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NUTRIENT STATUS OF THE ESTERO AMERICANO

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NUTRIENT STATUS OF THE ESTERO AMERICANO

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INTRODUCTION

The purpose of this report is to consider the present nutrient status of the Estero Americano, and to comment on the likely effects of adding high levels of nutrients from sewage discharge into this Estero. The comments are based on a general consideration of nutrients in aquatic environments, nutrient data which we have collected in the Estero Americano since May 1989, and a critical evaluation of information which has been collected by consultants for the Santa Rosa Subregional Water Reclamation System.

Among the major inputs reaching and affecting the environment from domestic sewage discharge are the essential plant nutrients, nitrogen and phosphorus. These nutrients can cause environmental problems in a variety of ways. First and simplest, the nutrients can cause blooms of algae--usually nuisance species, often ones which are toxic. These algae may be either planktonic or benthic taxa. The algal blooms in response to nutrient loading are ordinarily algae which are present in the environment, but which usually do not dominate. Large increases in algal abundance can greatly change the natural plant community structure. As an example, epiphytic algal growth on seagrasses can contribute to the demise of those seagrasses. Alteration of plant community structure can, in turn, affect the distribution and abundance of other organisms (e.g., fishes and infauna which live in the grass beds) in the ecosystem.

It is useful to point out parallels between aquatic system responses to nutrient enrichment and responses on land to fertilization. The algae responding to nutrient enrichment are analogous to terrestrial weeds which respond to fertilization. The weed species can outcompete more desirable species for space. Animals which feed on the weeds may also be undesirable and may outcompete desirable species. Moreover, the weed species are likely not to be good forage (or crop) plants.

Second, as the algae die, they decompose. Decomposition is an oxidation process which consumes oxygen dissolved in the water. As long as the processes of algal growth and decomposition proceed relatively slowly, gas exchange across the air-water interface largely compensates for buildup of oxygen during the day, associated with primary production, and nighttime depletion, associated with oxidation. Rapid organic production and oxidation typically accompany nutrient loading. Daytime production of organic matter and oxygen are not likely to be directly detrimental (although see below). However, such loading and metabolic enhancement favor nighttime oxygen depletion.

Organisms can be suffocated from lack of oxygen. Moreover, the depletion of oxygen from seawater causes oxidation process to shift to alternate oxidative pathways--especially sulfate reduction. A major product of sulfate reduction is hydrogen sulfide, a gas which is extremely toxic to organisms. Sulfate reduction and accompanying hydrogen sulfide production go on at slow rates in the sediments under normal conditions as materials are oxidized there. Addition of either inorganic nutrients or organic matter, especially in relatively protected water bodies, can cause such great increases in demand for oxidants that oxygen

becomes rapidly depleted and sulfate reduction becomes the major pathway of oxidation. Under such circumstances, sulfate reduction and hydrogen sulfide liberation can move from the sediments, up into the water column.

Third, free, unionized ammonia (a reduced form of nitrogen) is toxic and can be present in such high concentrations that it kills organisms. Free ammonia concentrations are a function of both total ammonium concentration and pH. The levels of free ammonia required for acute toxicity are typically around 15 μM . At a pH of 8 (typical of surface seawater which is not experiencing high primary production) total ammonium levels need to exceed about 280 μM for the free ammonia level to be reached. As pH increases, for example in response to daytime carbon dioxide uptake due to nutrient enhanced primary production, the total ammonia concentrations causing toxicity drop. At a pH of 8.5 (about the maximum commonly occurring in seawater, although higher values can occur in fresh water), the total ammonium concentration leading to acute toxicity is about 100 μM .

As a general rule of thumb, then, total ammonium concentrations in excess of about 200 μM can readily lead to free ammonia toxicity. Both because the unionized ammonia levels which are toxic vary among organisms and because the ratio of unionized ammonia to total ammonium varies with pH (which, in turn, can vary over a day-night cycle), this estimated toxic level is simply a general guideline.

Proliferation of toxic algae, elevated daytime pH in the presence of high total ammonium concentrations, and oxygen depletion from elevated rates of organic oxidation are all expected consequences of excess nutrient enrichment, especially in shallow, relatively sheltered water bodies. Events such as "kills" of fishes and other organisms are biotic responses which can be anticipated.

This report considers the specific effects to be anticipated from enhanced nutrient loading into the Estero Americano.

MATERIALS

Surface water samples were collected by scooping water with a bucket, over the side of a small boat. In this manner, immediate "edge effects" from nearshore sampling were avoided. Samples for nutrient analyses were handled either of two ways. For samples collected between May and September, water was immediately filtered through glass fiber filters into HCl-washed, sample rinsed polyethylene bottles. These bottles were held on ice until frozen within 2 hours of collection. For subsequent samples, water was held in 2-liter plastic containers, filtered within 2 hours of collection, then immediately frozen. This latter procedure proved to be more satisfactory because of the high suspended load content of some samples. In either case, the samples were returned frozen to the University of Hawaii for analysis by standard automated techniques of nutrient analysis adapted for oceanographic analysis.

