Environment Canada
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PERFORMANCE EVALUATION OF THE CITY OF WHITEHORSE SEWAGE TREATMENT LAGOONS

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by
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ABSTRACT

An evaluation of the Whitehorse sewage lagoon treatment system was conducted by personnel of the Environmental Protection Service (Yukon Branch) from May 26 to June 8th, 1986. Sampling for bacteriological, chemical and toxicity analyses as well as a tracer dye retention study were conducted.

Chemical and bacteriological analyses results indicate a marked improvement in the water quality of the Whitehorse Sewage lagoon since the sludge removal project in September 1985. The percentage of reduction for BOD_5, COD and NFR were 48, 31, and 87% respectively. The total and fecal coliform bacteria populations have been reduced by two orders of magnitude. In addition, the 96 hr. LC_{50} bioassay results indicated the samples were non-toxic.

Results from the Rhodamine WT tracer dye reveal that the retention times are approximately 60% of the theoretical retention time. There is evidence of short circuiting in all three of the cells studied. It is expected that the short circuiting is facilitated by the shape of the cells and the juxtaposition of the inlets to the outlets within each cell.

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1 INTRODUCTION

The study area is situated in the south central portion of the Yukon Territory (Lat. 60°43'N, Long. 135°03'W). The climate of the area can be described as continental subarctic having a mean annual temperature of -1.2°C.

The City of Whitehorse has a population of 17,250 (1986). The municipality has 3 wastewater treatment systems, all of these in the form of settling basins. The facility under study is known as the Whitehorse Sewage Lagoons. The areas of Whitehorse which are serviced by the Whitehorse Sewage lagoons are Downtown, Riverdale, Takhini, Hillcrest, and the Marwell Industrial area (Figure 1). The wastewater is predominantly domestic in origin from a contributing population of approximately 14,800 (T. Dillistone, pers. comm.). Two features unique to the Whitehorse wastewater are the extensive use of bleeders during periods of ground frost and the infiltration of ground water into the sewage collection system (T. Dillistone, pers. comm.). These conditions generate a relatively cold and dilute wastewater.

The Whitehorse sewage lagoons are comprised of four facultative cells which have been in operation since March, 1979. The configuration of the treatment facility is shown in Figure 2. Each cell is 6.1 m. deep and has an aqueous volume of 57,100 m^3. The cells were designed with suitable depth to allow the addition of aeration at a later date (N. Nuttal, pers. comm.).

The sewage is collected at the Marwell Lift Station (Figure 1) where it is screened through a rotating bar screen and then pumped across the river for 2.5 km. to the lagoons. The lagoon system was presently operating in the parallel mode, but subsequent to October 1985, the valving and wiers were adjusted to allow a series operation in order to increase the residence time. During the fall of 1985, the municipality removed the sludge in cell 1 and 2 using a floating sludge pumping system (Mud Cat) combined with land disposal.

The Whitehorse Area

Figure 1

Scale 1:25,000

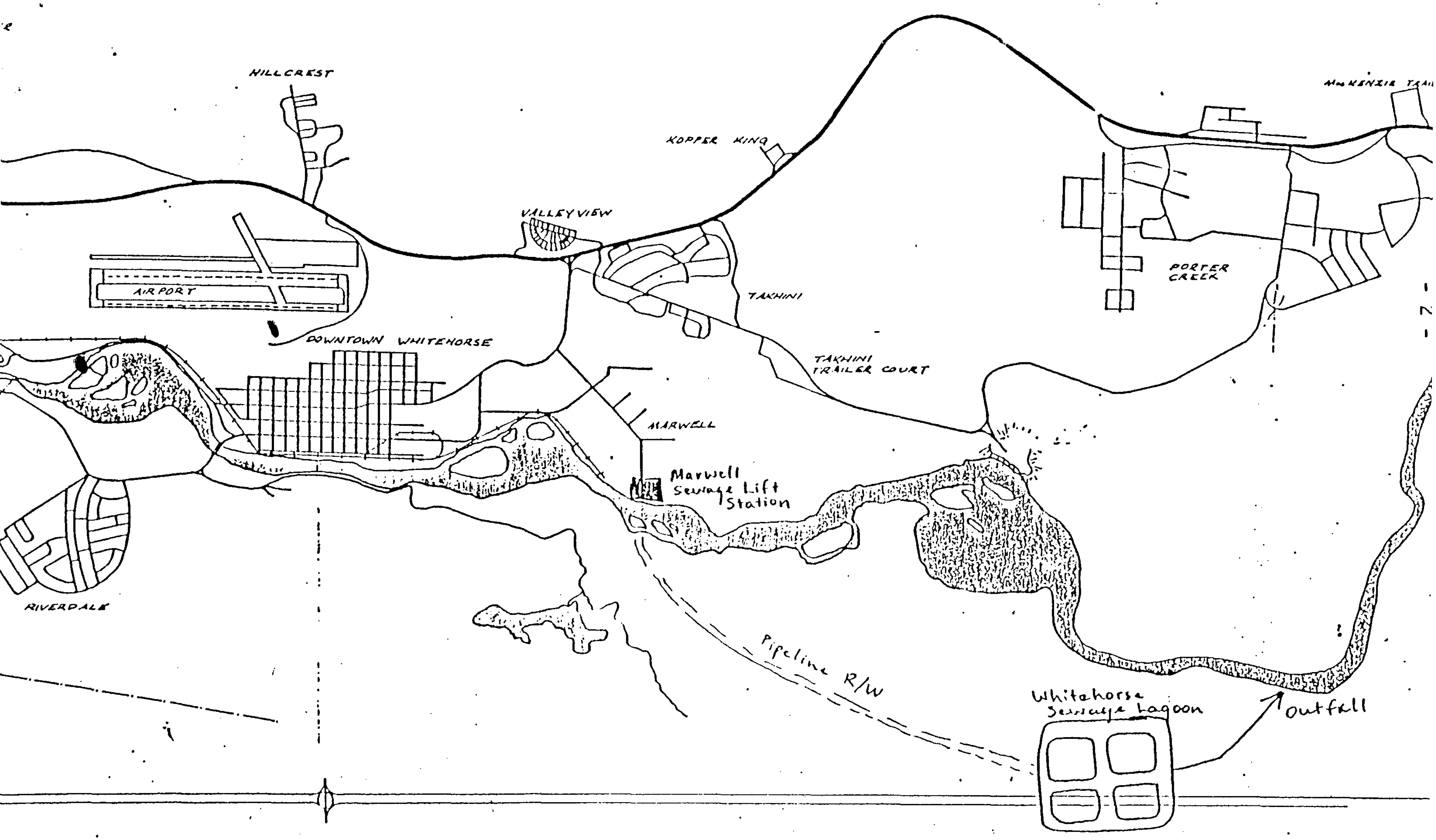
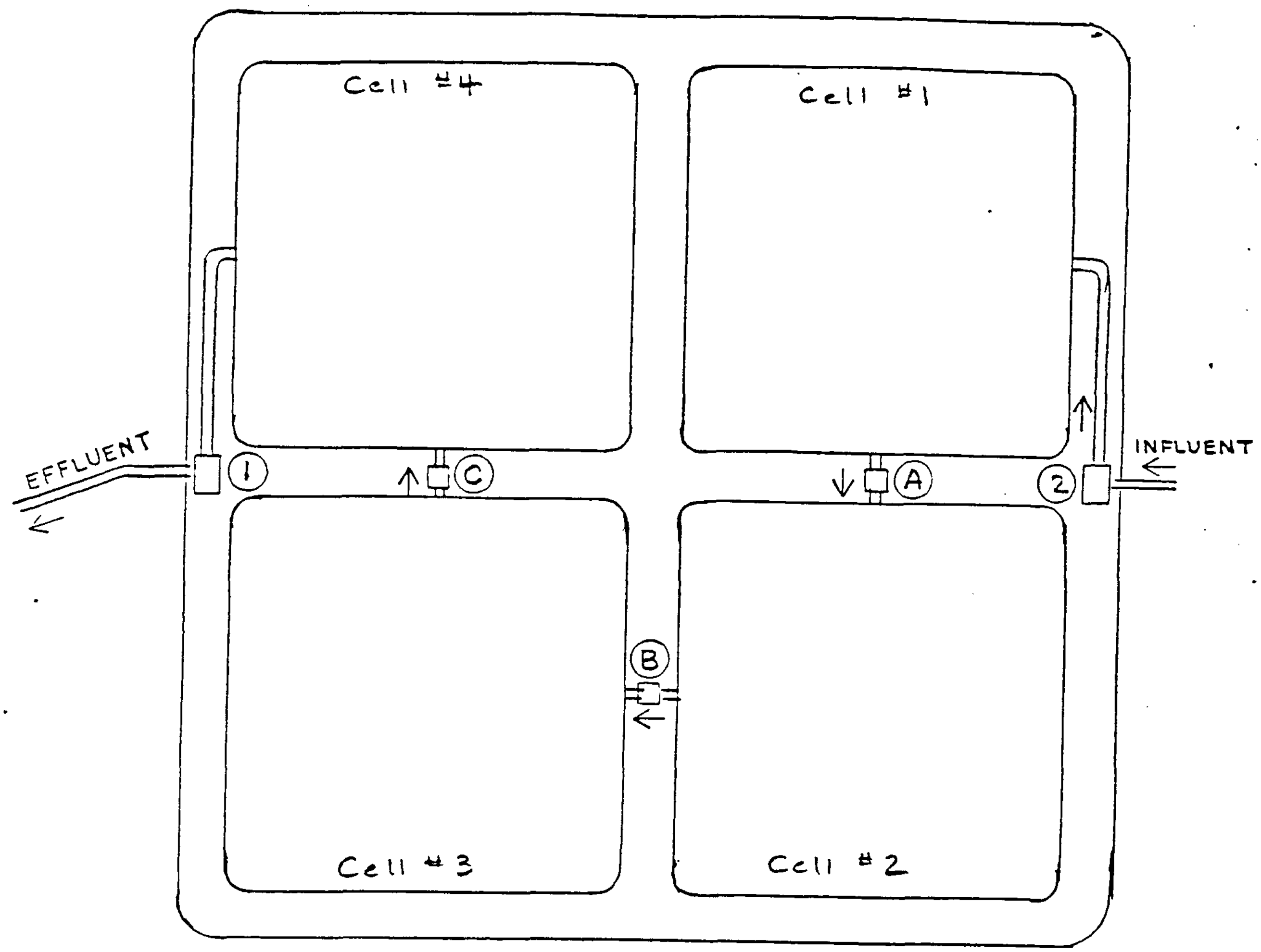


FIGURE 2 CITY OF WHITEHORSE SEWAGE LAGOONS



SAMPLING STATIONS ARE INDICATED:

Water Quality: 1(Effluent), 2(Influent)

Retention Study: A (Cell #1 decant)
B (Cell #2 decant)
C (Cell #3 decant)

Typical Cell Dimensions: 124 x 124 x 6.1 m (lxwxd)

Embankment Slope: 4:1

On April 3, 1986 the City of Whitehrose obtained a water licence pursuant to the Northern Inland Waters Act allowing them to discharge treated effluent into the Yukon River. In granting this licence, the Yukon Territory Water Board gave conditional approval subject to certain conditions being met. One important requirement is that the licencee must achieve a non-toxic (96 hr. LC_{50} Bioassay) effluent by January 1, 1989. Also the licencee must complete studies by January 1, 1987, on the feasibility of i) wastewater flow reduction, ii) heating the sewage iii) pretreating the sewage, and iv) increasing the retention times in the sewage lagoons.

Information collected by Environmental Protection in recent years, indicated that the effluent was toxic to fish (unpub. data in EPS regional files). In addition, studies completed by R. Allan in July 1985 indicated a short circuiting problem in the lagoons, and sludge accumulations of 7200 and 5700 m^3 in cells 1 and 2 respectively. Based on these sludge accumulations, the sludge production rate was calculated to be 0.65 m^3/day/1000 persons which is high compared to other communities (Bethell, 1981).
Subsequent to the 1985 summer's work by Environmental Protection and prior to the granting of the Water Licence, the City of Whitehorse attempted to improve the residence time in the lagoons by i) removing sludge and ii) altering flow patterns within the cells from parallel to series.

This report is an evaluation of the Whitehorse wastewater treatment system to 1) determine the cell retention times and flow characteristics, and 2) evaluate the effectiveness of the modifications to the sewage lagoon system.

This report presents the effluent quality data, sludge volumes and cell retention times.

2. SAMPLING AND ANALYTICAL METHODS

2.1 Water Quality

Samples for water chemistry analysis for the Whitehorse Sewage Lagoon facility were collected from two stations. The influent was collected from the Marwell Lift Station (Station 2) and the effluent, was collected from the final discharge point of the lagoon system (Station 1). Both stations utilized a 24 hour Isco composite sampler. Samples were collected and preserved in accordance with the procedures summarized in Appendix 1. Samples were shipped for analysis to the Environmental Protection laboratory in West Vancouver, B.C. Water samples for bioassay analysis were collected from the effluent discharge in 3 five gallon plastic jerry cans. The bioassay samples were sent to the Environmental Protection aquatic toxicity laboratory in North Vancouver in order to conduct a 96 hour LC_50 acute lethality bioassay.

Influent and effluent parameters measured in the field were pH, dissolved oxygen (DO), conductivity, and temperature. The pH was measured using a Fisher 1200 pH meter. The DO was measured using a YSI Model 57 dissolved oxygen meter and both temperature and conductivity measurements were taken using the YSI Model 33 conductivity meter.

Depth, temperature, conductivity and DO profiles were determined in situ for each of the 4 lagoon cells. Nine sampling points per cell were identified by grid stakes located on the berm perimeters. The sampling was performed from an inflatable boat. The conductivity, temperature and DO measurements were taken at depths 1, 3, and 5 m below the surface at 4 or 5 points per cell. Depth measurements were taken at all 9 sampling points using a hand-held Morrow fish ray DR-100 depth finder.

Parameters determined in the Whitehorse laboratory were biochemical oxygen demand (BOD_5) and fecal and total coliform counts (membrane filtration) (Department of Environment, 1979). The BOD_5 samples were collected from both the influent and effluent stations in plastic containers. Distilled water was used to make dilution concentrations of 5%, 7.5%, 10% and 12.5% for the influent and 7.5%, 10%, 12.5% and 15% for effluent. Three samples for each dilution were prepared along with three controls per station. The DO levels were measured initially and after five days of incubation at 20 C using the YSI Model 57 dissolved oxygen meter.

Coliform samples were collected at the influent and effluent stations in 6 oz. sterile jars. The influent samples were diluted to 10^{-30}, 10^{-4}, 10^{-5} and the effluent dilution factors were 10^{-4}, 10^{-5}, and 10^{-6}. Total and fecal coliforms were analyzed using the membrane filtration technique. Total coliforms were analyzed on Difo M-ENDO agar after an incubation period of 24 hours at 35 +/- 0.5°C. Fecal coliform densities were analyzed on Difo M-FC Agar medium after incubation at 44.5 +/- 0.2°C for 24 hours. Both analyses were started within 6 hours of the sample collection. Only plates containing between 10 and 100 colonies were considered to accurately represent the sample.

