APPENDIX V

Final Report on Caymanas Gardens Lagoon Performance
Fluid Systems Engineering Ltd.

August 1993

KINGSTON HARBOUR ENVIRONMENTAL PROJECT

Technical Memorandum

Process Monitoring of a Stabilization Pond System and
Evaluation of typical design parameters, Design Recommendations

(Prepared by Fluid Systems Engineering Limited - January 1993)

Introduction

As a follow up to the design and operational status evaluation of five stabilization pond wastewater treatment plants in Jamaica, prepared in June 1992, the Caymanas Gardens Stabilization Pond Wastewater Treatment Plant was monitored between August 1992 and January 1993. The performance of the facility has been evaluated based on the most suitable of the data obtained from routine analysis of process parameters. Operational information observed during the monitoring period is commented on. General comments are made with respect to construction practice and difficulties observed at a major stabilization pond construction project. Information on flow to the plant was determined using several approaches and eventually ratified in June 1993 when flow measuring/recording instrumentation was obtained.

The Caymanas Gardens Stabilization Ponds

Particular interest was drawn to this pond system as it is located on the Rio Cobre Dyke Road, adjacent to the proposed site at **Soapberry** for the location of the major wastewater treatment system for flows from Greater Kingston. The plant has been in operation for over 12 years and typically represents a fully operational facility.

Further, with the recent connection of a new housing subdivision to the plant, the system is expected to be operating at or beyond its original design capacity and hence its performance under current and future loading conditions are of special interest.

Process Monitoring

Over eight sets of samples were collected and analyzed during the monitoring period. Several difficulties were experienced which produced results which were acceptable. This was mainly due to the inexperience of the research assistants carrying out the laboratory work. **Table 1,** which is attached, summarizes the data collected.

The main difficulties were related to inexperience with the procedures for the BOD_5 analysis. Specifically, incorrect preparation of standard stock solutions for dilution water, the incorrect use of phosphate buffer solution, the need for pH adjustments where sample pH was above set limits, inadequate sample dilutions and unstable incubator temperatures due to incorrect settings and power failures were the causes of the ongoing problems. Some errors were also possibly introduced where the D.O. electrode used initially, was not small enough to sample the BOD bottles directly and the bottles' contents had to be emptied for analysis.

Samples were typically analysed for the following (after the laboratory staff had gained some confidence in the procedures and started producing results which were meaningful) ;

1. BOD_5
2. BOD_5 (filtered sample) for plant discharge.
3. Total Suspended Solids
4. $N - NH_3$
5. $N - N0_3$
6. MPN Total Coliforms
7. MPN E. Coli.
8. pH

General Description of the facility

The Caymanas Gardens Pond System comprises four ponds in series with an inlet chamber featuring a sharp crested rectangular weir and a chlorine contact tank at the plant outlet. The chlorine contact tank has a trapezoidal opening suitable for the installation of a weir device. The tank discharges to a nearby unpaved surface drain. The configuration of the pond systems is detailed in **Figure 1.**

In order to monitor flows out of the plant, a 90^{o} "V" Notched weir was installed in the chlorine contact tank. No chlorination is practiced at the facility. Plant flows were monitored by manual measurement of the depth of flow across the weir during all plant visits and over two twenty four (24) hour periods, A calibration table for the weirs is included as **Table 2**.

Notes on Operational observations

During the period over which the pond system was monitored, the dyke slopes and access to the ponds were quite overgrown. A fly and mosquito problem persisted throughout this period. This situation worsened with time and mosquito bites were a feature of the sampling exercise.

Near the end of the monitoring period, the ponds were cleared of emergent weeds and bush on the embankments. It is noteworthy that after clearance of the site, the mosquito problem disappeared. The fly nuisance persisted and this is associated with the existence of a scum layer in the first pond.

The design of pond systems should attempt to restrict the growth of emergent weeds and plant maintenance must provide for regular removal of the weeds that do grow. Routine scum removal is also recommended and this can be achieved by installing scum boards and collection cisterns in the section of the pond where wind action will normally result in the accumulation of floating solids and scum.

Discussion of results of process monitoring

The data from analyses during the first months of the monitoring program were not within the expected ranges and hence not considered reliable. Specific comments are made in the remarks on **Table 1** in this regard. The results obtained in the final analyses were considered useful. The BOD_5 procedure was not perfected even after several months of ongoing practice however, as significant variability was still being obtained for results of varying sample dilutions where oxygen (O_2) depletion was not a factor. Incomplete inhibition of nitrification in the test jars could be one factor affecting the tests.

Training for the routine analysis of water samples from wastewater treatment plants is prerequisite to being able to successfully operate such facilities. It was clearly demonstrated over the monitoring period that the ability to produce reliable data on the performance of these systems, goes well beyond having the appropriate equipment and reagents. Laboratory staff must be trained and seasoned in the detail and routine of the various procedures.

Plant loading - hydraulic

The hydraulic loading of the plant was estimated by monitoring influent flows over the rectangular sharp crested weir at the inlet structure to the ponds. A 90^o "V" Notched weir was installed in the chlorine contact tank and was also monitored.

Flows to the plant were sustained for most of the 24 hour period and did not reflect the diurnal variation typically associated with water consumption and sewage generation. This to some extent, is the result of all flows to the plant being from a pump station having a single duty pump. The depth of flow over the 3'-4" rectangular weir at the inlet to the plant was on average 1.25" with little variation at the times observed. Based on the weir calibration table, inflow to the plant was estimated to be approximately 137 igpm.

Flows from the pump station were monitored for the period 12/6/93 to 14/6/93 over 51 hours to give a total flow of 422,456 (US)gal. or 352,046 igals. The average flow to the plant over the period was 138 (US)gal. or 115 igpm. Based on the estimated system curve, the pump speed and the Gorman Rupp pumps being used, a flow of 290 igpm was expected. This flow occurred only intermittently and for most of the period monitored averaged 125 igpm. It is suspected that there is a blockage in the forced main to the plant which restricts flow from the pump station. Leaks in the pump main and waste observed at the inlet structure could account for the difference between the observed ~140 igpm and the measured 155 igpm normal flow from the pump station. A graphical record of the flows observed is shown at **Figure 2.**

Outflow from the plant was monitored at the 90^o "V" Notched weir which had 4" to 4.5" depth of flow throughout the 24 hour period. Based on the weir calibration table, outflow from the plant was estimated to be approximately 71 igpm. The average flow through the plant was therefore estimated at 105 igpm.

The estimated design hydraulic capacity of the plant is 0.15 MiGD or 104 igpm based on 3225 persons and a per capita contribution of 42.5 igpd/person. The plant is therefore operating at its estimated design hydraulic capacity. The difference between the estimated inflows and outflows from the system is approximately 32%. Evaporation losses are estimated at approximately 15 igpm or 9% of the inflows. It would therefore appear that some seepage occurs from the system.

Plant loading - organic

Influent BOD_5 levels measured are significantly below the design levels i.e. 131 mg/l raw sewage BOD_5, compared to 300 mg/l. Based on the estimated flows to the plant and the influent BOD_5, the organic load is reduced from a design provision of 452 lbs./d (i.e., 3225 persons @ .14 lbs/cap.d.) to an estimated 198 lbs./d. i.e. a 56% reduction.

Estimated plant removal efficiencies

Original design parameters

The design parameters for the Caymanas Gardens pond system are set out in **Table 3.** showing the typical parameters and rate kinetics for 1st-order type processes. The retention through the system is 22.3 days. This is without the addition of waste flows from Christian Pen a new subdivision recently connected to the system but not yet occupied. The model indicates excellent output from the system under these conditions.

Measured parameters

The actual conditions measured on the site indicated hydraulic loading at the design level. **Table 4**. shows the computed performance of the system for current loading conditions, based on 1st-order type rate kinetics. The reduction rates are reduced below those suggested by Marais and Shaw for BOD_5 and bacterial removal. The results suggest that there is reduced retention possibly due to the accumulation of sludge in pond 1. Complete nitrification is not being achieved in the system. High suspended solids levels and pH in the later ponds and in the effluent from the system are associated with a high algal population which is clearly visible.

It may be possible that in the particular situation being looked at, the impact of reduced retention is greater than that provided for in the Marais and Shaw models.

Before any such deduction can be made however, an extended period of flow measurement through the facility would be necessary, along with an extended period of reliable data of plant performance parameters.

Design and Construction practices and difficulties

The following are noteworthy design features and construction difficulties which have been observed during the design and construction of a major pond facility;

1. *Haulage of fill material should be planned to avoid the use of dykes to completed ponds, particularly those which are in service. Significant embankment damage can result from high wheel loads typical of trucks and scrapers hauling large volumes of fill.*

2. *Where clay lining is used to seal ponds, the thickness of clay budgeted for should be at least 1ft. where suitable material is available.*

3. *After placement and compaction of a clay lining, it is important that ponds be filled as quickly as possible to reduce or eliminate the cracking of the clay lining. At the average design flow, it will take over twenty (20) days to fill a pond. During construction, an adequate supply of suitable water is not always available for this operation.*

4. *If at all possible, ponds which are not yet placed in service should be filled with unpolluted or only slightly polluted water. Stagnant ponds with highly polluted water can develop dense algal mats and quickly become anoxic.*

5. *Where winds in excess of 20 knots are expected and the dimension of ponds exceed 200 ft., significant waves can be generated. During the filling of ponds, these waves can cause significant damage to the new pond by erosion of the clay lining to the side of the pond. Problems can also occur if water line structures installed to prevent wave erosion or control the growth of emergent plants are undermined. Floating "booms" can be useful in creating quiescence in areas at risk to erosion during pond filling operations.*

KINGSTON HARBOUR ENVIRONMENTAL PROJECT

TABLE 1.

	Sample Date	Sample Location	BOD_5 mg/L	BOD_5 (Filtered)	Total Sus. Solids	NH_3-N mg/L	NO_3-N mg/L	pH	MPN Total Coli.	MPN E/C	Remarks
1	16-Jul-92	Pond in	46		114			6.88			Procedure problems with
		Pond 1-2									BOD analysis, also incorrect
		Pond 2-3									dilutions.
		Pond 3-4									
		Pond out	16		169.8			9.2			
2	21-Oct-92	Pond in	6			8.4	0.093	7.4			Procedure problems with
		Pond 1-2									BOD analysis, also incorrect
		Pond 2-3									dilutions.
		Pond 3-4									
		Pond out	12.4			0.026	5.4	9.6			
3	28-Oct-92	Pond in	90					7.25			Procedure problems with
		Pond 1-2									BOD analysis, also incorrect
		Pond 2-3									dilutions.
		Pond 3-4									
		Pond out	22	3.9							
4	6-Nov-92	Pond in	47					7.51	>24,000	>24,000	Procedure problems with
		Pond 1-2									BOD analysis, also incorrect
		Pond 2-3									dilutions. Low dilution water
		Pond 3-4									D.O. levels with resulting
		Pond out	13	12				9.13	1100	70	oxygen depletion.
5	3-Dec-92	Pond in									Phosphate buffer added
		Pond 1-2	80					8.4	>24,000	>24,000	pre-maturely, incorrect
		Pond 2-3							9200	490	dilutions.
		Pond 3-4							50	20	
		Pond out	14					8.6	330	20	
		LABORATORY PROCEDURES REVIEWED AND RECOMMENDED BOD PROCEDURE DOCUMENTED FOR RESEARCH ASSISTANTS.									
6	16-Dec-92	Pond in	70	43				6.8			Dilution water with buffer
		Pond 1-2	2					7.8			added pre-maturely used.
		Pond 2-3	14					8.6			Incubator temperature set
		Pond 3-4	10					8.4			incorrectly inadvertently.
		Pond out	6.5	1.5				8.9			Pumps @ ponds out of service
7	13-Jan-93	Pond in	80.5	81	32			7.5	>24,000	>24,000	Earthquake, Power supply
		Pond 1-2	47		24			7.7	>24,000	140	irregular. Power outages for 2
		Pond 2-3	46		24			7.9	5400	110	days.
		Pond 3-4	28.5		24			8	2400	20	Inadequate dilution for Pond in.
		Pond out	18	19	36			8.4	490	50	
8	20-Jan-93	Pond in	131.6		124	12.5	28	7.4	>24,000	>24,000	N-NO_3 done using colorimetric
		Pond 1-2	47.3		20	10	11	7.5	>24,000	>24,000	method which is not
		Pond 2-3	37		36	10.5	9	7.6	>24,000	9200	appropriate for samples with
		Pond 3-4	24.2		52	8	14	8.1	>24,000	790	organics.
		Pond out	18	14	56	5.4	13	8.3	5400	490	

"V" - NOTCH WEIR DISCHARGES TABLE

Angle	Height (ft)	Q-coeff	H^2.5	tan°/2	cfs	igpm	Migd
90°	0.050	2.80	0.0006	1.0000	0.00	0.59	0.001
	0.100	2.65	0.0032	1.0000	0.01	3.14	0.005
	0.150	2.62	0.0087	1.0000	0.02	8.53	0.012
	0.200	2.58	0.0179	1.0000	0.05	17.28	0.025
	0.250	2.56	0.0313	1.0000	0.08	29.89	0.043
	0.300	2.53	0.0493	1.0000	0.12	46.69	0.067
	0.333	**2.53**	**0.0640**	**1.0000**	**0.16**	**60.61**	**0.087**
	0.350	2.52	0.0725	1.0000	0.18	68.38	0.099
	0.375	**2.52**	**0.0861**	**1.0000**	**0.22**	**81.25**	**0.117**
	0.400	2.51	0.1012	1.0000	0.25	95.10	0.137
	0.425	2.51	0.1178	1.0000	0.30	110.66	0.160
	0.450	2.50	0.1358	1.0000	0.34	127.15	0.183
	0.475	2.50	0.1555	1.0000	0.39	145.55	0.210
	0.500	2.49	0.1768	1.0000	0.44	164.80	0.238
	0.600	2.48	0.2789	1.0000	0.69	258.92	0.374
	0.700	2.48	0.4100	1.0000	1.02	380.66	0.549
	0.800	2.48	0.5724	1.0000	1.42	531.51	0.767
	0.900	2.48	0.7684	1.0000	1.91	713.50	1.030
width (ft)	0.950	2.48	0.8796	1.0000	2.18	816.76	1.179
2.00	1.000	2.48	1.0000	1.0000	2.48	928.51	1.340

"Sharp-Crested" WEIR DISCHARGES TABLE

N=2

P=1'

Length (ft)	Height (ft)	Q-coeff	H^1.5	eff.length	cfs	igpm	Migd
1.50	0.10	3.31	0.0316	1.4800	0.15	58.00	0.084
1.50	0.20	3.35	0.0894	1.4600	0.44	163.79	0.236
1.50	0.30	3.39	0.1643	1.4400	0.80	300.32	0.433
1.50	0.40	3.43	0.2530	1.4200	1.23	461.33	0.666
2.00	0.20	3.33	0.0894	1.9600	0.58	218.83	0.316
2.00	0.30	3.37	0.1643	1.9400	1.07	401.73	0.580
2.00	0.40	3.40	0.2530	1.9200	1.65	617.95	0.892
2.00	0.50	3.43	0.3536	1.9000	2.30	862.66	1.245
3.00	0.083	3.28	0.0241	2.9833	0.24	88.22	0.127
3.00	0.167	3.30	0.0680	2.9667	0.67	249.15	0.360
3.00	0.250	3.31	0.1250	2.9500	1.22	456.98	0.659
3.00	0.333	3.32	0.1925	2.9333	1.88	702.41	1.014
3.33	0.083	3.28	0.0241	3.3167	0.26	98.08	0.142
3.33	**0.104**	**3.29**	**0.0336**	**3.3125**	**0.37**	**137.04**	**0.198**
3.33	0.250	3.31	0.1250	3.2833	1.36	508.61	0.734
3.33	0.333	3.32	0.1925	3.2667	2.09	782.23	1.129

Measure "H" @ 2.5H upstream of the weir. Depth @ weir "P" must be > 2.5H for sharp crested weir.

TABLE 3.

