CHAPTER 121

MARINE MONITORING OF THE VICTORIA SEWERAGE SYSTEM

by

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ABSTRACT

The Capital Regional District of British Columbia, Canada, is implementing for the Greater Victoria area, a major sewerage plan based mainly on marine discharge by submerged outfalls. To assess effects on the receiving ecosystem, a thirty month monitoring program has been carried out at the site of a newly constructed 6000 foot marine outfall. Of the standard water quality parameters, several were established during the pre-discharge period as "gross sewage field indicators" at beach outfalls: nitrite, phosphate, total and fecal coliform bacteria, Secchi depths, Forel colour and salinity. The remaining parameters were not sensitive to the presence of effluent: temperature, dissolved oxygen, nitrate, silicate and chlorophyll. In the water surrounding the diffuser of the extended outfall, only total coliform values showed the presence of effluent once discharge was diverted from the beach outfall. Profiling techniques were employed for measuring chlorophyll, turbidity and Rhodamine dye. A method was developed for mapping coliform bacteria in the sediment surrounding the diffuser, as an index of the ability of the receiving water to assimilate effluent loads being discharged into it. It is stressed that monitoring programs should be included in plans for any major coastal operation.

INTRODUCTION

Long marine outfalls for discharging sewage effluent have been in operation at many locations and for many years along the west coast of the United States, and have in several cases been accompanied by extensive monitoring programs (eg. State Water Pollution Control Board 1956, Garber 1960, Ludwig & Onodera 1964, Ludwig & Storrs 1970). However, the Canadian west coast has only recently begun to consider the use of long outfalls, as well as their environmental suitability and hence the need for adequate monitoring.

Specifically, the Greater Victoria area is in the early phases of implementing a major sewerage disposal plan based mainly on marine discharge by extended outfalls, to replace a number of outfalls which discharge untreated municipal sewage at the shoreline. The rationale behind considering long marine outfalls for untreated sewage, rather than the construction of sewage treatment plants at this time, is that the area being serviced (FIG. 1) is surrounded by marine waters with a great deal of tidal flushing.

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Tidal currents of up to 2-3 knots (1.0-1.5 m/sec) result in continuous and large scale mixing off most of the coastline and should result in high dilution rates for discharged effluent.

When in April 1969 the provincial regulating authority issued a permit to the Capital Regional District for the construction and operation of a 6000 foot long outfall at Macaulay Point on the south coast of the area (FIGS. 1 & 2), it was stipulated that it should "carry out a sampling and surveillance program ... on the beaches and in the waters adjacent to the outfall and Macaulay Point". The reasons for requiring such a monitoring program were given in the letter of transmittal which read: "although there is a wealth of information throughout the world in support of the proposed method of disposal authorized, we have decided in the public interest to use the proposed outfall as a research project. It is the intention of the Pollution Control Branch to use the information gathered .... to verify the effectiveness of the proposed method of disposal and to document for future reference the suitability of long outfalls for the disposal of sewage in the coastal waters of British Columbia."

Accordingly, a group within the Department of Biology of the University of Victoria was requested to carry out an intensive two year monitoring program in order to collect data on the response to the discharged effluent of the receiving marine ecosystem. The program was designed to cover one year before and one year after operation of the outfall commenced in the summer of 1971. A program was established combining routine monitoring of a number of standard chemical, physical and biological parameters along with several more research-oriented projects aimed at studying the possible effects of the discharged effluent on certain components of the surrounding ecosystem. Members of the same group have also carried out a number of studies at several other outfall locations but the most extensive study has been carried out at the Macaulay Point outfall.

This outfall consists of a 36 inch (0.9 m) pipe, 6000 feet long (1829 m) with a multiport 500 foot (152 m) diffuser and discharging into approximately 200 feet (60 m) of water. Initial average daily discharge rates have been between 5 and 28 CFS (3 - 15 MGD, 14 - 68 X 10^6 l/day) with average flows of 45 CFS (24 MGD, 109 X 10^6 l/day) projected for the year 2015.* Prior to construction of this extended outfall, discharge was directly at the low water mark.

In order to obtain background data prior to initiation of discharge from the new outfall, sampling began in May of 1970. The University is scheduled to continue the initial program until the end of October 1972, thus giving 16 months of pre-discharge data and 14 months of post-discharge data.

In designing a monitoring program for a specific outfall, there are two basic aims: (1) to delimit the spatial extent of the effluent field, i.e. where is it? how concentrated is it? and (2) to estimate its impact on certain

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* And if a recent engineering study is put into effect, another outfall will be built in the same area, with projected flows in 2015 of close to 90 CFS (48 MGD, 218 X 10^6 l/day).

critical chemical and biological parameters. The latter of these two questions is the more complex and difficult, for it is impossible to monitor every aspect of the ecosystem in order to see what perturbations may be occurring. Thus we must fall back on a few selected, accurately measurable, indices. But even the relatively simple problem of delimiting the effluent field poses many problems, especially in an area such as the one under consideration where relatively low discharge rates couple with very large dilution rates to make the actual field an extremely elusive target.

METHODS

A sampling grid was established (FIG. 2) which included 10 offshore stations (W) and 6 shoreline stations (S). Subsequently, in response to a request from public health authorities for additional coliform data near the shore, an additional 8 shoreline stations (K) were established, for coliforms only. Sampling was carried out from a 30 foot (9 m) oceanographic launch, which allowed the shoreline stations to be occupied within 15 to 50 feet (5 - 15 m) of the actual shore. The stations have been sampled at approximately 3 week intervals. In addition, two control stations were sampled 3 or 4 times a year. They were located in the middle of the Juan de Fuca Strait and were intended to provide data on open water conditions so that data will be available which can unequivocally be considered as being removed from localized influence of either terrestrial runoff or sewage effluent.

Two of the shore stations were located within a few feet of two separate outfalls (S3, S6), one of which (S3) ceased operation in August 1971 while the other is still in operation. This means that data were available for indicating immediate and gross effects of relatively undiluted effluent, for indicating the clean-up effect of cessation of flow at an outfall,as well as for indexing the effects of putting a new offshore outfall into operation. In essence, there were two types of control data: one from open marine waters and one from a still-discharging shoreline outfall.

The parameters routinely measured at the surface were the following: temperature, Secchi depth, salinity, nitrite, nitrate, phosphate, silicate, oxygen, chlorophyll, total and fecal coliforms, and Forel colour.

On alternate sampling dates depth profiles were taken of salinity, temperature (BT) and total coliforms at 0, 4, 25 and 50 m.

RESULTS

A. Pre-Discharge Data

The 16 months pre-discharge data supply the information necessary for the selection of those parameters which were reliable gross sewage field indicators. FIGS. 3, 4, 5 and 6 are time series plots of four such parameters (nitrite, phosphate, total coliforms and fecal coliforms) and show the high values for stations S3 and S6, with S3 values dropping to background values following diversion of discharge to the 6000 foot outfall.

Of the 12 parameters routinely measured, 7 indicated the presence of effluent at the two shore outfall stations: nitrites, phosphates, water coliforms (total and fecal), Secchi, Forel and salinity. These can be called "gross sewage field indicators" since the observed changes were from water samples normally collected only a few feet from the two shoreline, surface, non-diffuser outfalls. They cannot therefore all be thought of as necessarily useful indicators of a well-diffused effluent field. Indeed we have found that in the water around the new extended outfall, these indices cannot be distinguished from stations farther removed, even the offshore control stations. The one possible exception was coliform bacteria. The remaining standard water quality indices appear to have little value for effective monitoring since they did not show any marked effluent effect even in the plumes of the two active shoreline outfalls. These parameters were: dissolved oxygen, nitrate (FIG. 7), silicate, chlorophyll (FIG. 8).