Tracer Dye Tests

The lagoon influent flowrate is controlled by a pump at the Marwell Lift Station. During each pump cycle, the pump operates for about 15 minutes and rests for about 20 minutes. However, depending on sewage loading, these intervals vary throughout the day. Flow measurements were taken on May 30 using a Marsh-McBurney current meter. Measurements were taken from the centre of the decant pipe in the manhole at 2 minute intervals. Station A and Station B data was collected over 2 and 1 1/2 pump cycles respectively. Total discharge characteristics were calculated from the rate of flow data collected and compared with the daily pumpage volumes recorded by the City at the Marwell lift station. The water level was also recorded at Station A during each velocity reading to determine if any fluctuations in water level occur during the pump cycle.

The characteristic retention times of the seage lagoon cells were determined using Rhodamine WT tracer dye. Rhodamine WT was the most suitable tracer dye for this study because it has a low photochemical decay rate and it is not appreciably absorbed by the soil particles. Samples were analyzed using a Model 10 Fluorometer calibrated with 100, 10 and 1 PPB standards. Wastewater collected at Station A prior to dye injection was used as the dilution water in the preparation of standards for Station A and B. New standards were prepared for the analysis of Station C data since dye from Stations A and B had penetrated into Cell 3. Dilution water was collected from Station C prior to injection.

A 500 ML slug of 100% Rhodamine WT dye was injected into each of the influent manholes of cells 1, 2, and 3 on May 26 (cells 1 and 2) and June 2nd (cell 3). The sampling stations, A, B, and C, were located at the decant manholes of cells 1, 2 and 3 respectively (Fig. 2). Programmable Isco wastewater samplers were set up at each station to collect samples on a predetermined sampling intervals. These intervals varied from 10 minutes to 4.5 hours depending on the station. Table 1 shows a summary of the dye injection and sampling intervals used at each station. No tracer data was collected for lagoon cell #4.

TABLE 1 DYE INJECTION AND SAMPLING DATA

Station	Cell	Injection PT	Injection Time	Sample Interval
A	1	Influent manhole from Marwell lift	0920 hr. 86.5.26	0930 86.05.25 30 min 0900 86.05.28
				1000 86.05.28 60 min 0900 86.05.30
				1000 86.05.30 4 hrs. 0900 86.06.02
B	2	STN A	1133 hrs. 86.5.26	1200 86.05.26 30 min 0900 86.05.28
				1000 86.05.28 60 min 0900 86.05.30
				1000 86.05.30 4.5 hr 0900 86.06.02
C	3	STN B	1005 hrs. 86.06.03	1010 86.06.03 10 min 1540 86.06.03
				1600 86.06.03 50 min 0900 86.06.04
				1000 86.06.04 60 min 0900 86.06.05

3. RESULTS

3.1 Water Quality

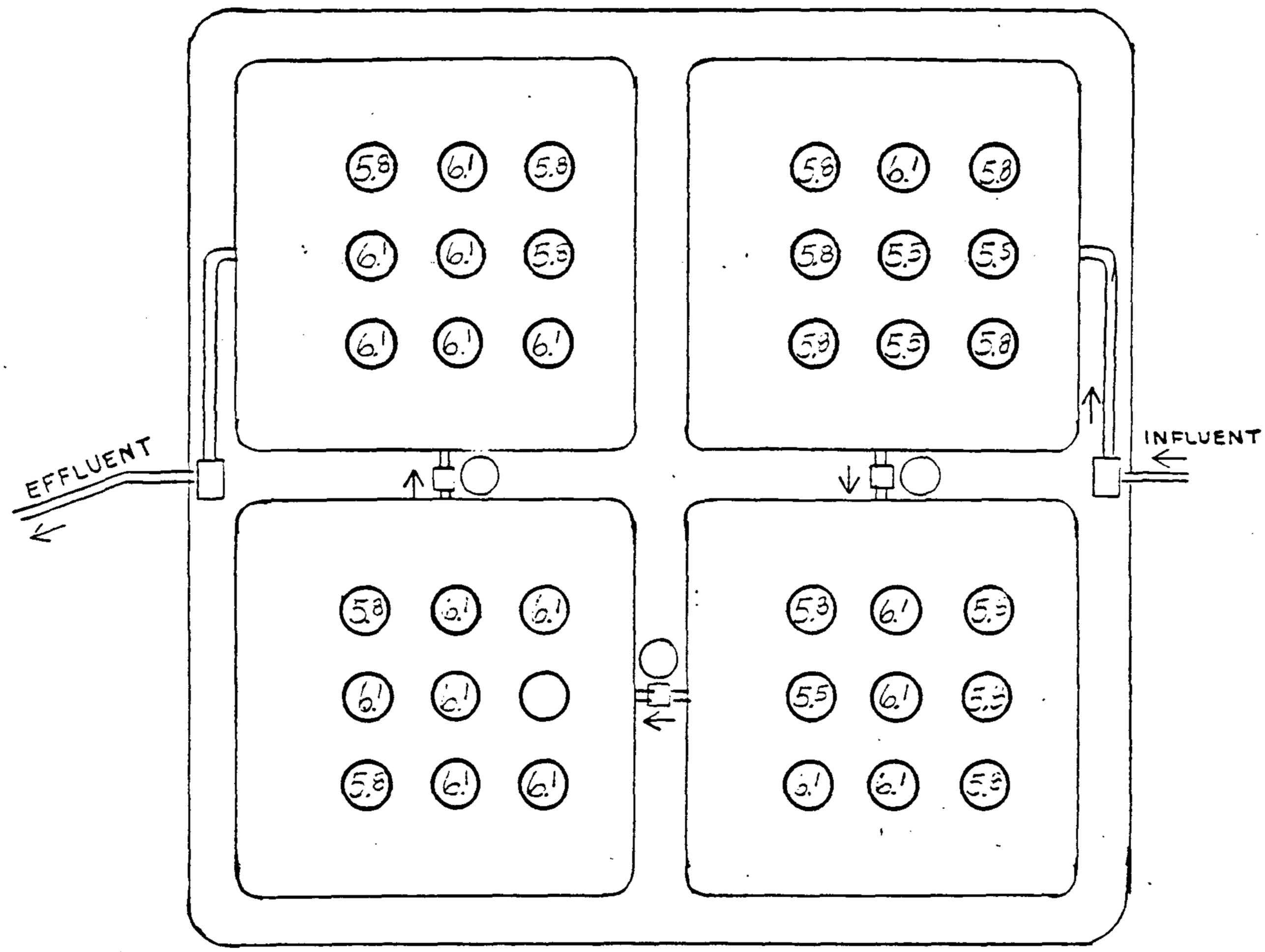
Results of water depth determinations are shown in Figure 3. Although sludge has already begun accumulating in cell 1, the data indicates that the sludge removal project conducted in September 1985 was successful. In a survey conducted prior to sludge removal May 30, 1985; average water depths were as follows; Cell 1 - 4.7 m, Cell 2 - 5.0 m, Cell 3 and 4 - 5.8 m.

Dissolved oxygen levels in three of the cells are given in Figure 4. All measurments at the 1 meter depth and below are less than 1 mg/L dissolved oxygen, confirming that anaerobic conditions are present. It was noted that oxygen was abundant ($<$ 5 mg/L) in the upper 0.5 m layer and abruptly decreased below this layer.

Figure 5 shows the temperature profiles for all the lagoon cells. The cells indicate a general trend of increasing temperatures throughout the lagoon system at the water surface due to solar radiation input. Each cell shows thermal stratification which is encouraged by the cubed shape of the cells and the juxtaposition of the decant points. The inlet and outlet for all cells are located at 4.0 m depth and approximately 60 m apart.

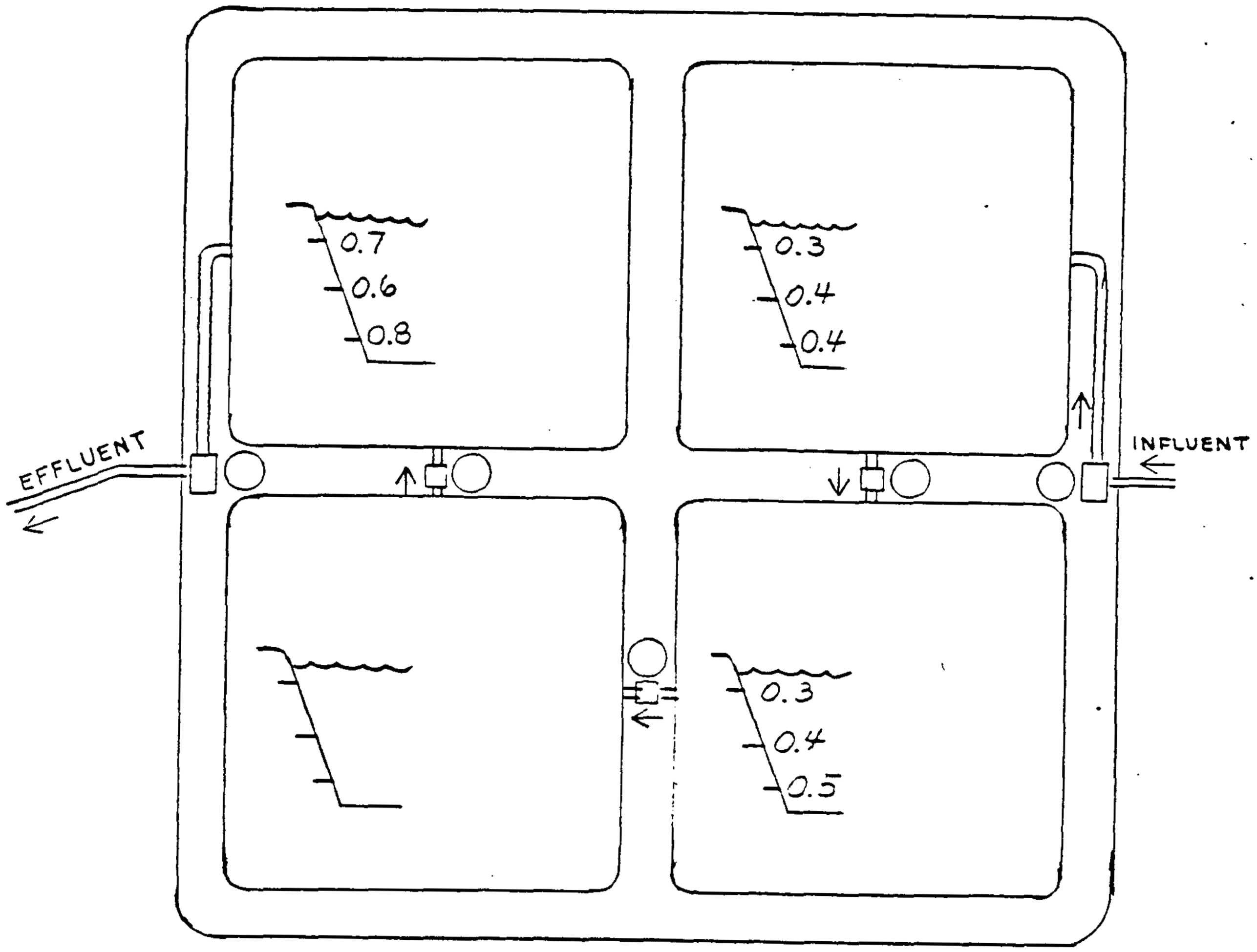
The results of the water quality analysis are presented in Table 2. The reduction of NFR, BOD_5, and COD in the effluent is 87%, 48%, and 31% respectively. The total and fecal coliform bacteria populations have been reduced by 2 orders of magnitude. In addition, the 96 hr. LC_{50} bioassay results were non-toxic. All of this data indicates improved treatment in the sewage lagoon system. This may be due to the benefits of sludge removal and the operation of the cells in series fashion in combination with the time of the year.

Fig.3 Lagoon Depth Profile



Total Depth ≃ 6.4m

Fig. 4 Lagoon Dissolved Oxygen Profile



Note: Dissolved oxygen was found in concentrations
5 mg/l in the upper 0.5 m layer.

Fig. 5 Lagoon Temperature Profile

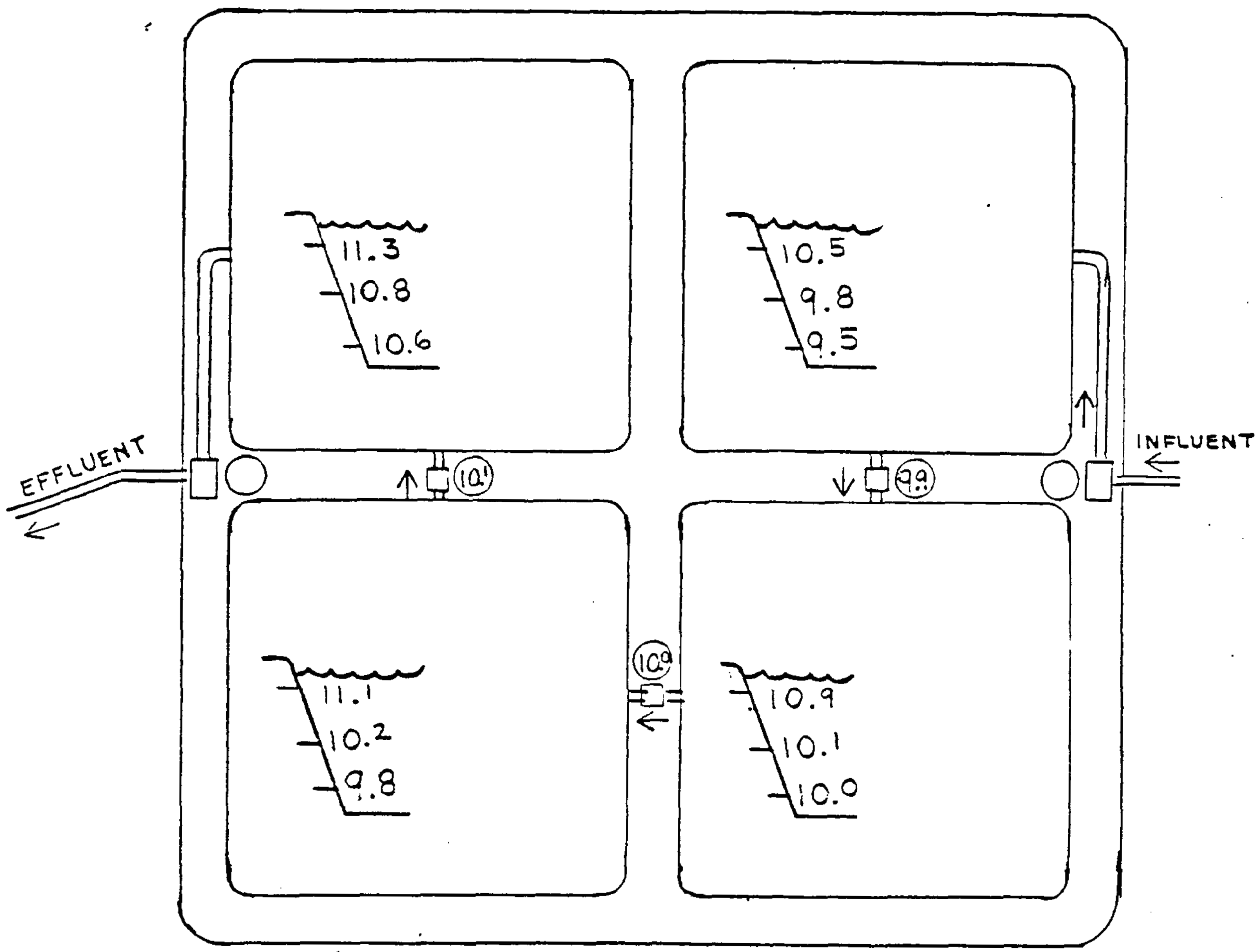


Table 2 WATER CHEMISTRY DATA COLLECTED AT THE WHITEHORSE SEWAGE LAGOONS, 1986

PARAMETER (mg/l unless noted)	STN. 1 Influent May 20	STN. 2 Effluent May 20	STN. 1 Influent Sept. 8	STN. 2 Effluent Sept. 8
Temperature °C	8.0	8.0	13.0	11.5
Dissolved Oxygen	4.0	1.4	2.3	3.3
pH Insitu	7.9	8.1	7.6	7.4
Lab	---	---	7.9	8.1
Cond. (umhos/cm)				
Insitu	267	260	305	290
Lab	382	400	420	425
Color (units)	20	20	20	20
Turbidity (F.T.U.)	20	3.5	4.5	2.3
Nonfilterable Residue	53	7	26	14
Filterable Residue	185	211	235	229
Biolog. Oxygen $Demand_5$	51	27	63	35
Chemical Oxygen Demand	133	92	---	---
Total Organic Carbon	23	23	23.2	12.2
Total Inorganic Carbon	24	33	31.8	26.0
Total Alkalinity	124	139	140	161
Total Hardness	115	112	126	131
Total Phosphate	2.55	1.7	2.38	2.32
Nitrite	<.005	.007	<.005	.007
Nitrate	<.005	.007	<.005	.007
Ammonia	8.1	6.8	6.93	8.59
Sulfate	40	30	34	23
Chloride	16.8	14.3	17.7	18.4
Surfactants	3.03	2.32	1.81	1.42
Phenols	.079	.079	.07	.02
Oils and Greases	14.0	0.33	30.5	2.0
Bioassay 96 hr. LC_{50}	---	Non toxic	---	Non toxic
Total Coliforms (#/100ml)	2.2×10^6	2.0×10^4	4.0×10^4	$5,0\times10^5$
Fecal Coliforms (#/100ml)	6.6×10^5	2.5×10^4	6.5×10^4	5.0×10^3

