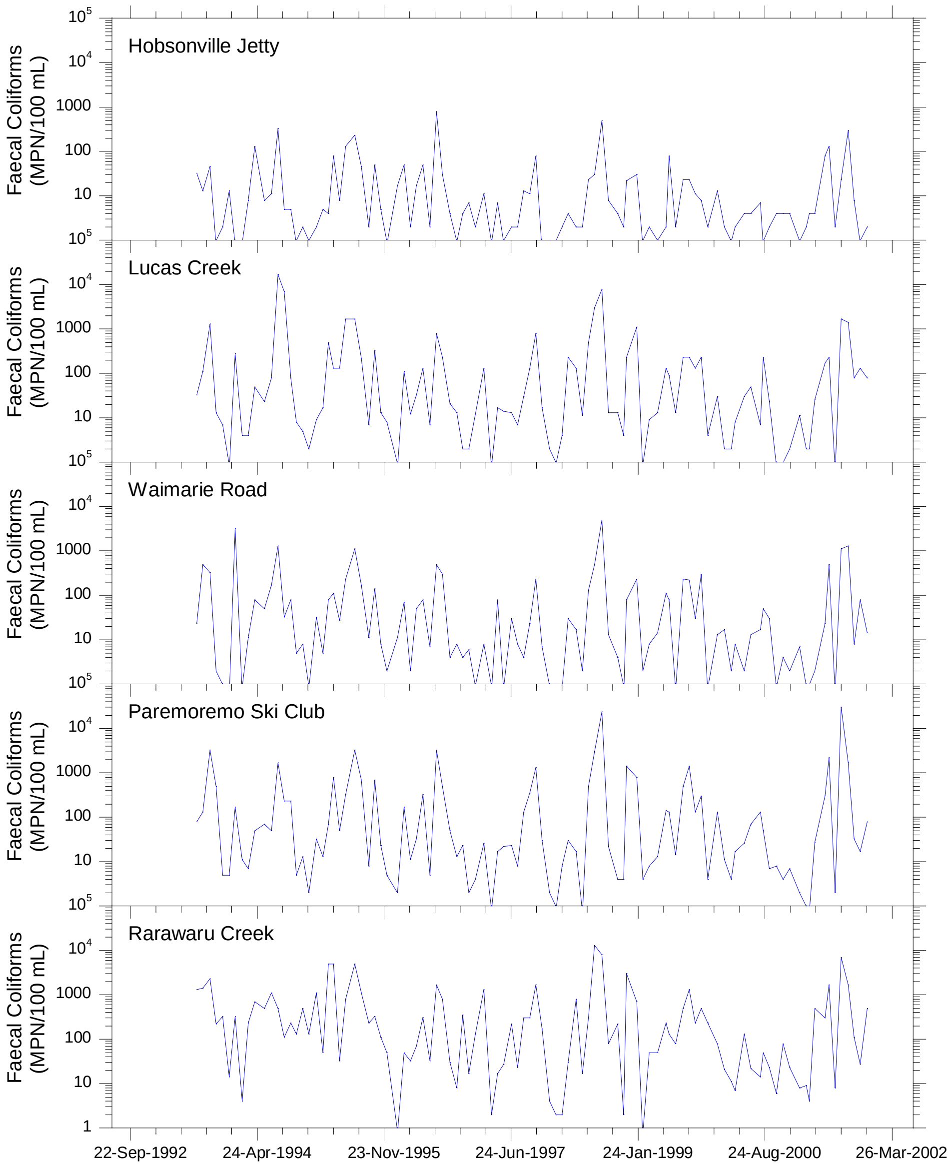
a) Faecal coliform (MPN/100 mL) during January 2001 - December 2001

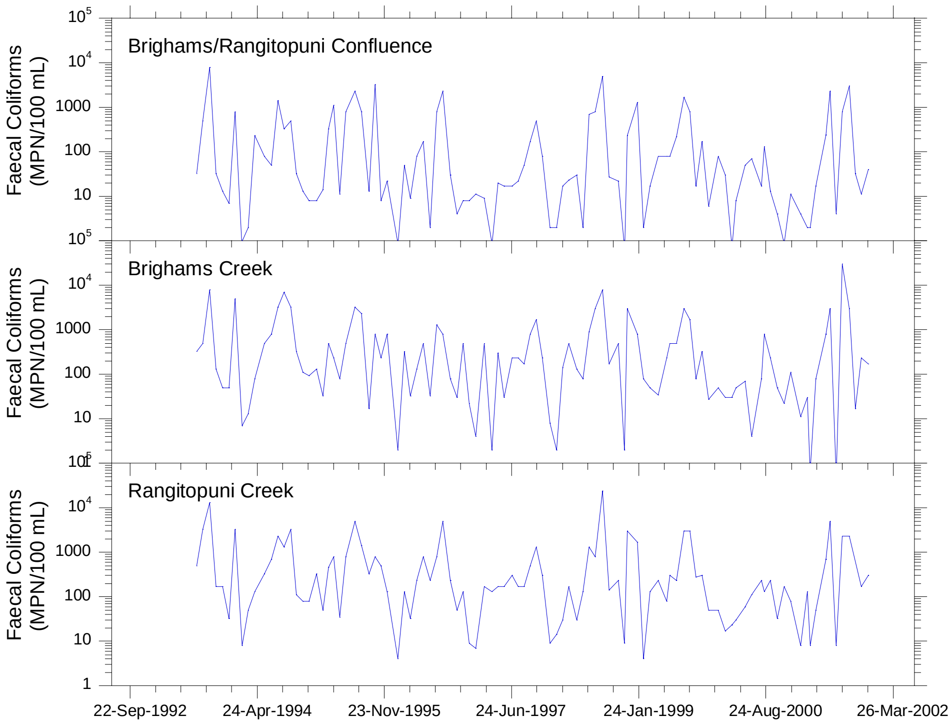
Date	Hobsonville	Lucas	Waimarie	Paremoremo	Rarawaru	Brighams/Rangitopuni	Brighams	Rangitopuni
30-Jan-01	1	11	7	2	8	4	11	8
02-Mar-01	2	2	1	1	9	2	30	130
14-Mar-01	4	2	1	1	4	2	1	8
09-Apr-01	4	26	2	27	500	17	80	50
24-May-01	80	170	23	300	300	240	800	700
12-Jun-01	130	230	500	2200	1700	2300	3000	5000
11-Jul-01	2	1	1	2	8	4	1	8
08-Aug-01	23	1700	1100	30000	7000	800	30000	2300
07-Sep-01	300	1400	1300	1700	1700	3000	3000	2300
04-Oct-01	8	80	8	33	110	33	17	
02-Nov-01	1	130	80	17	27	11	230	170
04-Dec-01	2	80	14	80	500	40	170	300
Median	4	80	11	30	205	25	125	170
IQR/Median %	881	220	1666	2160	386	1504	1068	865

b) Statistical summary for 1992-2001: Faecal coliform (MPN/100 mL)

	Hobsonville Jetty	Lucas Creek	Waimarie Road	Paremoremo Ski Club	Rarawaru Creek	Brighams/Rangitopuni confluence	Brighams Creek	Rangitopuni Creek
N	102	102	102	102	102	102	102	101
Median	4	23	14	29	130	30	170	170
Normality	F	F	F	F	F	F	F	F
Seasonality	Y	Y	Y	Y	Y	Y	Y	Y
Trend	NS	NS	NS	NS	99%	NS	NS	96%
Slope	NS	NS	NS	NS	-15	NS	NS	-15

c) The graphs on the following pages show faecal coliform measurements from January 1993 to December 2001 (where data available).


Hobsonville Jetty
Lucas Creek
Waimarie Road
Paremoremo Ski Club
Rarawaru Creek
Faecal Coliforms (MPN/100 mL)
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002


Brighams/Rangitopuni Confluence
Brighams Creek
Rangitopuni Creek
Faecal Coliforms (MPN/100 mL)
10⁵
10⁴
1000
100
10
1
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002