Though it might be expected that chlorophyll levels could be reduced in the extremely turbid effluent plume, this cannot be substantiated because of the problem of filtering such water and obtaining suitable chlorophyll extracts.

It might also be expected that dissolved oxygen would be severely reduced in the effluent plume, but this was not shown to be the case. Apparently, even with the relatively low dilution values in effect close to these outfalls, the dissolved oxygen in the receiving waters was sufficient to make up for any oxygen deficiency in the discharged effluent.

Silicates and nitrates also did not show elevated values at these outfall stations, apparently due to their natural high levels in the receiving waters.

B. Post-Discharge Data

After 59 years of discharge of untreated sewage from the old shoreline Macaulay Point outfall, effluent was diverted to the new 6000 foot outfall on August 24, 1971. On the immediate following sampling date (2 days later) at S3, water coliforms, nitrites, phosphates, salinity, Secchi and Forel had returned to normal shoreline background levels. (FIGS. 3, 4, 5 & 6). In the 11 months of data collected since then this pattern has not changed, while at the offshore (W) stations surrounding the diffuser there have been no detectable changes, with the possible exception of coliform bacteria.

Though only preliminary analysis of the data has been carried out to date, it suggests that from the time that discharge from the new outfall began, there has been a slight elevation of coliform values at some of the offshore stations surrounding the diffuser. The frequency of total coliform values greater than 1000 MPN/100 ml (the locally required water quality standard) was calculated and showed that stations W4 and W1 had the most frequent occurrence of such values. This was in contrast to the pre-discharge data in which stations W6 and W9 showed the highest frequency. Note that W6 is in fact a shoreline station and is expected to be high. Two other methods of analyzing the data (so that all coliform values were used, not just values greater than 1000 MPN) suggested slightly different distribution patterns, though all methods examined showed W4 as being consistently high during the post-discharge months. This distribution agrees with the most frequent direction of tidal flow (between east and south-east) which should give a higher frequency of elevated coliforms at W4.

One of the most probable reasons that well-marked effects have not been observed in the receiving waters is that the outfall was designed to carry much higher flows than presently in effect. The present dilution rates should thus be much higher than for the flow rates eventually anticipated. Indeed, the intermittent pumping regime presently in effect (5 min. on, 20 min. off) makes it doubly difficult to locate the effluent field with any of the standard parameters since there is not a steady state plume issuing from the diffuser but pulses of effluent that are rapidly diluted.

Using published values (Associated Engineering Services Ltd. 1966) for two constituents of effluent, it was possible to make a preliminary estimate of the dilutions involved in the receiving waters at Macaulay Point. The maximum total coliform level measured in raw sewage was 33 X 10^6 MPN/100 ml. The maximum level measured at W stations since discharge was 24 X 10^2 MPN/ml. Thus the most conservative estimate of a dilution rate (ignoring bacterial die-off) is 1.5 X 10^4. A similar dilution rate would be necessary to reduce the measured levels of phosphate (42 mg/l) in sewage to those encountered at the W stations. Thus a preliminary estimate of the dilutions in effect by the time the field has surfaced would be in the order of 1.5 X 10^4.

Because of the high dilutions in effect, it has proved difficult to determine from water quality measurements whether the field has been surfacing. It has been commonly noted that an aggregation of seagulls on the surface near the diffuser appeared to be related to the presence of visible particulate sewage. In order to determine whether these gulls might be a reliable indicator of the surfacing field, on each sampling date that the gulls were present, water samples were taken at the centre of the aggregation, designated as station W0. However, there has been no evidence from the water quality data that effluent is present at that station. In particular, there appeared to be no trend of elevated coliforms. On two occations more intensive surveys have been carried out at W0, by taking a number of coliform samples in a line through the apparent centre of the aggregation of gulls. But even these intensive surveys have been inconclusive in showing a correlation between the presence of gulls and the presence of effluent, as indexed by coliform bacteria. TABLE 1 shows that on February 15, 1972, there were no elevated coliform values, while on March 13, 1972, high values did occur but were well to one edge of the gulls. Subsequently surface samples containing apparent gross floatables have been collected and tested for coliforms. Both total and fecal values so obtained had high values, proving their sewage origin. It is these particles that are probably being fed on by the gulls. The fact that standard water coliform samples are not elevated at W0 results from high sub-surface dilution of the effluent. The buoyant phase however will concentrate at the air-water interface close to the diffuser.

Another method employed for field delimitation has been the use of the fluorescent dye, Rhodamine WT, injected into the pipe at the pumphouse and then traced in the water column by vertical and/or horizontal profiling using a subsurface pumping system flowing through a continuously recording fluorometer. In a dye study on April 13, 1972, the diffusing dye was located at depth very near the diffuser. It could then be traced to the surface and thereafter at the surface for a distance of some two miles over a time period of two hours. Even with a strong onshore wind, there was no apparent impinging by the effluent field on the shore, due to a strong tidal current parallel to the shore. However, the ability of a single boat to give an adequate three-dimensional picture of the movement of the dye was severely limited, so aerial photography is being included in the dye study program.

Ideally it would be advantageous to have a technique that allowed three-dimensional profiling of the effluent field, without introduction of expensive tracers such as dye or a radioactive material. One such method tested at the Macaulay Point outfall has involved the use of a transmissometer for measuring turbidity. However, with the high dilutions in effect at the Macaulay Point outfall, it was not found possible to detect the field with this instrument. At other outfall locations the instrument has proved to be more successful. Two sewage fields (one from a beach outfall, the other from a sub-tidal outfall at 50 foot depth) were detectable by means of a towed transmissometer (α meter) to distances of 2000 - 2500 feet from their sources. Comparison of analyses of discrete samples with turbidity (α values) indicated that effluent field profiles can be expressed in terms of coliform levels, though profile interpretation will be site-specific as well as season-specific, due to variations in turbidity caused by phytoplankton or by the particulate component of the sewage itself. This turbidity profiling technique also has been applied with positive results to outfalls for mining wastes discharges.

Recognizing the difficulties involved in tracing an effluent field in the water column itself, it would seem advantageous to use the underlying sediments in some manner so as to obtain a cumulative chart of the extent of horizontal movement of the effluent field. A sensitive index that can be obtained from the sediments is the presence of coliform bacteria. Since these bacteria sediment out, and are relatively specific to sewage. their presence in the sediments should be an indication of the persistent presence of effluent in the overlying waters. Using divers in the shallow waters around several shoreline outfalls, the extent of the sewage fields could be mapped. However, there was a large degree of variability resulting both from field sampling and laboratory analysis, so a more reproducible sampling technique was sought. This was particularly imperative since diver sampling was not feasible around the Macaulay Point outfall at depths of around 200 feet (60 m). A technique has been developed which employs VanVeen grab samples. Replicate subsamples can be obtained from the grab sample by coring into the sediment with a ½ inch diameter, sterile glass tube. Although there is still a large degree of sample variability, differences between stations close to and distant from the diffuser can readily be discerned (TABLE 2). The value of this technique lies in the fact that it is a cumulative index of the extent of the field, as well as an indicator of the ability of the receiving waters to assimilate the effluent loads being introduced into it. A field of fixed size and concentration would suggest that the interaction between effluent and the receiving waters had reached a steady state. On the other hand, a steady growth of the size of the field as well as in the numbers of organisms encountered would suggest that the overlying water column is not capable of "treating" the wastes being discharged to it. It thus should be an extremely valuable long term monitoring index.