TABLE 2 WATER CHEMISTRY DATA COLLECTED AT THE WHITEHORSE SEWAGE LAGOONS, 1986

PARAMETER (mg/l unless noted) Extractable Metals	STN. 1 Influent May 20	STN. 2 Effluent May 20	STN. 1 Influent Sept. 8	STN. 2 Effluent Sept. 8
Al	.56	.11	.19	.1
As	<.05	<.05	<.05	<.05
B	.089	.116	.12	.119
Ba	.058	.032	.042	.041
Be	<.001	<.001	<.001	<.001
Ca	25.4	25.2	28.0	29.7
Cd	<.002	.002	<.002	<.002
Co	<.005	<.005	<.005	<.005
Cr	.011	<.005	<.005	<.005
Cu	.07	.042	.053	.03
Fe	.681	.333	.348	.384
Mg	11.4	11.4	13.2	13.5
Mn	.06	.071	.083	.106
Mo	.006	<.005	.008	<.005
Na	21.3	20.7	21.9	20.7
Ni	<.02	<.02	<.02	<.02
P	3.1	3.0	2.77	2.95
Pb	.03	<.02	<.02	<.02
Sb	<.05	<.05	<.05	<.05
Se	<.05	<.05	<.05	<.05
Si	4.6	4.5	4.4	4.6
Sn	<.01	.03	.02	.02
Sr	.162	.175	.204	.212
Ti	.014	.018	.014	.007
V	<.005	<.005	<.005	<.005
Zn	.048	.029	.035	.016

3.2 Tracer Dye

The flow measurements for cells 1 and 2 can be seen in figures 6 and 7 respectively. Figure 6 illustrates that the pulsating influent into cell 1 from the Marwell Lift Station has little effect on the discharge rate at the Stn A decant point. Figure 7 further shows that pump fluctuations are completely dampened out by station B and therefore a constant rate of flow was assumed for tracer dye calculations.

The tracer dye washout curves for cells 1, 2 and 3 are shown in figures 8, 9 and 10 respectively (for more detail see Appendix III). Each cell has a characteristic peak within approximately 10 - 30 minutes after injection followed by a sharp decrease, and then a steady levelling off. This suggests that short circuiting is present in all cells. The peak loadings varied considerably from 22 ppb in cell 1 to 300 and 120 ppb in cells 2 and 3, respectively. since the highest degree of short circuiting should occur in the cell with the highest solids loading, the major peak in cell 1 was probably missed by the sample sequence at Station A (W. Randall, prs. com.). The tracer concentrations were calculated from 2 days (cell 3) to 7 days (cells 1 and 2). The concentrations were then converted to cummulative "mls" recovered using the conversion factor, 1 ppb = 0.001 ml/m^3. The background levels in Stations B and C were accounted for separately. The background in cell 2 was considered to be a percent of the volume of dye which had passed into B whereas the background in cell 3 as taken to be a constant of 4 ppb because it was studied four days after injections into cells 1 and 2.

The final volumetric dye balance is shown in Table 3. Recoveries of 96 and 99% were achieved in cells 2 and 3, respectively. In contrast, only 79% of the dye was recovered in cell 1. This, again is most likely due to a slug of dye escaping the cell undetected during the first hour after tracer injection.

The tracer residence times for the cells are shown in Table 4. The mean residence time corresponds to a 50% tracer dye recovery. The percent tracer was based on the total estimated percent recovery over the sampling time. Cell 1 has the highest mean residence time (5.3 days) and cell 2 has the lowest (3.8 days).

FIGURE 6

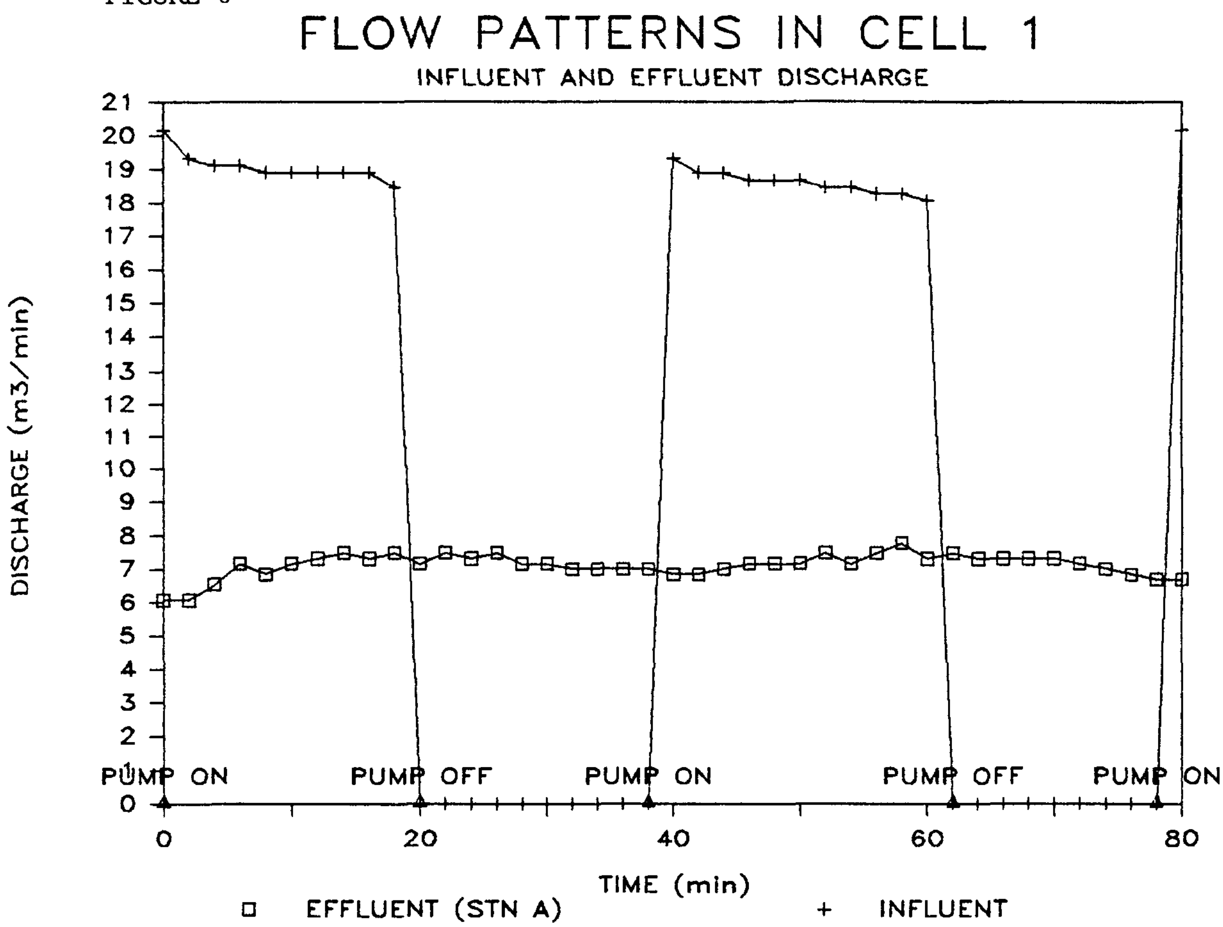


FIGURE 7

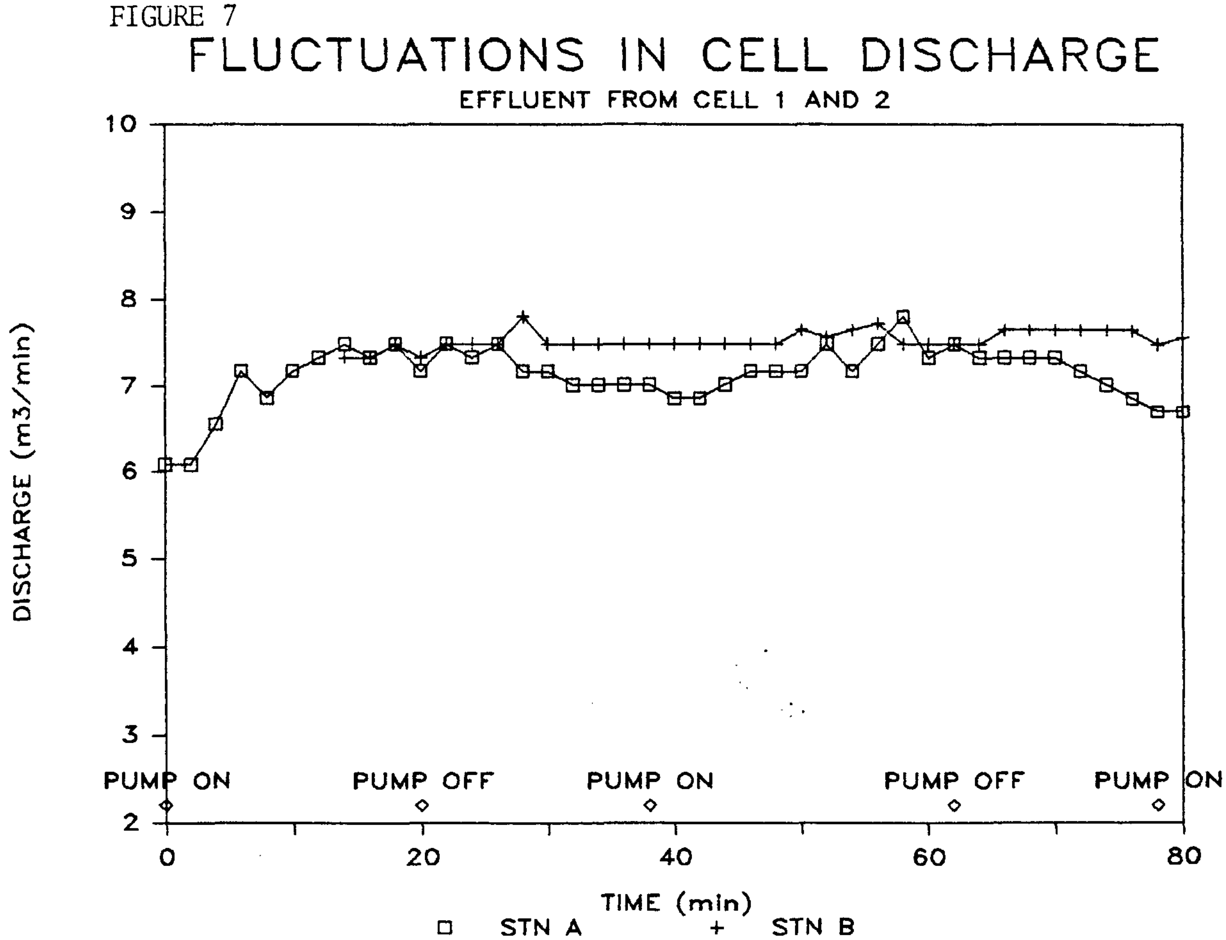
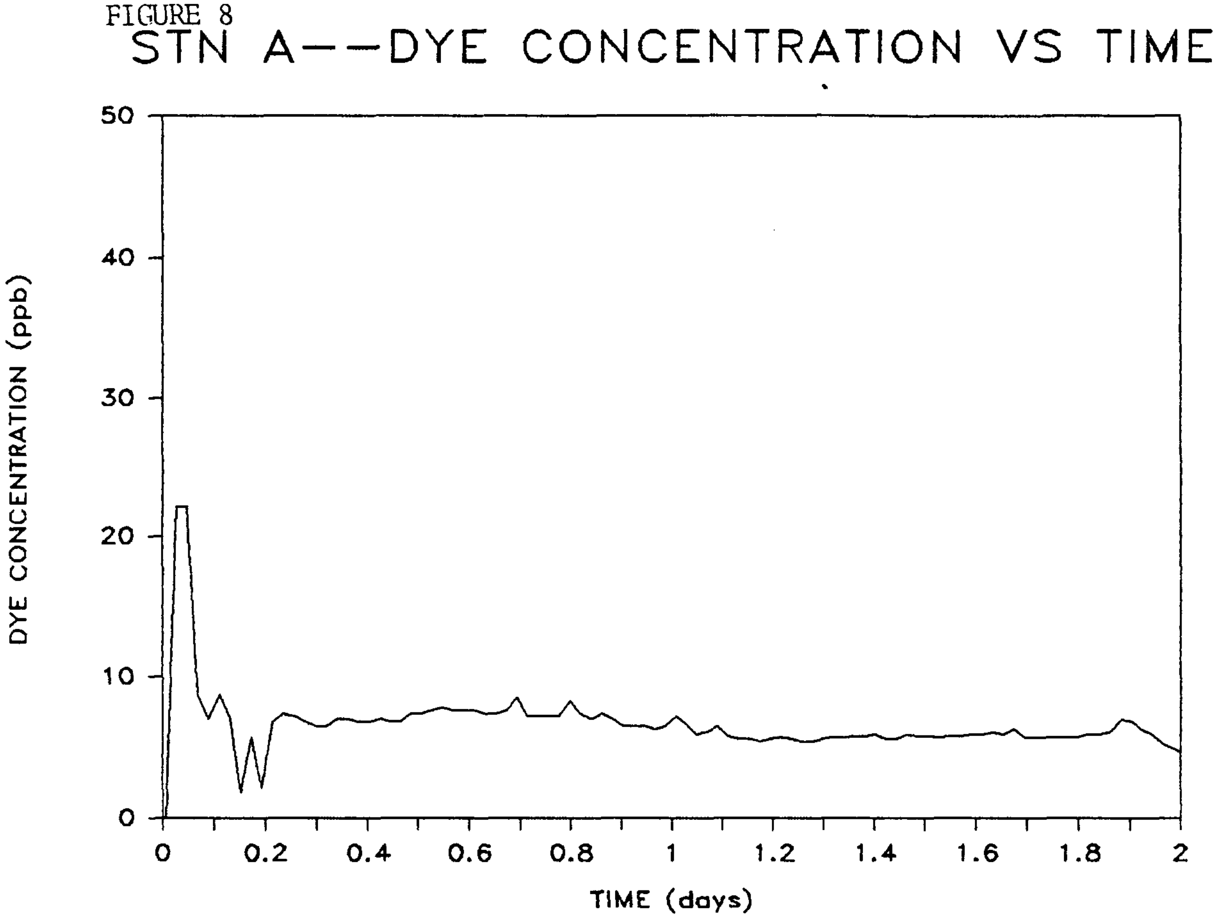