Total dissolved organic plus inorganic nutrients, measured after photo-oxidation of samples, are also reported in that table. Organic nutrient levels are determined as the difference

between total and inorganic nutrients. These values are not considered reliable at the high nutrient concentrations encountered in the head of the Estero. There can be interferences with the total P analysis, and ammonia and other volatile nitrogen compounds can be lost during the photo-oxidation. Therefore some of the dissolved N and P values obtained are negative. Dissolved organic carbon was measured on an Oceanography International total carbon analyzer, by infrared analysis after persulfate oxidation of organic matter. The data for dissolved organic nutrients and dissolved organic carbon are reported for the sake of completeness, but only the inorganic nutrient data are discussed in detail.

Samples were also collected for salinity analysis. These samples were held in sealed bottles for up to two months before analysis on a Plessey model 6230N laboratory salinometer. The salinometer was standardized approximately every 10 samples against a secondary standard; that standard was standardized against a primary (Copenhagen) standard seawater sample.

RESULTS

Table 1 summarizes the water quality data which were collected between May 1989 and March 1990 (approximately monthly intervals, except for June). Samples have been collected, but not yet analyzed, for April 1990. In general, the nutrient distributions indicated by our data do not differ significantly from those reported by the Santa Rosa consultants in their Technical report E8; the major difference is that our more intensive sampling allows us to see patterns not clearly apparent in the consultants' report. As a second point, our resolution is better at the low-nutrient (oceanic) end of the Estero, because we are using standard oceanographic analytical techniques useful for low-level nutrient determinations.

Figures 1-5 summarize the salinity and nutrient data with time and along the length of the Estero Americano. These data are presented in the form of 3-dimensional time-distance-concentration diagrams. The purpose of these diagrams is to show trends; the reader is urged to inspect the tabulated raw data (Table 1) as well.

First note salinity (Figure 1). Salinity in the outer portion of the Estero does not vary much and is about the same as oceanic salinity. In contrast, there is an increase in salinity during the summer and a sharp decrease in the winter. These salinity variations occur about 3.5 km from the Estero mouth and landward. In general terms, the salinity increase represents summer evaporation, while the winter decrease represents freshwater inflow. A minor complication is that at the upper end of the Estero, salinity begins to decrease in the late summer, before there is significant surface freshwater flow.

Three terms contribute to this decrease. Evaporation slows in the late summer and fall. Groundwater flow into the Estero Americano (unquantifiable at this time, but important at some level) begins to exceed evaporation and dilute the high salinity water. Some slow exchange between the outer and inner Estero tends to bring the inner Estero composition towards that of the

outer Estero. Once freshwater surface flow begins, it overwhelms the effects of both evaporation and groundwater flow--substantially depressing salinity in the inner Estero during the winter.

The outer 3.5 km of the Estero (about 65% of the free water area and 80% of the Estero volume) exchanges so rapidly with the ocean that there is very little salinity effect from evaporation and only a small effect from runoff. Based on the salinity, it is therefore convenient to consider the system as divided into two subsystems: The outer 3.5 km of the Estero is close to oceanic in water composition, especially during the summer when there is no freshwater flow. The inner portion of the Estero is progressively altered from oceanic composition, during the summer by evaporation and during the winter by freshwater flow. When flow is low (summer), the separation between the inner and outer Estero is more complete than when flow is higher (winter).

Next consider silicate (Figure 2). This is an important nutrient for consideration, for the following reason. Silicate is not an important product of sewage discharge (other than reflecting the Si content of local fresh water). Note that the winter salinity decrease at the head of the Estero coincides with a major increase in silicate. There is, however, some elevation of silicate at the head of the Estero even during the summer. There are two plausible explanations for this increase: groundwater input of silicate and some regeneration of silicate from the reaction of sediments in the Estero. The sediment reaction will include silicate minerals as well as the shells of siliceous organisms (for example diatoms). The low and relatively constant silicate values near the Estero mouth reflect the composition of seawater mixing into the Estero. In the winter, the freshwater influence on silicate concentration in the water extends to within approximately 2 km of the Estero mouth.

Phosphate concentrations are illustrated in Figure 3. Note that phosphate in the inner Estero is high in May of 1989, but decreases from that time until about December. In January, phosphate rises dramatically in response to freshwater inflow. These phosphate levels are extreme and are clearly associated with some major waste source--most probably wastes from a dairy on the intermittent stream, Americano Creek, at the head of the Estero. In general, phosphate levels in groundwater are low, because of P sorption onto mineral surfaces. This contrasts with silicate, which tends to be elevated in groundwater.

We therefore interpret the phosphate pattern as follows: There is a winter pulse of waste-laden, phosphorus-rich water, associated with the flow of Americano Creek. Over the summer, exchange of water at the head of the Estero with outer Estero water is very slow (evidenced by the salinity elevation at the head of the Estero). Americano Creek does not flow. Stagnant water in that creek can achieve extreme concentrations of phosphate. There is also phosphorus regeneration from organic matter in the sediments, washed into the Estero during the winter and deposited there. Slow exchange over the summer gradually rids the Estero of much of the excess phosphate carried into the Estero during the previous high-flow period, but does so

slowly--without elevating the phosphate concentration in the lower Estero very much.

The two forms of nitrogen (nitrate + nitrite, commonly reported analytically as nitrate, and ammonium) are illustrated in Figures 4 and 5 and are discussed together. Both ammonium and nitrate are readily available for uptake by plants. Ammonium is low in surface seawater and is ordinarily also low in groundwater; it is high in waste water, including both sewage effluent and barnyard waste. Ammonium is also the primary form of nitrogen released during the decomposition of organic matter. Note that ammonium is largely confined to the inner portion of the Estero, and is high during the first winter freshwater flow. An ammonium "spike" occurs during the first major freshwater inflow, in January, followed by somewhat lower values during the remainder of the winter.