Design of Facultative & Maturation Ponds

Caymanas Gardens

Design Parameters	1st Order Kinetics		Imperial		S.I.	
			430	units		
Population			3,225	persons	3,225	persons
Per Capita Wastewater Contribution			42.50	igpd	193.2	l/c.d
Per Capita BOD Contribution	*		0.140	lb/cap.d.	0.063	kg/cap.d
Infiltration @ 10%			0.01	Migd	62.29	
Influent Bacterial Conc. FC/100ml			4.00E+C	MPN/100ml	4.00E+07	MPN/100ml
Mean Min. monthly temp. °C			25	°C	25	°C
Effluent Standard Req'd BOD			20	mg/l	20	mg/l
Effluent Standard Req'd FC/100ml			<200	MPN/100ml	<200	MPN/100ml
No. of pond series			1		1	
Sewage Flow in each series	104	igpm	**0.15**	**Migd**	**685**	**cu. m/d**
Total organic load	452	lbs/d	**452**	**lbs./d**	**205**	**kg/d**
Influent BOD conc.			**299**	**mg/l**	**299**	**mg/l**
Facultative Pond #1 Design						
Rate kinetics - (Marais)	ki=0.3(1.05)^(T-20)		0.38	d^{-1}	0.38	d^{-1}
Retention period			9.00	days	9.00	days
Effluent BOD - pond #1 (Marais & Shaw)	Le=Li/(1+ki.t)		**67.19**	**mg/l**	**67.19**	**mg/l**
Pond mid depth area			54,364	ft^2	5,060	m^2
Pond mid depth area			1.25	acres	0.51	ha
Pond depth			4.00	ft.	1.22	m
Pond volume			217,455	$ft.^3$	6,169	m^3
Pond Side slopes			3	ft/ft	3	m/m
Pond length			185	ft.	56	m
Pond Width			294	ft.	90	m
Facultative Pond #2 Design						
Rate kinetics			0.38	d^{-1}	0.38	d^{-1}
Retention period			6.00	days	6.00	days
Effluent BOD - pond #2			15.11	mg/l	15.11	mg/l
Pond mid depth area			36,242	ft^2	3,373	m^2
Pond mid depth area			0.83	acres	0.34	ha
Pond depth			4.00	ft.	1.22	m
Pond volume			144,970	$ft.^3$	4,112	m^3
Pond Side slopes			3	ft/ft	3	m/m
Pond length			124	ft.	38	m
Pond Width			292	ft.	89	m
Maturation Pond #1 Design						
Coliform removal rate kinetics - (Marais)	Kb(t)=2.6(1.19)^(T-20)		6.20	d^{-1}	6.20	d^{-1}
Retention			4.25	days	4.25	days
Effluent FC /100ml - (Marais)	Ne=Ni/(1+Kb(t).t)^n		6.73E+02	MPN/100ml	6.73E+02	MPN/100ml
Pond mid depth area			25,672	ft^2	2,389	m^2
Pond mid depth area			0.59	acres	0.24	ha
Pond depth			4.00	ft.	1.22	m
Pond volume			102,687	$ft.^3$	2,913	m^3
Pond Side slopes			3	ft/ft	3	m/m
Pond length			155	ft.	47	m
Pond Width			166	ft.	51	m
Maturation Pond #2 Design						
Coliform removal rate kinetics			6.20	d^{-1}	6.20	d^{-1}
Retention			3.00	days	3.00	days
Effluent FC /100ml			34.29	MPN/100ml	34.29	MPN/100ml
Pond mid depth area			18,121	ft^2	1,687	m^2
Pond mid depth area			0.42	acres	0.17	ha
Pond depth			4.00	ft.	1.22	m
Pond volume			72,485	$ft.^3$	2,056	m^3
Pond Side slopes			3	ft/ft	3	m/m
Pond length			155	ft.	47	m
Pond Width			117	ft.	36	m
Total Pond Area			3.1	acres	1.3	ha
Total Retention Time			22.3	days	22.3	days
Overall Organic Loading Rate			146.3	lb/ac.d.	163.7	kg/ha.d
Total Area Required			3.5	acres	1.4	ha

TABLE 4.

Design of Facultative & Maturation Ponds						
	Caymanas Gardens					
Design Parameters	1st Order Kinetics		Imperial		S.I.	
			430	units		
Population			3,225	persons	3,225	persons
Per Capita Wastewater Contribution			42.50	igpd	193.2	l/c.d
Per Capita BOD Contribution	•		0.062	lb/cap.d.	0.028	kg/cap.d
Infiltration @ 10%			0.01	Migd	62.29	
Influent Bacterial Conc. FC/100ml			4.00E+0	MPN/100ml	4.00E+07	MPN/100ml
Mean Min. monthly temp. °C			25	°C	25	°C
Effluent Standard Req'd BOD			20	mg/l	20	mg/l
Effluent Standard Req'd FC/100ml			<200	MPN/100ml	<200	MPN/100ml
No. of pond series			1		1	
Sewage Flow in each series	104	igpm	0.15	Migd	685	cu. m/d
Total organic load	198	lbs/d	198	lbs./d	90	kg/d
Influent BOD conc.			131	mg/l	131	mg/l
Facultative Pond #1 Design						
Rate kinetics - (Marais)	Computed		0.20	d^{-1}	0.20	d^{-1}
Retention period			9.00	days	9.00	days
Effluent BOD - pond #1 (Marais & Shaw)	Actual		47.33	mg/l	47.33	mg/l
Pond mid depth area			54,364	ft^2	5,060	m^2
Pond mid depth area			1.25	acres	0.51	ha
Pond depth			4.00	ft.	1.22	m
Pond volume			217,455	$ft.^3$	6,169	m^3
Pond Side slopes			3	ft/ft	3	m/m
Pond length			185	ft.	56	m
Pond Width			294	ft.	90	m
Facultative Pond #2 Design						
Rate kinetics	Computed		0.05	d^{-1}	0.05	d^{-1}
Retention period			6.00	days	6.00	days
Effluent BOD - pond #2	Actual		37.26	mg/l	37.26	mg/l
Pond mid depth area			36,242	ft^2	3,373	m^2
Pond mid depth area			0.83	acres	0.34	ha
Pond depth			4.00	ft.	1.22	m
Pond volume			144,970	$ft.^3$	4,112	m^3
Pond Side slopes			3	ft/ft	3	m/m
Pond length			124	ft.	38	m
Pond Width			292	ft.	89	m
Maturation Pond #1 Design						
Coliform removal rate kinetics - (Marais)	Computed		5.88	d^{-1}	5.88	d^{-1}
Retention			4.25	days	4.25	days
Effluent FC /100ml - (Marais)	Actual		7.87E+02	MPN/100ml	7.87E+02	MPN/100ml
Pond mid depth area			25,672	ft^2	2,389	m^2
Pond mid depth area			0.59	acres	0.24	ha
Pond depth			4.00	ft.	1.22	m
Pond volume			102,687	$ft.^3$	2,913	m^3
Pond Side slopes			3	ft/ft	3	m/m
Pond length			155	ft.	47	m
Pond Width			166	ft.	51	m
Maturation Pond #2 Design						
Coliform removal rate kinetics	Computed		0.20	d^{-1}	0.20	d^{-1}
Retention			3.00	days	3.00	days
Effluent FC /100ml	Actual		491.72	MPN/100ml	491.72	MPN/100ml
Pond mid depth area			18,121	ft^2	1,687	m^2
Pond mid depth area			0.42	acres	0.17	ha
Pond depth			4.00	ft.	1.22	m
Pond volume			72,485	$ft.^3$	2,056	m^3
Pond Side slopes			3	ft/ft	3	m/m
Pond length			155	ft.	47	m
Pond Width			117	ft.	36	m
Total Pond Area			3.1	acres	1.3	ha
Total Retention Time			22.3	days	22.3	days
Overall Organic Loading Rate			64.3	lb/ac.d.	71.9	kg/ha.d
Total Area Required			3.5	acres	1.4	ha

CAYMANAS GARDENS

STABILIZATION PONDS

FIGURE 1.

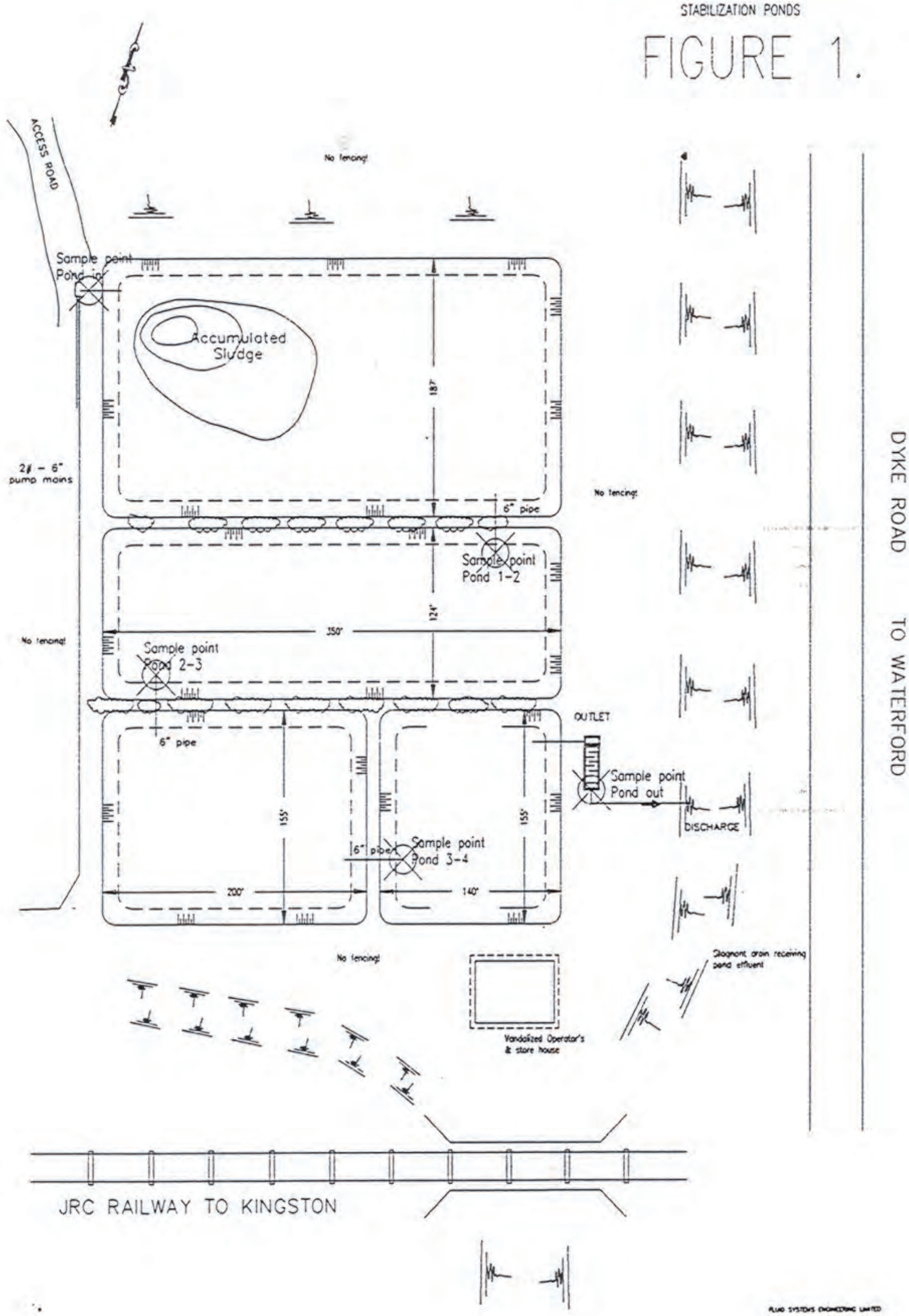
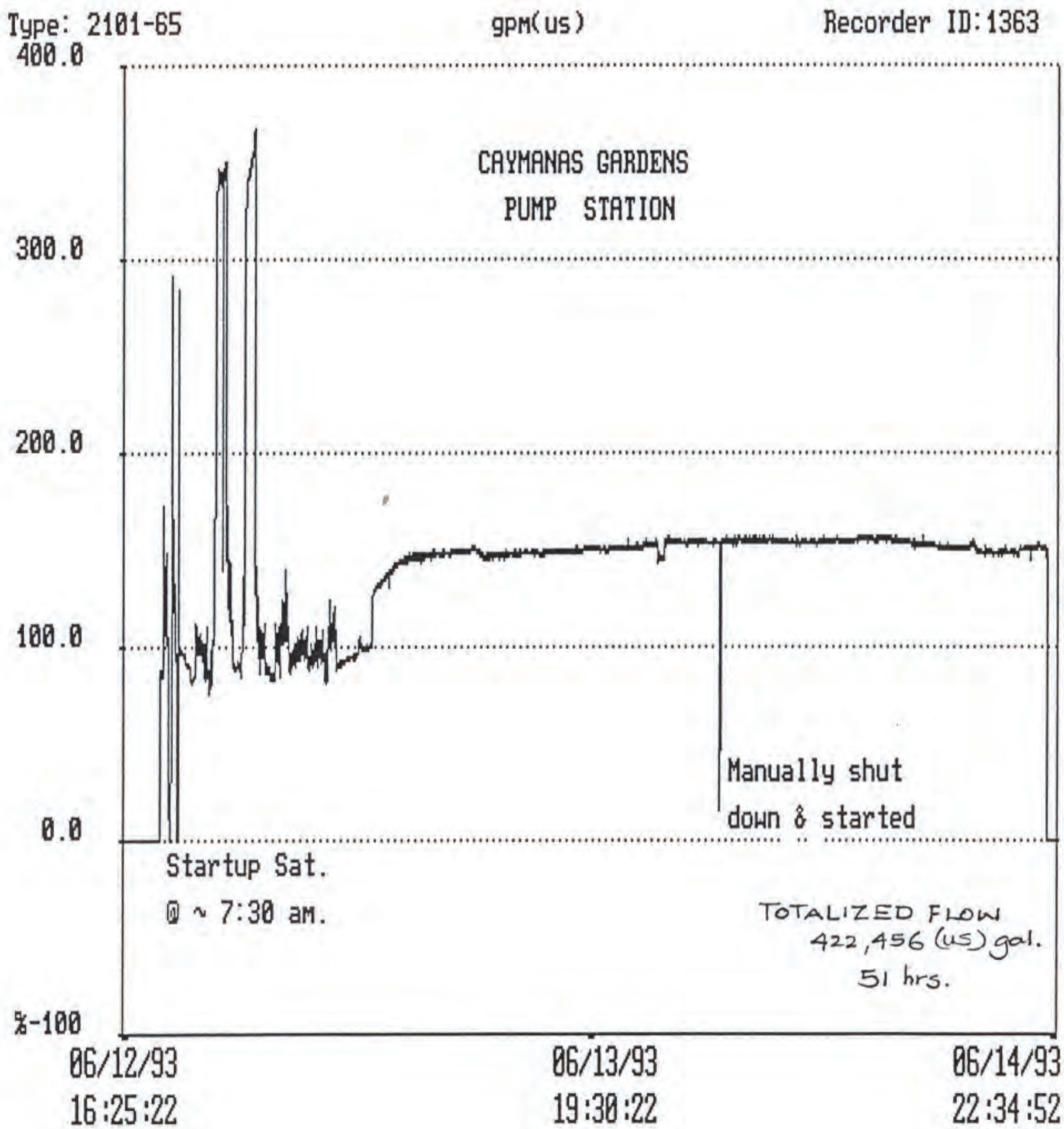


FIGURE 2.