Discussion so far has been mainly with regard to effluent field delimitation. What about some of the critical biological components of the ecosystem? The enriching effect of injecting large quantities of nutrients into receiving waters is one that has become of paramount importance in many fresh water systems where the resulting eutrophication has severely downgraded the usefulness of many of our lakes and rivers. The same principles apply in marine ecosystems: if nutrients are added, they must go somewhere. They must be taken up by primary producers (phytoplankton), raise the reservoir of inorganic nutrients in the water, or sediment out. But the inescapable fact is that most of them must enter biological processes and in so doing change the balanced relationships that have evolved in the evolutionary time scales preceeding such a man-induced change. The real problem is, however, to quantify the impact that such enrichment has on the environment. With marine waters already being heavily laden with essential nutrients, it could well be that even massive injections of nutrients would have no measurable effect. On the other hand, localized effects might well be of significance; or a long term, low rate of eutrophication might be occurring, but virtually impossible to detect. We could well pose the question as to what is the long term, cumulative effect of all the nutrients being discharged into the Straits of Georgia and Juan de Fuca, a marine system that is in essence a large estuary and has on its boundary urban centres such as Vancouver, Seattle,and Victoria,as well as a number of large pulp mills discharging large amounts of wastes (FIG. 1). For instance, the relatively small urban area of Victoria will be discharging something like 2600 tons of nitrogen, 1700 tons of phosphate a year over the next forty years (Associated Engineering Services Ltd. 1966). Are we unwittingly working toward a Great Lakes situation even here?

Routine sampling of chlorophyll (an index of phytoplankton biomass) should be able to detect any long term rise in primary productivity in a marine area, if carried out over a long enough time scale so that normal yearly variations can be taken into account. But this sort of approach is an extremely long term one, for slow eutrophication may well take decades before it is detectable. A small scale localized monitoring program is not in a position to carry out the necessary work for such a project. The sampling required should be over large areas since spatial variability of phytoplankton growth is very important. The Macaulay Point monitoring program has investigated whether a point source of nutrients such as the Macaulay Point outfall may be contributing to small scale, localized phytoplankton growth. The method employed has been continuous chlorophyll profiling using a pumping system in line with a continuously recording fluorometer. With this system, fairly detailed maps of phytoplankton concentrations can be prepared (eg. FIGS. 9 & 10). The results show that distribution of planktonic plants in an inshore environment is very complex; that surface runoff of nutrients, local topography and weather plus inputs from various types of effluent, all contribute to phytoplankton patchiness. To select out the possible enriching effect of a particular outfall will entail continued profiling over several years. However, these data are essential before it will be possible to say whether or not sewage disposal is effecting this critical component of the ecosystem.

One of the sampling problems involved with monitoring primary productivity is the large degree of temporal variability, making results dependent on the particular conditions of a specific sampling day. It would be advantageous to be able to measure some component of the ecosystem that is more fixed and which might show the cumulative effects of the presence of effluent. Fortunately such a component does exist, since the bottom communities of animals are much more stable than planktonic communities. Sampling of these bottom dwelling animals has been carried out around several of the outfalls under study. In particular, pre-discharge and post-discharge samples have been obtained around the Macaulay Point outfall. These collections are still being worked on but preliminary results show a marked increase of scavenger-type organisms such as large hermit crabs, *Paguristes turgidus*. The samples are to be checked for species associational and biomass changes, with interpretation in terms of changes in trophic structure and production.

Apart from planktonic plants and benthic animals, there are a large number of other crucial components of the ecosystem that can be influenced by the operation of marine outfalls, eg.planktonic animals, pelagic fish, bottom fish, seaweeds, marine mammals, protozoans and bacterial populations. Their numbers, species diversity and distribution can all be influenced, but to monitor them all would be extremely expensive as well as probably redundant. However, the other side of the problem is that "a priori" we can never be certain just which are *the* crucial parameters to measure, so judicious choices must be made when designing monitoring programs. The shotgun approach of many early monitoring programs can now begin to be replaced by much more carefully designed programs where the parameters measured, the number of stations and replications as well as sampling frequency can all be selected site-specifically on the basis of past experience with a view to optimizing useful results. It is no longer good enough to measure something just because we know how to or because everyone else is doing it.

Another crucial component of a well-designed monitoring program should be that such a program be initiated prior to the construction or operation of any structure that is liable to disrupt the environment. Even with well-documented control stations, it is not always possible to interpret data collected after the event, if there is no background, pre-event data against which to compare it. Thus, in the planning stages for any major coastal development, parallel with engineering discussions, consideration should be given to an appropriate monitoring program which should be implemented early enough so that background data can be obtained prior to construction.

It will increasingly become the responsibility of any developing agency to take environmental factors into consideration and at as early a stage as possible predict any major physical, chemical and biological effects that may occur. Environmental safety margins must become as important a criterion as engineering safety margins. However, for these to be realistic they must be based on predictions that arise from adequate oceanographic and marine ecological information obtained from well designed monitoring programs.

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TABLE 1

Coliform transects (MPN/100 ml) across seagull aggregations near end of Macaulay Point Outfall.

A. February 15, 1972. Stations approximately 20 feet apart.

							Aggregation of Gulls										
Station	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Total	70	40	<30	90	40	40	40	40	40	<30	<30	40	40	90	40	90	40
Fecal	<30	<30	<30	<30	<30	<30	40	<30	<30	<30	<30	<30	<30	<30	<30	40	40

B. March 13, 1972. Stations approximately 15 yards apart.

				Aggregation of Gulls								
Station	1	2	3	4	5	6	7	8	9	10	11	12
Total	70	90	<30	40	90	70	430	640	430	11,000	640	430
Fecal	<30	<30	<30	<30	40	<30	40	90	430	150	90	70

TABLE 2

Sediment coliform levels in the area of the Macaulay Point Outfall. Replicate samples were taken at W1 (at the diffuser) and W2 (½ mile offshore from diffuser).

Station	Subsample	Coliform Values (MPN/100ml) Total	Coliform Values (MPN/100ml) Fecal
W1	1	46,000	43,000
W1	2	46,000	24,000
W1	3	>110,000	43,000
W1	4	110,000	7,500
W1	5	>110,000	7,500
W1	6	46,000	4,300
W1	7	15,000	930
W1	8	46,000	4,300
W1	9	46,000	2,100
W1	10	110,000	2,400
Mean		68,500	13,903
Standard Oeviation		36,942	16,671

Station	Subsample	Coliform Values (MPN/100ml) Total	Coliform Values (MPN/100ml) Fecal
W2	1	930	430
W2	2	4,300	90
W2	3	2,100	90
W2	4	930	90
W2	5	2,100	230
W2	6	1,500	40
W2	7	750	40
W2	8	93	>30
W2	9	4,300	40
Mean		1,889	120
Standard Deviation		1,509	131