Nitrate can be somewhat elevated in surface seawater during the summer (upwelling) period; in the absence of upwelling surface seawater nitrate levels are typically low. Nitrate can also be very elevated in both surface freshwater flow and groundwater. Nitrate is also an oxidation product of ammonium. Besides being taken up by plants, nitrate can serve as an oxidant in the process known as denitrification. At the head of the Estero, nitrate shows an even more prominent spike than ammonium, associated with the first major freshwater inflow.

DISCUSSION

This discussion is designed to address the following point. { A repeated argument in the consultants' reports favoring the discharge of sewage effluent into the Estero Americano is that this discharge will improve the quality of water in the Estero. } Is this a legitimate conclusion? We start out by observing that the nutrient data which we have gathered in the Estero Americano do not particularly differ from the consultants' data--except that our sampling has been more intensive and our low-level values (using standard oceanographic techniques) are more reliable. The differences we present below, between our views and those represented by the consultants' reports therefore represent different interpretations of the significance of the water quality data, rather than essentially different data.

It is useful to divide these data into average values for the lower 3.5 km of the Estero (termed the outer Estero) and for the remainder of the Estero (inner Estero). The data are further divided into values collected well before the onset of the first significant freshwater flow of the season (i.e., May-November), then for the period from December to March (when both groundwater and surface flow are important). Also tabulated are the maximum concentrations of the inorganic nutrients in the Estero, as well as the number of outer Estero, Inner Estero, and Middle Road Bridge samples which exceed the proposed effluent nutrient concentrations. These data are also compared with data from the mouth of nearby Tomales Bay. We have been studying the nutrient dynamics of Tomales Bay as part of an independent program since 1985, so the Tomales bay mouth data provide a proxy for oceanic water composition. Table 2 summarizes all of these data.

In the first place, note that the mean salinity values according to the data categories are consistent with the information presented in the Results section of this document: There is relatively little salinity variation in the outer Estero, while the inner Estero salinity exceeds the ocean from May to November and is depressed substantially below the Estero from December to March. The outer Estero salinity values do fall somewhat outside the range of Tomales Bay during the winter, reflecting some influence from runoff.

Inorganic nutrient levels in the outer, oceanic portion of the Estero are lower than the inner Estero, approaching (although not, on average, reaching) values at the mouth of Tomales Bay. Again, the somewhat greater influence of winter runoff is apparent on the outer Estero nutrients. Inner Estero inorganic nutrients are substantially elevated above nutrient concentrations of the outer Estero, especially during the winter. However, except for ammonium (discussed below), average values of inorganic nutrient concentrations in the inner Estero are well below estimated effluent concentrations. It is true that inner Estero maximum values do generally exceed the effluent values. However, the high values are largely confined to Middle Road Bridge, with a few high values in the inner Estero during the winter freshwater pulse.

Ammonium values in the Estero and the effluent should not be interpreted independently of nitrate. Both forms of inorganic nitrogen are available to support primary production by algae and seagrasses, although ammonium is generally somewhat more readily available. The mean ammonium levels in the inner Estero during the winter exceed the estimated effluent ammonium concentration by about 40 μM . However, the winter nitrate values in the inner Estero are 700 μM below the effluent concentration. Therefore the total dissolved inorganic nitrogen of the effluent is 660 μM (31%) higher than the average dissolved inorganic nitrogen concentration in the inner Estero during the winter.

The Estero maximum ammonium concentration (~1200 μM , Table 2) can clearly lead to local, acute ammonia toxicity. However, such high levels are only encountered at one site on Americano Creek, 9.4 km from the Estero mouth (Middle Road Bridge). By the time water reaches a station 8.9 km from the Estero mouth (at the Franklin School Road Bridge), only one ammonium sample (out of 8 collected there) has exceeded the mean concentration of ~200 μM given for ammonium in the effluent water. One value at that location was just below 200 μM , and all other values were below 100 μM (<50% of the effluent concentration).

That portion of the Estero between those two bridges occupies about 3% of the Estero water area and 2% of the volume. The samples reported by the consultants to exhibit ammonia toxicity are all landward of the Franklin School Road Bridge. For all of the inner Estero except the 9.4 km station, only 6 samples out of 57 (11%) have exceeded 200 μM total ammonium. All of the high values occurred during February and March, when flow from Americano Creek was discharging into the Estero. No sample in the outer Estero has had ammonium concentrations in excess of 100 μM . Clearly any ammonia toxicity associated with the present Estero

water quality is a localized phenomenon, limited to the upper portion of the inner Estero or Americano Creek (Middle Road Bridge).

Discharging sewage with consistent, extreme levels of nitrate ($\sim 700 \mu\text{M}$) can be expected to result in uptake by plants, followed by decomposition; a major nitrogen decomposition product will be ammonium. Elevated total ammonium concentrations coupled with elevated daytime primary production can be expected to lead to levels of unionized ammonia well above the present levels found in the Estero Americano.