Type: 2101-65
gpm(us)
Recorder ID:1363
400.0
300.0
200.0
100.0
0.0
%-100
CAYMANAS GARDENS
PUMP STATION
Manually shut
down & started
Startup Sat.
@ ~ 7:30 am.
TOTALIZED FLOW
422,456 (US) gal.
51 hrs.
06/12/93
16:25:22
06/13/93
19:30:22
06/14/93
22:34:52

APPENDIX VI

Studies on Role of Phosphorus and Nitrogen in Harbour and Hunts Bay Eutrophication

VI. STUDIES ON ROLE OF PHOSPHORUS AND NITROGEN IN HARBOUR AND HUNTS BAY EUTROPHICATION

SENTAR's Phase 1 Report indicated that although nutrient loadings in the main Harbour would be reduced by implementation of the proposed sewerage scheme, loadings in Hunts Bay, particularly of phosphorus, would be increased. There was also some concern that certain wastewater disposal options under consideration could result in increased nutrient concentrations along the sensitive Hellshire Coast. Therefore, in order to better assess the potential impacts on eutrophication of the nutrient loadings associated with different disposal locations, SENTAR commissioned Dr. Dale Webber of the University of the West Indies to investigate the effects of adding nutrients to Harbour and ocean waters. His report follows.

To: Mr. Ken Hammon
Sentar Consultants Ltd.

Fax 403 269-1527

From: Dr. Dale Webber
Centre for Marine Sciences

Monday June 14, 1993

Ken,

Please find attached the report on background phosphates as agreed. My apologies for being late but unscheduled power outages have been very disruptive. Please advise as to next course of action re 24hr sampling, as you will see, circomstances conspired against us.

Report should be two typed pages and two pages of tables. Together with this page total fax length; 5 pages.

Best Regards,

UWI/SENTAR REPORT

June 7, 1993

Prepared by D.F. Webber

1. TO DETERMINE THE BACKGROUND PHOSPHORUS CONCENTRATION IN KINGSTON HARBOUR IN THE ABSENCE OF PHYTOPLANKTON UPTAKE.

Exercise 1.1.

Phytoplankton will naturally remove nutrients from the water for use in their normal metabolic processes. If this process is reduced or removed by a reduction in phytoplankton what will be the resultant effect on the nutrient concentrations?

In order to answer this, two experiments were conducted.

A. Hourly sampling of Harbour water (from Port Royal docks chosen for security reasons) over a 24 hr period was conducted. Table 1 shows time and date of sample, light climate, water temperature, salinity and phosphate values.

B. Four, twenty (20) L portions of water from the Harbour (specifically, Newport West, behind Gordon Cay) were collected and the phosphate concentration of the samples measured. Three samples were then be treated with a photosynthesis inhibitor, 3(3,4 Dichlorophenyl)-1,1 Dimethylurea (DCMU) and incubated under natural temperatures and light climate, and with the addition of air/O_2. The fourth 20 L sample was not treated with DCMU but received the same light and temperature considerations. The phosphate concentrations in these samples were be measured daily for three days. Table 2 shows the dates and phosphate values for all four 20 L samples over the three day period.

RESULTS

Table 1

Time	Light above water $\mu E\ s^{-1}$	Light in water $\mu E\ s^{-1}$	Temp. °C	Salinity ppt	Chlorophyll a mg m^{-3}	Phosphate $\mu g\ at\ l^{-1}$
2:00pm	0.27	0.26	29.0	33.5	3.203	< 0.25
3:00pm	127.4	0.56	28.0	35.0	1.642	< 0.25
4:00pm	122.4	0.58	29.0	34.0	2.249	< 0.25
5:00pm	119.1	0.69	29.0	33.0	1.692	< 0.25
6:00pm	65.2	0.26	29.0	33.5	1.816	< 0.25
7:00pm	0.45	0.26	27	35.0	1.580	< 0.25
8:00pm	-	-	28.5	33.0	1.692	< 0.25
9:00pm	-	-	28.5	26.0	6.787	0.78
10:00pm	-	-	28.0	25.0	7.549	0.78
11:00pm	-	-	28.0	22.5	9.304	0.78
12:00pm	-	-	28.0	22.0	9.762	1.31
1:00am	-	-	28.0	24.0	6.787	2.08
2:00am	-	-	28.0	28.0	7.092	2.08
3:00am	-	-	29.0	28.0	4.309	2.08
4:00am	-	-	29.0	28.0	5.948	1.56
5:00am	0.41	0.27	28.0	26.0	4.118	1.88
6:00am	60.0	0.32	28.0	25.0	5.378	2.29
7:00am	650.0	0.53	27.0	25.0	6.253	1.56
8:00am	930.0	0.72	27.0	26.0	5.681	1.56
9:00am	627.0	0.48	27.0	27.5	2.517	0.26
10:00am	350.0	0.42	29.0	32.0	1.169	1.31
11:00am	520.0	0.30	28.0	32.5	0.933	0.78
NOON	1918.0	0.73	29.5	32.5	0.510	0.26
1:00pm	1942.0	0.77	30.0	32.0	0.565	0.26
2:00pm	1664.0	0.89	29.5	32.0	1.792	< 0.25

Table 2

Date	Sample	Light μE s-1	Salinity ppt.	Temp. oC	Chlorophyll a mg m-3	Phosphate μg at l-1
26.05.93	Gordon Cay	132.5	33.0	28.0	9.457	3.65
27.05.93	DCMU 1	135.2	33.0	28.0	4.539	0.52
	DCMU 2	135.2	33.0	28.0	5.148	0.52
	DCMU 3	135.2	33.0	28.0	6.330	0.52
	No DCMU	135.2	33.0	28.0	6.864	0.78
28.05.93	DCMU 1	146.8	33.2	29.0	1.987	0.52
	DCMU 2	146.8	33.2	29.0	2.219	0.83
	DCMU 3	146.8	33.2	29.0	2.056	0.47
	No DCMU	146.8	33.2	29.0	3.873	0.52
29.05.93	DCMU 1	127.5	33.1	29.0	0.995	0.52
	DCMU 2	127.5	33.1	29.0	1.841	1.04
	DCMU 3	127.5	33.1	29.0	1.792	< 0.26
	No DCMU	127.5	33.1	29.0	2.707	0.26

DISCUSSION

Experiment A, did not adequately address the question proposed, primarily because the study area was affected by heavy rainfall which had occurred over the past three to four weeks across the entire island. Fresh water which enters Kingston Harbour via Hunts Bay and the gullies, is kept entrained during the day to the north western coast of the Harbour by strong south east winds. At night these winds subside and the fresh water spreads from Hunts Bay and the north western side of the harbour mouth to the eastern side of the harbour mouth.

By 9:00 pm sufficient fresh water had entered the Port Royal region (where samples were being taken) to lower the salinity from a normal 33 ppt. to 26 ppt. Further proof that this was an intrusion of fresh Hunts Bay water, was evidenced by the dramatic increase in Chlorophyll a and phosphate values (comparable with values normally obtained from Hunts Bay) which accompanied the fresh water (Table 1). It was therefore impossible to determine the background phosphate levels from this experiment. However, the extent of the influence of Hunts Bay waters after extreme rainfall was clearly determined from this study and should be considered when decisions are being taken concerning the possible use of Hunts Bay or nearby as a site for treated effluent.

The second experiment (Experiment B) was marginally more successful. It appears that enclosing water from Gordon Cay for 24 hrs with and without DCMU (photosynthesis inhibitor) resulted in reductions in chlorophyll a and phosphate values. There is no evidence to suggest an increase in phosphate content when phytoplankton photosynthesis is inhibited. Only one of three replicates showed an increase over a three day period (Table 2) but this increase was less than a third of the level of phosphates observed in the field. In fact, phosphate values seem to be reduced by the presence of DCMU. Phosphates may still be absorbed by phytoplankton but not utilised due to the inhibitory effects of the DCMU. These phosphates would be unable to be recycled until death and decay of the phytoplankton occurs and would thus be lost from the water column for some time. In three days phosphate values in the experimental containers were reduced from 3.67 μg at l^{-1} in the field to at least 1.04 μg at l^{-1} and at best 0.25 μg at l^{-1}. These values are still much greater than minimum Kingston Harbour phosphate values of 0.02 μg at l^{-1}, Wade and 0.01 μg at l^{-1}, Webber 1992 but not far from the mean values of either study.

Experiment B did however conclusively show that if a body of water, rich in phytoplankton and with high nutrient values, such as exists at Gordon Cay, is not further treated with nutrients, reduction in phytoplankton and nutrients will occur. This must be considered however, to be only the response of the water column, the influence of the sediments must be investigated to give the total picture, as they are another possible source or sink of nutrients in the marine environment.

REPEAT ENCLOSURE EXPERIMENT

PHOSPHATE AND NITRATE NUTRIENT ADDITIONS TO WATERS FROM HUNTS BAY, KINGSTON HARBOUR AND LIME CAY AREA

Introduction

As a follow up to the initial experiment presented on July 14, 1993, a repeat experiment was designed and conducted to determine the effect of nutrient additions to the waters of Hunts Bay, the Upper Basin of Kingston Harbour and the Lime Cay shelf area. This experiment was conducted as a repeat of two experiments previously conducted during July of 1993.

Methods

Water was collected from Hunts Bay on Thursday, September 2, 1993. Salinity, dissolved oxygen, light climate and temperature were determined in situ. Phytoplankton biomass, zooplankton numbers, NO_3-N, and PO_4-P were determined in order to enable the best simulation of the natural environment. The methodology is described in point form below in exercises 1 and 2.

Exercise 1

a. Collect a large volume (20 L) of experimental water from a designated station eg Hunts Bay.

b. Record light profile, temperature, dissolved oxygen, salinity, pH in situ and under experimental conditions, once stability has been established.

c. Homogenise the water sample and remove three 1 litre portions and filter for chlorophyll a measurements.

d. Homogenise the sample and pour 1 litre portions into twelve sterilised plastic 2 litre flasks and cover with cotton wool.

e. To three flasks add phosphate only, to three nitrate only, to a third three phosphate and nitrate, and the final three to be used as a control. Nutrients should be added to yield a final concentration of 100 μg at l^{-1} PO_4-P and 600 μg at l^{-1} NO_3-N.

f. Incubate labelled samples in randomised block design and under artificial environmental conditions similar to those in situ (as far as possible, all twelve flasks should be exposed to the same light intensity and temperatures).

g. Samples must be agitated regularly to prevent lodging on flask surface.

h. Keep experiment going until significant increase in algae is observed or about 1 week.

g. Conduct chlorophyll a analysis on each sample to determine algal biomass increase as a result of treatment.

REPEAT FOR KINGSTON HARBOUR AND LIME CAY.

Exercise 2

a. Collect a large volume (80 L) of experimental water from a designated station eg Hunts Bay.

Same as exercise 1 b. and c.

d. Homogenise the water samples and remove eight 10 l portions and place each in a 20 l carbouy passing through a 100 μm mesh to remove zooplankton.

e. To two carbouys add phosphate only, to another two nitrate only, to a third two phosphate and nitrate, and the final two to be used as a control. Nutrients should be added to yield a final concentration of 100 μg at l^{-1} PO_4-P and 600 μg at l^{-1} NO_3-N.

f. Incubate in natural environment similar to that from which samples were taken at Port Royal Marine Laboratory.

REPEAT FOR KINGSTON HARBOUR AND LIME CAY.

On Monday September 6, 1993 (four days after setting up enclosures) a 250 ml portion was removed from each treatment and analyzed for phytoplankton biomass and nutrients.

Results

The following environmental conditions were recorded in the field and simulated as far as possible in the bottle enclosures:

Light= 230 to 980 $\mu E\ s^{-1}$

Temperature= 31°C

Salinity= 29 to 35 ppt

pH = 8.1

Dissolved oxygen = 5.1 to 6.3 mg m^{-3}.

See tables and graphs attached for changes in nutrient and chlorophyll values throughout the experiment.

Discussion

i) Lime Cay/Shelf (Ocean influenced waters)

1. Chlorophyll a

Phytoplankton biomass increased in response to phosphate additions, nitrate additions and thus also increased in response to additions of both phosphates and nitrates together. The greatest increase above "normal" values (greater then 10 fold increase) was observed in ocean influenced waters as would be expected since phytoplankton in these oligotrophic waters would make maximum use the nutrients added during the experiment. The increase observed, from 0.35 mg m^{-3} to 5.732 mg m^{-3} indicates that should nutrients of this concentration be released in the Cays area the water quality could rapidly become as poor as Kingston Harbour.

2. Nitrate-N

The response of the planktonic community to an increase in nitrate nitrogen appears to be dramatic. The sharp increase in biomass is further accentuated when nitrates are introduced with phosphates. This is seen especially in carbouy enclosures, suggesting that **both nutrients are limiting in the Cays (ocean influenced) waters.** This was expected since the water used for the experiment was taken between Lime and Drunken Mans Cays outside the influence of Kingston Harbour water and representative of nutrient poor waters.

3. Phosphate-P

The experiments conducted in July of 1993, suggested that phosphate was the limiting nutrient to the Cays area as well as the Inner Harbour. The present experiment seems to contradict this suggestion, since both nitrate and phosphate when applied alone resulted in significant increases in phytoplankton biomass. Moreover, the high residual phosphate values observed after seven days suggests that further biomass increases would have resulted if the experiment were allowed to continue for a longer period.

ii) Harbour

1. Chlorophyll a

The addition of phosphates to Harbour waters did not result in an increase in phytoplankton biomass however the biomass was maintained over the entire seven days of the experiment. In bottle enclosures, nitrate additions however resulted in a doubling in biomass after four days and a tripling after seven days. Additions of both nutrients together, produced small increases only after seven days in bottle enclosures but produced dramatic ten to twelve fold increases in carbouy enclosures. Here, the increase to 27.871 mg m^{-3} suggests that with the introduction of nutrients of the concentrations added in this experiment, Kingston Harbour waters could become as poor in quality as Hunts Bay.

2. Nitrate-N

More nitrate was removed from the bottle enclosures with nitrate only added, than those with both nitrate and phosphate added. This may explain the greater biomass observed in the nitrate only enclosures, suggesting the nitrate is more needed than phosphate although both nutrients may be limiting. In the carbouy enclosures however more nitrates were removed from the N + P enclosures and concurrently a greater biomass was observed in the N + P enclosures.

3. Phosphate-P

The suggestion of phosphate limitation from the previous experiment of July, was not substantiated in the present experiment since additions of did not result in significant increase in biomass. Also, less phosphate was used up in phosphate only enclosures than in nitrate + phosphate enclosures. This suggests that nutrient additions in Kingston Harbour water produce greatest effect when the nutrients are mixed.

iii) Hunts Bay

1. Chlorophyll a

Phytoplankton biomass (≈ 21.88 mg m^{-3}) on the day of collection (Initial) was markedly lower than values during the previous experiment but in keeping with the biomass values observed in Hunts Bay over the 1992 summer sampling programme (≈ 14 - 55 mg m^{-3}). High phytoplankton biomass in bottle enclosures was maintained (compared with values observed in the initial sample) and exceeded when Nitrate-N only as well as when Nitrate-N and Phosphate-P were added together. Additions of Nitrate-N only resulted in maximum biomass values as observed during the last experiment of July 1993, but only after 7 days. Ten litre carbouy enclosures also showed similar results, with even higher biomass values but this was observed within the first four days. After four days when most of the nutrients had already been used up, a rapid decline in biomass (crash) resulted. These observations seem to confirm previous suggestions that **Nitrate-N appears to be the limiting nutrient to phytoplankton in Hunts Bay.**

2. Nitrate-N

Approximately 100 μg at l^{-1} residual NO_3-N was found in the initial sample. The addition of 600 μg at NO_3-N to the N-only and N+P samples maintained and increased the phytoplankton biomass for four days. More residual NO_3-N (< 8 μg at l^{-1}) was found in the N-only samples, than in the N+P of carbouy enclosures. This, along with maximum chlorophyll a (phytoplankton biomass) in the N+P carbouy samples, indicate a greater use of available nitrogen when phosphorous is present.

3. Phosphate-P

Less than 8 μg at l^{-1} residual PO_4-P was found in the initial sample, twice as much as values observed during the experiment of July 1993. The addition of 100 μg at l^{-1} PO_4-P was not sufficient to maintain the phytoplankton biomass in the bottle enclosures but was sufficient in the carbouy enclosures for the first four days. Unlike the experiment of July, more phosphates were used by the phytoplankton in N+P samples than in P-only samples during the present experiment. While the presence of phosphate + nitrates is necessary to produce healthy phytoplankton growth, phosphate does not appear to be a limiting nutrient.