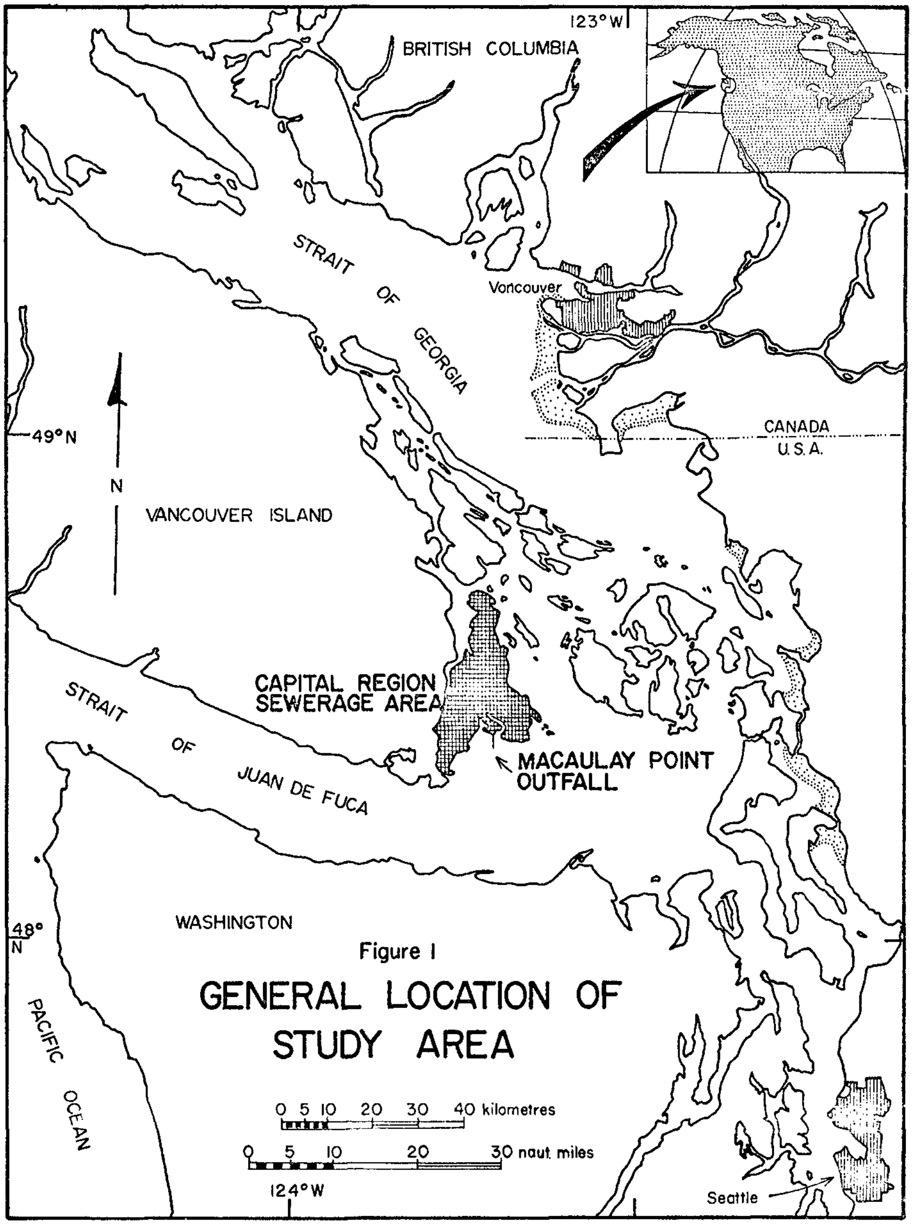

Figure I

GENERAL LOCATION OF STUDY AREA

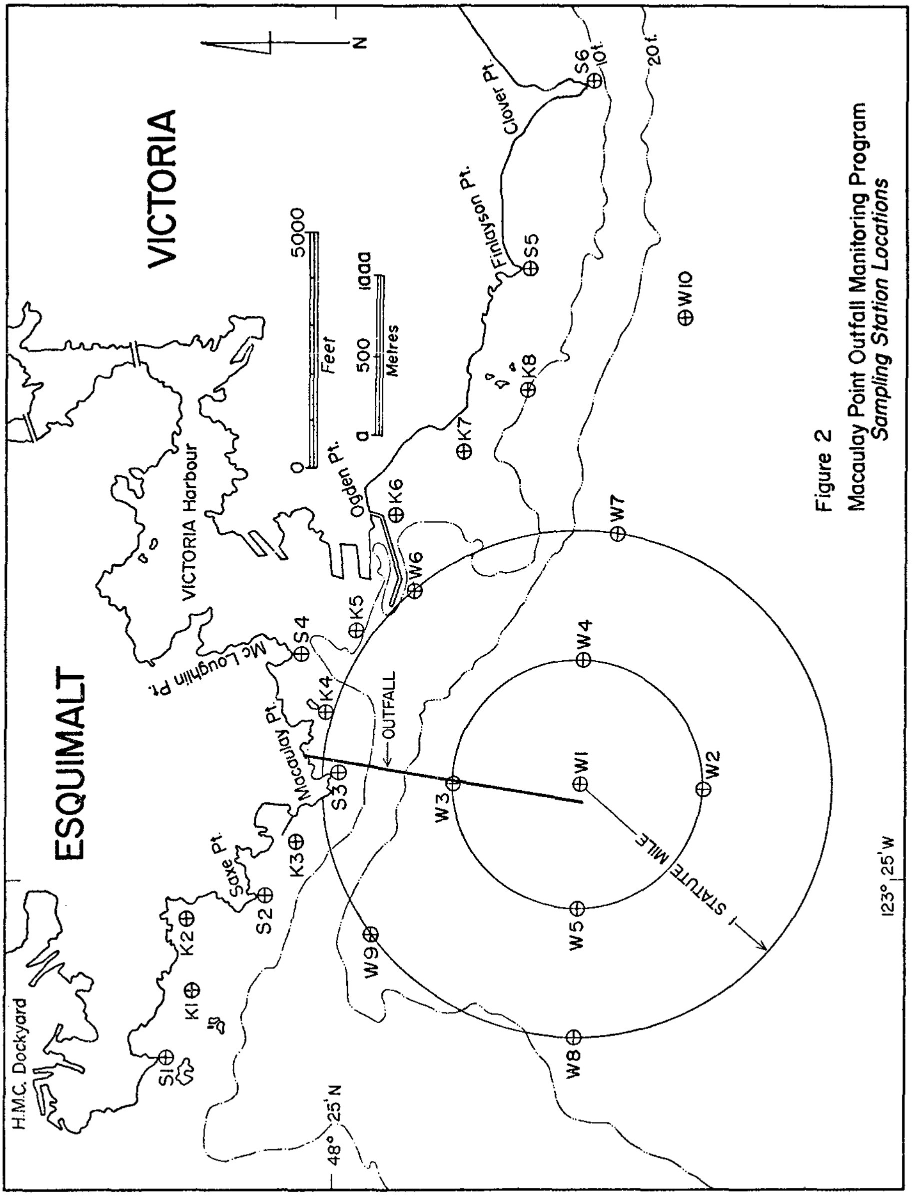

Figure 2
Macaulay Point Outfall Monitoring Program
Sampling Station Locations

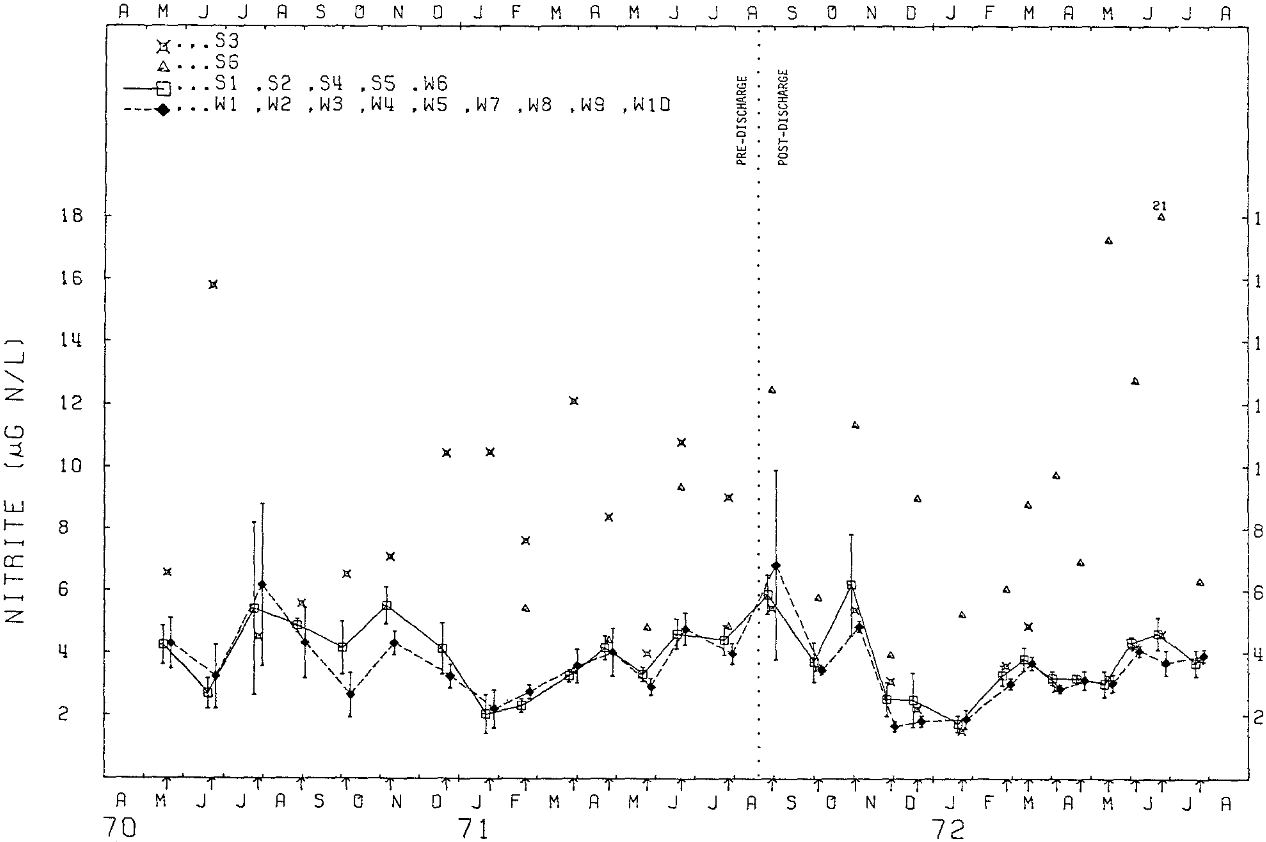

FIGURE 3. MEAN NITRITE VALUES (computer-drawn time series)
Vertical lines represent ± 1 standard deviation of the mean. Arrows on X axis denote