It is difficult to conclude from this analysis that sewage discharge into the Estero Americano is going to improve water quality there--at least with respect to inorganic nutrient concentrations. The outer, oceanic portion of the Estero has water quality not greatly different from oceanic, and certainly within a tolerable range. This is especially true during the summer, that period when discharge of effluent into the Estero is supposed to occur. Water quality in the inner Estero is poor. However, in general it is not as enriched in nutrients as is the sewage effluent which might be dumped into the Estero. Moreover, the period with poorest water quality is the period with high flow. The high flow conditions result in some deterioration of water quality in the outer, oceanic portion of the Estero and probably in the coastal waters immediately adjacent to the Estero mouth.

Some calculations from consultants' report E14 are also useful for comparison with the present situation in the Estero Americano. In that report, it is estimated that $> 80,000 \text{ lb}$ of nitrogen ($> 2.3 \times 10^6 \text{ mols N}$) from animal wastes presently reach the Estero annually, via inflow from Americano Creek. A major role of the sewage discharge is (supposedly) to get rid of this nitrogen from animal wastes.

The sewage effluent has a total of approximately 1 mmol N/liter , and the direct discharge of this effluent is projected to be approximately $3 \times 10^9 \text{ liters/year}$ (i.e., 7 cfs, for 1983 days per year). Most of this N is readily available (as nitrate). Simple arithmetic yields a nitrogen discharge in this waste water of $3 \times 10^6 \text{ mols N/year}$. This discharge does not include additional N which will reach the Estero and/or the ocean via percolation through the groundwater or direct runoff from the spray fields. It therefore is clear that the sewage effluent will actually deliver more nitrogen (and, presumably, more phosphorus) to the Estero annually than is presently being delivered from animal wastes. Moreover, unless cattle and other farm animals are removed from the watershed, the total nutrient load to the Estero will include both the predicted sewage discharge and at least some fraction of the present animal waste products. It is unlikely that the number of cattle will decrease once irrigated pasture is available. By the time we consider direct discharge, percolation through the groundwater, and runoff from the spray fields, the predicted net effect of sewage discharge into the Estero would be at least to double the present nutrient loading, rather than to lower it.

SUMMARY AND CONCLUSIONS

We have approached the issue of the effects of sewage discharge into the Estero Americano from three vantages: the general effects of nutrients on receiving waters, the present and likely future water quality of the Estero Americano in the face of sewage discharge, and the present and likely future mass balance of nutrient loading into the Estero.

In the first place, we considered the general topic of the effects of nutrients on the environment. In general, it is not considered desirable to discharge sewage nutrients into surface waters. A report by the National Academy of Sciences considers eutrophication of coastal waters to be a major environmental problem. Biotic processes of nutrient uptake by algae, alteration of community structure, and processes associated with the decay of algae all lead to a predicted degradation of the environment. The degradation can include a variety of toxic effects. One way to alleviate such problems during sewage discharge into the ocean is to discharge materials at depth (i.e., below the lighted zone of the ocean). Plants cannot take up nutrients there. That water may mix back up into the lighted zone, but outfalls can be designed so that dispersion and dilution minimize the environmental consequences of the release. Discharge of water into the Estero Americano does not meet this criterion for environmental protection.

Blooms of the nuisance algae, Ulva and Enteromorpha, already occur on the mud flats near the mouth of the Estero. These algae are typically associated with elevated nutrient concentrations. There are several reasons to believe that these blooms will be increased by effluent discharge. If the consultants' reports are correct, the various "enhancement" effects associated with effluent discharge can be expected to increase water clarity (undoubtedly a fundamentally desirable effect), by flushing suspended sediments out of the Estero. Primary production in highly turbid estuaries is often limited by light penetration into the water. If water in the Estero does become clearer, plants which are presently limited by the availability of light will be able to grow more rapidly. This will be particularly true in the summer, when major effluent discharge is projected to occur and when solar radiation is highest. Elevated nutrient levels, especially with clearer water, will also favor more rapid algal growth. Therefore these nuisance algae (and perhaps others) can be expected to increase substantially in abundance. Enhanced daytime primary production will raise the pH and elevate unionized ammonia concentrations relative to total ammonium--perhaps causing increased ammonia toxicity. Decomposition of these algae can be expected to lead to increased sulfate reduction, both on the sediment surface and in the water column. The algal decomposition will also tend to convert effluent nitrate, through organic matter, to ammonium, exacerbating the potential for ammonia toxicity.

Secondly, we have considered the present water quality (nutrients and salinity only) of the Estero Americano, based on data we have collected. We have compared the nutrient concentrations in the Estero with the composition listed in the

consultants' reports for mean effluent concentrations of nutrients. Considering the fact that even the inner Estero, with rather poor water quality, has lower average nutrient concentrations than the effluent, it is difficult to construct an argument by which effluent discharge will lower the nutrient concentration in the Estero. It does appear to be true that the effluent discharge will be lower in nutrient content than the maximum levels of nutrients presently found in the Estero. These high concentrations represent transient features which occur in the inner Estero during the winter. Such concentrations tend not to occur during the summer, when light favors rapid plant growth and when sewage discharge into the Estero is expected to occur.

Finally, we consider the consultants' estimate of animal waste production in the Estero Americano. This estimate is compared with their estimate of effluent discharge. There will be more nutrients delivered in the direct effluent discharge than the nutrient loading presently being produced by farm animals. Nutrients in water used for irrigation are not included in the consultants' mass balance estimates, but at least some fraction of these nutrients will enter the Estero and coastal ocean via runoff from the sprayfields and groundwater contamination and discharge. Therefore it is also difficult to create a mass-balance argument as to why sewage discharge will lower nutrient delivery to the Estero.