Bottle vs carbouy enclosures

The results obtained from the two treatments (bottle and carbouy enclosures) were significantly different in two ways. Firstly, carbouy enclosures always produced higher biomass values than did bottle enclosures. This was expected since water used for the carbouy enclosures were devoid of zooplankton (having been filtered out) and was exposed to full and natural sunlight, not a laboratory simulation light bank. The removal of zooplankton evidently allowed the phytoplankton to make fullest use of the nutrients added hence the high biomass observed and the peak in biomass in only four days.

Secondly, bottle enclosures seemed to maintain the nutrients which were added for a longer period and thus higher phytoplankton biomass values were obtained after seven days while carbouy enclosures all showed maximum values after four days. It is difficult to determine whether these observations are purely due to the different treatments applied to bottle and carbouy enclosures of whether the volume of water provided some other influence not considered here.

Summary

Nutrient addition to the waters of any of these three areas will result in significant increases in phytoplankton biomass and a reduction in water quality. Hunts bay seems least likely to be adversely affected since it already receives sufficient nutrients to produce phytoplankton biomass values equal to the highest observed in both the July and September experiments.

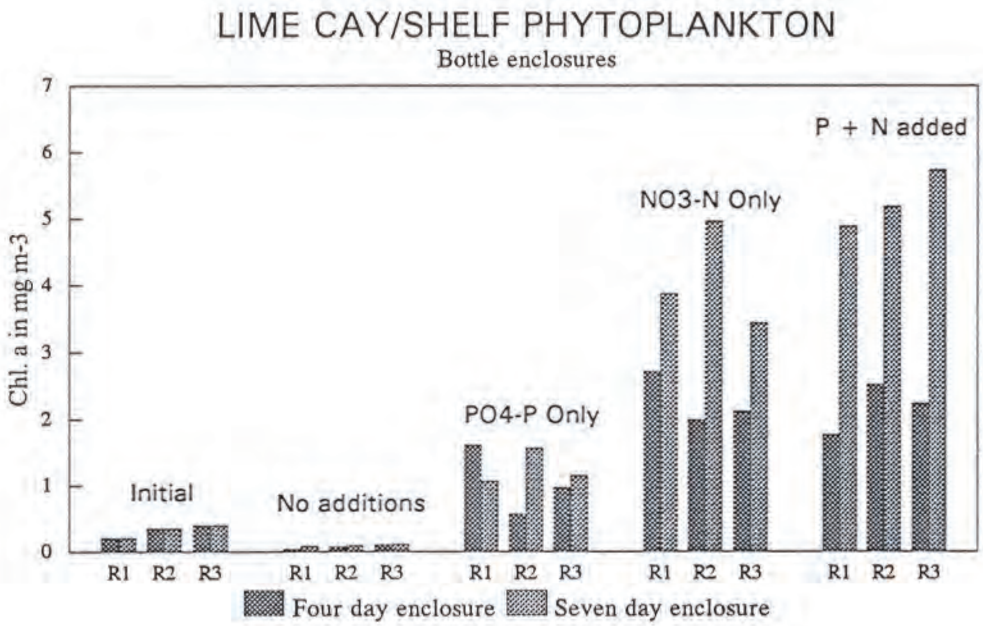
The phytoplankton of Hunts Bay appear to be nitrogen limited, in as far as maintaining the high phytoplankton biomass which has been observed to exist there. Any reduction of the nitrogen released into Hunts bay should therefore reduce phytoplankton biomass even if phosphates are increased. This conclusion stands from the July experiment. The nutrient which may be limiting to both Harbour and Cays waters cannot be determined from two experiments, since on each occasion conflicting results were obtained. This may be the result of water samples being collected at two different times of the year, or it may be due to the presence of a different assemblage of organisms which indeed have different limiting features. The latter has some support as can be surmised from a recent paper by *Fong et al.* 1993 (a copy of which I shall enclose). Again however I must caution that this experiment must be considered in light of the fact that involves artificial enclosures, removal of zooplankton and controlled nutrient additions, and thus is an oversimplification of the natural open environment.

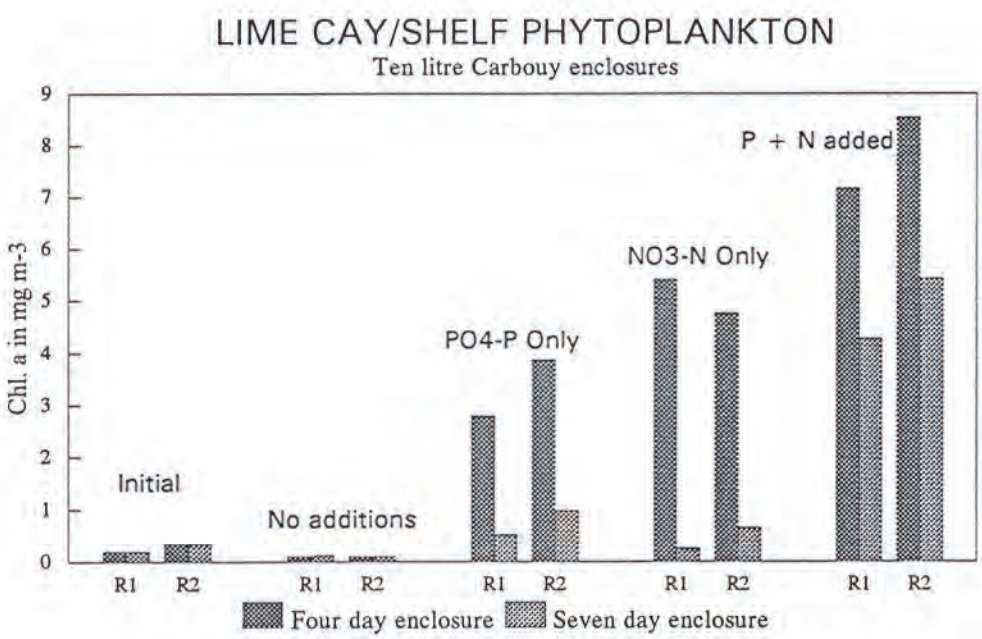
NUTRIENT ADDITION EXPERIMENT SAMPLES FROM 1 LITRE BOTTLE ENCLOSURES

SAMPLE	September 6 Chl a mg m-3	Res. PO4-P ug at l-1	Res. NO3-N ug at l-1	September 9 Chl a mg m-3	Res. PO4-P ug at l-1	Res. NO3-N ug at l-1
Initial Ocean rep 1	0.205	0.068	1.93	0.205	0.068	1.93
Initial Ocean rep 2	0.352	0.046	2.786	0.352	0.046	2.786
Initial Ocean rep 3	0.401	0.085	5.23	0.401	0.085	5.23
Ocean - - rep 1	0.032	0.014	0.458	0.086	0.007	0.385
Ocean - - rep 2	0.075	0.017	0.894	0.095	0.009	0.594
Ocean - - rep 3	0.103	0.018	1.45	0.111	0.011	1.05
Ocean - P rep 1	1.617	25.94	0.351	1.072	24.67	0.297
Ocean - P rep 2	0.573	47.5	0.675	1.567	25.32	0.567
Ocean - P rep 3	0.976	36.75	0.984	1.153	21.5	0.845
Ocean N - rep 1	2.712	0.024	214.2	3.871	0.006	59.4
Ocean N - rep 2	1.991	0.026	318.45	4.957	0.021	79.64
Ocean N - rep 3	2.122	0.037	245.97	3.434	0.004	105.1
Ocean N+P rep 1	1.766	31.85	184.2	4.88	21.4	124.2
Ocean N+P rep 2	2.513	27.43	254.9	5.185	16.4	98.2
Ocean N+P rep 3	2.234	15.64	210.2	5.732	9.65	84.68
Initial Harb. rep 1	1.946	0.643	34.5	1.946	0.643	34.5
Initial Harb. rep 2	2.843	0.87	65.4	2.843	0.87	65.4
Initial Harb. rep 3	2.075	1.76	49.9	2.075	1.76	49.9
Harbour - - rep1	0.673	0.432	21.87	0.986	0.342	13.77
Harbour - - rep2	0.453	0.354	19.24	1.075	0.232	12.54
Harbour - - rep3	0.683	0.742	13.11	0.543	0.532	9.84
Harbour - P rep 1	1.265	15.4	16.78	2.388	6.63	10.32
Harbour - P rep 2	1.627	13.34	27.15	1.083	10.32	18.45
Harbour - P rep 3	1.567	6.58	20.84	1.64	5.621	11.73
Harbour N - rep 1	3.259	0.45	145.6	6.177	0.241	95.11
Harbour N - rep 2	5.948	0.634	127.3	11.36	0.143	75.9
Harbour N - rep 3	4.783	0.193	89.2	7.982	0.274	59.24
Harbour N+P rep 1	2.531	8.64	197.2	5.795	4.832	102.4
Harbour N+P rep 2	2.934	12.35	167.55	7.159	3.64	93.55
Harbour N+P rep 3	2.867	9.74	210.22	5.213	5.32	117.3
Initial HB rep 1	18.33	3.67	98.5	18.33	3.67	98.5
Initial HB rep 2	22.843	7.54	78.54	22.843	7.54	78.54
Initial HB rep 3	24.43	6.94	106.5	24.43	6.94	106.5
Hunts bay - - rep 1	2.654	0.193	21.55	3.87	0.097	9.58
Hunts bay - - rep 2	1.087	0.063	18.5	2.086	0.045	12.57
Hunts bay - - rep 3	2.067	0.532	29.47	2.013	0.34	21.55
Hunts bay - P rep 1	5.795	12.43	54.84	7.397	9.87	30.18
Hunts bay - P rep 2	8.223	10.54	49.95	6.253	7.976	32.45
Hunts bay - P rep 3	9.543	9.54	38.45	5.798	7.57	25.4
Hunts bay N - rep 1	27.757	0.345	45.2	34.47	0.134	15.4
Hunts bay N - rep 2	21.321	0.642	32.54	90.75	0.241	12.1
Hunts bay N - rep 3	23.877	0.535	56.8	43.92	0.237	10.68
Hunts bay N+P rep 1	35.691	3.423	31.5	18.455	2.54	20.2
Hunts bay N+P rep 2	20.59	4.764	29.57	22.42	1.575	16.45
Hunts bay N+P rep 3	31.768	3.421	24.11	20.55	2.74	18.13

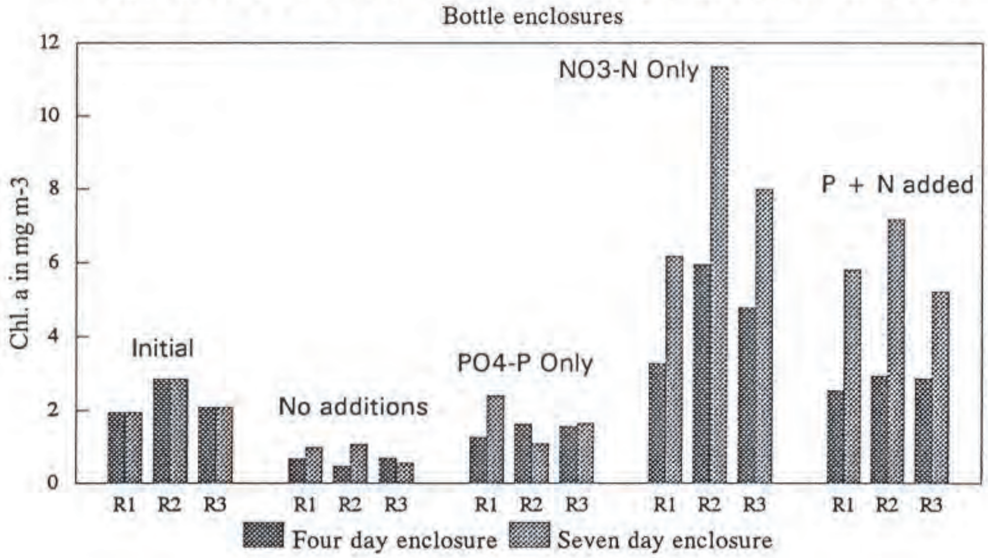
NUTRIENT ADDITION EXPERIMENT SAMPLES FROM 20 LITRE CARBOUY ENCLOSURES

SAMPLE	September 6 Chl a mg m-3	Res. PO4-P ug at l-1	Res. NO3-N ug at l-1	September 9 Chl a mg m-3	Res. PO4-P ug at l-1	Res. NO3-N ug at l-1
Initial Ocean rep 1	0.205	0.068	1.93	0.205	0.068	1.93
Initial Ocean rep 2	0.352	0.046	2.786	0.352	0.046	2.786
Ocean - - rep 1	0.097	0.012	1.45	0.131	0.008	0.103
Ocean - - rep 2	0.106	0.008	0.89	0.104	0.014	0.094
Ocean - P rep 1	2.787	23.64	0.475	0.526	21.34	0.089
Ocean - P rep 2	3.862	27.52	0.684	0.976	19.87	0.064
Ocean N - rep 1	5.414	0.019	251.7	0.258	0.005	56.54
Ocean N - rep 2	4.765	0.017	286.45	0.652	0.011	45.68
Ocean N+P rep 1	7.168	23.1	215.6	4.27	18.43	21.54
Ocean N+P rep 2	8.541	14.63	154.32	5.43	17.85	37.15
Initial Harb. rep 1	1.946	0.643	34.5	1.946	0.643	34.5
Initial Harb. rep 2	2.843	0.87	65.4	2.843	0.87	65.4
Harbour - - rep1	0.873	0.352	21.55	0.763	0.264	15.25
Harbour - - rep2	1.071	0.632	18.65	0.987	0.465	11.58
Harbour - P rep 1	2.542	12.58	16.57	1.765	5.78	12.14
Harbour - P rep 2	2.891	10.87	13.24	2.043	9.33	9.45
Harbour N - rep 1	5.975	0.414	154.24	6.54	0.314	95.22
Harbour N - rep 2	4.081	0.145	124.87	9.15	0.131	103.45
Harbour N+P rep 1	25.319	8.86	95.21	12.534	4.352	71.582
Harbour N+P rep 2	27.871	9.65	54.66	9.604	3.862	24.22
Initial HB rep 1	18.33	3.67	98.5	18.33	3.67	98.5
Initial HB rep 2	22.843	7.54	78.54	22.843	7.54	78.54
Hunts bay - - rep 1	2.911	0.236	34.9	2.985	0.078	8.45
Hunts bay - - rep 2	3.987	0.142	46.21	1.658	0.056	21.51
Hunts bay - P rep 1	23.793	14.35	25.69	3.654	6.85	14.2
Hunts bay - P rep 2	25.961	9.64	24.59	4.78	4.787	7.36
Hunts bay N - rep 1	82.363	0.246	24.21	13.42	0.112	8.54
Hunts bay N - rep 2	92.132	0.386	15.22	24.23	0.211	7.36
Hunts bay N+P rep 1	98.225	3.154	15.64	14.564	1.96	5.65
Hunts bay N+P rep 2	106.72	2.849	12.36	11.54	1.07	4.21