APPENDIX 61: UPPER WAITEMATA HARBOUR – ENTEROCOCCI

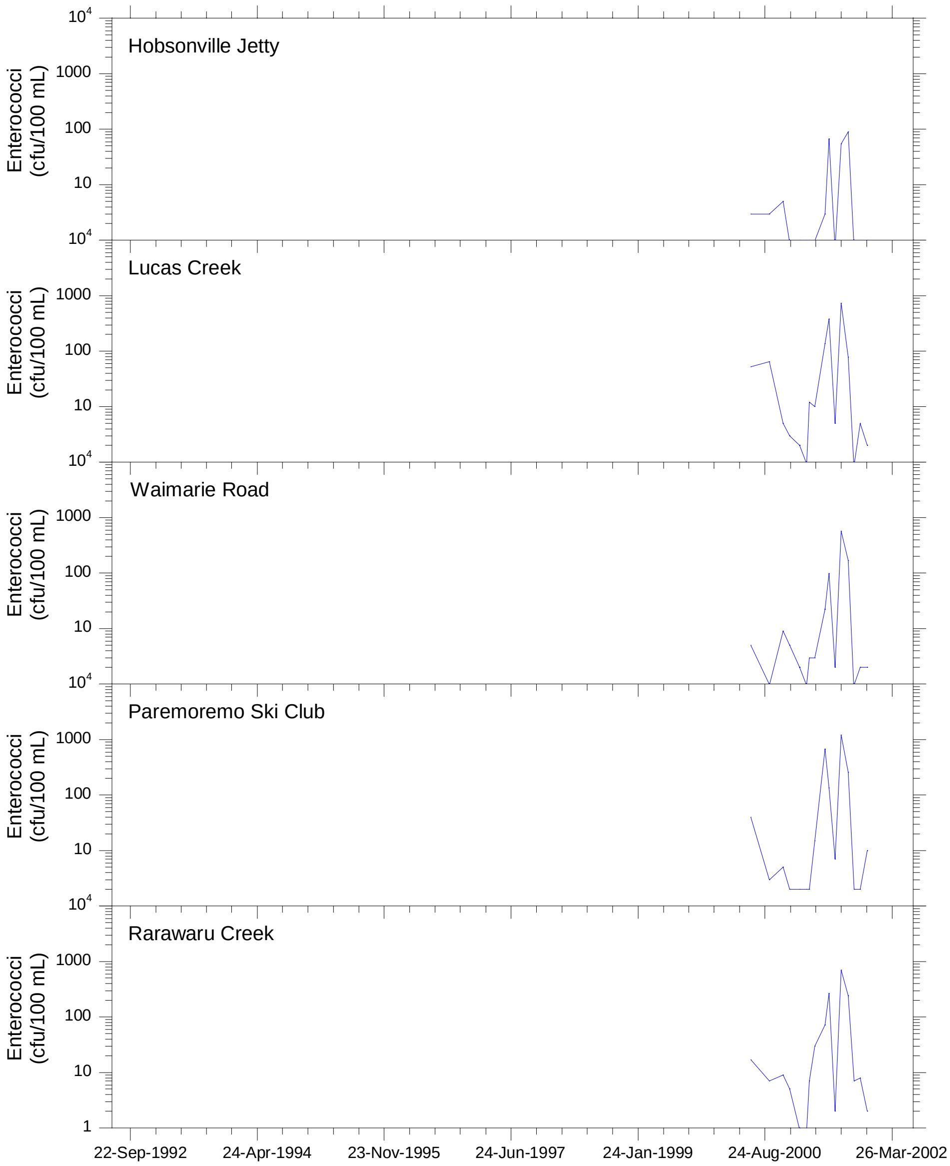
a) Enterococci (cfu/100 mL) during January 2001 - December 2001

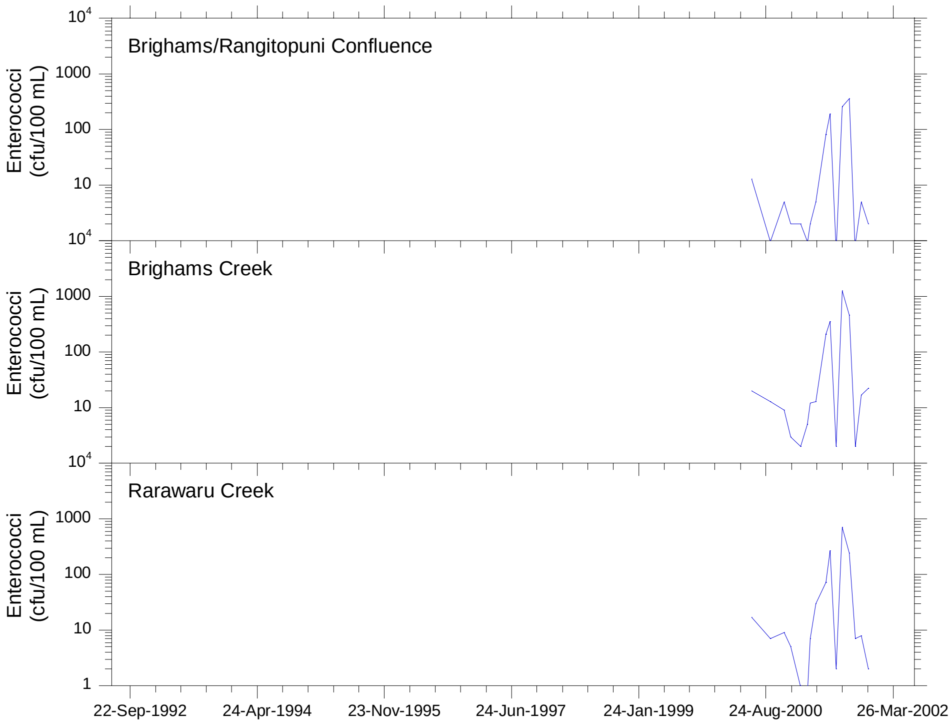
Date	Hobsonville	Lucas	Waimarie	Paremoremo	Rarawaru	Brighams/Rangitopuni	Brighams	Rangitopuni
30-Jan-01	<2	2	2	2	<2	2	2	7
02-Mar-01	<2	<2	<2	2	<2	<2	5	5
14-Mar-01	<2	12	3	2	7	2	12	5
09-Apr-01	<2	10	3	15	30	5	13	7
24-May-01	3	138	22	680	72	82	210	320
12-Jun-01	68	380	98	134	270	190	350	260
11-Jul-01	<2	5	2	7	2	<2	2	8
08-Aug-01	54	740	570	1220	710	260	1280	1860
07-Sep-01	90	78	170	260	240	360	460	250
04-Oct-01	<2	<2	<2	2	7	<2	2	
02-Nov-01	<2	5	2	2	8	5	17	8
04-Dec-01	<2	2	2	10	2	2	22	40
Median	1	8	3	9	8	5	15	8
IQR/Median %	1475	1213	1560	1924	1493	3760	1605	3100

b) Statistical summary for 1992-2001: Enterococci (cfu/100 mL)

	Hobsonville Jetty	Lucas Creek	Waimarie Road	Paremoremo Ski Club	Rarawaru Creek	Brighams/Rangitopuni confluence	Brighams Creek	Rangitopuni Creek
N	16	16	16	16	16	16	16	14
Median	1	8	3	6	8	4	13	19
Normality	F	F	F	F	F	F	F	F
Seasonality	N	N	N	N	N	N	N	Y
Trend	INS.	INS.	INS.	INS.	INS.	INS.	INS.	INS.
Slope	INS.	INS.	INS.	INS.	INS.	INS.	INS.	INS.

c) The graphs on the following pages show faecal enterococci from January 1993 to December 2001 (where data available).


Hobsonville Jetty
Lucas Creek
Waimarie Road
Paremoremo Ski Club
Rarawaru Creek
Enterococci (cfu/100 mL)
10⁴
1000
100
10
1
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002