FIGURE 8


STN A--DYE CONCENTRATION VS TIME
DYE CONCENTRATION (ppb)
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
TIME (days)

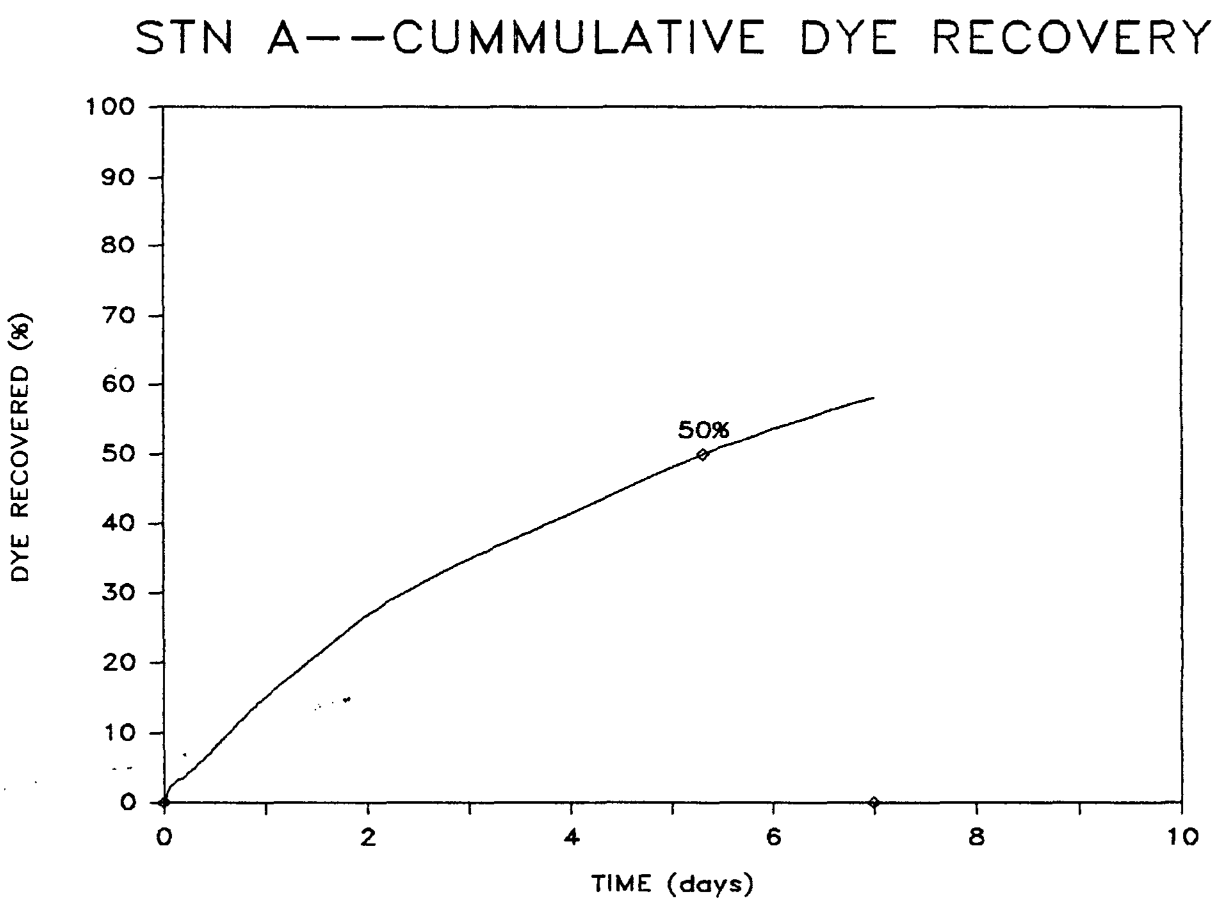
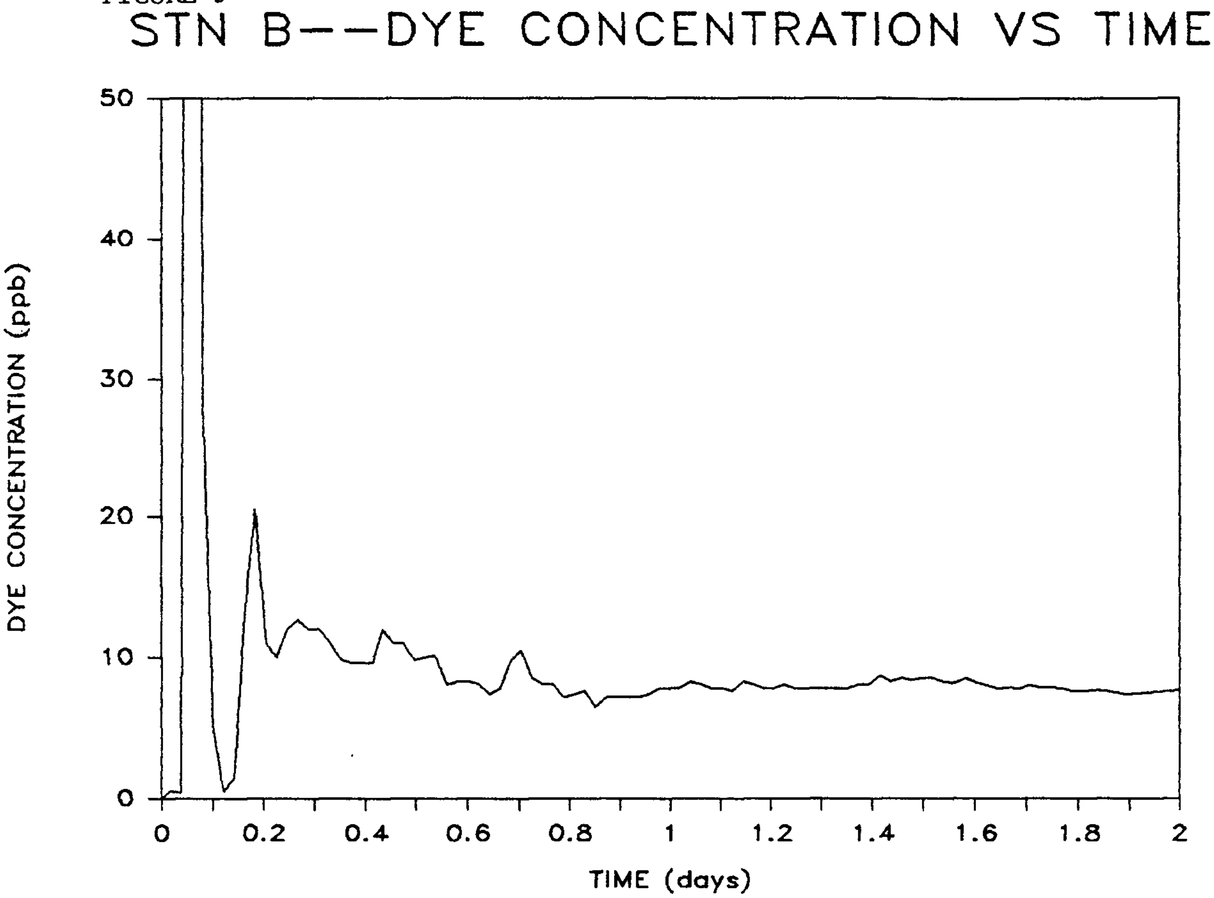

STN A--CUMMULATIVE DYE RECOVERY
DYE RECOVERED (%)
100
90
80
70
60
50
40
30
20
10
0
50%
0
2
4
6
8
10
TIME (days)

FIGURE 9


STN B--DYE CONCENTRATION VS TIME
DYE CONCENTRATION (ppb)
TIME (days)
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

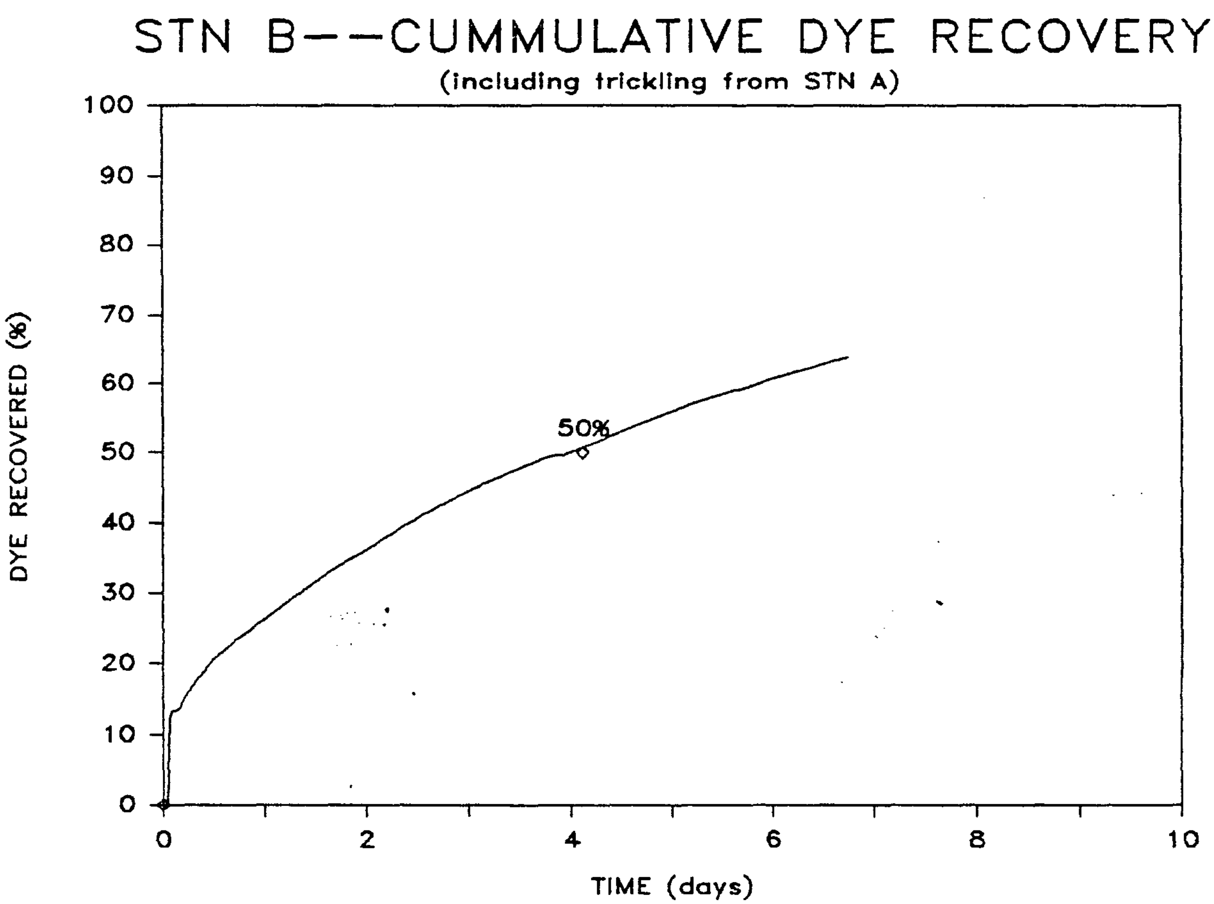
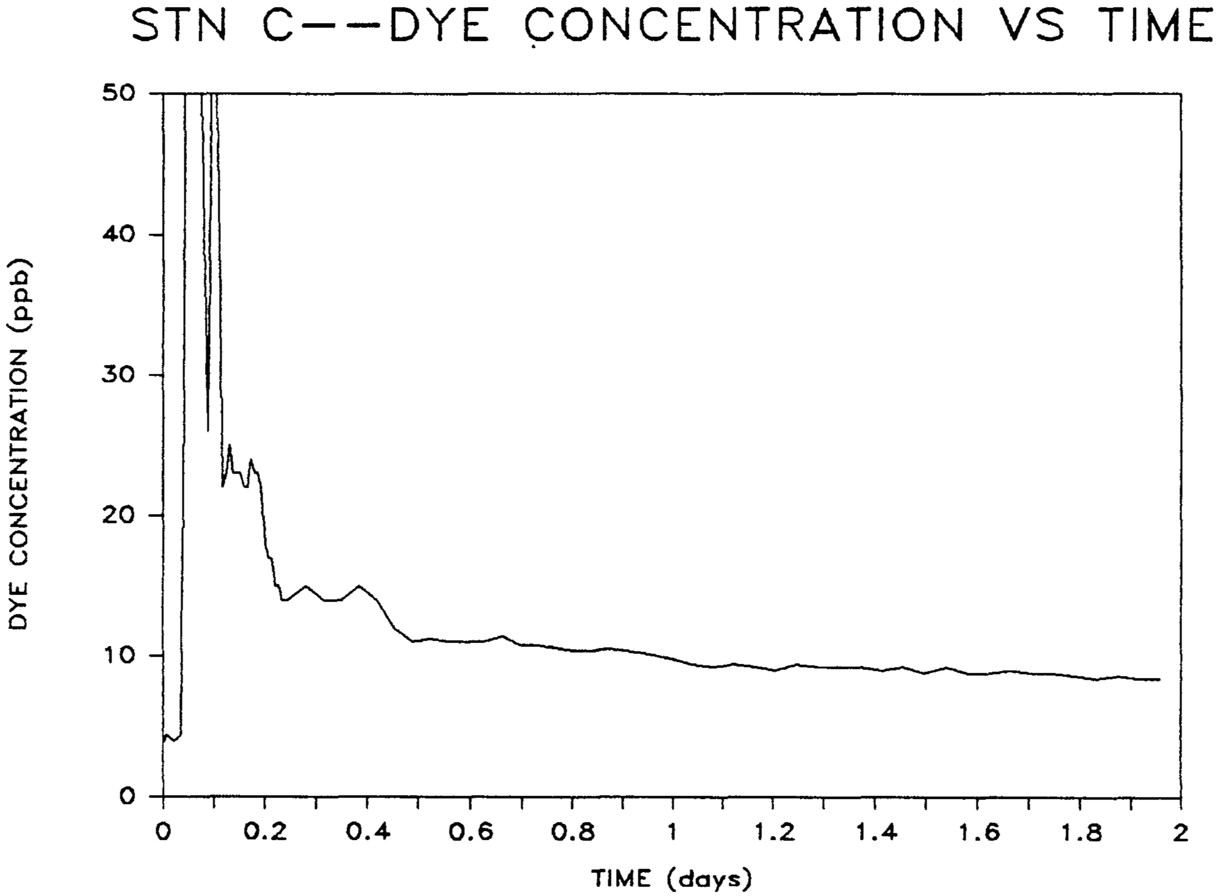