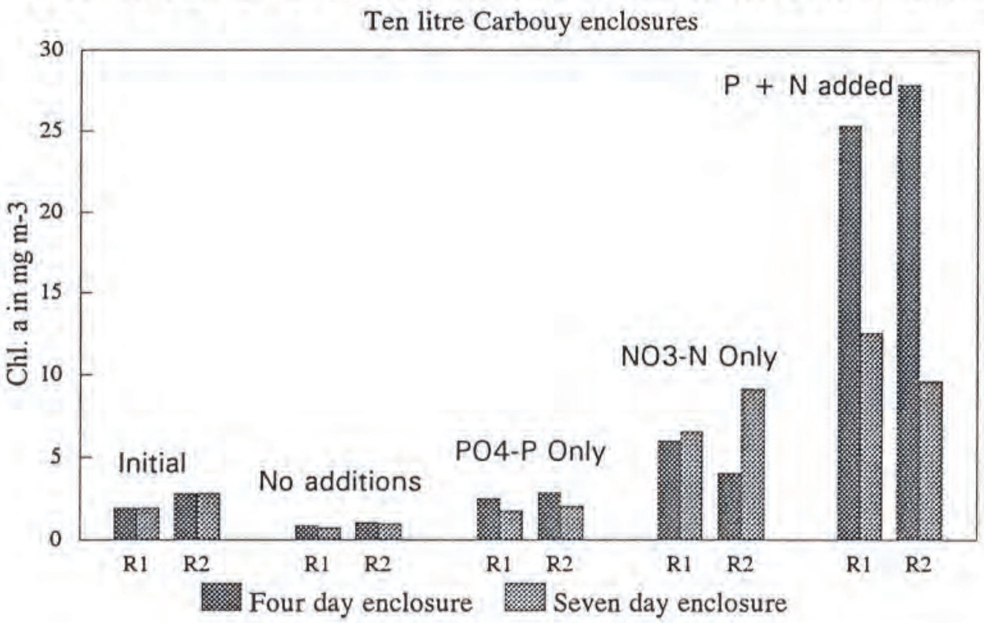

LIME CAY/SHELF PHYTOPLANKTON
Bottle enclosures
Chl. a in mg m-3
0
1
2
3
4
5
6
7
Initial
No additions
PO4-P Only
NO3-N Only
P + N added
R1 R2 R3
R1 R2 R3
R1 R2 R3
R1 R2 R3
R1 R2 R3
Four day enclosure
Seven day enclosure


LIME CAY/SHELF PHYTOPLANKTON
Ten litre Carbouy enclosures
Chl. a in mg m-3
0
1
2
3
4
5
6
7
8
9
Initial
No additions
PO4-P Only
NO3-N Only
P + N added
R1 R2
R1 R2
R1 R2
R1 R2
R1 R2
Four day enclosure
Seven day enclosure

HARBOUR PHYTOPLANKTON



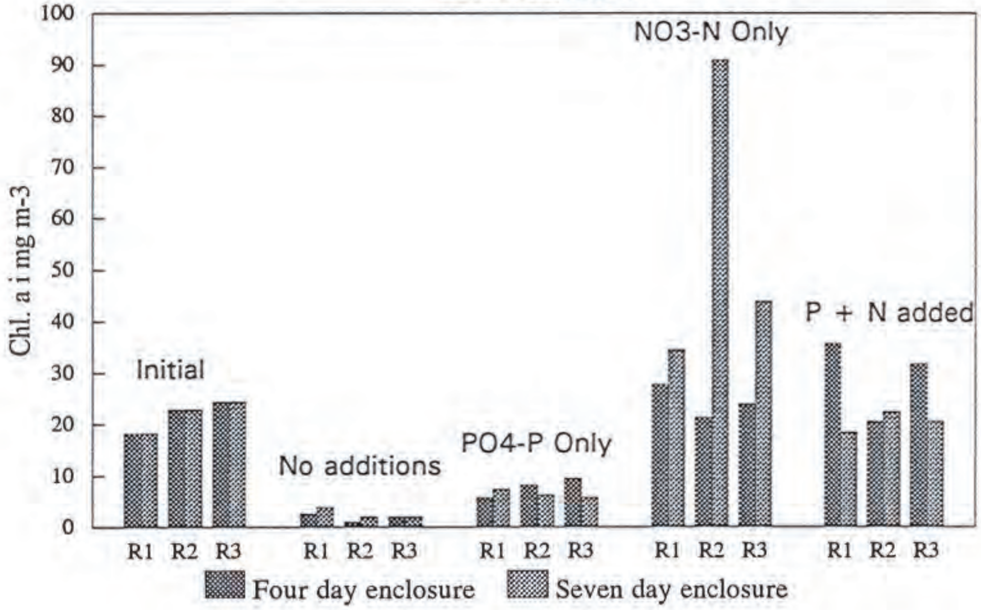
HARBOUR PHYTOPLANKTON



TAU

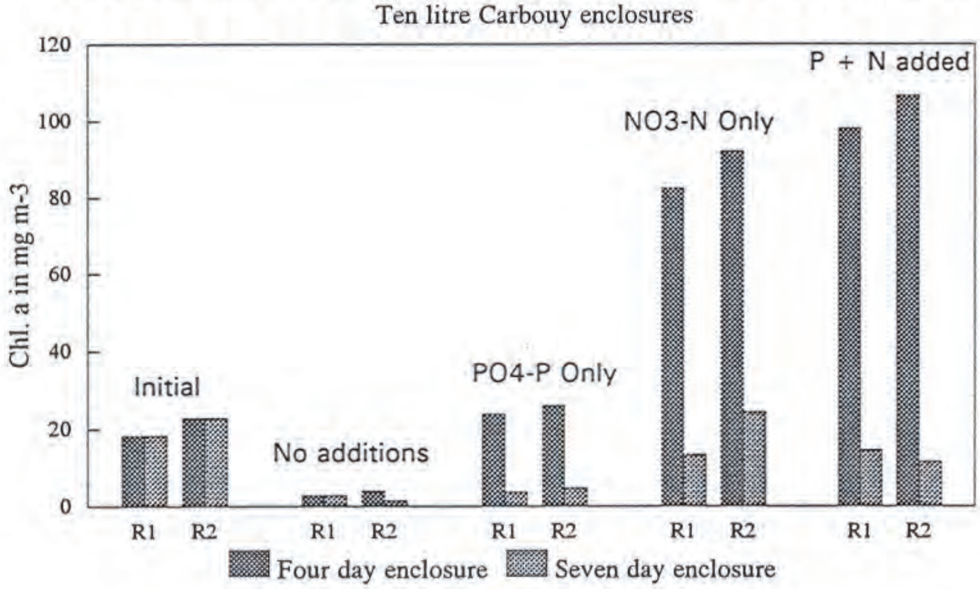
HUNTS BAY PHYTOPLANKTON

Bottle enclosures



HUNTS BAY PHYTOPLANKTO

Ten litre Carbouy enclosures



RW

UWI/SENTAR NUTRIENT ADDITION EXPERIMENT

July 14, 1993. By: Dale F. Webber

Aim: To determine the response of phytoplankton from three coastal areas to the introduction of nutrients.

Introduction

The proposed release of treated effluent into the marine environment can result in numerous direct and indirect responses. The planktonic community is usually the first to respond and provides perhaps the most obvious response to the inflow of even treated sewage since treatment of sewage often does not remove all the associated nutrients. This experiment attempted to identify the probable effect on the phytoplankton community should residual nutrients from treated sewage be released into the marine coastal environment.

Methods

Water was taken from three coastal areas. A site influenced by oceanic waters, between Drunkenmans Cay and Lime Cay, a Harbour site, Station 10 near Harbour Head and a Hunts Bay site. Temperature, salinity, light climate, dissolved oxygen, pH, nutrients and phytoplankton biomass as chlorophyll a were determined in situ or as soon as possible after collection.

The water collected at each station was agitated and divided into sixteen 1 l portions and four 10 l portions. These portions were organised to receive the following treatments in five replicates.

Ocean Station:

Four 1 l bottles and one 10 l bottle with no nutrient additions.
Four 1 l bottles and one 10 l bottle with phosphates only added.
Four 1 l bottles and one 10 l bottle with nitrates only added.
Four 1 l bottles and one 10 l bottle with both phosphates and nitrates added.

D.W.Z

Harbour Station (Station 10 from summer samples):

Four 1 l bottles and one 10 l bottle with no nutrient additions.

Four 1 l bottles and one 10 l bottle with phosphates only added.

Four 1 l bottles and one 10 l bottle with nitrates only added.

Four 1 l bottles and one 10 l bottle with both phosphates and nitrates added.

Hunts Bay Station:

Four 1 l bottles and one 10 l bottle with no nutrient additions.

Four 1 l bottles and one 10 l bottle with phosphates only added.

Four 1 l bottles and one 10 l bottle with nitrates only added.

Four 1 l bottles and one 10 l bottle with both phosphates and nitrates added.

The light climate was adjusted to simulate as close as possible the natural light climate. However, because the bottles were arranged in a randomised block design some bottles received more or less light than under normal condition. However, the randomised block design ensured that there was no bias towards a treatment or location. Temperature, salinity, and pH were checked daily for the two weeks of the experiment but dissolved oxygen was not measured since the samples had to be aerated. The phosphates added to the appropriate bottles (100 μg at l^{-1} PO_4-P) were determined based on 10 fold increase over the average phosphate concentration from the six gullies and rivers which discharge into Hunts Bay during the summer sampling programme of 1992 (10.55 μg at l^{-1} PO_4-P). The nitrates added to the appropriate bottles (600 μg at l^{-1} NO_3-N) were determined to allow a 1:6 ratio of P to N.

The experiment was started on Wed. June 23, 1993 and nutrients added on that day as soon as the waters acclimated. After observations for four days with no obvious increase in phytoplankton growth, nutrients were again added on 27/06/93 but in double concentration. At the end of the experiment, residual nutrients, phytoplankton biomass (measured as chlorophyll a) and zooplankton abundances were assessed.

DW. 3

Results

i) Initial results

		Ocean	Harbour	Hunts Bay
In citu :	Temperature in °C	29.0	29.0	29.3
	Salinity in ppt.	35.0	32.5	22.0
	D.O. in mg l^{-1}	7.4	6.8	6.4
	Surface Light in $\mu E\ s^{-1}$	615	446	861

PO_4-P in μg at l^{-1} see table 1
NO_3-N in μg at l^{-1} see table 1
Chlorophyll a in mg m-3 see table 1
pH = 8.45

ii) Laboratory conditions

Temperature in °C = 28 - 30
Salinity in ppt = Ocean 35.0, Harbour 32.5, Hunts Bay 22.0
Light in $\mu E\ s^{-1}$ = 140 to 300
pH = 8.64

iii) Final results
See Table 1 and Fig. 1, 2 and 3.

DX 4

Discussion

The addition of nutrients to coastal waters produced different effects on the phytoplankton communities of each location. The expected rapid increase in growth rate and biomass due to increased nutrient supply was not widely observed. Nutrients were added on a second occasion to stimulate growth but without success. Phytoplankton communities in some samples were prevented from making maximum use of available nutrients by large zooplankton populations. This was especially true of samples with high residual phosphates which were also those to which only phosphate was added.

Ocean influenced phytoplankton appeared to be phosphate limited (Fig. 1) with nitrate only additions resulting in no increase in biomass. This was evident despite a greater phosphate concentration in all initial samples collected over those values obtained during summer of 1992. However, the large amount of both added nutrients remaining in the water column at the end of the experiment (Table 1) indicates a second limiting factor, which could be the increased grazing pressure of the zooplankton. This limiting factor is especially important in an enclosure experiment. The lack of similarity in phytoplankton biomass between some replicates is a indication of the differential grazing in each bottle rather than differential growth rates.

Phytoplankton populations from Kingston Harbour were apparently also phosphate limited (Fig. 2) since PO_4-P only additions resulted in marked increases in biomass while NO_3-N only additions and no nutrient additions resulted in reductions in biomass. However, additions of both nutrients surprisingly did not produce increased growth.

Hunts Bay phytoplankton biomass showed a dramatic reduction over the two week incubation period despite PO_4-P and NO_3-N additions although these reductions were not as significant in samples treated with NO_3-N only (Fig. 3). However, phytoplankton

DWS

communities from the Harbour and in ocean affected water are exposed to varied light climates due to the water depth in these areas. The phytoplankton community of Hunts Bay is usually exposed to a variable but higher light climate due to the shallow water column. Variability is usually greater due to fluvial input and soft shallow sediment with strong wave action, but a shallow water column ensures that light is readily available providing turbulence does not exist.

Appendix 1 which will be appended will enable a fuller understanding of the special case in Hunts Bay. A second experiment has already begun using only Hunts Bay water and exposing this water to similar nutrient conditions as in the present experiment but with full sunlight (ie. conducted in situ) and with zooplankton removed. This should allow for a prediction of the maximum possible phytoplankton growth under increased nutrient conditions.

Summary and conclusions

- The release of treated sewage (with elevated phosphates only or in combination with nitrates) into the Port Royal Cays area, near Drunkenmans and Lime Cay would result in rapid increase in phytoplankton and reduction in water quality.
- The introduction of treated sewage (with elevated phosphates) would further increase the phytoplankton population there and lead to a further reduction in the water quality.
- The release of treated sewage into Hunts Bay **APPARENTLY** has no deleterious effect on the water quality, & may even result in a reduction in phytoplankton population but this will confirmed by appendix 1 to be submitted on July 21, 1993.
- Phosphate values obtained during the sampling programme of summer 1992 were much lower than in present samples. While this may be the result of consistent rainfall over the past 4 to 6 months it also suggests that phosphates may not be as limiting as was previously thought.

DX.6

TABLE 1

SAMPLE	Chl a mg m-3		Res. PO4-P ug at l-1		Res. NO3-N ug at l-1		ZOOPLANKTON nos. m-3
Initial Ocean rep 1	0.609		0.084		5.42		
Initial Ocean rep 2	0.439		0.032		3.76		
Initial Ocean rep 3	0.532	0.476	0.102	.071	2.79	4.10	
Initial Ocean rep 4	0.416		0.058		1.09		
Initial Ocean rep 5	0.386		0.079		7.43		
Ocean - - rep 1	0.036		0.006		3.26		2000
Ocean - - rep 2	0.043		0.012		2.14		
Ocean - - rep 3	0.029	.045	0.018	.014	2.11	2.26	1800
Ocean - - rep 4	0.084		0.025		0.56		
Ocean - - rep 5	0.035		0.007		3.23		1740
Ocean - P rep 1	0.896		263.4		1.03		680000
Ocean - P rep 2	0.911		210.5		0.82		
Ocean - P rep 3	0.709	1.057	185.9		1.32		723000
Ocean - P rep 4	1.169		257.9		0.73		
Ocean - P rep 5	1.601		120.5		1.34		540000
Ocean N - rep 1	0.029		0.043		654		58000
Ocean N - rep 2	0.035		0.021		867		
Ocean N - rep 3	0.029	.036	0.086		1247		36900
Ocean N - rep 4	0.063		0.023		863		
Ocean N - rep 5	0.023		0.014		967		49000
Ocean N+P rep 1	0.622		287.8		978		124000
Ocean N+P rep 2	1.673		210.5		1537		
Ocean N+P rep 3	0.809	1.212	257.4		876		103900
Ocean N+P rep 4	1.376		254.2		965		
Ocean N+P rep 5	1.582		232.3		1654		96000
Initial Harb. rep 1	3.089		1.27		97.6		
Initial Harb. rep 2	2.859		0.64		112.8		
Initial Harb. rep 3	2.597	2.698	0.83		54.6		
Initial Harb. rep 4	2.047		0.78		103.5		
Initial Harb. rep 5	2.898		1.03		126.7		
Harbour - - rep1	0.709		0.43		35.7		2000
Harbour - - rep2	0.732		0.042		53.6		
Harbour - - rep3	0.841	.845	0.087		46.7		2100
Harbour - - rep4	0.673		0.034		55.3		
Harbour - - rep5	1.271		0.067		76.3		1970
Harbour - P rep 1	4.271		257.5		33.6		240000
Harbour - P rep 2	3.241		243.6		34.7		
Harbour - P rep 3	5.384	3.839	136.4		23.7		253000
Harbour - P rep 4	3.019		246.7		46.8		
Harbour - P rep 5	3.279		108.8		75.3		231000
Harbour N - rep 1	1.045		0.074		636		14000
Harbour N - rep 2	0.995		0.056		876		
Harbour N - rep 3	1.343	1.008	0.087		675		15700
Harbour N - rep 4	0.722		0.057		1239		
Harbour N - rep 5	0.933		0.086		985		13000