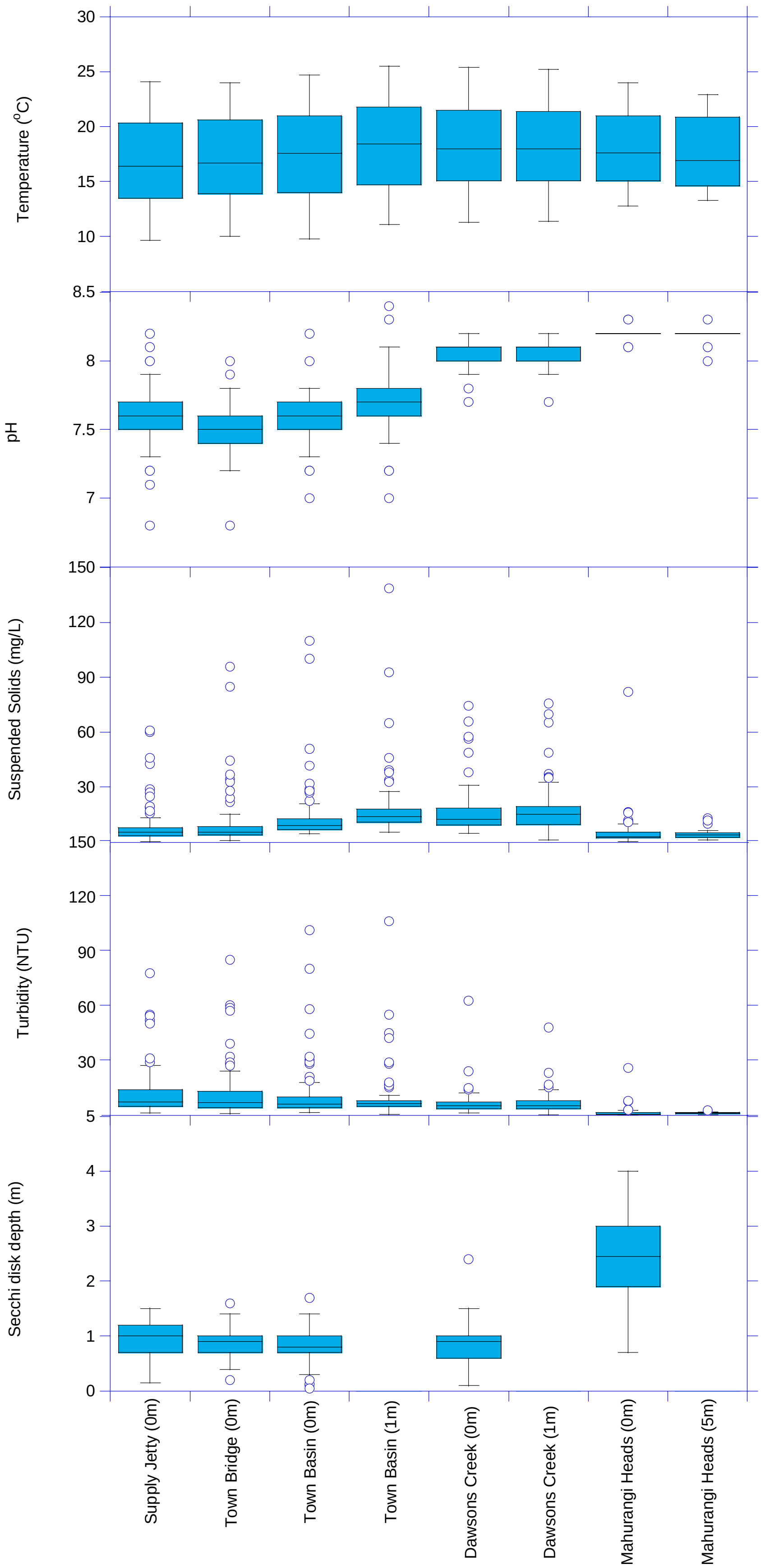


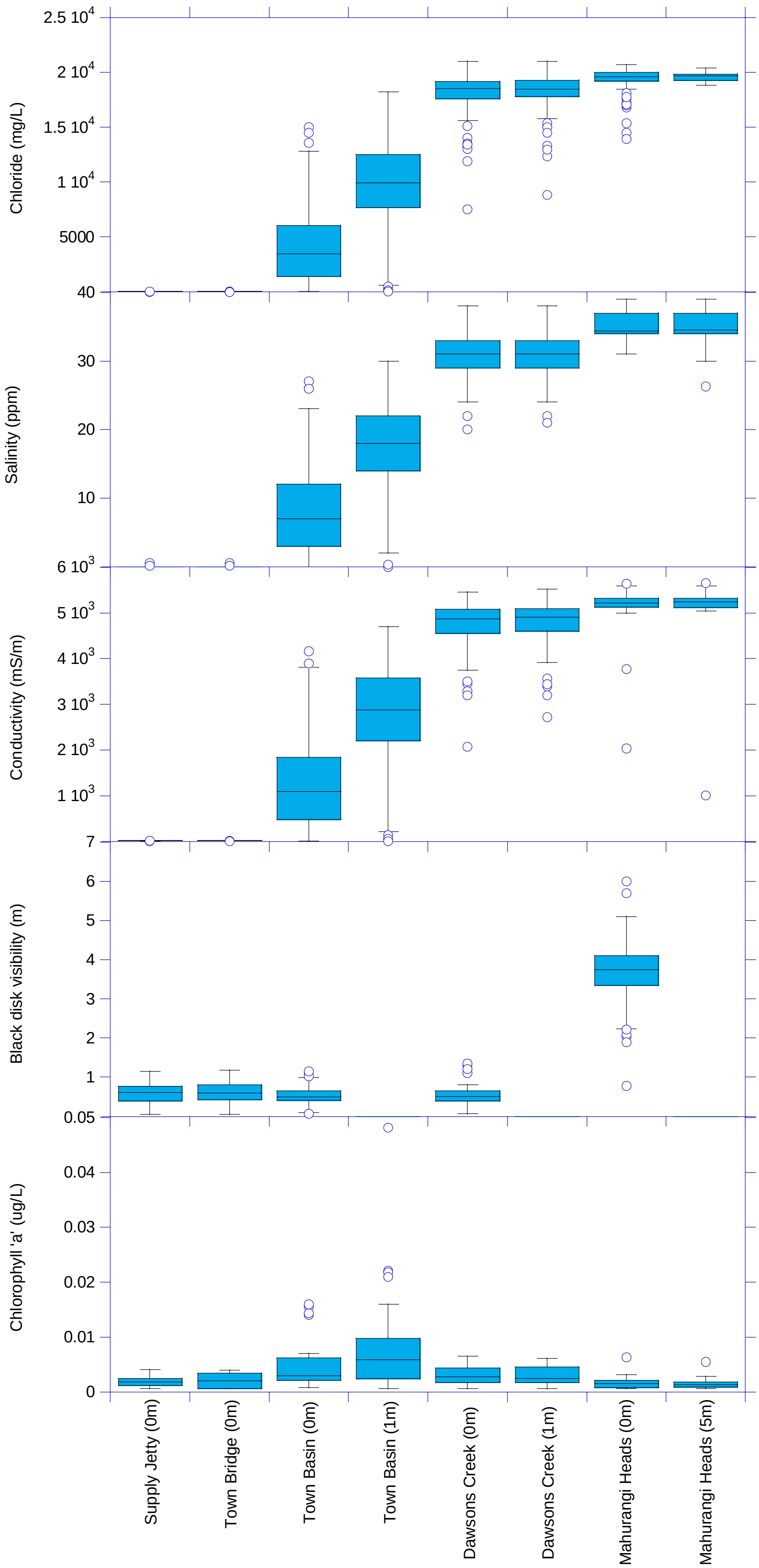
Brighams/Rangitopuni Confluence
Brighams Creek
Rarawaru Creek
Enterococci (cfu/100 mL)
10^4
1000
100
10
1
22-Sep-1992
24-Apr-1994
23-Nov-1995
24-Jun-1997
24-Jan-1999
24-Aug-2000
26-Mar-2002

APPENDIX 62: BOX PLOTS SHOWING BETWEEN SITE COMPARISONS FOR EACH OF THE THREE WATERBODIES.

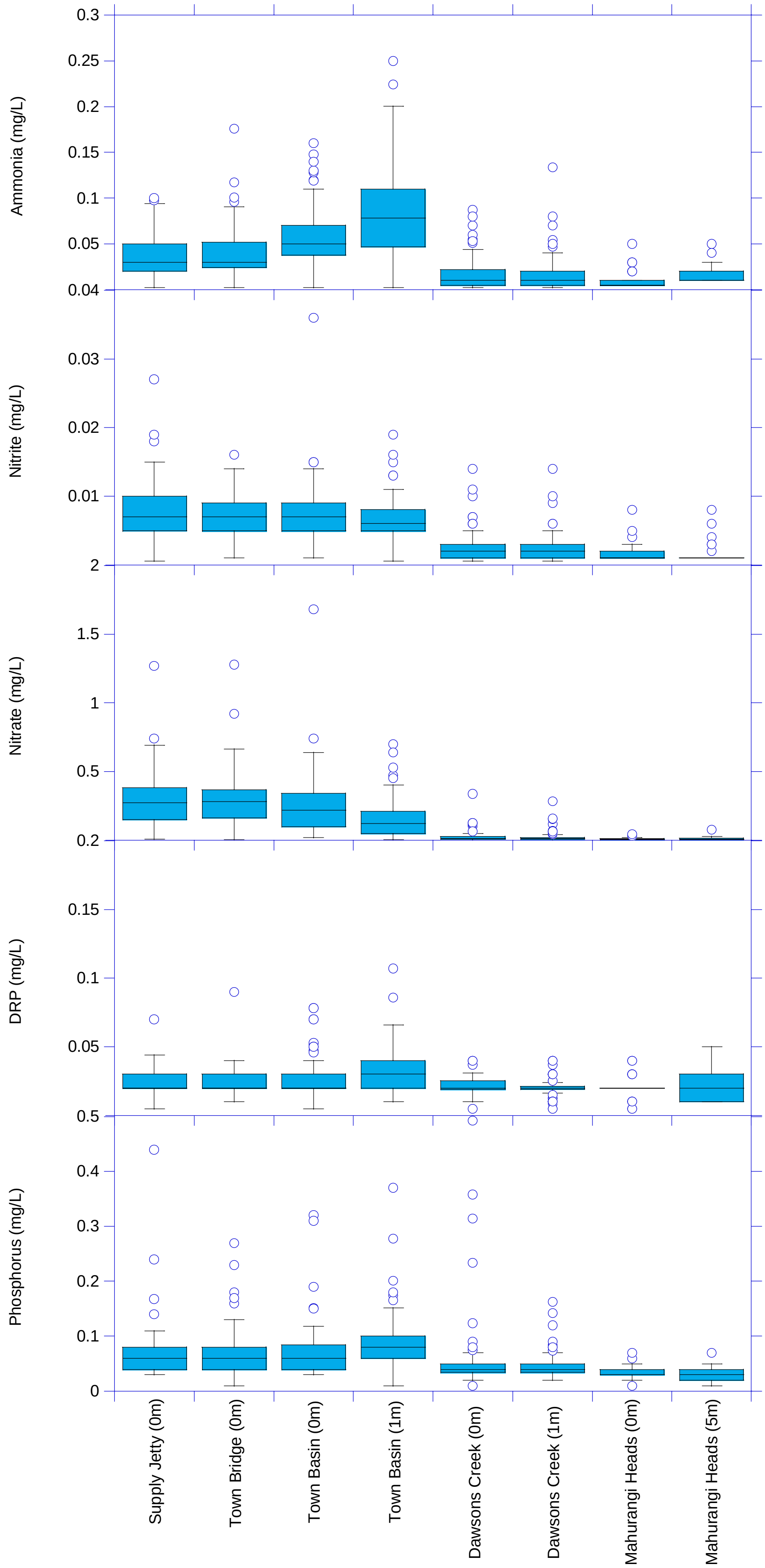
Each box encloses 50% of the data with the median value of the variable displayed as a line. The top and bottom of the box mark the limits of ± 25% of the variable population. The lines extending from the top and bottom of each box mark the minimum and maximum values within the data set that fall within an acceptable range. Any value outside of this range, called an outlier, is displayed as an individual point.