STN B--CUMMULATIVE DYE RECOVERY
(including trickling from STN A)
DYE RECOVERED (%)
TIME (days)
50%
0
10
20
30
40
50
60
70
80
90
100
2
4
6
8
10

FIGURE 10


STN C--DYE CONCENTRATION VS TIME
DYE CONCENTRATION (ppb)
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
TIME (days)

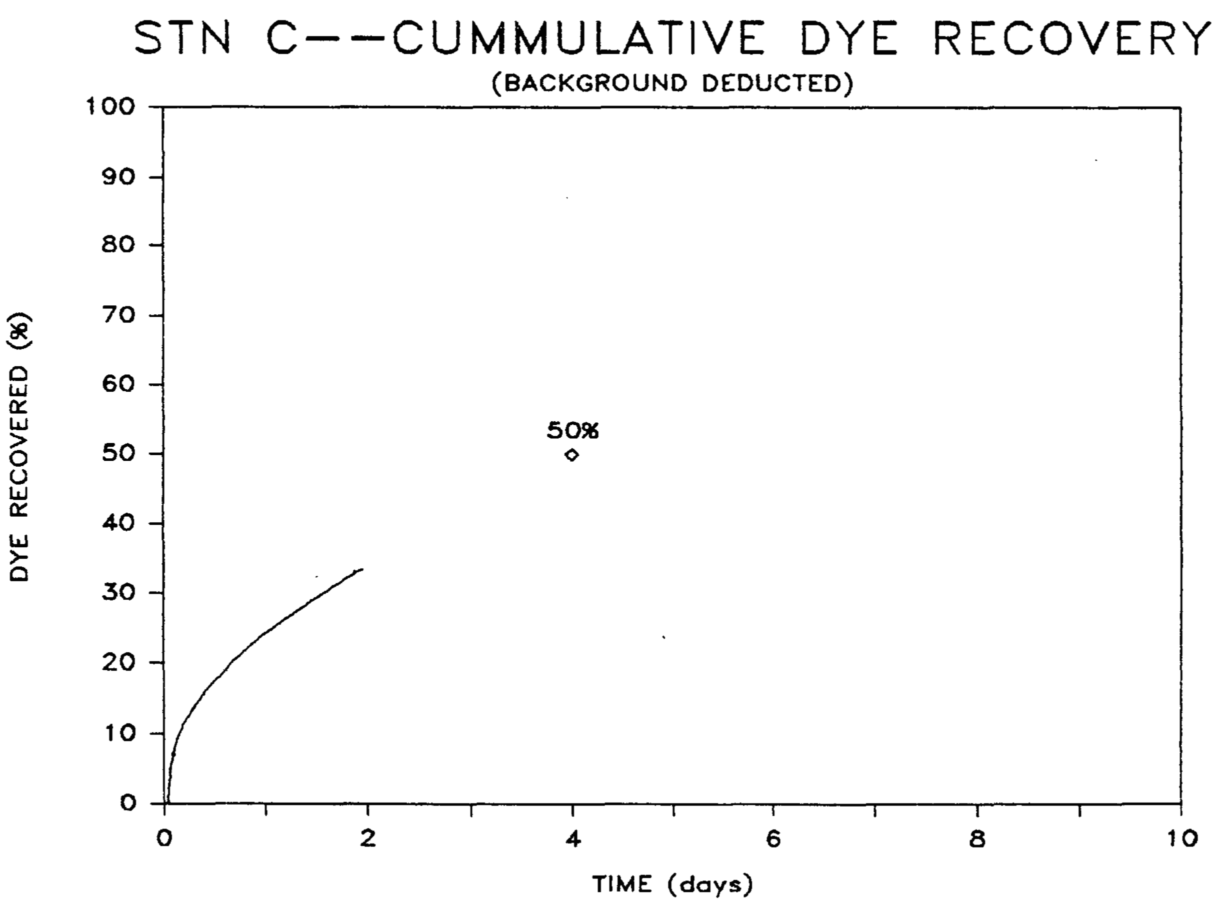

STN C--CUMMULATIVE DYE RECOVERY
(BACKGROUND DEDUCTED)
DYE RECOVERED (%)
100
90
80
70
60
50
40
30
20
10
0
50%
0
2
4
6
8
10
TIME (days)

TABLE 3: STATUS OF DYE AFTER FINAL SAMPLING

STATION A: (7 DAYS AFTER INJECTION)

	(mL)	(%)
TOTAL DYE ADDED = SLUG INJECTION.......	500	100
TOTAL DYE RECOVERED....................	285	57
DYE REMAINING IN CELL.....(2.2 PPB)....	113	22
TOTAL DYE ACCOUNTED FOR................	392	79
UNACCOUNTED DYE........................	102 mL	21 %

STATION B: (6.75 DAYS AFTER INJECTION)

	(mL)	(%)
TOTAL DYE IN = SLUG + DYE RECOVERED AT A	785	
TOTAL DYE RECOVERED..................	503	64
DYE REMAINING IN CELL.....(4.5 PPB)...	249	32
TOTAL DYE ACCOUNTED FOR..............	752	96
UNACCOUNTED DYE......................	33 mL	4 %

STATION C: (1.95 DAYS AFTER INJECTION)

	(mL)	(%)
TOTAL DYE IN = SLUG + BACKGROUND IN C (4PPB)	726	
TOTAL DYE RECOVERED..................	246	49
DYE REMAINING IN CELL.....(8.4PPB)....	474	50
TOTAL DYE ACCOUNTED FOR..............	720	99
UNACCOUNTED DYE......................	6 mL	1 %

CELL VOLUMES: CONVERSION FACTOR: 1 PPB = 0.001 mL/M^3

A=53650 M^3
B=55220 M^3
C=56420 M^3

TABLE 4: OBSERVED RESIDENCE TIMES OF LAGOON CELLS

	CELL A	CELL B	CELL C
MINIMUM RESIDENCE TIME	40 MIN	87 MIN	60 MIN
10% EFFLUENT HAS RESIDENCE TIME LESS THAN	18 HRS	2.5 HRS	4.8 HRS
20%	1.5 DAYS	12 HRS	18 HRS
30%	2.5 DAYS	1.5 DAYS	1.6 DAYS
40%	3.8 DAYS	2.3 DAYS	2.5 DAYS
EFFLUENT MEAN RESIDENCE TIME (50%)	5.3 DAYS	3.8 DAYS	4 DAYS

The longer retention period calculated for cell 1 relative to the other cells seems unlikely since cell 1 has the lowest aqueous volume due to the higher solids loading and sludge accummulation and the fluctuating influent flow rate will tend to transport the injected dye in the turbulent plume directly to the decant without thorough mixing (W. Randle, pers. comm.). It would therefore seem reasonable that the amount of dye observed at Station A was underestimated during the first sampling hour. This unrecorded slug of dye would result in overestimating the actual retention times.

In W. Randle's review of the data (Appendix III), he was able to correct the observed data to minimize the error caused by the infrequent sample period during the initial hour after dye injection. The estimated hydraulic retention times are shown in Table 5. The data indicates that the corrected retention times are about 60% of the theoretical hydraulic retention times. This demonstrates that the lagoons are not completely mixed and that short circuiting of waste-water treatment occurs.

TABLE 5: RETENTION TIMES AND TRACER CONCENTRATIONS

STN	Design Retention (days)	Observed Retention (days)	Corrected Retention (days)
A	5.1	5.3	3.03
B	5.3	3.8	3.19
C	5.4	4.0	3.40
D	-	-	3.40 (estimated)
Total			13

CONCLUSIONS

The most important parameters for municipal sewage systems in northern communities are dissolved oxygen, toxicity and pathogenic bacterial contamination (Bethall, 1981). This study has revealed that the water quality of the Whitehorse sewage treatment facility is improved from last year, following the sludge removal project in September, 1986. Chemical analysis shows a larger percentage reduction in BOD_5, COD, and NFR; bacteriological results indicate total and fecal coliform reductions by two orders of magnitude; the bioassay results showed a non-toxic effluent. The successful results are attributed to the conversion of the cell set up from parallel to series, the sludge removal project (cells 1 and 2) and the seasonal factor of increased biological activity during the spring and summer.

The flow rate measurements demonstrate that the frequent pumping cycles from the Marwell Lift station have a minimal effect on discharges between the cells. The tracer dye washout curves illustrate the major peak concentration to occur within 10-30 minutes after the slug injection. It is evident that the rate of sampling should be very frequent (ie. continuous) during the first two hours to record the major peak tracer concentration.

The duration of tracer dye monitoring varied between cells. Cell 1 and 2 were studied for 7 days whereas cell 3 was only studied for 2 days due to time constraints. All cells have demonstrated some short circuiting. The observed mean residence time for cells 1 and 2 were 5.3, and 3.8 days respectively. However, when the data is corrected to account for the dye escaping during the first hour of mixing, the corrected retention times are 3.03 days for cell 1, 3.19 days (cell 2), and 3.40 days (cell 3). The corrected mean retention times are 60% of the design hydraulic retention times and demonstrate that wastewater flow is short circuiting in the treatment cells.

The high degree of short circuiting in all cells might be due to the configuration of the inlets and outlets. Short circuiting could be minimized through several ways such as the installation of submerged deflection baffles, altering the decant pipe elevations, or introducing mechanical mixing within the cells. Any combination of the above would increase the efficiency of the wastewater treatment facility possibly resulting in a reduction in maintenance costs through less frequent sludge removal and an improvement in the quality of the effluent being discharged into the environment.

REFERENCES

Bethell, G. Start-up Characteristics and Performance Evaluation of an Anaerobic Sewage Lagoon North of 60°, EPS Regional Program Report No. 81-9, March 1981.

Department of Environment, Department of Fisheries and Oceans, Laboratory Manual, Environmental Protection Service, Fisheries and Marine Service (1979).

Dillistone Ted, Municipal Engineer, City of Whitehorse, June 4, 1986 (personal communication).

Environment Canada, Pollution Sampling Handbook, Pacific Region Laboratory Services, Fisheries Operations and Environmental Protection Service (1976).

Ferguson, K.D., A Performance Evaluation of the Village of Lake Cowichan Sewage Treatment lagoons EPS Regional Program Report; 78-4, June 1978.

Griffin, M.L., Freeze, Nichols, Model Studies of the Dead Storage Within Sediment Ponds, 1983 symposium on Surface Mining, Hydrology, Sedimentology and Reclamation, Pg. 113 - 119.

Metcalf & Eddy, Wastewater Engineering: Treatment, Disposal and Reuse, McGraw-Hill, Boston, 1979.

Randle, Wayne, Whitehorse Lagoon Tracer Studies, Wastewater Technology Centre, Conservation and Protection, Burlington, Ontario Project #11 July 30, 1986 (unpublished).

Stanley and Associates Engineering Ltd, City of Whitehorse Wastewater Treatment Project, Pre-Design Report, November, 1976.

APPENDIX I

FIELD AND LABORATORY METHODS

APPENDIX I TABLE 1 WATER SAMPLE COLLECTION, PREPARATION AND ANALYSIS METHODS

PARAMETER	DETECTION LIMIT	COLLECTION AND PREPARATION PROCEDURE[1]	ANALYTICAL PROCEDURE	METHOD SECTION[2]
Temperature	0.1°C	_In situ_ measurement.	YSI Model 33 Conductivity Meter	
Conductivity	0.2 umhos/cm	_In situ_ measurement. Lab measurement was taken from the same sample as NH_3 below.	YSI Model 33 Conductivity Meter Radiometer Conductivity Meter (CDMC)	044
Dissolved Oxygen	1.0 mg/l	_In situ_ measurement. The instrument was calibrated in the field under water saturated air conditions.	YSI Model 57 Dissolved Oxygen Meter	
pH		Small aliquots of sample were measured soon after collection. Instrument was calibrated using 7.0 buffering solution.	Potentiometric	080
Non-Filterable Residue (NFR)	5.0 mg/l	Sample was filtered through a pre-weighed glass fibre filter with a 1.5 um pore size.	Filtration, Drying And Weighing Of Residue On Filter	104
Filterable Residue (FR)	10.0 mg/l	Same sample as NH_3.	Filtration, Drying And Weighing Of Filtrate	100

APPENDIX I TABLE 1 WATER SAMPLE COLLECTION, PREPARATION AND ANALYSIS METHODS (continued)

PARAMETER	DETECTION LIMIT	COLLECTION AND PRESERVATION PROCEDURE[1]	ANALYTICAL PROCEDURE	METHOD SECTION[2]
Ammonia NH_3-N	0.005 mg/l	Single samples collected in 2 litre linear polyethylene containers. Each container was rinsed 3 times with sample before it was filled. No preservatives. Stored at 4°C.	Phenol Hypochlorite-Colorimetric-Automated	058
Colour	5 (colour units)	Same sample as NH_3.	Platinum-Cobalt Visual Comparison	040
Turbidity	0.1 (FTU)	Same sample as NH_3.	Nephelometric Turbidity	130
Total Alkalinity	1.0 mg/l as $CaCO_3$	Same sample as NH_3.	Potentiometric Titration	006
Total Phosphate T PO_4-P	0.005 mg/l	Same sample as NH_3.	Acid-persulphate, Autoclave Digestion	086
Nitrite NO_2-N	0.005 mg/l	Same sample as NH_3.	Diazotization-Colorimetric-Automated	070
Nitrate NO_3-N	0.01 mg/l	Same sample as NH_3.	Cadmium Copper Reduction Colorimetric Automated	072
Sulphate SO_4	1.0 mg/l	Same sample as NH_3.	Barium Chloranilate -UV Spectrophotometric	122
Chloride Cl	0.5 mg/l	Same sample as NH_3.	Thiocyanate-Combined Reagent-Colorimetric	024

APPENDIX I TABLE 1 WATER SAMPLE COLLECTION, PREPARATION AND ANALYSIS METHODS (continued)

PARAMETER	DETECTION LIMIT	COLLECTION AND PRESERVATION PROCEDURE[1]	ANALYTICAL PROCEDURE	METHOD SECTION[2]
Extractable Metals	mg/l	Single samples collected in 200 ml linear polyethylene bottles. Each bottle was rinsed 3 times with sample before filling. Preserved to a pH <1.5 using 2.0 ml concentrated HNO_3.	Inductively Coupled Argon Plasma (ICAP) combined with Optical Emission Spectrometer (OES)	300
Al	0.05			
As	0.05			
B	0.001			
Ba	0.001			
Be	0.001			
Ca	0.1			
Cd	0.002			
Co	0.005			
Cr	0.005			
Cu	0.005			
Fe	0.005			
Mg	0.10			
Mn	0.001			
Mo	0.005			
Na	0.5			
Ni	0.02			
P	0.05			
Pb	0.02			
Sb	0.05			
Se	0.05			
Si	0.1			
Sn	0.01			
Sr	0.001			
Ti	0.002			
V	0.01			
Zn	0.002			

APPENDIX I TABLE 1 WATER SAMPLE COLLECTION, PREPARATION AND ANALYSIS METHODS (continued)