sampling dates. Note symbol displacement to left and right of sampling date in order to reduce overlap.

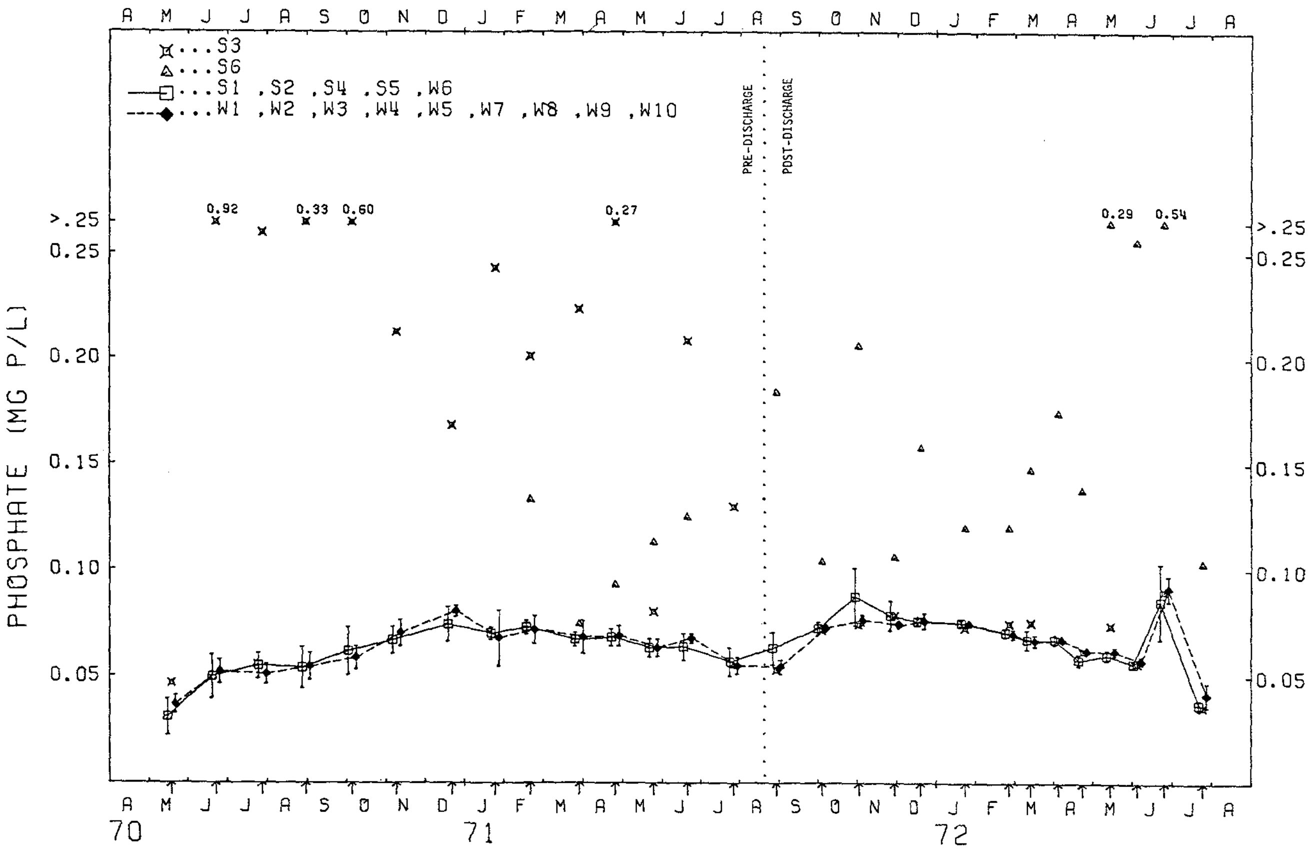

FIGURE 4. MEAN PHOSPHATE VALUES (computer-drawn time series)
Vertical lines represent ± 1 standard deviation of the mean. Arrows on X axis denote sampling dates. Note symbol displacement to left and right of sampling date in order to reduce overlap.