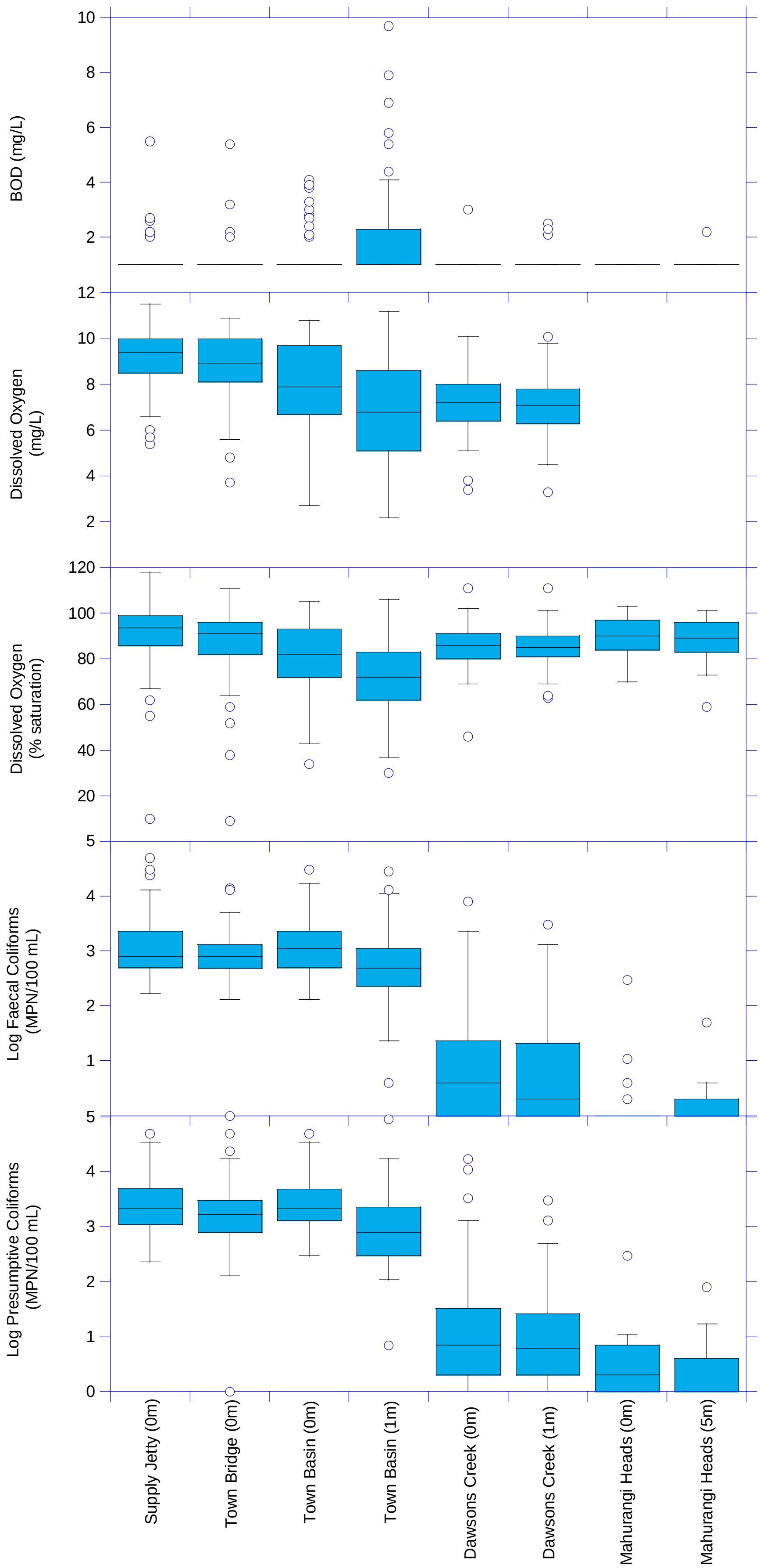
(a) Mahurangi Estuary

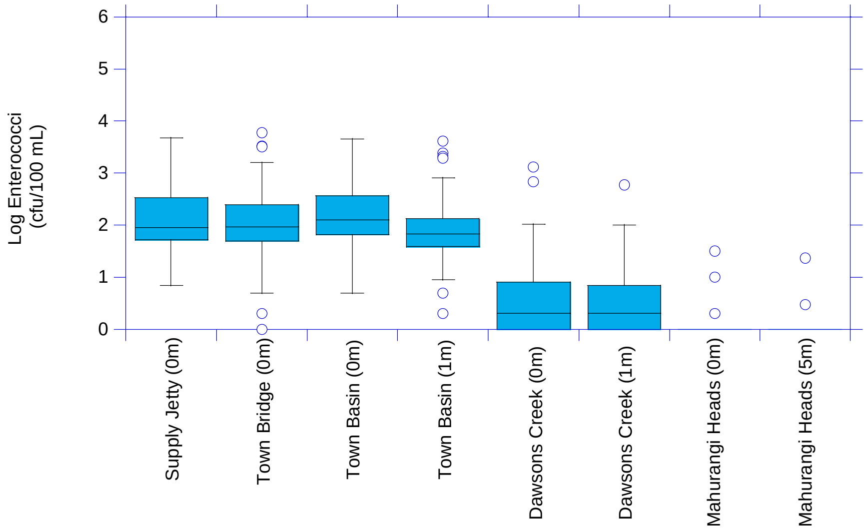




Chloride (mg/L)
2.5 10^4
2 10^4
1.5 10^4
1 10^4
5000
40
Salinity (ppm)
30
20
10
6 10^3
Conductivity (mS/m)
5 10^3
4 10^3
3 10^3
2 10^3
1 10^3
7
Black disk visibility (m)
6
5
4
3
2
1
0.05
Chlorophyll 'a' (ug/L)
0.04
0.03
0.02
0.01
0
Supply Jetty (0m)
Town Bridge (0m)
Town Basin (0m)
Town Basin (1m)
Dawsons Creek (0m)
Dawsons Creek (1m)
Mahurangi Heads (0m)
Mahurangi Heads (5m)

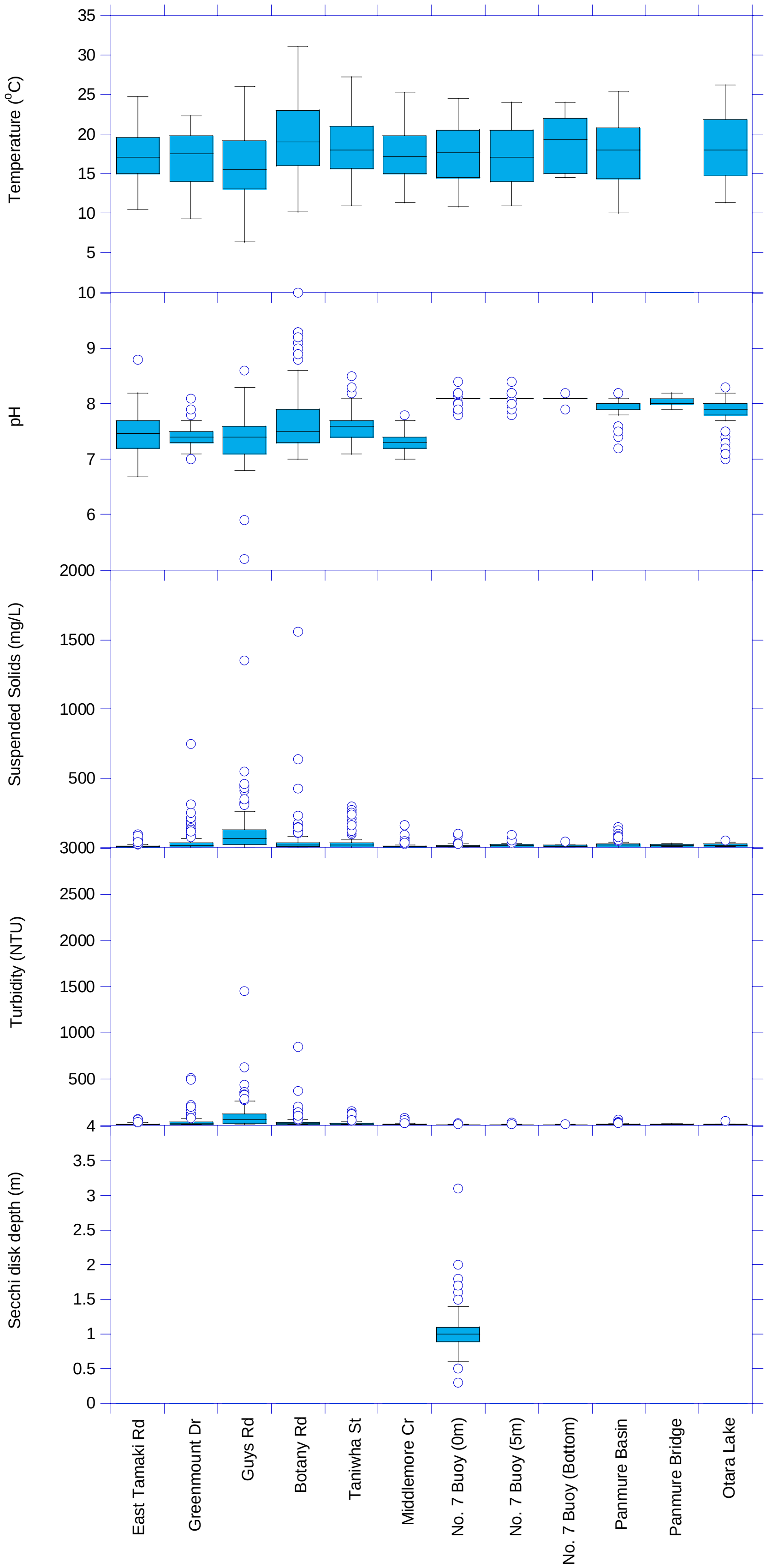

Ammonia (mg/L)
Nitrite (mg/L)
Nitrate (mg/L)
DRP (mg/L)
Phosphorus (mg/L)
0.3
0.25
0.2
0.15
0.1
0.05
0.04
0.03
0.02
0.01
2
1.5
1
0.5
0.2
0.15
0.1
0.05
0.5
0.4
0.3
0.2
0.1
0
Supply Jetty (0m)
Town Bridge (0m)
Town Basin (0m)
Town Basin (1m)
Dawsons Creek (0m)
Dawsons Creek (1m)
Mahurangi Heads (0m)
Mahurangi Heads (5m)