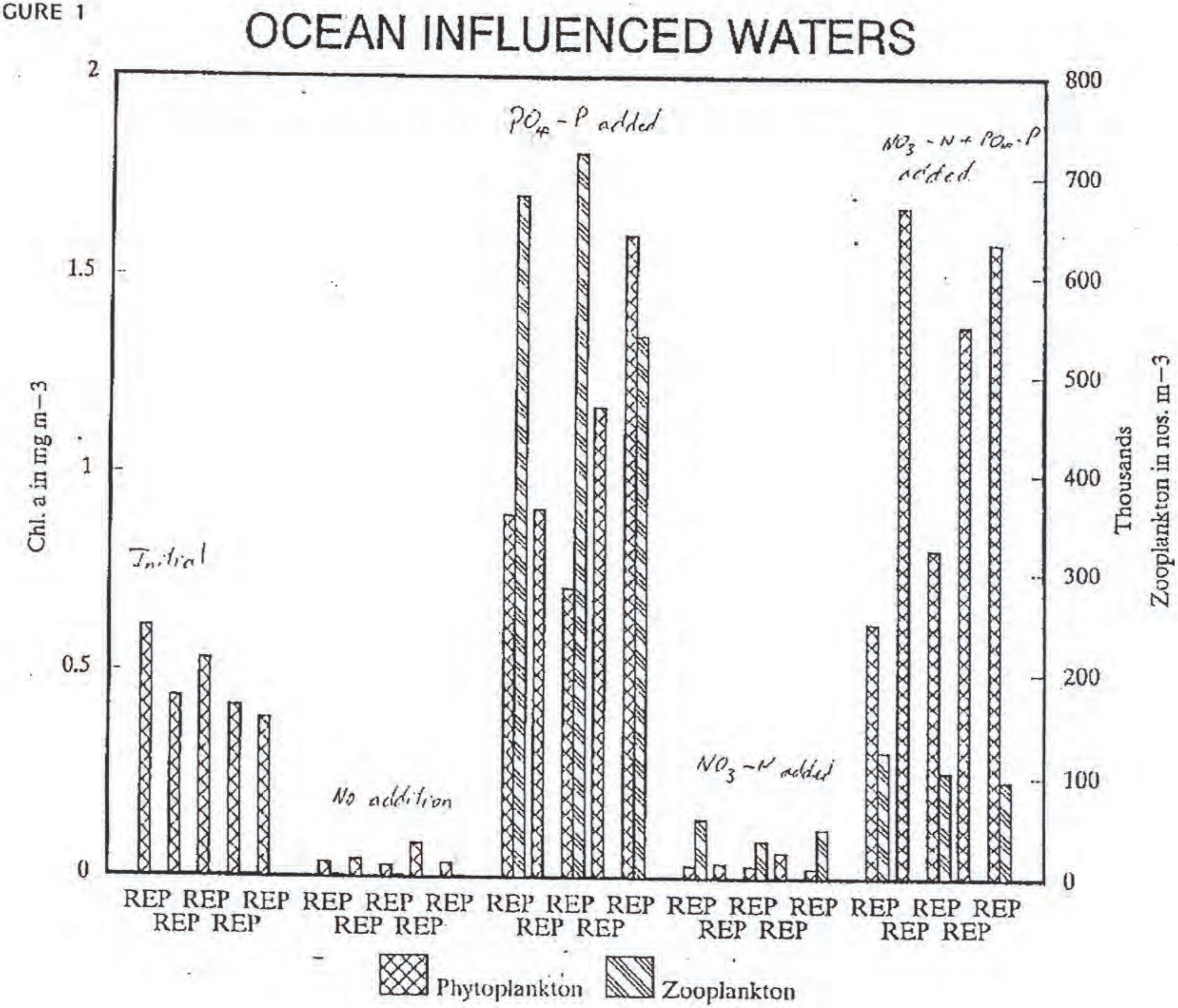
DW.7

TABLE 1 (cont)

Harbour N+P rep 1	1.221		246.3	980	28000
Harbour N+P rep 2	1.232		132.5	798	
Harbour N+P rep 3	1.274	1.268	133.4	986	26700
Harbour N+P rep 4	1.294		98.7	685	
Harbour N+P rep 5	1.319		102.3	1865	28700
Initial HB rep 1	95.765		4.31	169	
Initial HB rep 2	103.716		11.21	227	
Initial HB rep 3	87.754	92.6	3.54	275	
Initial HB rep 4	93.653		4.75	164	
Initial HB rep 5	81.865		2.69	196	
Hunts bay - - rep 1	16.294		1.42	142	34000
Hunts bay - - rep 2	19.394		0.96	35	
Hunts bay - - rep 3	21.219	17.5	0.098	42	32200
Hunts bay - - rep 4	18.684		1.234	64	
Hunts bay - - rep 5	11.821		1.326	65	30000
Hunts bay - P rep 1	13.727		241.4	41	187000
Hunts bay - P rep 2	12.583		123.6	53	
Hunts bay - P rep 3	12.964	13.9	98.3	57	210000
Hunts bay - P rep 4	15.872		103.2	86	
Hunts bay - P rep 5	14.271		134.7	42	196000
Hunts bay N - rep 1	22.878		1.92	654	44000
Hunts bay N - rep 2	19.447		2.45	765	
Hunts bay N - rep 3	24.022	23.5	1.65	977	42300
Hunts bay N - rep 4	26.329		0.998	1345	
Hunts bay N - rep 5	24.881		0.965	665	41000
Hunts bay N+P rep 1	10.295		234.4	464	30000
Hunts bay N+P rep 2	8.778		133.1	876	
Hunts bay N+P rep 3	11.058	11.3	166.4	978	23000
Hunts bay N+P rep 4	13.051		143.7	1254	
Hunts bay N+P rep 5	13.062		96.5	537	26000

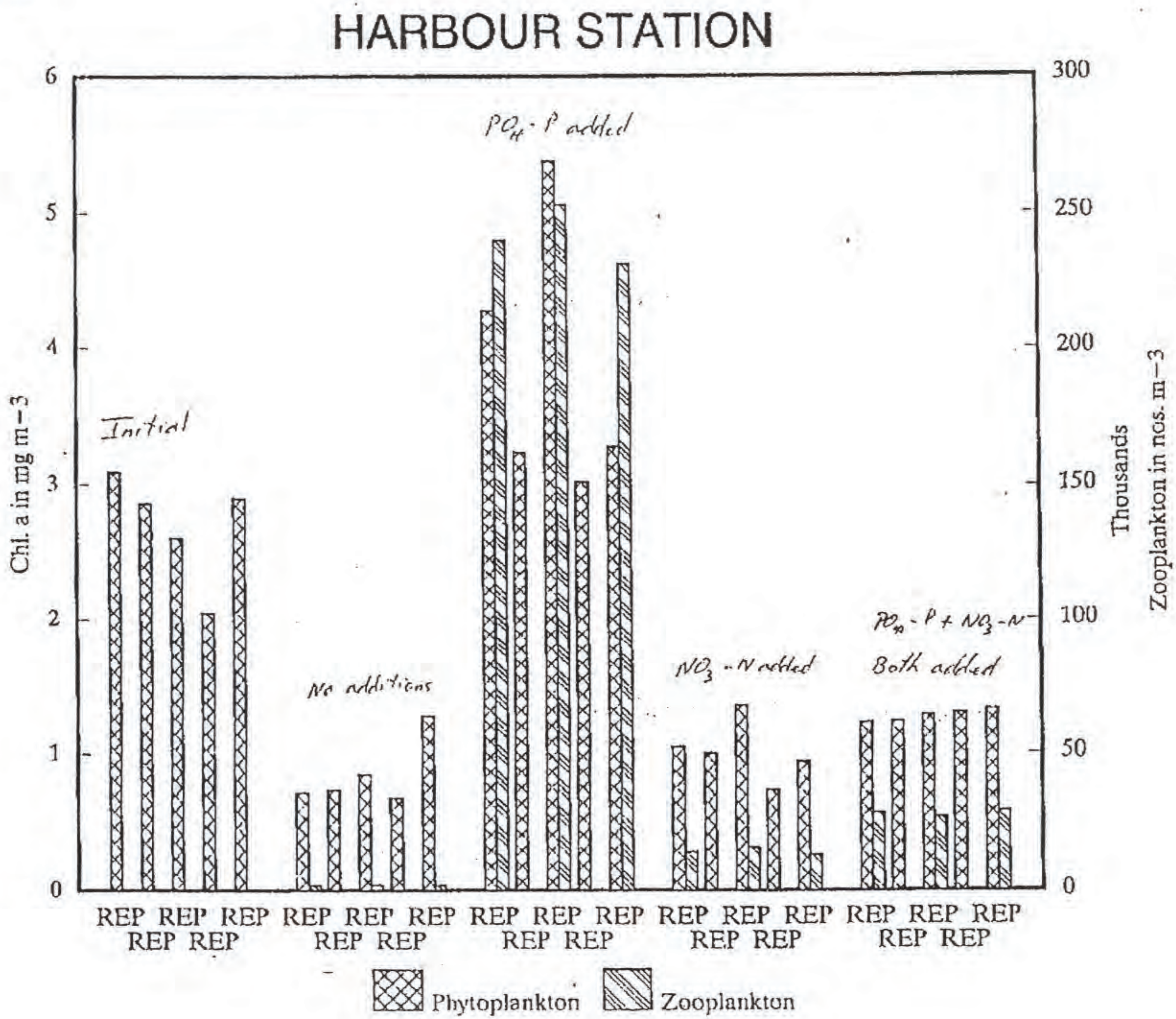
DX 8

FIGURE 1



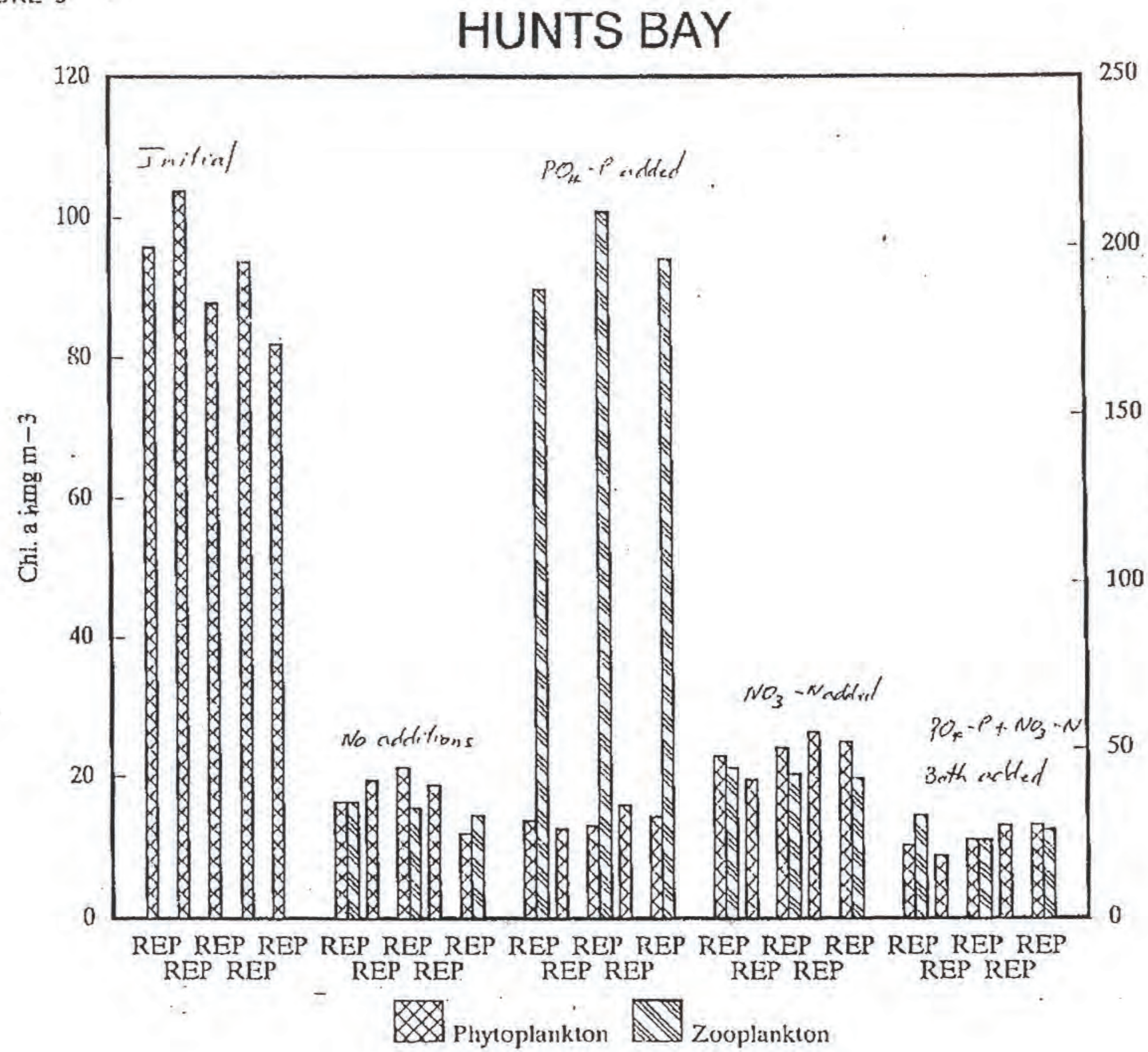
OCEAN INFLUENCED WATERS
Chl. a in mg m−3
0
0.5
1
1.5
2
Initial
No addition
PO4 - P added
NO3 - N added
NO3 - N + PO4 - P added
REP REP REP REP REP
REP REP REP REP REP
REP REP REP REP REP
REP REP REP REP REP
REP REP REP REP REP
Phytoplankton
Zooplankton
0
100
200
300
400
500
600
700
800
Thousands
Zooplankton in nos. m−3

FIGURE



HARBOUR STATION
Chl. a in mg m−3
Thousands
Zooplankton in nos. m−3
0
1
2
3
4
5
6
0
50
100
150
200
250
300
Initial
No additions
PO4-P added
NO3-N added
PO4-P + NO3-N
Both added
REP REP REP REP REP REP REP REP REP REP REP REP REP REP REP
REP REP REP REP REP REP REP REP REP REP
Phytoplankton
Zooplankton

FIGURE 3


HUNTS BAY
120
100
80
60
40
20
0
Chl. a μmg m−3
250
200
150
100
50
0
Thousands
Zooplankton in nos. m−3
Initial
No additions
PO_4-P added
NO_3-N added
PO_4-P + NO_3-N
Both added
REP REP REP REP REP REP REP REP REP REP REP REP REP REP REP
REP REP REP REP REP REP REP REP REP REP
Phytoplankton
Zooplankton

APPENDIX 1

Introduction

As an addition to the initial experiment presented on July 14, 1993, a second experiment was designed and conducted to determine the effect of nutrient additions to the waters of Hunts Bay. This was thought to be prudent, considering the large number of zooplankton found in the Hunts Bay waters, as well as the inability of the previous experiment to adequately simulate the range in light climate which Hunts Bay normally experiences.

Methods

Water was collected from Hunts Bay on Tuesday July 13, 1993. Salinity, dissolved oxygen, light climate and temperature were determined in situ. Phytoplankton biomass, zooplankton numbers, NO_3-N, and PO_4-P were determined in order to enable the best simulation of the natural environment.

The water sample collected was divided into 12 equal 10 l portions. A pair of replicate portions was identified for each treatment and the following nutrients added to each pair of replicates:

P+N rep 1 & 2 = 100 μg at l^{-1} PO_4-P and 600 μg at l^{-1} NO_3-N

P only rep 1 & 2 = 100 μg at l^{-1} PO_4-P

1/2 P only rep 1 & 2 = 50 μg at l^{-1} PO_4-P

N only rep 1 & 2 = 600 μg at l^{-1} NO_3-N

1/2 N only rep 1 & 2 = 300 μg at l^{-1} NO_3-N

Blank rep 1 & 2 = No nutrients added

All samples were exposed to the following range of conditions in a randomised block design within a water bath tank at U.W.I. :

Light = 664 to 1085 $\mu E\ s^{-1}$
Temperature = 27 to 33 °C

On Friday July 16, 1993, a 250 ml portion was removed from each treatment and analyzed for phytoplankton biomass and nutrients. Based on the reduction of nutrients observed in these samples over a three day period, the samples were treated with a second application of nutrients however this was applied in double strength to approximate the maximum possible effects of nutrient additions.

Results

See table 1 and graphs attached.