In summary, we predict the following responses to discharge of nutrient-rich sewage effluent into the inner portion of the Estero Americano. Nutrient concentrations in the inner Estero, the outer Estero, and the coastal ocean receiving waters will be elevated. The altered water quality will cause more rapid growth of noxious "weed species" of algae in the outer Estero and in the coastal ocean adjacent to the Estero mouth. Biotic community structure will be further altered in ways which cannot be rigorously predicted but which seem likely not to favor the indigenous biota (e.g., the seagrasses and saltmarsh vegetation, and the associated fauna). Levels of the toxic substances, hydrogen sulfide and unionized ammonia, will be elevated in the Estero proper, even though total ammonium and unionized ammonia may be lowered in the intermittent stream flowing into the Estero. With respect to nutrients, at least, discharge of treated sewage effluent into the Estero Americano cannot be viewed as an environmental enhancement of this Estero.

Table 1. Water composition data collected in Estero Americano between May 1989 and January 1990. Available data for the mouth of Tomales Bay, collected at bimonthly intervals, is shown as a proxy for Bodega Bay water composition. Distance in km from Estero mouth. All samples are surface samples collected by scooping water into a well-rinsed bucket. Nutrient samples were filtered, either in the field immediately after sampling, or in the laboratory within 2 hours of collection, and then frozen until analysis within 6 weeks of collection, according to slight modifications of standard automated techniques. Salinity samples were analyzed with a laboratory salinometer.

			dist	sal	DOC	DIP	DOP	N+N	NH4	DON	Si
			KM	o/oo	mM	μM	μM	μM	μM	μM	μM
TB0 ¹	05	MAY	---	33.31	0.04	1.1	0.2	11	0.4	4.5	11
EA6 ²	05	MAY	0.0	33.63	0.05	2.6	0.2	20	2.2	14	32
EA5	05	MAY	0.4	33.20	0.08	3.4	0.2	6.7	5.5	22	26
EA4	05	MAY	0.8	32.47	0.12	3.5	0.3	3.6	3.1	24	19
EA3	05	MAY	1.5	31.94	0.18	4.4	0.4	1.8	3.1	36	19
EA1	05	MAY	2.0	31.41	0.18	4.2	0.2	1.1	1.5	31	14
EA2	05	MAY	3.0	32.92	0.15	3.4	0.4	0.5	1.2	31	16
EA7	05	MAY	3.5	27.12	0.26	8.0	0.9	19	5.4	54	26
EA8	05	MAY	4.0	24.70	0.32	14	0.0	38	11	65	51
EA9	05	MAY	4.5	23.94	0.25	7.5	1.1	37	13	9.0	56
TB0	07	JUL	---	33.89	0.05	2.1	0.3	11	4.0	7.0	30
EA0	07	JUL	0.0	33.95	0.05	2.6	0.3	24	5.9	7.6	42
EA1	07	JUL	1.5	33.97	0.05	3.0	0.5	23	6.2	11	43
EA2	07	JUL	2.6	33.99	0.05	2.9	0.2	24	6.6	11	43
EA3	07	JUL	3.5	35.48	0.15	6.0	0.1	21	13	33	61
EA4	07	JUL	4.3	34.67	0.08	3.9	0.0	22	4.5	16	49
EA5	07	JUL	5.4	35.98	0.11	5.1	0.3	19	11	19	64
EA6	07	JUL	6.3	36.74	0.13	5.6	0.4	20	12	21	69
EA7	07	JUL	7.1	38.37	0.19	7.2	0.8	19	12	29	73
EA8	07	JUL	8.9	36.23	0.40	11	1.9	0.3	0.9	67	10
EA9	07	JUL	9.4	25.29	0.90	79	5.3	0.3	1.7	129	77
EA10	11	JUL	10.3	0.69	4.25	63	5.6	1.9	1.5	132	210
EA0	11	JUL	0.0	34.03	0.09	3.4	0.0	21	8.0	8.8	45
CFG ³	11	JUL	0.0		0.16	8.8	3.4	8.8	49	39	32