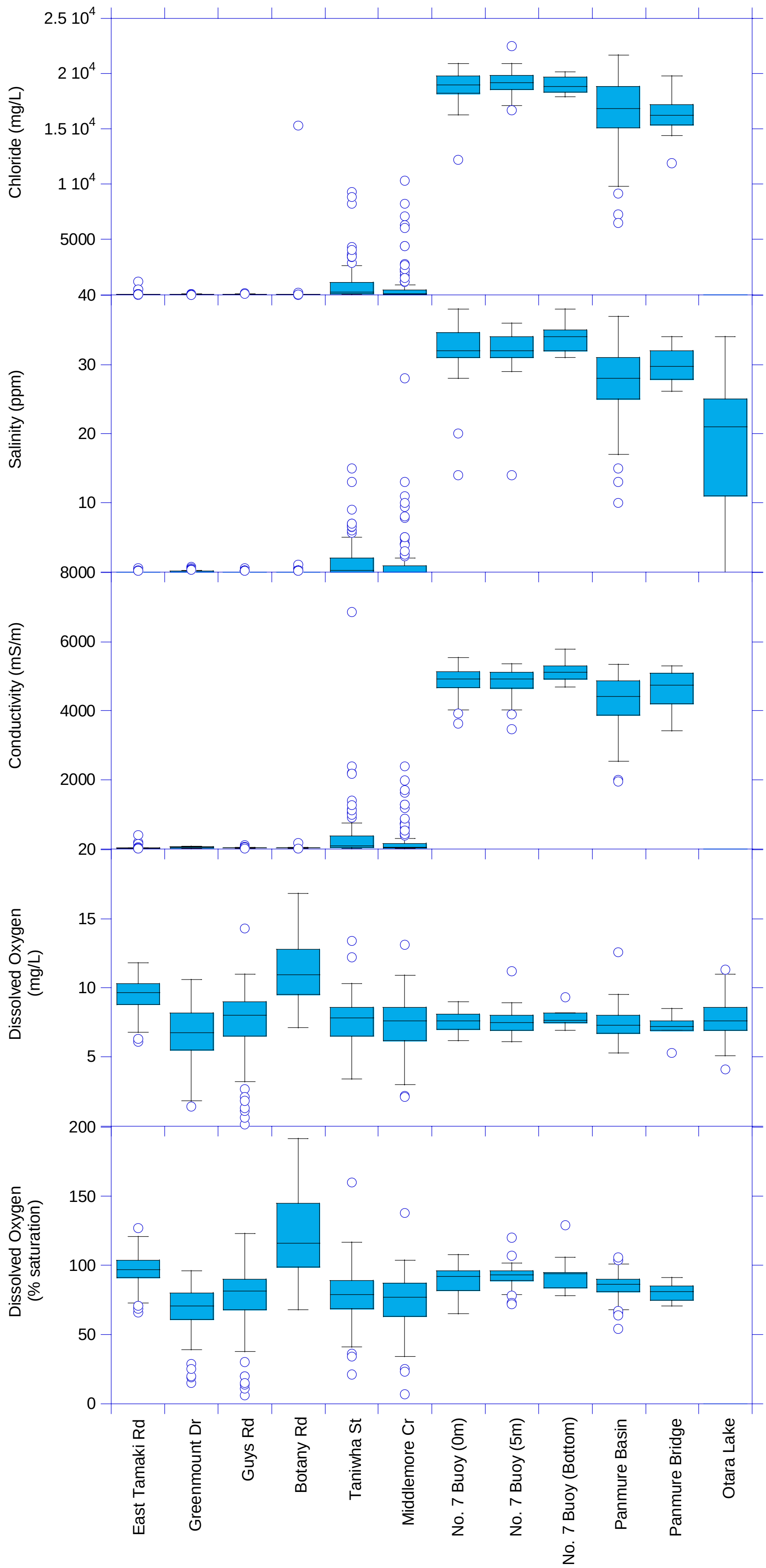

BOD (mg/L)
Dissolved Oxygen (mg/L)
Dissolved Oxygen (% saturation)
Log Faecal Coliforms (MPN/100 mL)
Log Presumptive Coliforms (MPN/100 mL)
Supply Jetty (0m)
Town Bridge (0m)
Town Basin (0m)
Town Basin (1m)
Dawsons Creek (0m)
Dawsons Creek (1m)
Mahurangi Heads (0m)
Mahurangi Heads (5m)

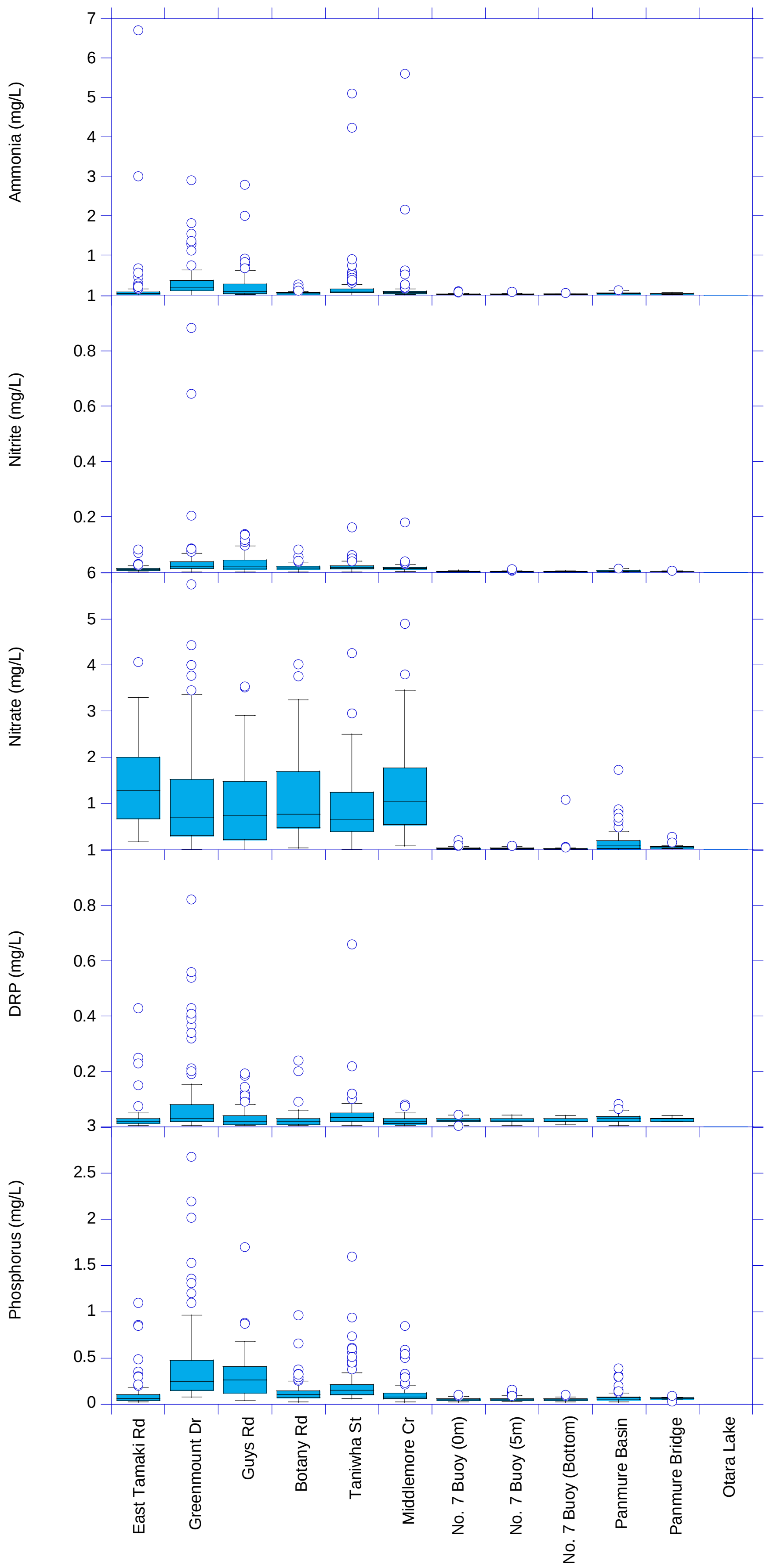


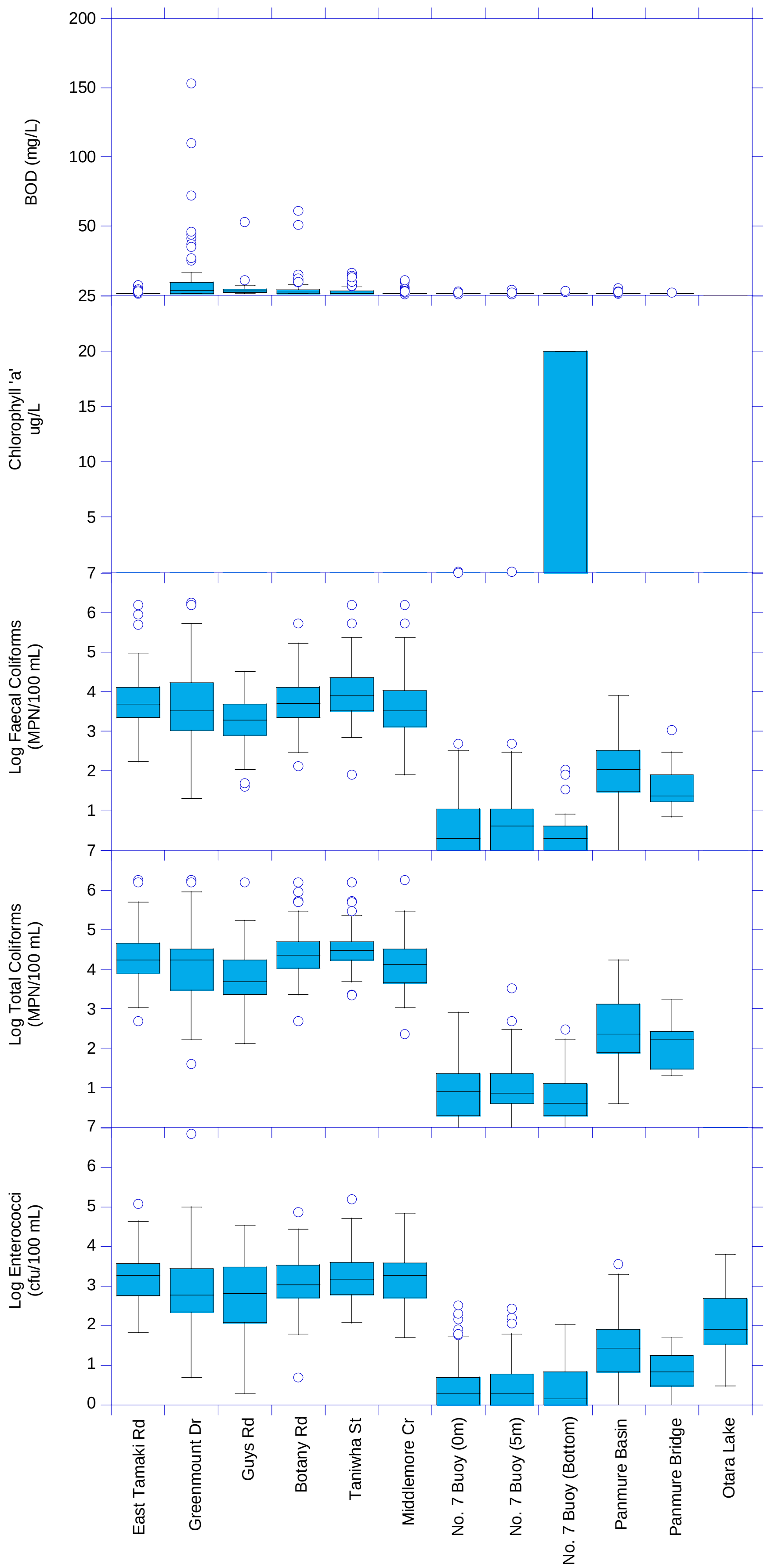
Log Enterococci
(cfu/100 mL)
0
1
2
3
4
5
6
Supply Jetty (0m)
Town Bridge (0m)
Town Basin (0m)
Town Basin (1m)
Dawsons Creek (0m)
Dawsons Creek (1m)
Mahurangi Heads (0m)
Mahurangi Heads (5m)