Discussion

1. Chlorophyll a

Phytoplankton biomass ($\approx$ 62 mg m^{-3}) on the day of collection (day 1) was marginally higher than the biomass values observed in Hunts Bay over the 1992 summer sampling programme ($\approx$ 14 - 55 mg m^{-3}). This value appears to be normal (regular) for Hunts Bay waters. High phytoplankton biomass was maintained (compared with values observed in the initial sample) only when Nitrate-N and Phosphate-P were added together. Additions of Nitrate-N and ½ Nitrate-N concentrations resulted in biomass values within the accepted range of Hunts Bay based on last summer's indications. Phosphate-P additions produced no more phytoplankton growth than did samples which received no nutrient additions. These observations suggest that **Nitrogen** may be limiting in Hunts Bay waters.

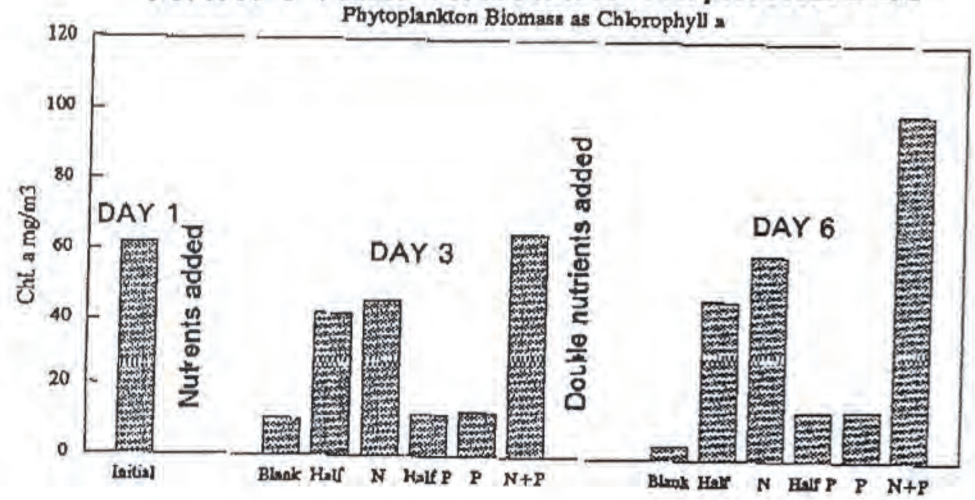
HUNTS BAY NUTRIENT EXPERIMENT

	Day 1
Chl r 1 mg/m3	55.29
Chl r 2 mg/m3	67.27
Light uE/s	1004
Salinity ppt	20
Temp. oC	29
D.O. mg/l	4.8
BOD mg/l	10.82
Zooplk. nos/m3	36000
PO4-P r 1 ugat/l	1.155
PO4-P r 2 ugat/l	2.61
NO3-N r 1 ugat/l	85.34
NO3-N r 2 ugat/l	72.65

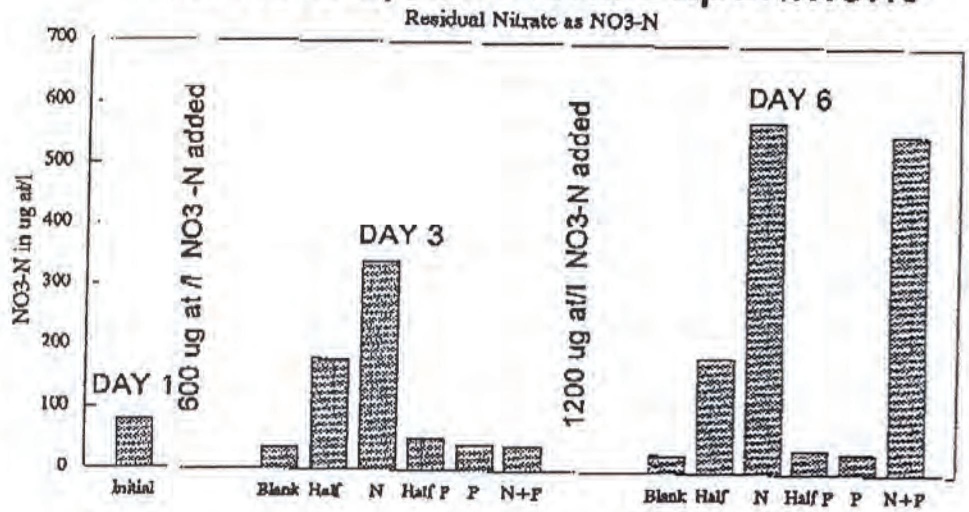
Day 3	Blank	Half N	N	Half P	P	N+P
Chl r 1 mg/m3	11.13	43.31	45.77	12.53	12.36	62.98
Chl r 2 mg/m3	9.43	41.34	46.27	10.57	12.64	67.43
Light uE/s	664 to 1085					
Salinity ppt	20					
Temp. oC	27 to 33					
PO4-P r 1 ugat/l	1.485	1.115	0.99	3.96	4.21	4.67
PO4-P r 2 ugat/l	1.324	1.034	0.92	3.78	5.32	5.98
NO3-N r 1 ugat/l	45.21	164.5	305	56.4	47.67	46.3
NO3-N r 2 ugat/l	25.46	196.21	378	46.2	35.21	31.87

Day 6	Blank	Half N	N	Half P	P	N+P
Chl r 1 mg/m3	3.52	48.75	63.38	14.36	15.32	92.98
Chl r 2 mg/m3	4.67	45.26	56.32	12.9	12.97	107.4
Light uE/s	664 to 1085					
Salinity ppt	20					
Temp. oC	27 to 33					
PO4-P r 1 ugat/l	0.758	0.832	0.873	7.64	24.08	10.54
PO4-P r 2 ugat/l	0.68	0.943	0.643	5.74	21.03	13.75
NO3-N r 1 ugat/l	36.8	198.5	510	42.1	36.8	521
NO3-N r 2 ugat/l	22.3	175.6	640	35.3	32.1	590

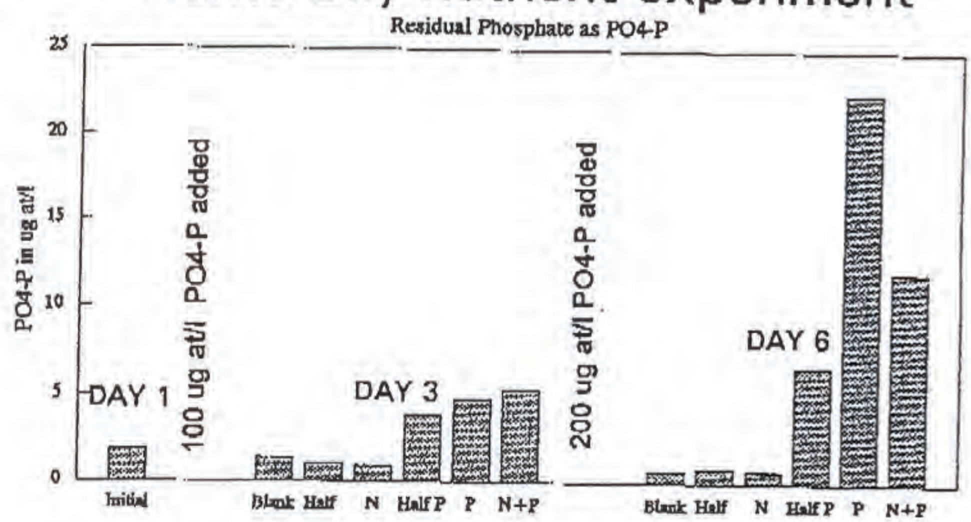
Hunts Bay nutrient experiment



Hunts Bay nutrient experiment



Hunts Bay nutrient experiment



The addition of double nutrient concentrations (to N+P treatment) on day 3 resulted in a dramatic increase in phytoplankton biomass (almost doubled that of 3 days before). Samples which received double Nitrate-N and Nitrate-N increased to values similar to those observed in Hunts Bay, while again Phosphate-P additions resulted in no phytoplankton biomass increase and in fact a decrease occurred as sedimentation of old and dead cells occurred. **Nitrate-N thus appears to be the limiting nutrient in Hunts Bay.**

The very high chlorophyll a value (107.4 mg m^{-3}) due to double Nitrate and Phosphate (N+P) concentration additions is not unprecedented. Samples collected from Gordon Cay during summer of 1992 had biomass values as high as 132 mg m^{-3} and samples taken from Hunts Bay on June 23, 1993 had biomass values of 103 mg m^{-3}. The maximum experimental value of 107.4 mg m^{-3} may thus be considered to be possible under present environmental conditions (although it may be rare) since Nitrate-N values entering Hunts Bay have been recorded to be as high as 2451 µg at l^{-1} (29/11/92) compared with 1200 µg at l^{-1} added during the experiment.

2. Nitrate-N

Less than 100 µg at l^{-1} residual NO_3-N was found in the initial sample. The addition of 600 µg at NO_3-N to the N-only and N+P samples maintained the phytoplankton biomass for three days. However, far less residual NO_3-N (<50 µg at l^{-1}) was found in the N+P samples, than in the N-only sample (>300 µg at l^{-1}). This, along with maximum chlorophyll a (phytoplankton biomass) in the N+P samples, indicate a greater use of available nitrogen when phosphorous is present. Background nitrates in Hunts Bay appears to be 30 µg at l^{-1} . This was the minimum residual nitrates found in samples which had no nutrient additions as well as samples to which nutrients were added. Generally, nitrate concentrations were reduced by at least 50%, while phytoplankton biomass increased by 75% over three days.

3. Phosphate-P

Less than 3 μg at l^{-1} residual PO_4-P was found in the initial sample. The addition of 100 μg at l^{-1} PO_4-P was not sufficient to maintain the phytoplankton biomass in the ½-P and P-only samples. But most of the phosphate was used up as only 5 μg at l^{-1} was left as residual. Unlike nitrates, no more phosphates were used by the phytoplankton in N+P samples than in P-only samples. The greater use of phosphates in N+P samples, over P-only samples, only occurred when nutrient additions were doubled after day 3. While the presence of phosphate plus nitrates is necessary to produce healthy phytoplankton growth, phosphate does not appear to be a limiting nutrient.

Summary

The phytoplankton of Hunts Bay appear to be nitrogen limited, in as far as maintaining the high phytoplankton biomass which has been observed to exist there. The reduction of the nitrogen released into Hunts bay should therefore reduce phytoplankton biomass even if phosphates are increased. This experiment must be considered in light of the fact that involves artificial enclosures, removal of zooplankton and controlled nutrient additions, and thus is an oversimplification of the natural open environment.

APPENDIX VII

UWA SENTAR Communications

a) Liguanea Groundwater Analyses

b) Significance of Absorption Pit Recharge on Liguanea Aquifer

VII. UWA/SENTAR COMMUNICATIONS

During Phase 1 of the project, based on existing data and relevant literature, it was assumed that soakaway ground disposal was causing elevated nitrate levels which flow into the Harbour, but that soil adsorption largely removed phosphorus from the groundwater.

During the latter stages of the Phase 1 study, efforts were initiated to confirm the assumption of low phosphorus loadings. This was indeed confirmed as documented in a series of communications between SENTAR and UWA, that follow.

In addition SENTAR requested UWA to expand on their assessment of the importance of maintaining absorption pit recharge of the Liguanea Aquifer.

Their brief assessment is also included in this Appendix, indicating that if sewage recharge volumes were reduced by more than 48% from current levels, with abstraction of water maintained at present levels, a saline intrusion would occur. If the City were fully sewered, they estimate this intrusion would move the saline front inland a further 200 meters. It would also probably imply that a marked reduction would occur in the opportunity for abstraction of non-saline water.

8091 922-9670/5 TELEX 2356 PETCORP JA

Underground Water Authority
P.O Box 91,
Kingston 7.

Dear Mr. Wright,

Below is the result of the one (1) water sample received April 28,1993.

TESTS	RESULTS
B.O.D	1.80 mg/1
NITRATES	56.32 mg/1
TOTAL PHOSPHORUS	0.158 mg/1

KINGSTON HARBOUR ENVIRONMENTAL PROJECT

Liguanea Aquifer Well Monitoring Programme

Location	Date	Analysis	pH	BOD5	N - NO3	Total Phosphorus
Well (FFR)	5-May-93	U.W.I. - Botany	6.6	13	123.2	0.3
Well (JRFN)	5-May-93	U.W.I. - Botany	6.6	13.2	127	0.3

UNDERGROUND WATER AUTHORITY
ESTABLISHED BY THE UNDERGROUND WATER CONTROL ACT, 1959

TEL: 92-70293
92-70189
92-77848
92-70077
FAX: (809)977-0179

HOPE GARDENS
P.O. BOX 91,
KINGSTON 7.

REF: GW II-1

Mau 19, 1993

SENTAR
13 West Kings House Rd
Kingston 10

Attention : Mr H. Beckford

Dear Sirs,

Subject : Water Samples Results

Below are the results of the two water samples collect on May 5, 1993.

Parameters	JWN	BP
B.O.D	2.65 mg/l	2.72 mg/l
Nitrate	51.59 mg/l	53.68 mg/l
Total Phosphorus	0.16 mg/l	0.17 mg/l

JWN - J. Wray and Nephew well; BP - Brothers of the Poor Well (See map attatched).

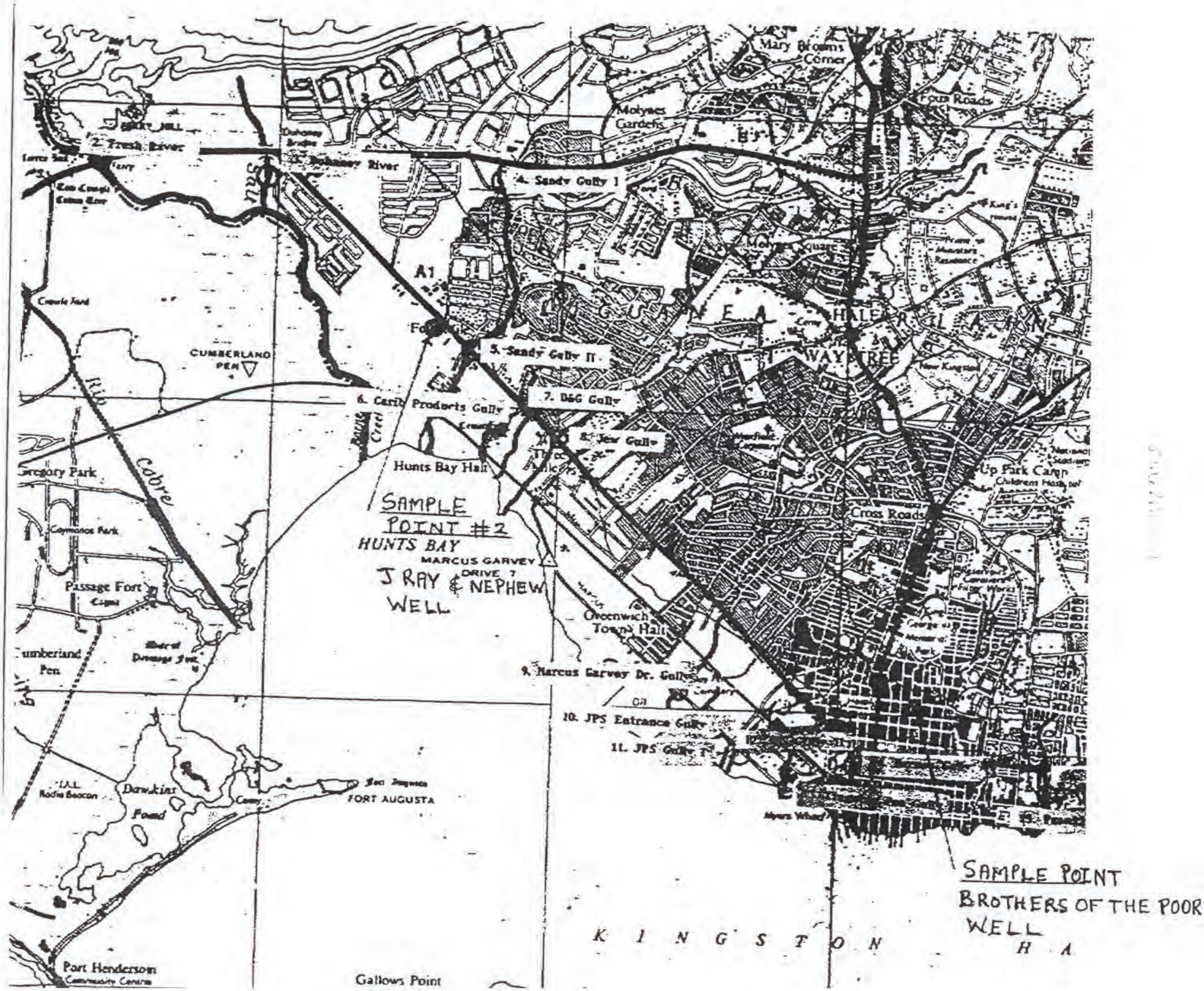
The results for the previous sample from the J. Wray and Nephew well have already been submitted to SENTAR.