PARAMETER	DETECTION LIMIT	COLLECTION AND PRESERVATION PROCEDURE[1]	ANALYTICAL PROCEDURE	METHOD SECTION[2]
As	0.00050	Same sample as metals.	Hydride Generation - ICAP	350
Cd	0.0005	Same as sample metals.	Graphite Furnace Atomic Absorption Spectrophotometry	330
Cu	0.001	Same sample as metals.		
Pb	0.001	Same sample as metals.		
Ag	0.0005	Same sample as metals.		
K	0.01 mg/l	Same sample as metals.	Flame Atomic Absorption Spectrophotometry	340
Total Hardness	0.030 mg/l as $CaCO_3$	Same sample as metals.	The sum of the ICAP results for Mg x 4.116 and Ca x 2.497 reported as mg/l $CaCO_3$	

1 As described in Environment Canada (1976).

2 As described in Department of Environment (1979).

APPENDIX II

TRACER DYE WORKSHEET

AND RAW GRAPHS

WHITEHORSE SEWAGE LAGOON DYE RETENTION WORKSHEET

DAYS A	STN A (PPB)	DAYS B	STN B (PPB)	DAYS C	STN C (PPB)	DYE RECOVERY PER TIME (ML) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (ML) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (%) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (%) MINUS BACKGROUND #DYE-B	#DYE-C
0	0	0	0	0	4	0.028	0	0	0.028	0	0	0.006	0	0	0	0
0.01	0	0.02	0.6	.00	4	0.139	0.113	0.000	0.167	0.113	0.000	0.033	0.023	0.000	0.022	0.000
0.03	22.1	0.04	0.4	0.01	4.4	0.153	0.084	4.636	0.320	0.196	4.636	0.064	0.039	0.927	0.038	0.003
0.05	22.1	0.06	300	0.01	4.3	0.299	62.685	4.636	0.620	62.881	9.271	0.124	12.576	1.854	12.190	0.007
0.07	8.7	0.08	28.4	0.02	4	0.279	5.934	1.825	0.898	68.816	11.096	0.180	13.763	2.219	13.330	0.007
0.09	7	0.10	4.8	0.03	4.1	0.286	1.003	1.468	1.184	69.819	12.565	0.237	13.964	2.513	13.493	0.008
0.11	8.7	0.12	0.5	0.03	4.4	0.306	0.104	1.825	1.491	69.923	14.390	0.298	13.985	2.878	13.502	0.014
0.13	7	0.14	1.4	0.04	28	1.950	0.293	1.468	3.441	70.216	15.858	0.688	14.043	3.172	13.522	0.348
0.15	1.8	0.16	13	0.05	120	8.358	2.716	0.378	11.799	72.932	16.235	2.360	14.586	3.247	14.003	1.964
0.17	5.7	0.19	20.5	0.06	78	5.433	4.283	1.196	17.231	77.215	17.431	3.446	15.443	3.486	14.783	2.995
0.19	2.1	0.21	11	0.06	71	4.945	2.298	0.440	22.177	79.514	17.872	4.435	15.903	3.574	15.181	3.928
0.22	6.7	0.23	10	0.07	69	4.806	2.090	1.405	26.982	81.603	19.277	5.396	16.321	3.855	15.540	4.834
0.24	7.4	0.25	12	0.08	52	3.622	2.507	1.552	30.604	84.111	20.829	6.121	16.822	4.166	15.976	5.502
0.26	7.2	0.27	12.7	0.08	37	2.577	2.654	1.510	33.181	86.764	22.339	6.636	17.353	4.468	16.434	5.962
0.28	6.8	0.29	12	0.09	26	1.811	2.507	1.426	34.992	89.272	23.766	6.998	17.854	4.753	16.862	6.269
0.30	6.5	0.31	12	0.10	57	3.970	2.507	1.363	38.962	91.779	25.129	7.792	18.356	5.026	17.289	7.007
0.32	6.5	0.33	11	0.10	57	3.970	2.298	1.363	42.932	94.078	26.493	8.586	18.816	5.299	17.674	7.745
0.34	7	0.35	9.8	0.11	39	2.716	2.048	1.468	45.649	96.125	27.961	9.130	19.225	5.592	18.009	8.233
0.36	7	0.37	9.6	0.12	22	1.532	2.006	1.468	47.181	98.131	29.429	9.436	19.626	5.886	18.336	8.483
0.38	6.8	0.39	9.6	0.13	23	1.602	2.006	1.426	48.783	100.137	30.856	9.757	20.027	6.171	18.661	8.748
0.40	6.8	0.41	9.6	0.13	25	1.741	2.006	1.426	50.524	102.143	32.282	10.105	20.429	6.456	18.980	9.041
0.42	7	0.44	12	0.14	23	1.602	2.507	1.468	52.126	104.651	33.750	10.425	20.930	6.750	19.390	9.305
0.44	6.8	0.46	11	0.15	23	1.602	2.298	1.426	53.728	106.949	35.177	10.746	21.390	7.035	19.758	9.570
0.47	6.8	0.48	11	0.15	23	1.602	2.298	1.426	55.330	109.247	36.603	11.066	21.849	7.321	20.122	9.835
0.49	7.4	0.50	9.8	0.16	22	1.532	2.048	1.552	56.862	111.295	38.155	11.372	22.259	7.631	20.439	10.085
0.51	7.4	0.52	10	0.17	22	1.532	2.090	1.552	58.395	113.385	39.708	11.679	22.677	7.942	20.762	10.336
0.53	7.6	0.54	10.1	0.17	24	1.672	2.110	1.594	60.066	115.495	41.302	12.013	23.099	8.260	21.086	10.615
0.55	7.8	0.56	8.1	0.18	23	1.602	1.692	1.636	61.668	117.188	42.938	12.334	23.438	8.588	21.335	10.879
0.57	7.6	0.58	8.3	0.19	23	1.602	1.734	1.594	63.270	118.922	44.532	12.654	23.784	8.906	21.590	11.144
0.59	7.6	0.60	8.3	0.19	22	1.532	1.734	1.594	64.802	120.656	46.126	12.960	24.131	9.225	21.841	11.395
0.61	7.6	0.62	8.1	0.20	18	1.254	1.692	1.594	66.056	122.349	47.720	13.211	24.470	9.544	22.077	11.590
0.63	7.4	0.64	7.4	0.21	17	1.184	1.546	1.552	67.240	123.895	49.273	13.448	24.779	9.855	22.295	11.771
0.65	7.4	0.66	7.8	0.22	17	1.184	1.630	1.552	68.424	125.525	50.825	13.685	25.105	10.165	22.527	11.952
0.67	7.6	0.69	9.8	0.22	15	1.045	2.048	1.594	69.469	127.572	52.419	13.894	25.514	10.484	22.832	12.105
0.69	8.5	0.71	10.5	0.23	15	1.045	2.194	1.783	70.514	129.766	54.202	14.103	25.953	10.840	23.163	12.258
0.72	7.2	0.73	8.5	0.24	14	0.975	1.776	1.510	71.489	131.542	55.712	14.298	26.308	11.142	23.407	12.398
0.74	7.2	0.75	8.1	0.25	14	1.463	1.692	1.510	72.951	133.235	57.223	14.590	26.647	11.445	23.643	12.607

WHITEHORSE SEWAGE LAGOON DYE RETENTION WORKSHEET

DAYS A	STN A (PPB)	DAYS B	STN B (PPB)	DAYS C	STN C (PPB)	DYE RECOVERY PER TIME (ML) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (ML) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (%). #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (%) MINUS BACKGROUND #DYE-B	#DYE-C
0.76	7.2	0.77	8.1	0.28	15	5.224	1.692	1.510	78.175	134.927	58.733	15.635	26.985	11.747	23.881	13.373
0.78	7.2	0.79	7.2	0.32	14	4.876	1.504	1.510	83.051	136.432	60.243	16.610	27.286	12.049	24.081	14.069
0.80	8.3	0.81	7.4	0.35	14	4.876	1.546	1.741	87.926	137.978	61.984	17.585	27.596	12.397	24.291	14.766
0.82	7.4	0.83	7.6	0.39	15	5.224	1.588	1.552	93.150	139.566	63.536	18.630	27.913	12.707	24.512	15.532
0.84	7	0.85	6.5	0.42	14	4.876	1.358	1.468	98.025	140.924	65.005	19.605	28.185	13.001	24.691	16.228
0.86	7.4	0.87	7.2	0.45	12	4.179	1.504	1.552	102.204	142.429	66.557	20.441	28.486	13.311	24.895	16.786
0.88	7	0.89	7.2	0.49	11	3.831	1.504	1.468	106.035	143.933	68.025	21.207	28.787	13.605	25.100	17.273
0.90	6.5	0.91	7.2	0.52	11.2	3.900	1.504	1.363	109.936	145.438	69.389	21.987	29.088	13.878	25.302	17.775
0.92	6.5	0.94	7.2	0.56	11	3.831	1.504	1.363	113.766	146.942	70.752	22.753	29.388	14.150	25.497	18.262
0.94	6.5	0.96	7.4	0.59	11	3.831	1.546	1.363	117.597	148.488	72.115	23.519	29.698	14.423	25.704	18.750
0.97	6.3	0.98	7.8	0.63	11	3.831	1.630	1.321	121.428	150.118	73.437	24.286	30.024	14.687	25.930	19.237
0.99	6.5	1.00	7.8	0.66	11.4	3.970	1.630	1.363	125.398	151.748	74.800	25.080	30.350	14.960	26.154	19.753
1.01	7.2	1.02	7.8	0.70	10.8	3.761	1.630	1.510	129.159	153.378	76.311	25.832	30.676	15.262	26.373	20.226
1.03	6.6	1.04	8.3	0.73	10.8	3.761	1.734	1.384	132.920	155.112	77.695	26.584	31.022	15.539	26.615	20.700
1.05	5.9	1.06	8.1	0.77	10.6	3.691	1.692	1.238	136.612	156.804	78.933	27.322	31.361	15.787	26.852	21.160
1.07	6.1	1.08	7.8	0.80	10.4	3.622	1.630	1.280	140.233	158.434	80.212	28.047	31.687	16.042	27.076	21.605
1.09	6.5	1.10	7.8	0.84	10.4	3.622	1.630	1.363	143.855	160.064	81.576	28.771	32.013	16.315	27.302	22.051
1.11	5.8	1.12	7.6	0.87	10.5	3.657	1.588	1.217	147.512	161.652	82.792	29.502	32.330	16.558	27.518	22.504
1.13	5.6	1.14	8.3	0.91	10.4	3.622	1.734	1.175	151.134	163.386	83.967	30.227	32.677	16.793	27.756	22.950
1.15	5.6	1.16	8.1	0.94	10.2	3.552	1.692	1.175	154.686	165.079	85.142	30.937	33.016	17.028	27.988	23.382
1.17	5.4	1.19	7.8	1.00	9.8	5.461	1.630	1.133	160.146	166.709	86.274	32.029	33.342	17.255	28.210	24.028
1.19	5.6	1.21	7.8	1.04	9.4	3.928	1.630	1.175	164.075	168.338	87.449	32.815	33.668	17.490	28.431	24.479
1.22	5.7	1.23	8.1	1.08	9.2	3.845	1.692	1.196	167.919	170.031	88.645	33.584	34.006	17.729	28.660	24.914
1.24	5.6	1.25	7.8	1.12	9.4	3.928	1.630	1.175	171.847	171.661	89.819	34.369	34.332	17.964	28.877	25.365
1.26	5.4	1.27	7.8	1.16	9.2	3.845	1.630	1.133	175.692	173.291	90.952	35.138	34.658	18.190	29.093	25.800
1.28	5.4	1.29	7.8	1.20	9	3.761	1.630	1.133	179.453	174.920	92.085	35.891	34.984	18.417	29.306	26.218
1.30	5.6	1.31	7.8	1.25	9.4	3.928	1.630	1.175	183.381	176.550	93.259	36.676	35.310	18.652	29.519	26.669
1.32	5.7	1.33	7.8	1.29	9.2	3.845	1.630	1.196	187.226	178.180	94.455	37.445	35.636	18.891	29.730	27.104
1.34	5.7	1.35	7.8	1.33	9.2	3.845	1.630	1.196	191.071	179.810	95.651	38.214	35.962	19.130	29.944	27.538
1.36	5.8	1.37	8.1	1.37	9.2	3.845	1.692	1.217	194.916	181.502	96.867	38.983	36.300	19.373	30.166	27.973
1.38	5.8	1.39	8.1	1.41	9	3.761	1.692	1.217	198.677	183.195	98.084	39.735	36.639	19.617	30.385	28.391
1.40	5.9	1.41	8.7	1.45	9.2	3.845	1.818	1.238	202.521	185.013	99.321	40.504	37.003	19.864	30.625	28.825
1.42	5.6	1.44	8.3	1.50	8.8	3.678	1.734	1.175	206.199	186.747	100.496	41.240	37.349	20.099	30.850	29.227
1.44	5.6	1.46	8.5	1.54	9.2	3.845	1.776	1.175	210.044	188.523	101.671	42.009	37.705	20.334	31.082	29.661
1.47	5.9	1.48	8.4	1.58	8.8	3.678	1.755	1.238	213.721	190.278	102.908	42.744	38.056	20.582	31.308	30.062
1.49	5.8	1.50	8.5	1.62	8.8	3.678	1.776	1.217	217.399	192.054	104.125	43.480	38.411	20.825	31.538	30.464