(b) Tamaki Estuary

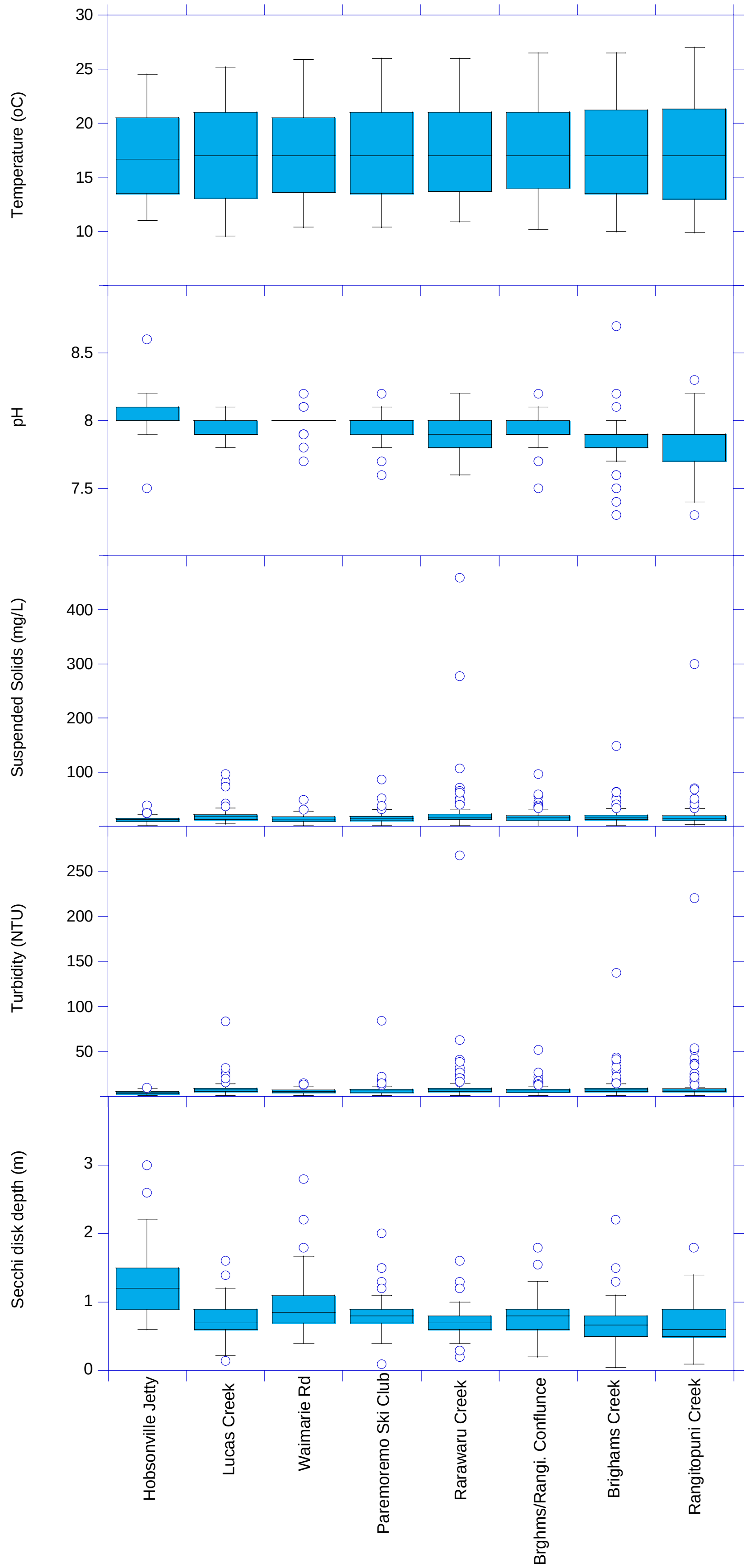


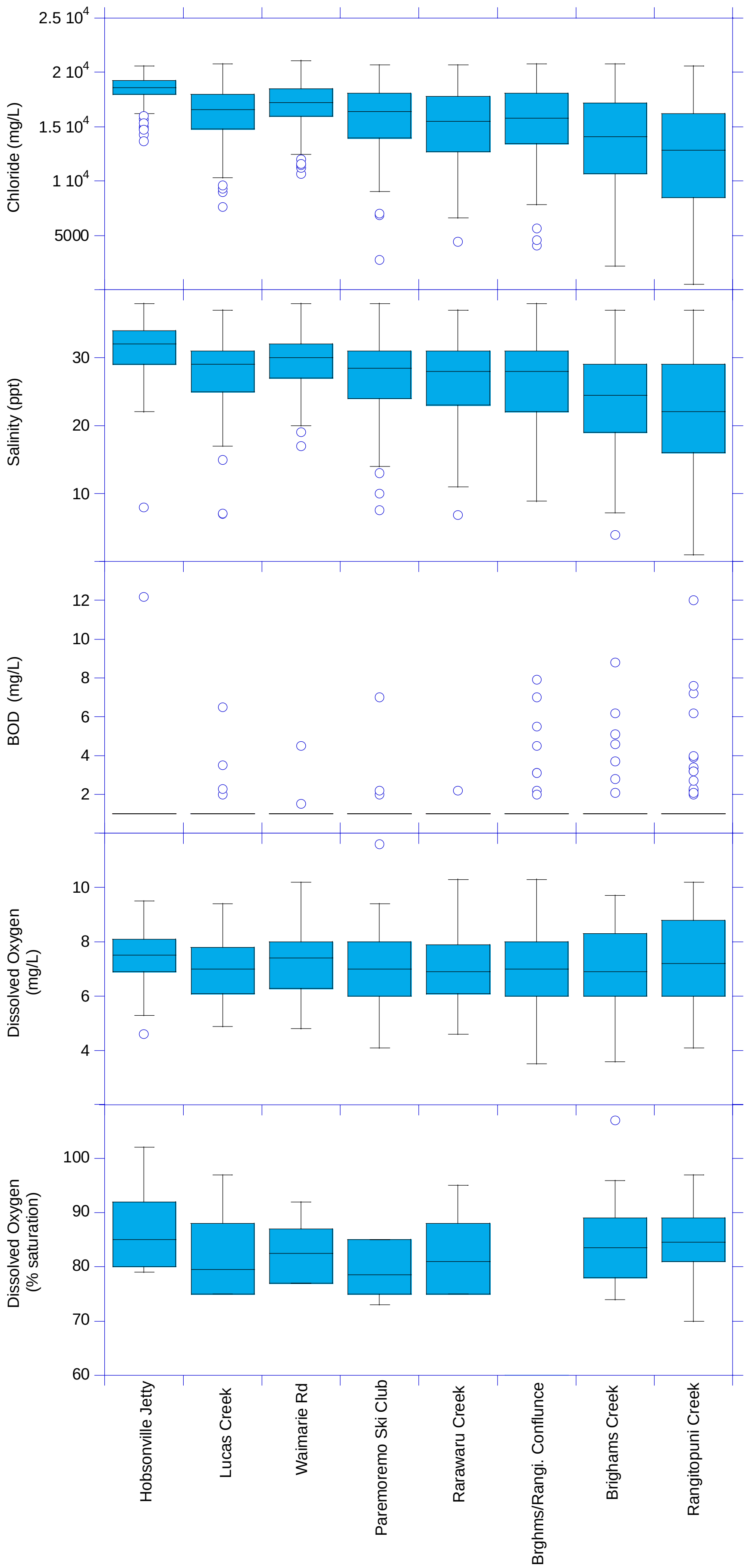

Chloride (mg/L)
2.5 10^4
2 10^4
1.5 10^4
1 10^4
5000
40
Salinity (ppm)
30
20
10
8000
Conductivity (mS/m)
6000
4000
2000
20
Dissolved Oxygen (mg/L)
15
10
5
200
Dissolved Oxygen (% saturation)
150
100
50
0
East Tamaki Rd
Greenmount Dr
Guys Rd
Botany Rd
Taniwha St
Middlemore Cr
No. 7 Buoy (0m)
No. 7 Buoy (5m)
No. 7 Buoy (Bottom)
Panmure Basin
Panmure Bridge
Otara Lake