Enclosed is the bill from PCJ for one thousand and thirty nine dollars and fifty cents ($1039.50) for the analysis of the 3 water samples.

Please make cheque payable to PCJ for this amount. The UWA will bill SENTAR at a later date.

Yours truly

Earl Wright


2. Fresh River
3. Duhaney River
4. Sandy Gully 1
5. Sandy Gully II
6. Carib Products Gully
7. D&G Gully
8. Jew Gully
9. Marcus Garvey Dr. Gully
10. JPS Entrance Gully
11. JPS Gully
A1
Mary Brooms Corner
Four Roads
Molynes Gardens
CUMBERLAND PEN
Rio Cobre
Gregory Park
Caymanas Park
Passage Fort
Cumberland Pen
Hunts Bay Halt
Greenwich Town Hall
Cross Roads
Up Park Camp
Children's Hospital
National Stadium
Dawkins Pond
FORT AUGUSTA
Port Henderson
Community Centre
Gallows Point
Myers Wharf
K I N G S T O N H A
SAMPLE POINT #2
HUNTS BAY
MARCUS GARVEY DRIVE 7
J RAY & NEPHEW WELL
SAMPLE POINT
BROTHERS OF THE POOR WELL

Memo to: Earl Wright, UWA
From: Ken Hamman, SENTAR
Date: June 15, 1993
Re: Kingston Harbour Environmental Project
Liguanea Aquifer Results

The enclosed tabulation summarizes data we have recently received , together with the earlier historical information on nitrate concentrations. Some information is needed to help to interpret the information and to understand the apparent discrepancies. Would you please advise us on the following points:

-we suspect historical data reporting nitrate concentration in mg/l is indeed NO3 but we think results provided by the PCJ lab may, in fact, be N-NO3, a conventional way to report nitrate today. Can you confirm whether this is NO3 or N - NO3.

-we believe the results reported under notes 2 and 3 represent split samples UWA provided to PCJ and to UWI, via Maurice Jones respectively, taken from the J Wray and Nephew and the Bros. of the Poor wells on May 5, 1993. However, the references provided by Maurice Jones for location do not allow us to be certain of this. Would you please check and advise whether these are indeed split samples with results from two laboratories.

-can you also advise of the location of the Apr 28 well sample (note 4 reference in the table). We will also contact Maurice Jones directly to pose questions to him regards uncertain units in UWI lab reporting.

Yours truly,

SENTAR CONSULTANTS LTD.

K.A. Hamman, P.Eng.
Project Manager

cc. Maurice Jones

TABULATION SHOWS LIGUANEA GROUNDWATER ANALYSES

	N-NO3	NO3	TOTAL P	BOD5	pH	LOCATION SERIAL
NOTE 1	-	98 - 118 mg/l	-	-	-	LOWER WELLS '71-74
NOTE 1	-	19 -26 mg/l	-	-	-	UPPER WELLS '74-76
NOTE 2	-	53.68 mg/l	0.17 mg/l	2.72 mg/l	-	BROS OF POOR WELL
NOTE 2	-	51.59 mg/l	0.16 mg/l	2.65 mg/l	-	J WRAY & NEPHEW WELL
NOTE 3	127*	-	0.3*	13.2*	6.6	JFRN WELL ?
NOTE 3	123.2*	-	0,3*	13.0*	6.6	FFR WELL ?
NOTE 4	-	56.32 mg/l	0.158 mg/l	1.80 mg/l	-	WELL LOCATION UNKNOW

NOTE 1 - UWA HISTORICAL DATA PER WD 1
NOTE 2 - UWA SAMPLES MAY 5, 1993 TESTED BY PCJ LAB
NOTE 3 - UWA SAMPLES MAY 5, 1993 REPORTED BY M. JONES - UWI BOTANY LAB
NOTE 4 - UWA SAMPLES APR 28, 1993 TESTED BY PCJ LAB - LOCATION UNKNOWN
* UNITS UNKNOWN, SAMPLES BELIEVED TO BE A SPLIT OF MAY 5 SAMPLES JFRN MAY BE J WRAY?

TABULATION SHOWS LIGUANEA GROUNDWATER ANALYSES

	N-NO3	NO3	TOTAL P	BOD5	pH	LOCATION SERIAL
NOTE 1	-	98 - 118 mg/l	-	-	-	LOWER WELLS '71-74
NOTE 1	-	19 -26 mg/l	-	-	-	UPPER WELLS '74-76
NOTE 2	-	53.68 mg/l	0.17 mg/l	2.72 mg/l	-	BROS OF POOR WELL
NOTE 2	-	51.59 mg/l	0.16 mg/l	2.65 mg/l	-	J WRAY & NEPHEW WELL
NOTE 3	127*	-	0.3*	13.2*	6.6	JFRN WELL
NOTE 3	123.2*	-	0,3*	13.0*	6.6	FFR WELL
NOTE 4	-	56.32 mg/l	0.158 mg/l	1.80 mg/l	-	WELL LOCATION UNKNOW

NOTE 1 - UWA HISTORICAL DATA PER WD 1

NOTE 2 - UWA SAMPLES MAY 5, 1993 TESTED BY PCJ LAB

NOTE 3 - UWA SAMPLES MAY 5, 1993 REPORTED BY M. JONES - UWI BOTANY LAB

NOTE 4 - UWA SAMPLES APR 28, 1993 TESTED BY PCJ LAB - LOCATION UNKNOWN

M E M O

To : Mr. K. A. Hamman (SENTAR)

From : Earl Wright (UWA)

Date : June 17, 1993

Subject : Kingston Harbour Environmental Project
Liguanea Aquifer Results

The Clarification to queries raised in memo of June 15, 1993 are as follows:

1. Historical data from the UWA are reported in mg/l as No. 3.
2. The analysis done by PCJ also reports nitrate in mg/l as No. 3
3. The results reported in Notes 2 and 3 represents split samples for the J. Wray and Nephew and Brothers of the Poor Wells (See TABULATION)
4. The results in Note 4 is for J Wray and Nephew Well. The sample was taken on April 28, 1993 and analysed by the PCJ Lab.

I do hope this information will clarify the apparent discrepancies.

E. Wright
UNDERGROUND WATER AUTHORITY

KINGSTON HARBOUR PROJECT

TABULATION SHOWS LIGUANEA GROUNDWATER ANALYSES

	N-NO3	NO3	TOTAL P	BOD5	PH	LOCATION SERIAL
NOTE 1	-	88 - 118 mg/l	-	-	-	LOWER WELLS '71-74
NOTE 1	-	19 -26 mg/l	-	-	-	UPPER WELLS '74-78
NOTE 2	-	53.68 mg/l	0.17 mg/l	2.72 mg/l	-	BROS OF POOR WELL
NOTE 2	-	51.59 mg/l	0.16 mg/l	2.65 mg/l	-	J WRAY & NEPHEW WELL
NOTE 3	127*	-	0.3*	13.2*	6.8	JFRN WELL ? J. WRAY & NEPHEW WEL
NOTE 3	123.2*	-	0.3*	13.0*	6.6	FFR WELL ? BROS. OF THE POOR WEL
NOTE 4	-	56.32 mg/l	0.156 mg/l	1.60 mg/l	-	WELL LOCATION UNKNOWN → J. WRAY & NEPHEW

NOTE 1 - UWA HISTORICAL DATA PER WD 1

NOTE 2 - UWA SAMPLES MAY 5, 1993 TESTED BY PCJ LAB

NOTE 3 - UWA SAMPLES MAY 5, 1993 REPORTED BY M. JONES - UWI BOTANY LAB

NOTE 4 - UWA SAMPLES APR 28, 1993 TESTED BY PCJ LAB - LOCATION UNKNOWN

* UNITS UNKNOWN, SAMPLES BELIEVED TO BE A SPLIT OF MAY 5 SAMPLES JFRN MAY BE J WRAY?

UNDERGROUND WATER AUTHORITY

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HOPE GARDENS
P.O. BOX 91,
KINGSTON 7.

REF: CW 11-1

June 28, 1993

FEED FAX THIS END

FAX
To: Ken Hamman
Dept.: STANLEY
Fax No.: 403 269 1526
No. of Pages: 2
From: H. Beckford
Date: July 1/93
Company: SENTAR (Ja)
Fax No.: 809-968 5820
Comments: Water sample from fast flowing aquifer
Post-it™ fax pad 7903

SENTAR Consultants Ltd
13 West Kings House Road
Kingston 10

Attention : Mr H. Beckford

Dear Sirs

Subject : Water Sample Analysis

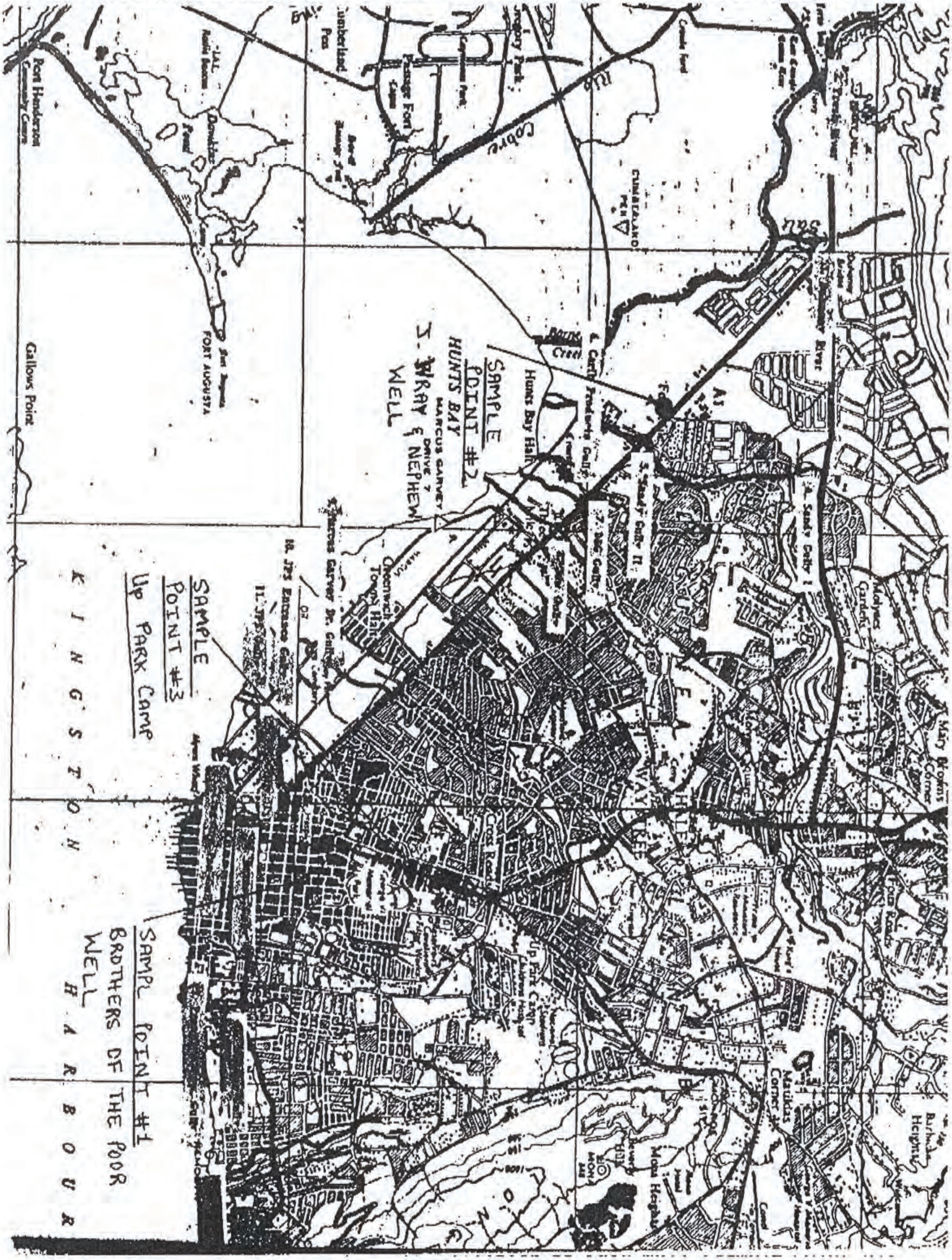
Below are the results of the water sample collected from the Up-Park Camp well.

Parameters	Sample
B.O.D	1.56 mg/l
Nitrate	39.6 mg/l
Total Phosphorus	0.16 mg/l

The attached map shows the location of this well (Sample Point 3).

Yours truly

Earl Wright


SAMPLE POINT #2
HUNTS BAY
J. WRAY & NEPHEW WELL
SAMPLE POINT #3
UP PARK CAMP
SAMPL POINT #1
BROTHERS OF THE POOR WELL
KINGSTON HARBOUR
Gallows Point
FORT AUGUSTA
Hunts Bay Halt
Duhaney River
Molynes Gardens
Mary Browns Corner
Constant Spring Gully
Cross Roads
Up Park Camp
Matilda's Corner
Mona Heights
Barbican Heights
Marcus Garvey Drive
Greenwich Town

IMPACT OF ABSORPTION PIT RECHARGE TO THE LIGUANEA AQUIFER

In the UWA's report on the Liguanea aquifer it was stated that waste water was a major contributor to groundwater storage in the alluvium aquifer.

The volume of recharge contributed by waste water was based on a NWC supply of 74.6 MCM/yr. Karle and Associates 1989, has given a NWC supply of 79.2 MCM/yr.

There is disposal of at least 10% of this water in areas other than those underlain by the alluvium aquifer and therefore does not contribute directly to recharging of the aquifer.

A significant portion of the waste water generated IS treated and does not go to directly recharging the aquifer. The volume of treated sewage is estimated at between 25 and 30 MCM/yr. (Average 27.5 MCM/yr).

Based on a 1991 census of 562,073 for the KMA and 100 M^3/yr. of waste water (NWC) - then

Total Waste Water Generated	-		56.2 MCM
Waste Water Treated	-	27.5 MCM	MCM
Disposed of in other areas	-	5.5 "	33.0 MCM
Available for Recharge	-		23.2 MCM

If this 23.2 MCM/yr. is removed from recharging the alluvium aquifer then by the formula $h = \frac{Q}{As}$ where

h - water level fall
Q = volume of sewage recharge
A = area of aquifer
s - storage coefficient (0.10 to 0.14)

the fall in water level would be 2.5 m (s = 0.10) to 1.8 m (s = 0.14).

Based on water balance calculations for the Liguanea alluvium aquifer (Appendix 1 Page 1-2, Section 1.4.1 SENTAR. Phase 1 Working Document - August 1992) the volume of outflow needed to keep the saline front stationary was 11.9 MCM and additional water available for abstraction was 12 MCM/yr.

Removing this 23.2 MCM/yr. of sewage recharge would negate the additional abstraction of 12 MCM /yr. and reduce outflow by 11.2 MCM/yr. With an outflow of 0.7 MCM./yr. and using Q = ThW/2L, the saline front would move a further 200 meters inland.

An acceptable level of reduction of sewage recharge would be 48% which would keep outflow the same and maintain the saline front, but negating the additional water available for abstraction from the alluvium. Abstraction would therefore have to remain at the present 9.0 MCM/yr.