Table 1, continued

			dist KM	sal o/oo	DOC mM	DIP μM	DOP μM	N+N μM	NH4 μM	DON μM	Si μM
EA0	31	JUL	0.0	34.02	0.04	2.1	0.3	23	1.1	8.3	45
EA1	31	JUL	1.5	34.12	0.04	2.4	0.2	21	3.1	7.4	48
EA2	31	JUL	2.6	34.08	0.06	2.5	0.2	24	2.2	7.9	52
EA3	31	JUL	3.5	35.26	0.09	3.5	0.3	21	5.7	14	62
EA4	31	JUL	4.3	36.52	0.13	4.8	0.8	14	6.5	27	66
EA5	31	JUL	5.4	36.70	0.12	4.8	0.7	15	6.8	23	67
EA6	31	JUL	6.3	36.87	0.12	4.9	0.7	14	6.6	25	80
EA7	31	JUL	7.1	40.03	0.23	7.7	1.3	0.2	0.3	40	59
EA8	31	JUL	8.9	41.01	0.37	2.0	1.8	0.1	0.1	59	26
TB0	07	SEP	---	33.60	0.05	0.9	0.5	0.6	0.4	11	17
EA0	06	SEP	0.0	33.72	0.06	1.0	0.4	0.2	0.2	10	15
EA1	06	SEP	1.5	33.72	0.07	1.2	0.5	0.2	1.3	14	17
EA2	06	SEP	2.6	33.76	0.08	1.3	0.4	0.5	2.2	14	20
EA3	06	SEP	3.5	33.93	0.07	2.8	0.9	2.9	7.4	22	30
EA4	06	SEP	4.3	33.98	0.10	2.8	0.3	3.3	8.7	14	33
EA5	06	SEP	5.4	34.62	0.12	3.7	0.6	9.9	12	20	54
EA6	06	SEP	6.3	35.36	0.13	4.2	0.5	14	18	19	67
EA7	06	SEP	7.1	35.80	0.29	4.8	0.5	14	28	17	75
EA8	06	SEP	8.9	38.08	0.17	11	1.4	14	50	31	107
EA9	06	SEP	9.4	45.83	0.43	76	6.0	0.3	1.5	192	164
EA0	05	OCT	0.0	33.73	0.07	1.8	0.7	12	2.0	29	15
EA1	05	OCT	1.5	33.74	0.06	1.8	0.2	12	2.7	22	7
EA2	05	OCT	2.6	33.75	0.06	1.9	0.2	13	3.8	24	7
EA3	05	OCT	3.5	33.81	0.06	2.4	0.2	14	7.2	29	7
EA4	05	OCT	4.3	33.89	0.06	2.6	0.3	14	7.2	31	10
EA5	05	OCT	5.4	34.04	0.08	3.1	0.4	15	12	37	11
EA6	05	OCT	6.3	34.18	0.09	3.1	0.4	16	15	40	9
EA7	05	OCT	7.1	34.22	0.11	3.9	0.4	18	25	54	11
EA8	05	OCT	8.9	33.27	0.29	8.9	1.3	47	98	178	33
TB0	09	NOV	---	33.52	0.04	1.6	0.2	12	3.1	5.6	27
EA0	08	NOV	0.0	33.53	0.04	1.6	0.3	11	7.5	25	7
EA1	08	NOV	1.5	33.52	0.04	1.7	0.2	12	5.3	23	6
EA2	08	NOV	2.6	33.53	0.04	1.9	0.2	13	6.5	27	7
EA3	08	NOV	3.5	33.54	0.06	2.2	0.2	15	8.8	34	10
EA4	08	NOV	4.3	33.50	0.06	2.3	0.4	17	11	40	11
EA5	08	NOV	5.4	32.46	0.07	2.5	0.4	19	12	43	12
EA6	08	NOV	6.3	32.44	0.09	3.0	0.5	30	24	66	12
EA7	08	NOV	7.1	30.07	0.16	4.3	0.6	55	48	112	9
EA8	08	NOV	8.9	25.16	0.29	4.7	1.4	101	30	139	9
EA9	08	NOV	9.4	31.65	0.74	24	1.6	6.3	2.7	97	88

Table 1, continued

			dist KM	sal o/oo	DOC mM	DIP μM	DOP μM	N+N μM	NH4 μM	DON μM	Si μM
EA0	11	DEC	0.0	33.40	0.10	1.2	0.3	7.7	3.7	12	16
EA1	11	DEC	1.5	33.37	0.09	1.3	0.2	7.8	3.2	5.5	14
EA2	11	DEC	2.6	33.36	0.08	1.3	0.2	7.9	3.2	5.7	14
EA3	11	DEC	3.5	33.35	0.08	1.4	0.2	7.9	3.2	6.2	14
EA4	11	DEC	4.3	33.36	0.08	1.3	0.2	7.5	3.7	6.1	15
EA5	11	DEC	5.4	33.33	0.09	1.4	0.2	7.3	4.1	6.5	18
EA6	11	DEC	6.3	33.31	0.10	1.6	0.1	7.9	4.9	7.3	18
EA7	11	DEC	7.1	33.29	0.11	1.8	0.3	9.3	5.1	7.8	22
EA8	11	DEC	8.9	29.18	0.23	2.4	0.5	29	10	14	56
EA9	11	DEC	9.4	23.28	0.57	17	1.2	75	29	33	117
TB0	08	JAN	---	33.43	0.05	1.3	0.1	11	0.7	5.0	17
EA0	07	JAN	0.0	32.64	0.10	1.5	0.0	9.6	2.0	6.3	15
EA1	07	JAN	1.5	33.02	0.08	1.4	0.2	9.4	2.5	6.2	16
EA2	07	JAN	2.6	32.24	0.09	1.3	0.2	8.9	3.1	6.8	16
EA3	07	JAN	3.5	32.19	0.09	1.1	0.5	8.7	6.4	14	19
EA4	07	JAN	4.3	31.80	0.10	1.4	0.2	8.1	3.9	7.5	17
EA5	07	JAN	5.4	28.45	0.11	1.4	0.3	7.0	5.0	11	21
EA6	07	JAN	6.3	27.00	0.13	2.1	0.3	11	8.1	13	27
EA7	07	JAN	7.1	24.97	0.16	2.7	0.4	13	8.5	15	32
EA8	07	JAN	8.9	21.93	0.23	2.7	0.6	48	18	14	77
EA9	07	JAN	9.4	14.79	0.49	9.0	0.7	149	16	17	66
EA9	08	JAN	9.4		3.14	170	18	229	986	198	234
EA9	09	JAN	9.4		2.34	154	11	55	693	214	262
EA9	10	JAN	9.4		2.49	152	11	0	696	253	293
EA9	12	JAN	9.4	0.66	5.15	150	7.9	13	779	***	281
EA9	13	JAN	9.4	0.56	4.48	154	12	55	1183	***	220
EA9	15	JAN	9.4	0.50	2.19	82	0.5	97	256	118	231
EA9	24	JAN	9.4	0.47	1.91	74	*** ⁴	22	473	26	361
EA0	07	FEB	0.0		0.40	1.2	0.4	12	1.1	32	32
EA1	07	FEB	1.5		0.45	1.1	0.8	9.4	1.1	30	30
EA2	07	FEB	2.6		0.56	4.6	0.9	13	19	50	48
EA3	07	FEB	3.5		0.63	7.4	1.1	14	44	33	60
EA4	07	FEB	4.3		0.97	15	0.5	20	95	27	92
EA5	07	FEB	5.4		1.38	25	0.0	27	164	36	137
EA6	07	FEB	6.3		2.38	59	***	54	277	62	249
EA7	07	FEB	7.1		2.35	99	15	61	206	182	446
EA8	07	FEB	8.9		2.65	93	2.1	65	341	165	311
EA9	07	FEB	9.4		2.41	103	8.5	39	320	106	492
EA9	04	MAR	9.4		2.78	83	***	25	230	117	241