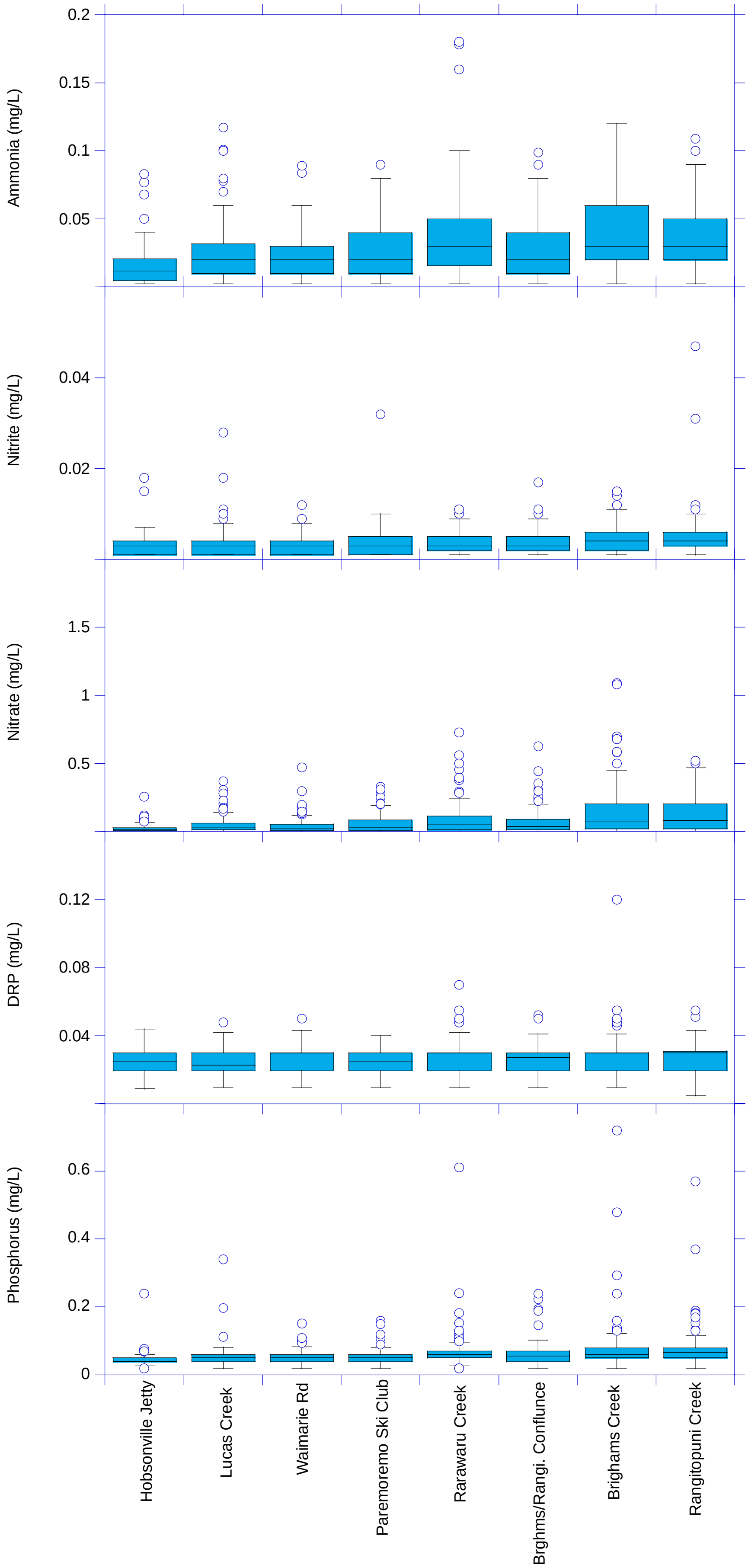

Ammonia (mg/L)
Nitrite (mg/L)
Nitrate (mg/L)
DRP (mg/L)
Phosphorus (mg/L)
East Tamaki Rd
Greenmount Dr
Guys Rd
Botany Rd
Taniwha St
Middlemore Cr
No. 7 Buoy (0m)
No. 7 Buoy (5m)
No. 7 Buoy (Bottom)
Panmure Basin
Panmure Bridge
Otara Lake

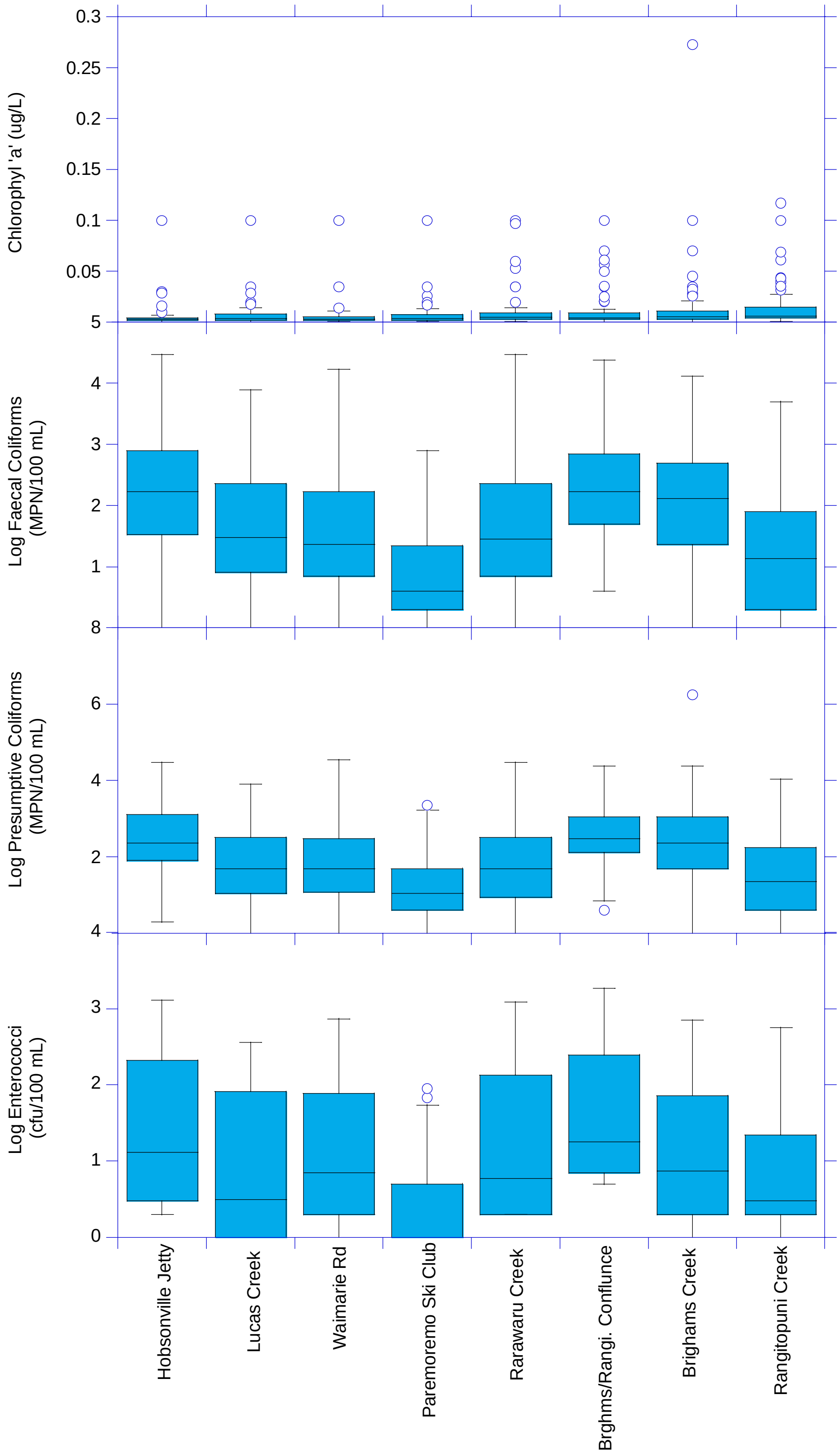

BOD (mg/L)
200
150
100
50
25
Chlorophyll 'a' ug/L
20
15
10
5
7
Log Faecal Coliforms (MPN/100 mL)
6
5
4
3
2
1
7
Log Total Coliforms (MPN/100 mL)
6
5
4
3
2
1
7
Log Enterococci (cfu/100 mL)
6
5
4
3
2
1
0
East Tamaki Rd
Greenmount Dr
Guys Rd
Botany Rd
Taniwha St
Middlemore Cr
No. 7 Buoy (0m)
No. 7 Buoy (5m)
No. 7 Buoy (Bottom)
Panmure Basin
Panmure Bridge
Otara Lake

(c) Upper Waitemata Harbour




Chloride (mg/L)
2.5 10^4
2 10^4
1.5 10^4
1 10^4
5000
Salinity (ppt)
30
20
10
BOD (mg/L)
12
10
8
6
4
2
Dissolved Oxygen (mg/L)
10
8
6
4
Dissolved Oxygen (% saturation)
100
90
80
70
60
Hobsonville Jetty
Lucas Creek
Waimarie Rd
Paremoremo Ski Club
Rarawaru Creek
Brghms/Rangi. Conflunce
Brighams Creek
Rangitopuni Creek


Ammonia (mg/L)
0.2
0.15
0.1
0.05
Nitrite (mg/L)
0.04
0.02
Nitrate (mg/L)
1.5
1
0.5
DRP (mg/L)
0.12
0.08
0.04
Phosphorus (mg/L)
0.6
0.4
0.2
0
Hobsonville Jetty
Lucas Creek
Waimarie Rd
Paremoremo Ski Club
Rarawaru Creek
Brghms/Rangi. Conflunce
Brighams Creek
Rangitopuni Creek


Chlorophyl 'a' (ug/L)
Log Faecal Coliforms (MPN/100 mL)
Log Presumptive Coliforms (MPN/100 mL)
Log Enterococci (cfu/100 mL)
Hobsonville Jetty
Lucas Creek
Waimarie Rd
Paremoremo Ski Club
Rarawaru Creek
Brghms/Rangi. Conflunce
Brighams Creek
Rangitopuni Creek

APPENDIX 63: ANOVA RESULTS

In order of increasing medians, except for Secchi depth and dissolved oxygen (which are reversed), so that going from left to right generally corresponds to worsening water quality. Chloride, conductivity and salinity are in increasing order but not of water quality. Differences are at the 95% level of statistical significance ($p<0.05$) and are based on non-parametric analysis using a Kruskal-Wallis test procedure.