WHITEHORSE SEWAGE LAGOON DYE RETENTION WORKSHEET

DAYS A	STN A (PPB)	DAYS B	STN B (PPB)	DAYS C	STN C (PPB)	DYE RECOVERY PER TIME (ML) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (ML) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (%) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (%) MINUS BACKGROUND #DYE-B	#DYE-C
1.51	5.8	1.52	8.5	1.66	9	3.761	1.776	1.217	221.160	193.830	105.341	44.232	38.766	21.068	31.765	30.881
1.53	5.7	1.54	8.3	1.70	8.8	3.678	1.734	1.196	224.837	195.565	106.537	44.967	39.113	21.307	31.984	31.283
1.55	5.8	1.56	8.2	1.75	8.8	3.678	1.713	1.217	228.515	197.278	107.754	45.703	39.456	21.551	32.198	31.684
1.57	5.8	1.58	8.5	1.79	8.6	3.594	1.776	1.217	232.109	199.054	108.970	46.422	39.811	21.794	32.422	32.068
1.59	5.9	1.60	8.2	1.83	8.4	3.510	1.713	1.238	235.619	200.768	110.208	47.124	40.154	22.042	32.631	32.436
1.61	5.9	1.62	8	1.87	8.6	3.594	1.672	1.238	239.213	202.439	111.445	47.843	40.488	22.289	32.839	32.820
1.63	6	1.64	7.8	1.91	8.4	3.510	1.630	1.259	242.723	204.069	112.704	48.545	40.814	22.541	33.039	33.188
1.65	5.9	1.66	7.9	1.95	8.4	3.510	1.651	1.238	246.234	205.720	113.942	49.247	41.144	22.788	33.242	33.556
1.67	6.3	1.69	7.8	4			1.630	1.321		207.349	115.263		41.470	23.053	33.441	
1.69	5.7	1.71	8				1.672	1.196		209.021	116.459		41.804	23.292	33.646	
1.72	5.7	1.73	7.9				1.651	1.196		210.672	117.654		42.134	23.531	33.846	
1.74	5.7	1.75	7.9				1.651	1.196		212.322	118.850		42.464	23.770	34.044	
1.76	5.7	1.77	7.8				1.630	1.196		213.952	120.046		42.790	24.009	34.237	
1.78	5.7	1.79	7.6				1.588	1.196		215.540	121.241		43.108	24.248	34.422	
1.80	5.7	1.81	7.6				1.588	1.196		217.128	122.437		43.426	24.487	34.596	
1.82	5.9	1.83	7.7				1.609	1.238		218.737	123.674		43.747	24.735	34.773	
1.84	5.9	1.85	7.6				1.588	1.238		220.325	124.912		44.065	24.982	34.953	
1.86	6	1.87	7.5				1.567	1.259		221.892	126.171		44.378	25.234	35.133	
1.88	6.9	1.89	7.4				1.546	1.447		223.439	127.618		44.688	25.524	35.166	
1.90	6.8	1.94	7.5				3.134	1.426		226.573	129.044		45.315	25.809	35.556	
1.92	6.2	1.98	7.6				3.176	1.301		229.749	130.345		45.950	26.069	35.950	
1.94	5.9	2.02	7.7				3.218	1.238		232.967	131.582		46.593	26.316	36.349	
1.97	5.2	2.06	7.7				3.218	1.091		236.185	132.673		47.237	26.535	36.748	
2.03	4.3	2.10	7.6				3.176	2.706		239.361	135.379		47.872	27.076	37.138	
2.07	4.4	2.14	7.3				3.051	1.846		242.411	137.225		48.482	27.445	37.508	
2.11	4.4	2.19	7.4				3.092	1.846		245.504	139.071		49.101	27.814	37.884	
2.15	4.4	2.23	7.4				3.092	1.846		248.596	140.917		49.719	28.183	38.259	
2.19	4.3	2.27	7.3				3.051	1.804		251.647	142.721		50.329	28.544	38.629	
2.24	4.3	2.31	7.3				3.051	1.804		254.698	144.525		50.940	28.905	38.997	
2.28	4.2	2.35	7.2				3.009	1.762		257.706	146.287		51.541	29.257	39.356	
2.32	4.2	2.39	7				2.925	1.762		260.632	148.049		52.126	29.610	39.701	
2.36	4.1	2.44	7.1				2.967	1.720		263.599	149.769		52.720	29.954	40.051	
2.40	4	2.48	7.1				2.967	1.678		266.566	151.447		53.313	30.289	40.401	
2.44	4	2.52	7.1				2.967	1.678		269.533	153.125		53.907	30.625	40.747	
2.49	4	2.56	7.1				2.967	1.678		272.500	154.803		54.500	30.961	41.097	
2.53	4	2.60	6.9				2.884	1.678		275.384	156.481		55.077	31.296	41.432	

WHITEHORSE SEWAGE LAGOON DYE RETENTION WORKSHEET

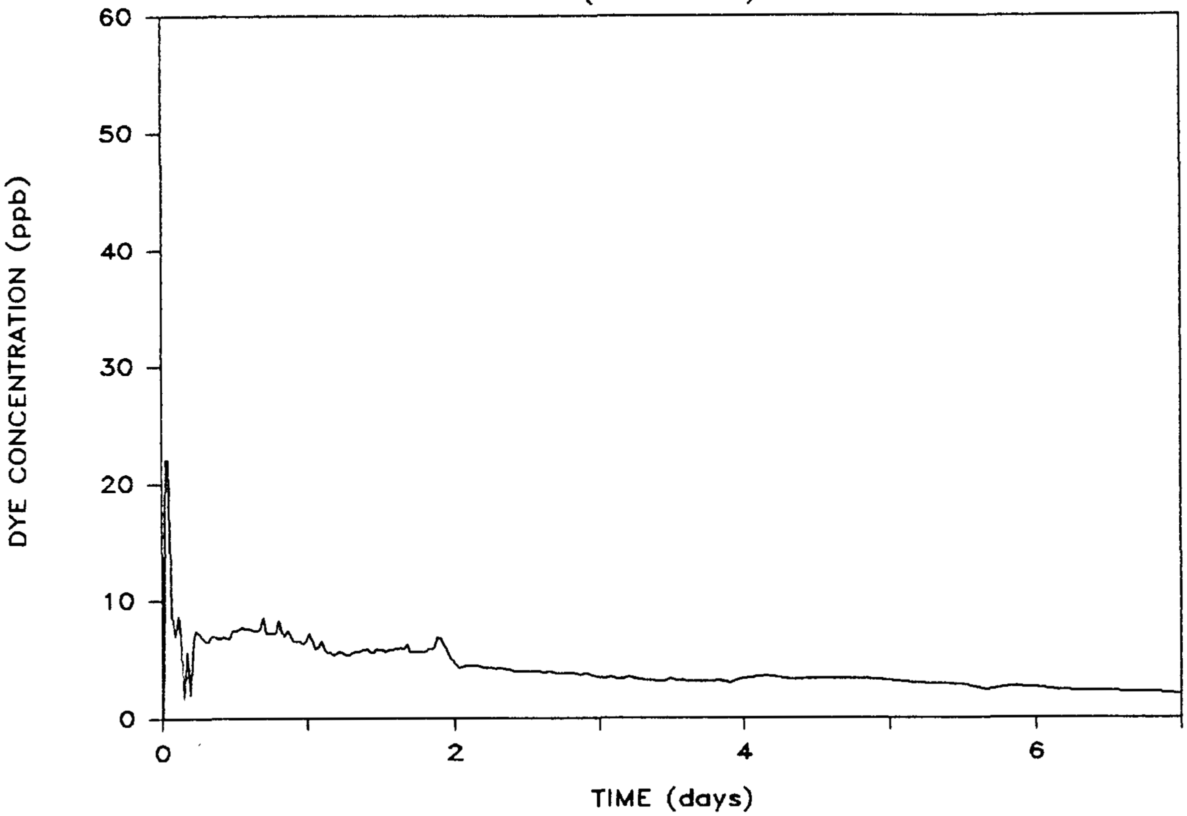
DAYS A	STN A (PPB)	DAYS B	STN B (PPB)	DAYS C	STN C (PPB)	DYE RECOVERY PER TIME (ML) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (ML) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (%) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (%) MINUS BACKGROUND #DYE-B	#DYE-C
2.57	4	2.64	6.8				2.842	1.678		278.225	158.159		55.645	31.632	41.760	
2.61	3.9	2.69	7				2.925	1.636		281.151	159.795		56.230	31.959	42.098	
2.65	4	2.73	7				2.925	1.678		284.076	161.473		56.815	32.295	42.437	
2.69	3.8	2.77	6.8				2.842	1.594		286.918	163.067		57.384	32.613	42.760	
2.74	3.8	2.81	6.8				2.842	1.594		289.759	164.662		57.952	32.932	43.086	
2.78	3.8	2.85	6.7				2.800	1.594		292.559	166.256		58.512	33.251	43.408	
2.82	3.8	2.89	6.7				2.800	1.594		295.359	167.850		59.072	33.570	43.731	
2.86	3.7	2.94	6.6				2.758	1.552		298.117	169.402		59.623	33.880	44.044	
2.90	3.8	2.98	6.4				2.675	1.594		300.792	170.996		60.158	34.199	44.345	
2.94	3.6	3.02	6.2				2.591	1.510		303.383	172.507		60.677	34.501	44.633	
2.99	3.5	3.06	6.2				2.591	1.468		305.974	173.975		61.195	34.795	44.918	
3.03	3.4	3.10	6.1				2.549	1.426		308.523	175.401		61.705	35.080	45.197	
3.07	3.5	3.14	6.2				2.591	1.468		311.114	176.870		62.223	35.374	45.484	
3.11	3.4	3.19	6				2.507	1.426		313.621	178.296		62.724	35.659	45.761	
3.15	3.4	3.23	6				2.507	1.426		316.129	179.722		63.226	35.944	46.037	
3.19	3.5	3.27	6				2.507	1.468		318.636	181.191		63.727	36.238	46.314	
3.24	3.4	3.31	5.9				2.466	1.426		321.102	182.617		64.220	36.523	46.585	
3.28	3.3	3.35	6				2.507	1.384		323.609	184.001		64.722	36.800	46.851	
3.32	3.2	3.39	5.9				2.466	1.342		326.075	185.344		65.215	37.069	47.117	
3.36	3.2	3.44	5.8				2.424	1.342		328.499	186.686		65.700	37.337	47.375	
3.40	3.1	3.48	5.8				2.424	1.301		330.922	187.987		66.184	37.597	47.635	
3.44	3.1	3.52	5.7				2.382	1.301		333.305	189.287		66.661	37.857	47.889	
3.49	3.4	3.56	5.6				2.340	1.426		335.645	190.714		67.129	38.143	48.135	
3.53	3.2	3.60	5.6				2.340	1.342		337.985	192.056		67.597	38.411	48.380	
3.57	3.2	3.64	5.5				2.298	1.342		340.283	193.399		68.057	38.680	48.619	
3.61	3.1	3.69	5.4				2.257	1.301		342.540	194.699		68.508	38.940	48.848	
3.65	3.1	3.73	5.4				2.257	1.301		344.797	196.000		68.959	39.200	49.078	
3.69	3.1	3.77	5.2				2.173	1.301		346.970	197.300		69.394	39.460	49.299	
3.74	3.1	3.81	5.4				2.257	1.301		349.226	198.601		69.845	39.720	49.525	
3.78	3.1	3.85	5.4				2.257	1.301		351.483	199.901		70.297	39.980	49.745	
3.82	3.2	3.89	5.4				2.257	1.342		353.740	201.244		70.748	40.249	49.640	
3.86	3.1	3.94	5.8				2.424	1.301		356.164	202.544		71.233	40.509	49.595	
3.90	3	4.12	5.7				10.719	1.259		366.883	203.803		73.377	40.761	50.685	
3.94	3.2	4.31	6.1				11.471	1.342		378.354	205.145		75.671	41.029	51.860	
3.99	3.4	4.50	6				11.283	1.426		389.637	206.572		77.927	41.314	52.993	
4.15	3.6	4.69	5.8				10.907	6.041		400.545	212.613		80.109	42.523	54.081	

WHITEHORSE SEWAGE LAGOON DYE RETENTION WORKSHEET

DAYS A	STN A (PPB)	DAYS B	STN B (PPB)	DAYS C	STN C (PPB)	DYE RECOVERY PER TIME (ML) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (ML) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (%) #DYE-C	#DYE -B	#DYE-A	CUMM DYE RECOVERY (%) MINUS BACKGROUND #DYE-B	#DYE-C
4.32	3.3	4.87	5.8				10.907	5.538		411.452	218.150		82.290	43.630	55.179	
4.49	3.4	5.06	5.7				10.719	5.705		422.171	223.856		84.434	44.771	56.249	
4.65	3.4	5.25	5.4				10.155	5.705		432.326	229.561		86.465	45.912	57.244	
4.82	3.4	5.44	4.9				9.215	5.705		441.541	235.267		88.308	47.053	58.154	
4.99	3.2	5.62	4.7				8.839	5.370		450.379	240.637		90.076	48.127	58.966	
5.15	3	5.81	4.6				8.651	5.034		459.030	245.671		91.806	49.134	59.757	
5.32	2.9	6.00	5.4				10.155	4.866		469.185	250.537		93.837	50.107	60.761	
5.49	2.8	6.19	4.6				8.651	4.699		477.835	255.236		95.567	51.047	61.573	
5.65	2.4	6.37	4.6				8.651	4.027		486.486	259.263		97.297	51.853	62.378	
5.82	2.7	6.56	4.5				8.462	4.531		494.948	263.794		98.990	52.759	63.164	
5.99	2.6	6.75	4.5				8.462	4.363		503.411	268.157		100.682	53.631	63.942	
6.15	2.4							4.027			272.185			54.437		
6.32	2.3							3.860			276.044			55.209		
6.49	2.3							3.860			279.904			55.981		
6.65	2.2							3.692			283.596			56.719		
6.82	2.2							3.692			287.287			57.457		
6.99	2.1							3.524			290.811			58.162		

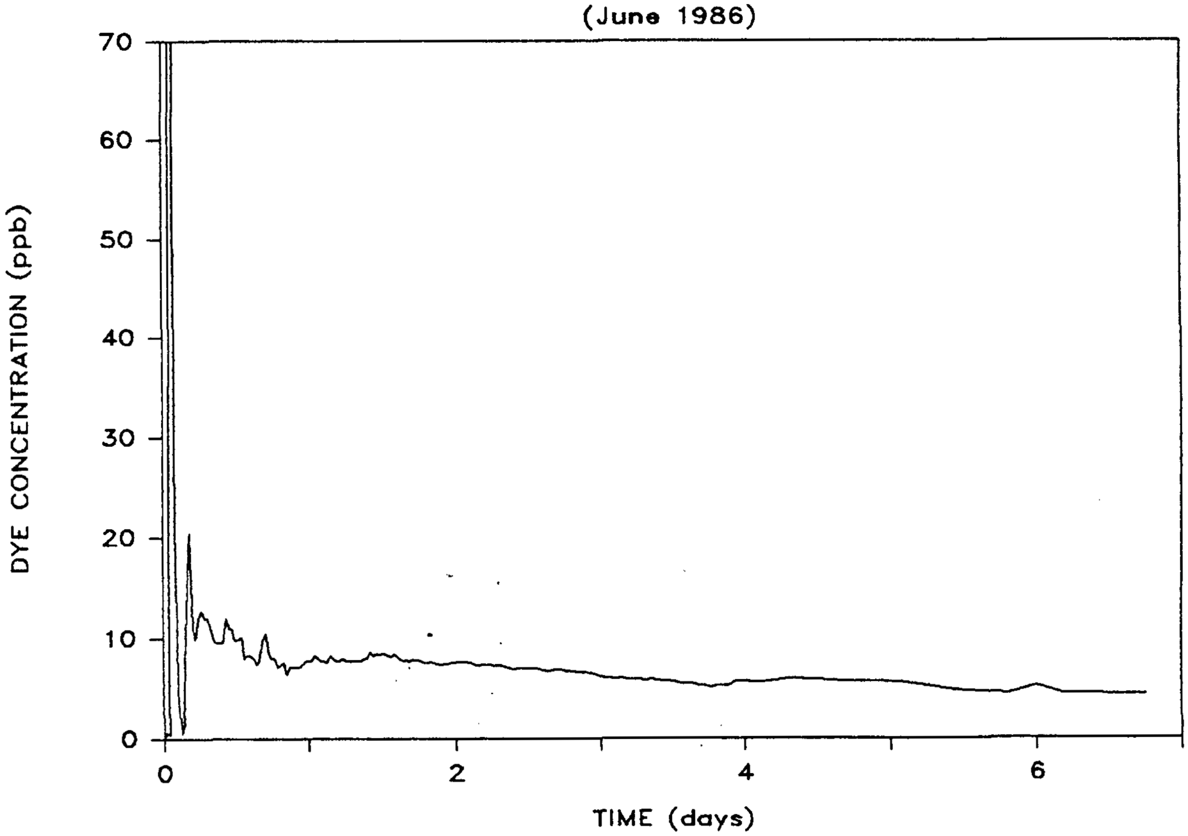
STN A--TRACER DYE WASHOUT CURVE

(June 1986)