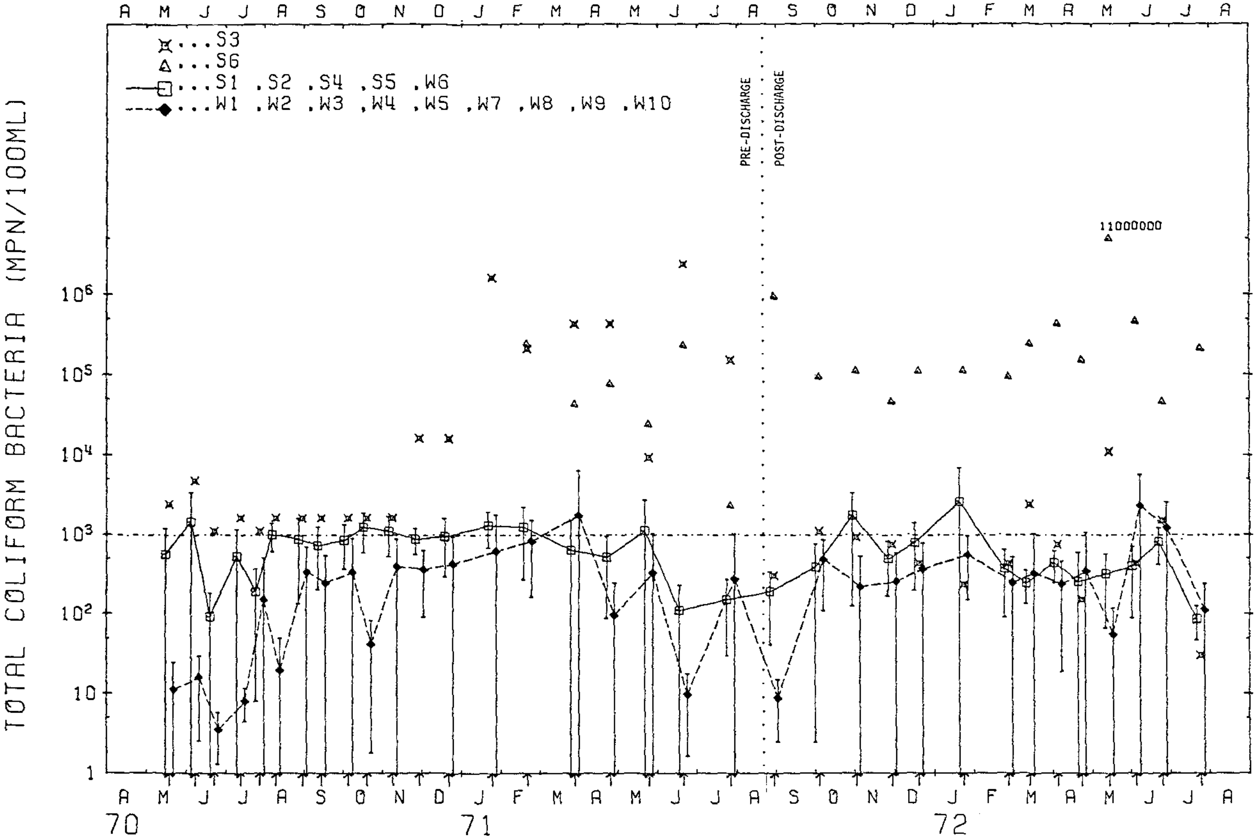

FIGURE 5. MEAN TOTAL COLIFORM BACTERIA VALUES (computer-drawn time series) Vertical lines represent ± 1 standard deviation of the mean. Arrows on X axis denote sampling dates. Note symbol displacement to left and right of sampling date in order to reduce overlap.

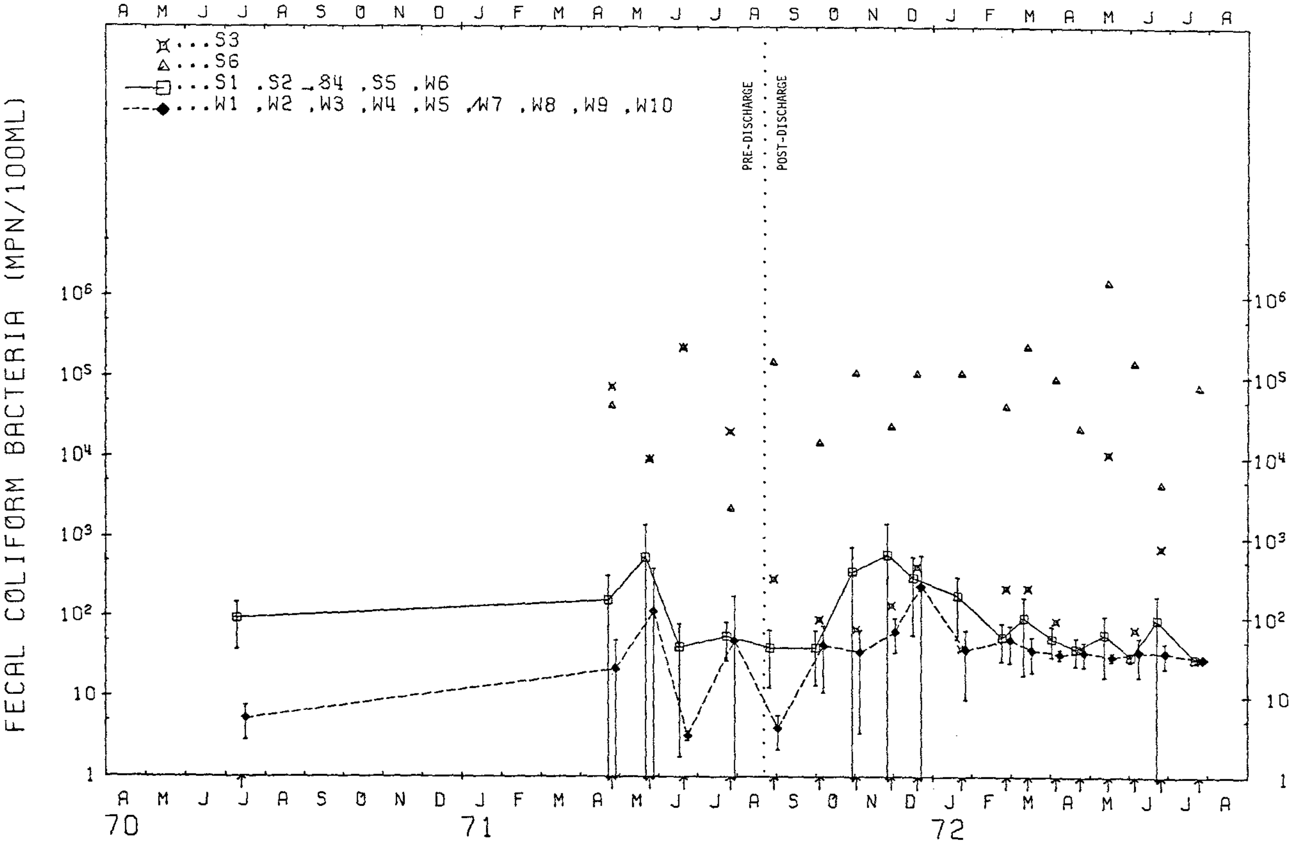

FIGURE 6. MEAN FECAL COLIFORM BACTERIA VALUES (computer-drawn time series)
Vertical lines represent ± 1 standard deviation of the mean. Arrows on X axis denote sampling dates. Note symbol displacement to left and right of sampling date in order to reduce overlap.