Table 1, continued

			dist	sal	DOC	DIP	DOP	N+N	NH4	DON	Si
			KM	o/oo	mM	μ M	μ M	μ M	μ M	μ M	μ M
EA0	09	MAR	0.0	33.23	0.11	1.4	0.4	5.2	2.1	15	28
EA1	09	MAR	1.5	32.24	0.13	1.9	1.0	6.5	2.4	23	32
EA2	09	MAR	2.6	21.32	0.90	14	1.6	14	54	48	108
EA3	09	MAR	3.5	17.73	1.18	20	1.4	19	93	39	137
EA4	09	MAR	4.3	16.48	1.27	21	1.0	20	90	52	141
EA5	09	MAR	5.4	5.95	2.10	47	0.0	32	222	82	261
EA6	09	MAR	6.3	1.72	2.21	72	3.7	37	288	111	345
EA7	09	MAR	7.1	1.12	2.28	99	2.1	40	285	103	473
EA8	09	MAR	8.9	0.80	2.14	105	0.9	46	196	102	542
EA9	09	MAR	9.4	0.39	2.53	124	***	24	272	82	496

¹TB denotes samples collected at the mouth of Tomales Bay, as part of an independent investigation. The TB samples reported were all collected either on the same day as Estero samples or one day after an Estero sampling.

²EA denotes Estero Americano samples. Transects from July 1989 to January 1990 have used a standard set of sample locations; the transect stations in May 1989 did not conform to this standard.

³CFG denotes a sample taken at the discharge point for the California Fish Growers effluent.

⁴*** indicates negative number; analytical problems, as discussed in text.

Table 2. Comparison of salinity and inorganic nutrients between the Tomales Bay mouth (as a proxy of coastal ocean conditions), the outer 3.5 km of Estero Americano (outer Estero), the remainder of the Estero (inner Estero), and the mean effluent concentrations. Data are divided into the dry season (May-November) and the wet season (December-March). Data reported are mean $\pm$ std. dev.

SITE	SALINITY (o/oo)	INORG. P μ M	NITRATE μ M	AMMONIUM μ M	SILICATE μ M
Tomales mouth					
May-Nov.	33.5 $\pm$ 0.4	1.3 $\pm$ 0.5	8 $\pm$ 6	2 $\pm$ 1	22 $\pm$ 9
Dec.-Mar.	33.2 $\pm$ 0.4	1.2 $\pm$ 0.1	9 $\pm$ 2	1 $\pm$ 1	15 $\pm$ 4
Outer Estero					
May-Nov.	33.4 $\pm$ 1.5	2.8 $\pm$ 1.5	13 $\pm$ 9	4 $\pm$ 3	26 $\pm$ 18
Dec.-Mar.	30.7 $\pm$ 5.3	3.9 $\pm$ 5.5	10 $\pm$ 3	15 $\pm$ 26	37 $\pm$ 36
Inner Estero					
May-Nov.	34.2 $\pm$ 4.8	11 $\pm$ 19	20 $\pm$ 20	16 $\pm$ 20	49 $\pm$ 37
Dec.-Mar.	15.8 $\pm$ 13.9	60 $\pm$ 58	42 $\pm$ 46	255 $\pm$ 306	206 $\pm$ 165
Estero maximum deviation from oceanic					
	46 (high)	170	229	1183	542
	0.4 (low)				
Effluent Concentration		129	743	214	
Frequency at which Estero concentrations exceed effluent (number above effluent/total samples)					
Outer Estero		0/45	0/45	0/45	
Inner Estero ¹		0/47	0/47	5/47	
Middle Rd. Bridge		5/15	0/15	10/15	

¹ Inner Estero below Middle Road Bridge

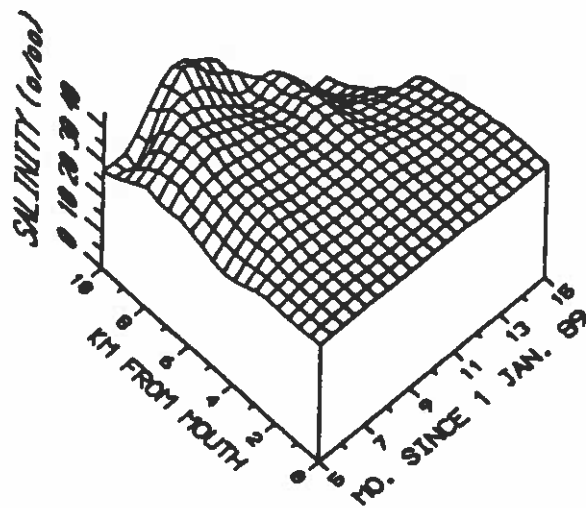


Figure 1. Salinity as a function of time (expressed in months since 1 January 1989) and distance from the mouth of the Estero Americano.