Upper Waitemata Harbour

Physical descriptors

Temperature: UW1 = UW2 = UW3 = UW4 = UW5 = UW6 = UW7 = UW8
pH: UW1 = UW2 = UW3 = UW4 = UW5 = UW6 = UW7 = UW8
SS: UW1 = UW3 < UW2 = UW4 = UW5 = UW6 = UW7 = UW8
Turbidity: UW1 < UW3 = UW4 = UW6 = UW8 < UW2 = UW5 = UW7
Secchi disk: UW1 > UW3 > UW4 = UW6 > UW2 = UW5 = UW7 > UW8
(decreasing order of medians)

Salinity

Chloride: UW5 = UW7 = UW8 < UW2 = UW4 = UW6 < UW3 < UW1
Salinity: UW7 = UW8 < UW2 = UW4 = UW5 = UW6 < UW3 < UW1
Conductivity: UW2 = UW3 = UW4 = UW5 = UW6 = UW7 = UW8 < UW1
(NB very small data set)

BOD and DO

BOD: UW1 = UW2 = UW3 = UW4 = UW5 = UW6 = UW7 = UW8
DO (mg/L): UW1 > UW2 = UW3 = UW4 = UW5 = UW6 = UW7 = UW8
(insufficient % saturation data)

Nutrients and chl *a*

Ammonia-N: UW1 = UW3 < UW2 = UW4 = UW5 = UW6 < UW7 = UW8
Nitrite-N: UW1 = UW2 = UW3 = UW4 = UW5 = UW6 < UW7 = UW8

Nitrate-N: UW1 = UW3 < UW2 = UW4 = UW5 = UW6 < UW7 = UW8

DRP: UW1 = UW2 = UW3 = UW4 = UW5 = UW6 = UW7 = UW8
(Dissolved reactive phosphorus)

Total-P: UW1 < UW2 = UW3 = UW4 = UW6 < UW5 = UW7 < UW8

Chlorophyll *a*: UW1 = UW3 < UW2 = UW4 = UW5 = UW6 = UW7 = UW8

Microbiological quality

Total coliform: UW1 = UW3 < UW2 = UW4 = UW6 < UW5 = UW7 = UW8
(Presumptive coliform)

Faecal coliform: UW1 < UW3 = UW2 < UW4 = UW6 < UW5 = UW7 = UW8

Enterococci UW1 = UW3 = UW6 < UW2 = UW4 = UW5 = UW7 = UW8

Key: UW1 = Hobsonville Jetty; UW2 = Lucas Creek; UW3 = Waimarie Road; UW4 = Paremoremo Ski Club; UW5 = Rarawaru Creek; UW6 = Brighams/Rangitopuni confluence; UW7 = Brighams Creek; UW8 = Rangitopuni Creek.

Mahurangi Harbour

Physical descriptors

Temperature:	M01 = M02 = M03 = M04 = M05 = M06 = M07
pH:	M01 = M02 = M03 = M04 < M05 = M06 < M07
SS:	M07 < M01 = M02 < M03 < M04 = M05 = M06
Turbidity:	M07 < M05 = M06 < M01 = M02 = M03 = M04
Secchi disk: (decreasing order of medians)	M07 > M01 = M02 = M03 = M04 = M05 = M06

Salinity

Chloride:	M01 = M02 < M03 < M04 < M05 = M06 < M07
Salinity:	M01 = M02 < M03 < M04 < M05 = M06 < M07
Conductivity:	M01 = M02 < M03 < M04 < M05 = M06 < M07

BOD and DO

BOD:	M01 = M02 = M03 = M05 = M06 = M07 < M04
DO (%):	M01 = M02 = M07 > M03 = M05 = M06 > M04

Nutrients and chl *a*

Ammonia-N:	M05 = M06 = M07 < M01 = M02 = M03 < M04
Nitrite-N:	M05 = M06 = M07 < M02 = M03 = M04 < M01
Nitrate-N:	M05 = M06 = M07 < M04 < M01 = M02 = M03
DRP: (Dissolved reactive phosphorus)	M01 = M02 = M03 = M05 = M06 = M07 < M04
Total-P:	M07 < M05 = M06 < M01 = M02 = M03 < M04
Chlorophyll *a*:	M01 = M02 = M07 < M03 = M05 = M06 < M04

Microbiological quality

Total coliform: (Presumptive coliform)	M05 = M06 = M07 < M04 < M01 = M02 < M03
Faecal coliform:	M05 = M06 = M07 < M04 < M01 = M02 < M03
Enterococci	M05 = M06 = M07 < M01 = M02 = M04 < M03

Key: M01 = Warkworth Supply Jetty; M02 = Warkworth Town Bridge; M03 = Warkworth Town Basin (surface); M04 = Warkworth Town Basin (1 m); M05 = Dawson’s Creek (surface); M06 = Dawson’s Creek (1 m); M07 = Mahurangi Heads (surface). (NB Mahurangi Heads surface and 5 m are not significantly different ($p < 0.001$) for all variables).

Tamaki Estuary

Physical descriptors

Temperature:	T1 = T2 = T3 = T7 = S1/0 = S1/5 < Basin = Weir = T6 < T4
pH:	T2 = T3 = T7 < T1 < T4 = T6 < Weir < Basin < S1/0 = S1/5
SS:	T1 = T7 < S1/0 < S1/5 = T2 = T4 = T6 = Basin < T3
Turbidity:	S1/0 < S1/5 = T1 < Basin = T7 < T6 = T4 < T2 < T3
Secchi disk:	insufficient data for ANOVA

(decreasing order of medians)

Salinity

Chloride:	T1 = T3 = T4 < T2 < T7 < T6 < S1/0 = S1/5 = Basin
Salinity:	T1 = T2 = T3 = T4 = T6 = T7 < Basin < S1/0 = S1/5
Conductivity:	T1 < T3 = T4 < T2 = T7 < T6 < S1/0 = S1/5 = Basin

BOD and DO

BOD:	T1 = T6 = T7 = S1/0 = S1/5 = Basin < T3 = T4 < T2
DO (%):	T4 > T1 > S1/0 = S1/5 > Basin > T3 = T6 = T7 > T2

Nutrients and chl *a*

Ammonia-N:	S1/0 = S1/5 < Basin = T4 < T1 < T7 < T6 = T3 < T2
Nitrite-N:	S1/0 = S1/5 < Basin = T1 < T7 < T2 = T3 = T4 = T6
Nitrate-N:	S1/0 = S1/5 < Basin < T2 = T3 = T4 = T6 < T1 = T7
DRP: (Dissolved reactive phosphorus)	S1/0 = S1/5 < T1 = T3 = T4 = T7 = Basin < T2 = T6
Total-P:	S1/0 = S1/5 < T1 = Basin < T4 = T7 < T6 < T2 = T3
Chlorophyll *a*:	insufficient data for ANOVA

Microbiological quality

Total coliform: (Presumptive coliform)	S1/0 = S1/5 < Basin < T3 < T1 = T2 = T7 < T4 = T6
Faecal coliform:	S1/0 = S1/5 < Basin < T3 < T1 = T2 = T4 = T7 < T6
Enterococci	S1/0 = S1/5 < Basin < T2 = T3 < T1 = T4 = T6 = T7

Key: T1 = Otara Creek; T2 = Pakuranga Creek – Greenmount Drive; T3 = Pakuranga Creek – Guys Rd; T4 = Pakuranga Creek – Botany Rd; T6 = Omaru Creek; T7 = Otaki Creek; S1/0 = No. 7 Buoy (surface); S1/5 = No. 7 Buoy (5 m); Basin = Panmure Basin; Weir = Otara Lake weir. (NB insufficient Panmure Bridge results for ANOVA).

APPENDIX 64: DESCRIPTION OF WATER QUALITY VARIABLES

INTRODUCTION

The following section provides a summary of general information about the variables used in the water quality surveys including; what they measure, and relevance to water suitability for various uses.

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.

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 exchange of oxygen between the waterbody and the atmosphere. 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.

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/L 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

Chloride in these studies is used to indicate the relative proportions of seawater and freshwater in waters that have been sampled. This is in response to tides and indicates whether stream samples are reflecting catchment land use characteristics. The major natural source of chloride for freshwater streams is from groundwater, which in the Auckland Region ranges from 17-40 mg/L depending on the geology concerned. Seawater chloride is typically about 20,000 mg/L. 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.

The New Zealand Ministry of Health Department guideline value for chloride (recommended upper limit for the avoidance of taste and corrosion problems) in water used for human consumption is 250 mg/L (MoH, 2000).

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 streams 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.

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 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 production 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, 1999). 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.

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, 1985).

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, 1985). Water for use as potable supply is limited to 10 mg/L on public health grounds.

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.

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.

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 (ANZECC, 2000).