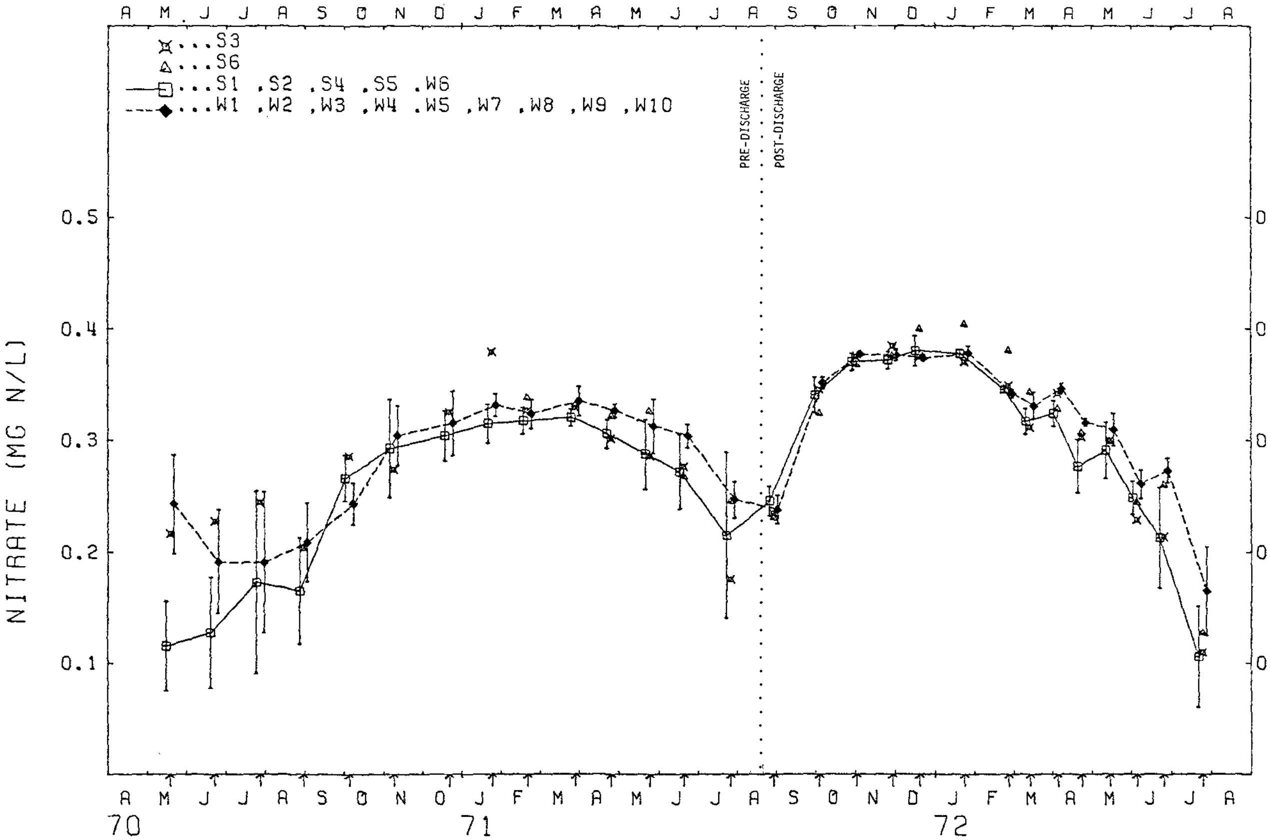

FIGURE 7. MEAN NITRATE VALUES (computer-drawn time series)
Vertical lines represent ± 1 standard deviation of the mean. Arrows on X axis denote sampling dates. Note symbol displacement to left and right of sampling date in order to reduce overlap.

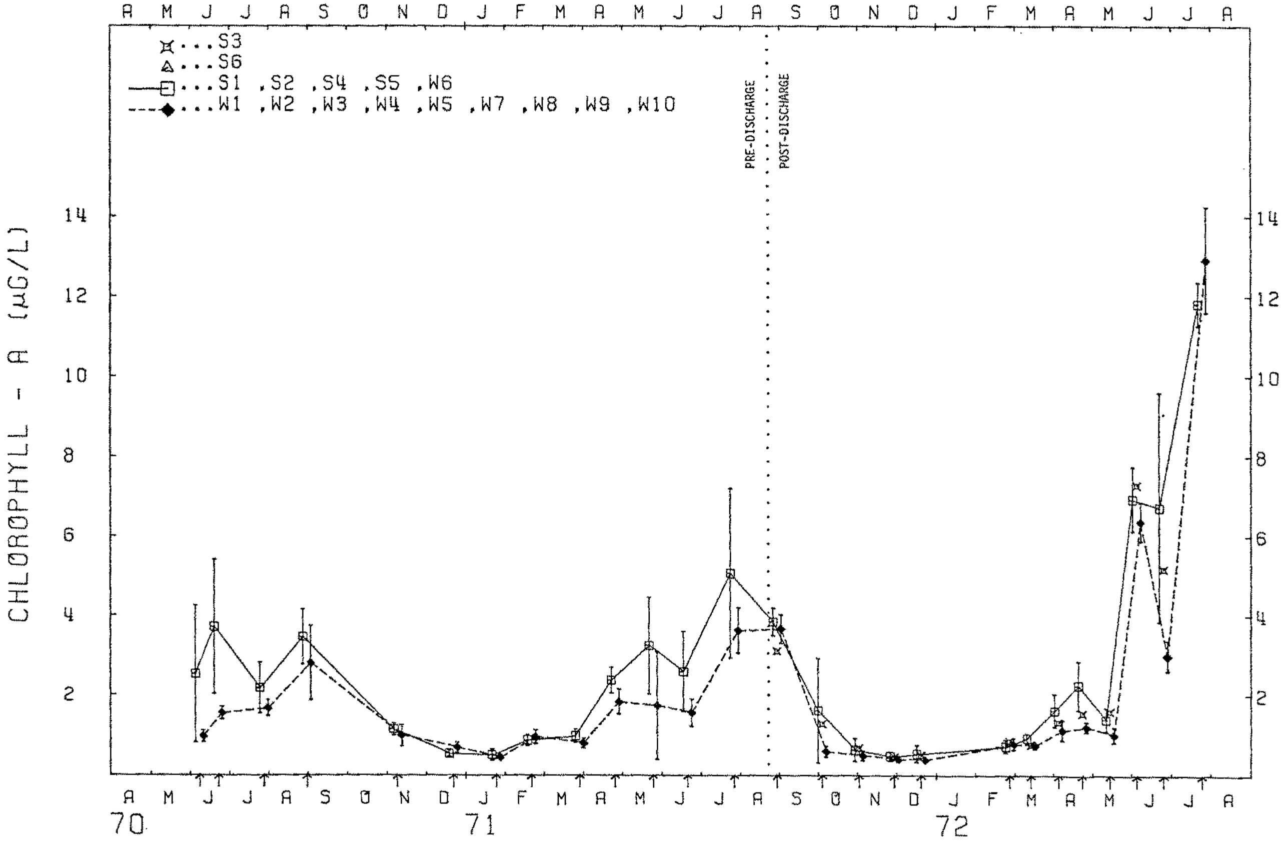

FIGURE 8. MEAN CHLOROPHYLL-A VALUES (computer-drawn time series)
Vertical lines represent ± 1 standard deviation of the mean. Arrows on X axis denote sampling dates. Note symbol displacement to left and right of sampling date in order to reduce overlap.