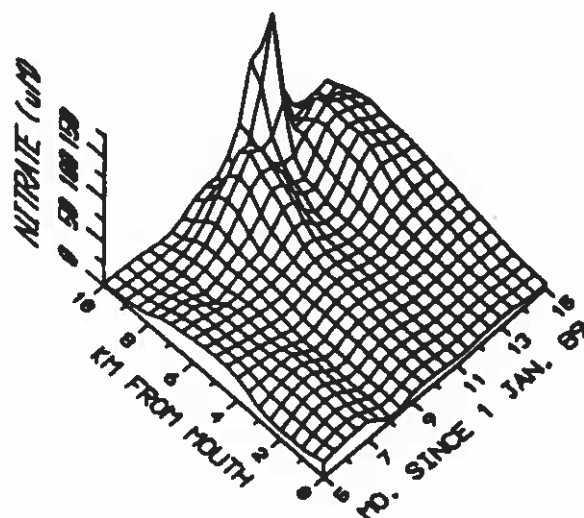


Figure 4. Nitrate as a function of time (expressed in months since 1 January 1989) and distance from the mouth of the Estero Americano.

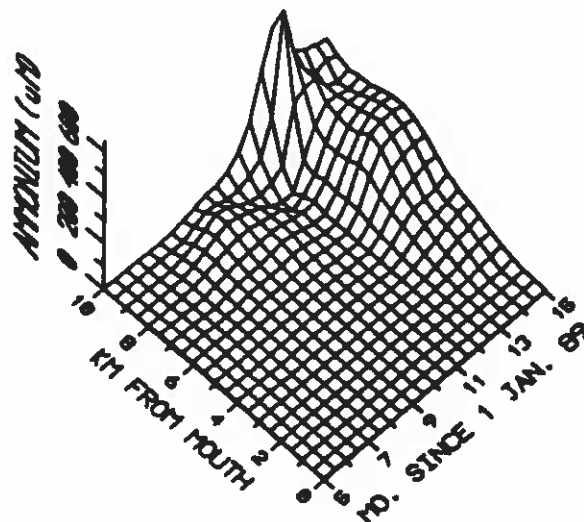


Figure 5. Ammonium as a function of time (expressed in months since 1 January 1989) and distance from the mouth of the Estero Americano.

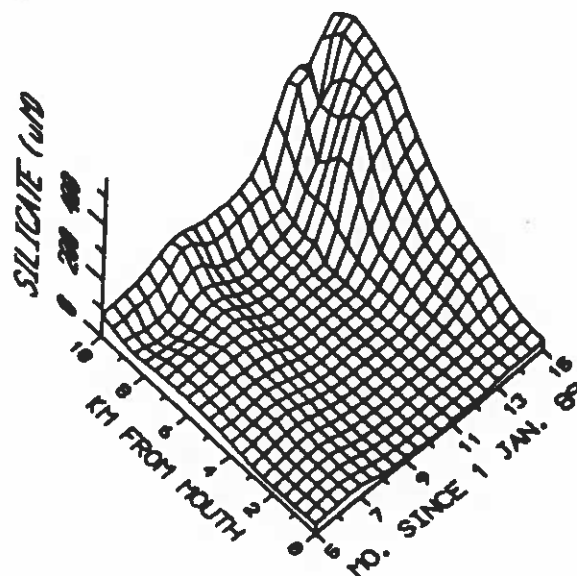


Figure 2. Silicate as a function of time (expressed in months since 1 January 1989) and distance from the mouth of the Estero Americano.

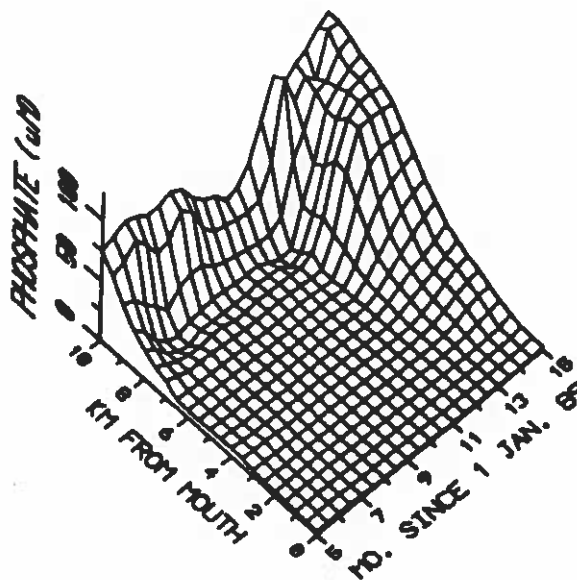


Figure 3. Phosphate as a function of time (expressed in months since 1 January 1989) and distance from the mouth of the Estero Americano.