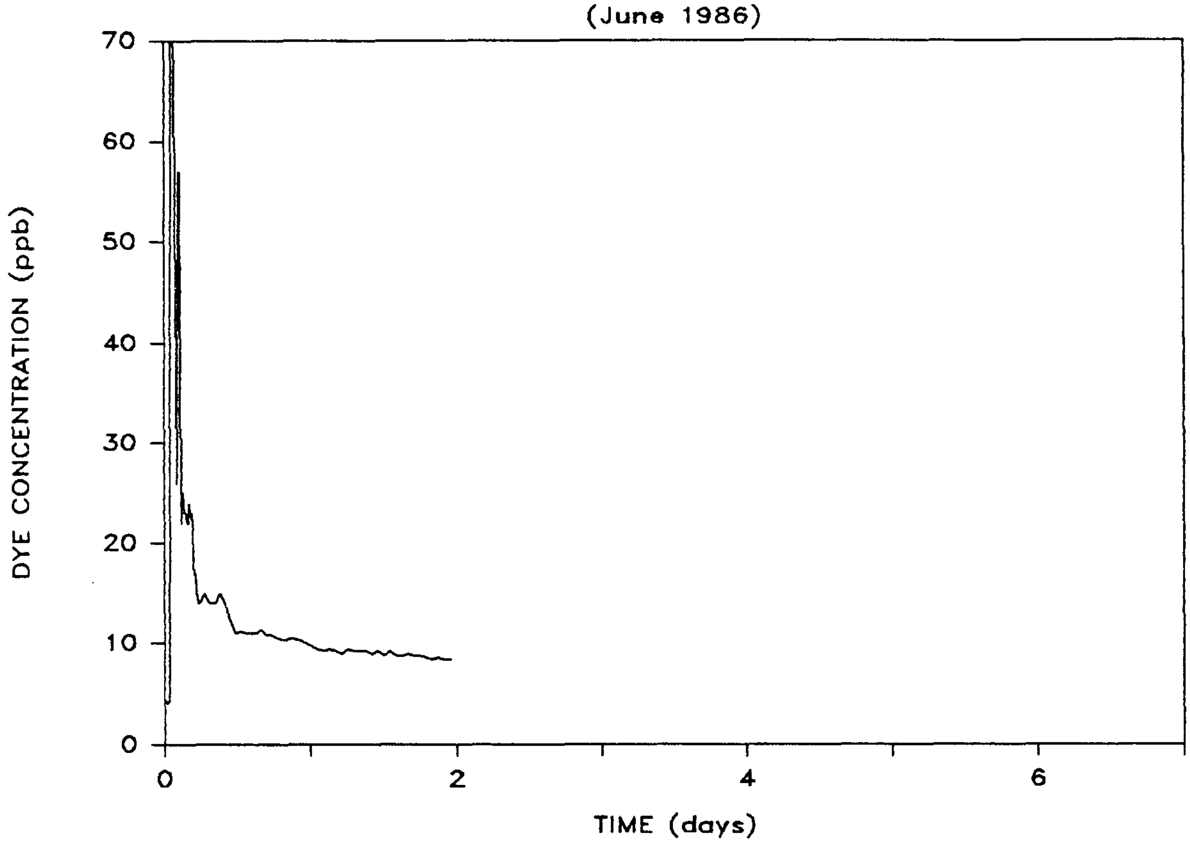
STN B--TRACER DYE WASHOUT CURVE

(June 1986)



STN C--TRACER DYE WASHOUT CURVE

(June 1986)



APPENDIX III

UNPUBLISHED DATA BY W. RANDLE,

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WHITEHORSE LAGOON TRACER STUDIES:

1. STUDY METHODOLOGY:

The tracer washout curves for cells #1, #2, and #3 (figs. 8 to 10), show evidence of short-circuiting for each of the cells. Since the highest degree of short circuiting is expected for the cell with the highest solids loading, you may have missed the major peak at Station A occurring between 10 minutes and 40 minutes after injection into the influent of cell #1. Therefore, a sampling interval of perhaps 5 to 10 minutes for the first 30 minutes may have been warranted.

The data for cell #3 indicates that station C was sampled for 2 days. A mean residence time of 4 days was predicted by extrapolating from the plot of %Recovery verses time (fig.10). This method is valid only if you assume that the residence time characteristics of cell #3 are the same as either #1 or #2. A longer sampling period at station C would have avoided the need to extrapolate the data.

No tracer data for the effluent of cell lagoon #4 was collected. Obtaining tracer data for cell #4 would have been useful as it would have given an indication of the overall treatment performance of the 4 lagoons in series.

For future studies, if possible, a tracer study should be implemented on all 4 lagoons by first injecting a slug of tracer at the influent to cell #1 and sampling at 5 to 10 minute intervals for the one to two hours to ensure detection of short-circuiting tracer at the effluent of cell #4. Consequently, samples should be collected for about 2 theorectical HRT's. (approximately 11 days). This ensures that no truncation error will result in the washout curve due to early termination of the sampling program. In any case, at the end of 2 HRT's the concentration of tracer in the samples will likely be nearing the sensitivity limit of the detection technique.

2. DATA ANALYSIS

Table 1 summarizes the results obtained from analysis of the tracer data for Whitehorse.

TABLE 1

STN.	theoretical HRT (days)	%Tr	%Tr*	estimated HRT (days)	Cmax theory (ppb)	Cmax measured (ppb)
A	5.1	46	73.4	3.03	11.1	22.1
B	5.3	43	95.5	3.19	16.9	300
C	5.4	21	77.9	3.40	15.3	120

NOTE : q(mean flow)= 7.3 m3/min

The theorectical HRT was estimated by dividing the volume of the cell by the mean flow through the cell.

Tracer recovery estimates were calculated in two ways. The estimates %Tr were based on the area under the tracer washout curves as calculated using the trapezoidal rule. In addition, as a major problem with estimates for tracer recovery is that they vary with the length of time of sampling, tracer recovery estimates, %Tr*, were made which included truncation error estimates. (Terminating the sampling program results in the truncation of the tracer distribution curve and, consequently, lower values for %Recovery.) Truncation error estimates were calculated by fitting a mathematical model to the "tail" of the tracer washout curves, and estimating the areas under the tail from the time of truncation to infinity. The equation is of the form:

$$A(trunc)=Co^{*}(HRT)^{*}\exp[-t(trunc)/HRT]$$

where the model parameters HRT, and Co are estimated from the slope and intercept, respectively, of the washout curve tail from time "t" to time "t(trunc)".

Calculation of mean hydraulic retention times was based on the method in your paper (ie., from the plot of %Recovery versus time). However, instead of of assuming 100% tracer recovery to develop the plots, the %Tr* values (which included estimates of the truncation errors) were used. As a result, the estimates in Table 1, above, are lower than the mean HRT estimates reported in your paper.

The mean retention time for cell #3 was calculated using the model parameters HRT and Co in the general tracer wash-out curve equation :

$$C=Co*exp(-t/HRT)$$

Predicted concentrations were calculated from t=1.95 days to t=6.99 days. The concentrations were converted to cumulative "mls" recovered using your conversion factor (1ppb=.001ml/m3), and then to % tracer recovered based on the total estimated %Recovery over infinite time (ie. %Tr* values). The mean retention time, as reported in Table 1, was the time corresponding to 50% tracer recovery.

Assuming a total working volume for cell #1 of 53 650 m^3, 500 ml injection of Rhodamine WT, and complete mixing, the expected maximum tracer concentration was calculated as follows:

$$Cmax(theory)=Tm/V$$

where, Tm=mass of tracer injected, micro grams(ug)

V=total working volume of lagoon, litres(l)

(Note : specific gravity of Rhodamine WT dye=1.19)

$$Cmax(theory)=\frac{500ml \times 100\% \times 1.19 \times 10^6 \ ug/g}{53\ 650\ m3 \times 1000\ l/m3}$$

$$Cmax(theory)=11.1\ ug/l \text{ or } 11.1\ ppb$$

In Table 1, the values for Cmax(theory), as calculated above, are compared to the values for Cmax(meas), the maximum measured concentrations from the tracer washout curves.

DISCUSSION:

The estimated mean retention times in Table 1 are about 60% of the the theoretical cell residence times, demonstrating that the lagoons are not completely mixed. Comparisons of Cmax(theory) to Cmax(meas) indicate that short-circuiting of tracer is taking place in all three cells. Further, the results indicate that cell #1 exhibits a lower degree of short-circuiting than cells #2 and #3 (i.e. for #1 Cmax(meas)/Cmax(theory)=2, for #2 Cmax(meas)/Cmax(theory)=18, for #3 Cmax(meas)/Cmax(theory)=8). However, this doesn't make sense as cell #1 has not only the highest solids loading but also the lowest estimated mean retention time. Therefore, as mentioned earlier, we suspect that a major peak in tracer concentration occurred at Station A between 10 minutes and 40 minutes following tracer injection.

The incomplete tracer recovery estimates for cells #1 and #3 may be due to several factors: (a) poor flow estimates, (b) inaccurate estimates of the amount of tracer injected, or (c) poor fluorometer calibration. Incomplete tracer recoveries are the rule rather than the exception in tracer studies.

The high degree of short-circuiting in all cells might be due to the configuration of the inlets and outlets (ref. fig.2 of your report). For example, the flow in Cell #1 probably follows the path shown in fig. A, below.

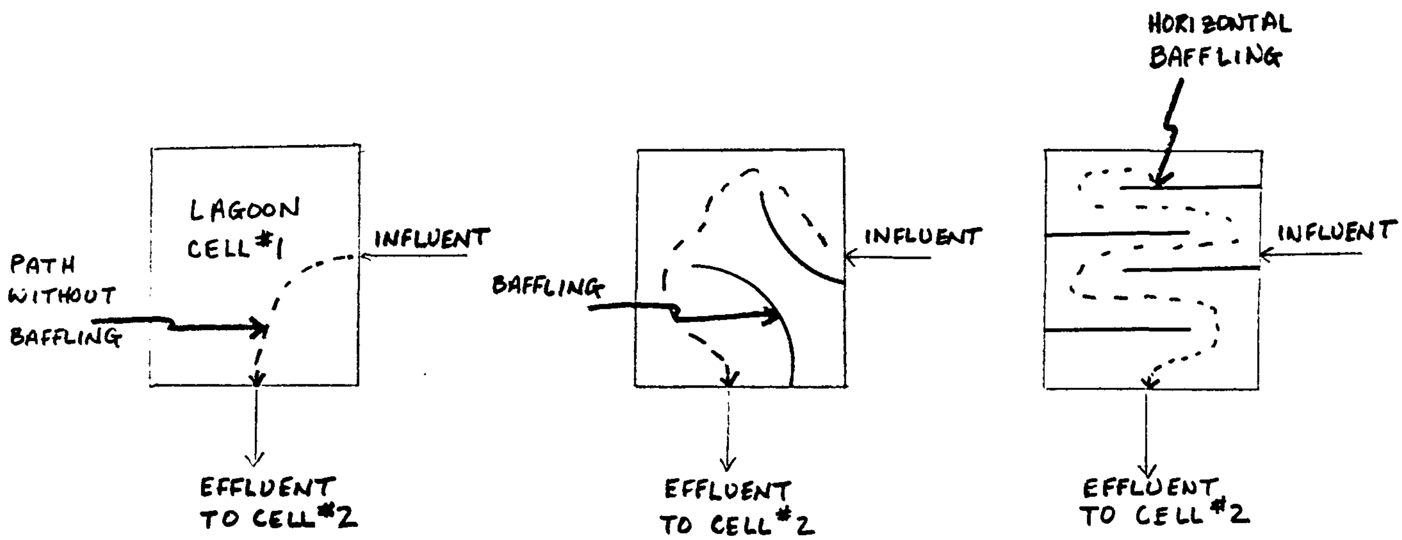

FIG. A FIG. B FIG. C

The incoming flow will proceed along a path of least resistance, that is, directly from inlet to outlet as outlined by the dotted lines in figure A. A configuration such as that shown in figures B or C would lower the degree of short-circuiting by ensuring greater distribution of flow throughout the cell before exiting through the outlet to cell #2. Although only suggestions, the addition of some baffling is worth considering in view of the high degree of short-circuiting in all cells.

Finally, a short comment on pulsating influent flows. In our opinion this type of flow would tend to increase the degree of short-circuiting within the lagoon. The non-uniformity of the flow would probably transport the tracer directly to the effluent without adequate mixing.

APPENDIX IV

WATER CHEMISTRY DATA
COLLECTED IN 1985

Table I WATER CHEMISTRY DATA COLLECTED AT THE WHITEHORSE SEWAGE LAGOONS, 1985

PARAMETER (mg/l unless noted)	STN. 1 Influent March 20	STN. 1 Influent July 17	STN. 4 Effluent All cells March 20	STN. 2 Effluent NE cell July 17	STN. 3 Effluent NW cell July 17
Temperature °C	6.0	13.5	1.0	13.0	13.0
Dissolved Oxygen	4.2	9.2	1.6	0.6	0.6
pH Insitu	7.65	7.8	7.1	7.6	7.6
Lab	7.5	7.57	7.1	7.07	7.07
Cond. (umhos/cm)					
Insitu	240	290	240	320	325
Lab	440	425	385	445	445
Color (units)	40	10	20	40	40
Turbidity (F.T.U.)	31	2.8	15	13	11
Nonfilterable Residue	49	39	9	16	17
Filterable Residue	277	400	200	300	800
Biolog. Oxygen Demand$_5$	75	18	43	38	44
Chemical Oxygen Demand	150	115	50	150	150
Total Organic Carbon	30.7	33.4	9.9	37.2	34.9
Total Inorganic Carbon	47.4	39.5	39.4	47.9	49.1
Total Alkalinity	156	140	144	152	152
Total Hardness	105	---	106	131	
Total Phosphate	3.6	1.4	2.0	2.5	2.5
Nitrite	.005	.075	<.007	.016	.014
Nitrate	<.01	.014	<.01	<.005	<.005
Ammonia	12.9	7.4	9.18	9.2	9.5
Sulfate	35	34	31	34	34
Chloride	12.6	19.6	12.5	21.1	20.9
Surfactants	---	.11	---	.79	.46
Phenols	.039	.016	.056	.035	.041
Oils and Greases	23	4	5	<20	4
Bioassay 96 hr. LC_{50}	---	---	67.4%	---	---
Total Coliforms (#/100ml)	2.9×10^6	---	1.2×10^5	---	---
Fecal Coliforms (#/100ml)	8.8×10^6	---	2.6×10^5	---	---

TABLE 1 WATER CHEMISTRY DATA COLLECTED AT THE WHITEHORSE SEWAGE LAGOONS, 1985 (cont.)

PARAMETER (mg/l unless noted) Extractable Metals	STN. 1 INFLUENT March 20	STN. 4 EFFLUENT March 20
Al	.21	<.05
As	<.05	<.05
B	.005	.03
Ba	.041	.03
Be	<.001	<.001
Ca	22.1	22.3
Cd	<.002	<.002
Co	<.005	<.005
Cr	<.005	<.005
Cu	.055	.025
Fe	.276	.244
Mg	11.7	12.0
Mn	.089	.078
Mo	.005	<.005
Na	22.2	17.2
Ni	<.02	<.02
P	4.08	2.61
Pb	.02	<.02
Sb	<.05	<.05
Se	<.05	<.05
Si	.9	.8
Sn	.02	<.01
Sr	.151	.154
Ti	.004	.008
V	<.005	<.005
Zn	.059	.024