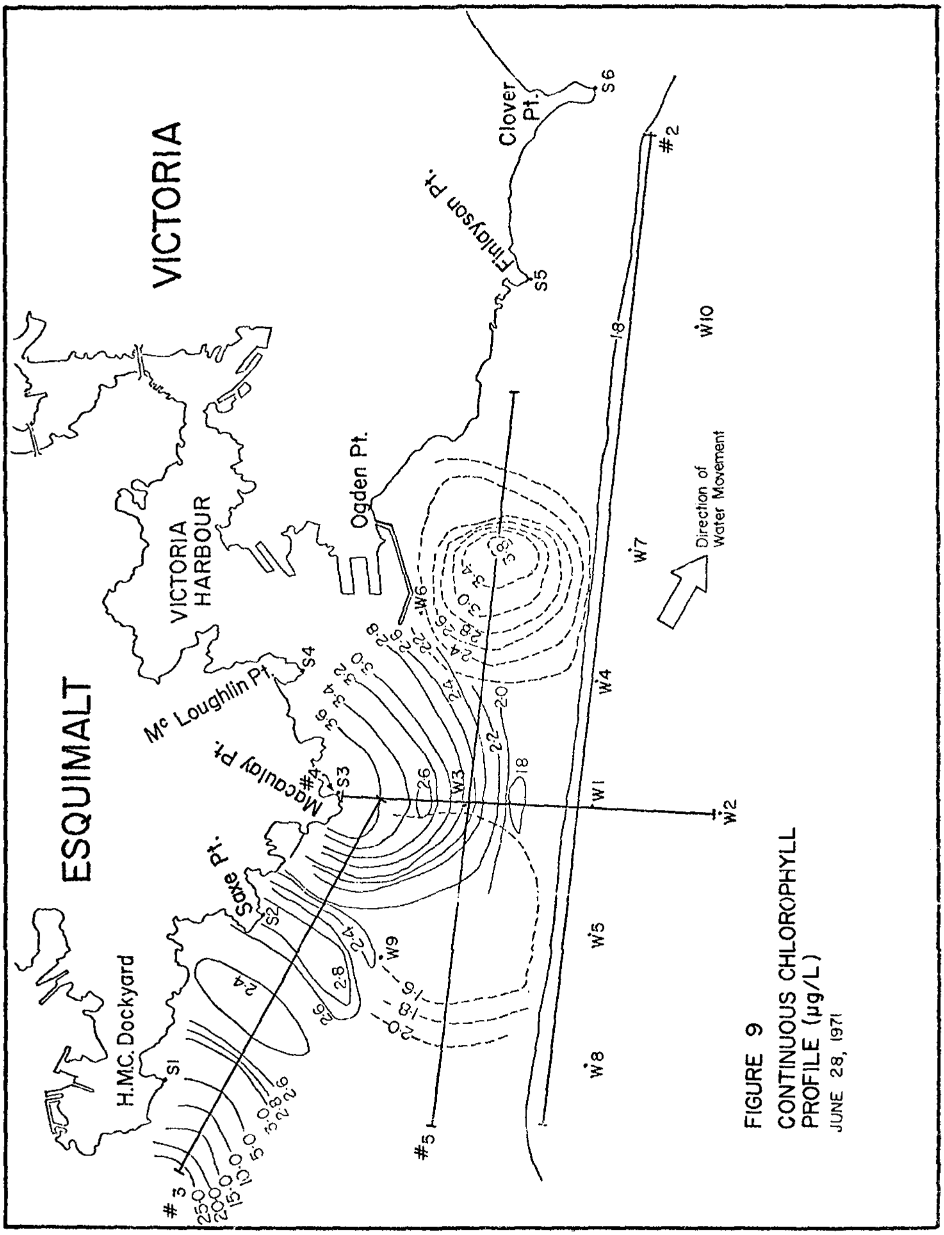

FIGURE 9
CONTINUOUS CHLOROPHYLL PROFILE (µg/L)
JUNE 28, 1971

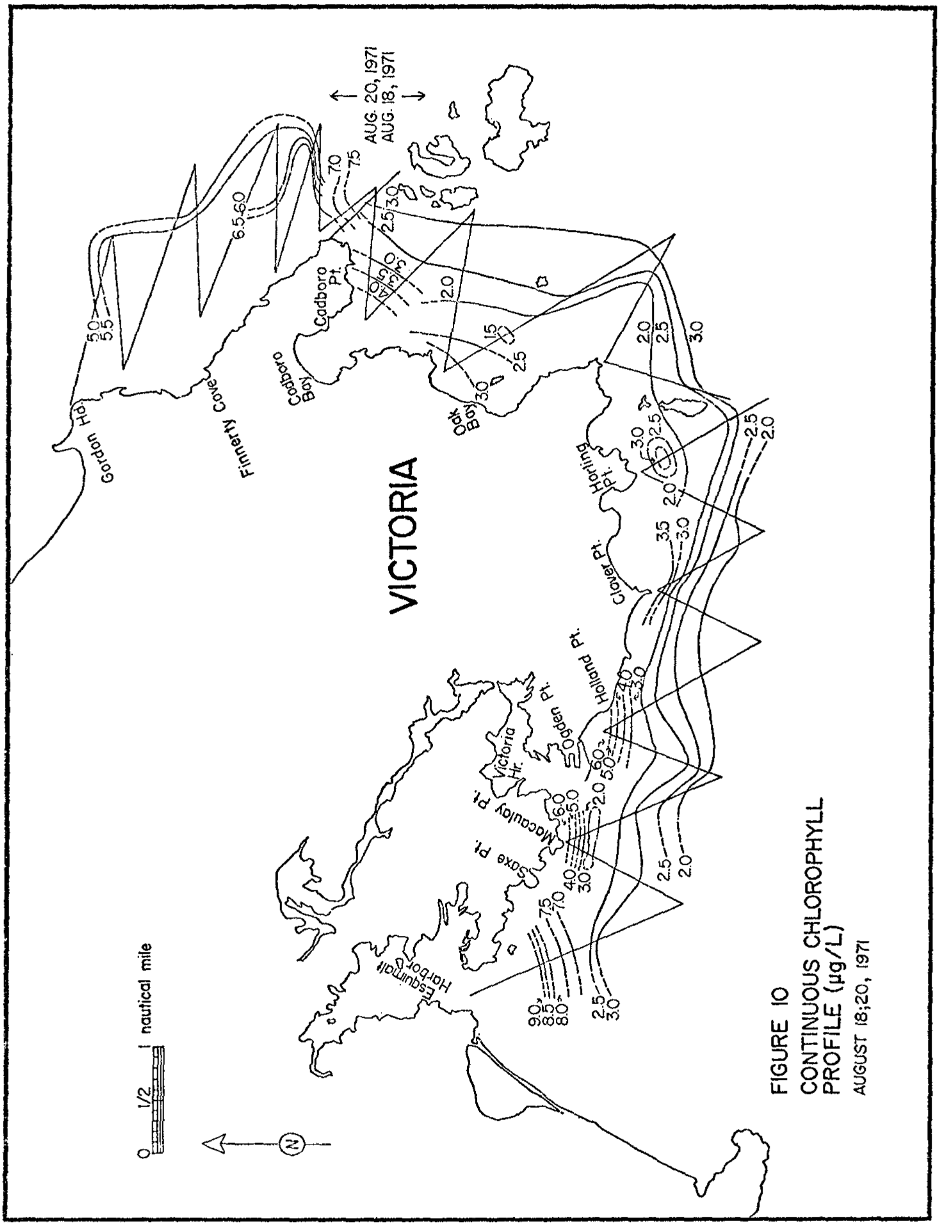

FIGURE 10
CONTINUOUS CHLOROPHYLL PROFILE (µg/L)
AUGUST 18;20, 1971