Pacific Southwest
Region IX
California

RICHARDSON BAY EFFLUENT DILUTION STUDY

A Working Paper

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*A Working Paper presents results of investigations which are to some extent limited or incomplete. Therefore, conclusions or recommendations, expressed or implied, are tentative.

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RICHARDSON BAY EFFLUENT DILUTION STUDY

Background and Purpose

The discharge of sewage effluent into Richardson Bay has affected its ecology, economics and aesthetic appeal. One notable effect has been the contamination of shellfish beds, resulting in the termination of commercial shellfishing more than forty years ago and the eventual quarantining of all shellfish beds in Richardson Bay. Another is severe eutrophication in certain portions of the bay, a problem made obvious by the stench of decaying algae during the summer months.

Two waste water treatment plants discharge secondary treated municipal effluent into the head of Richardson Bay (Figure 1). The Richardson Bay Sanitation District plant, which discharges approximately 0.2 mgd, is located on the north shore of Richardson Bay to the east of Strawberry Point, and the Mill Valley Sanitation District plant, which discharges approximately 1.5 mgd, is located at the upper end of the bay arm to the west of Strawberry Point. The treatment processes in both plants are similar, except that the sludge in the Richardson Bay plant is incinerated, while the sludge in the Mill Valley plant is centrifuged and dried.

The outfall from the Richardson Bay plant terminates under 18 inches of gravel a few feet out from the high tide line. At high tide the flow produces a boil, and at low tide it creates a rivulet which meanders down the mud flats for a few hundred feet to the water's edge. The Mill Valley effluent flows into an open canal. From there it is channeled through mud flats to the waters of Richardson Bay.

As a first step toward alleviating the bacteriological and eutrophication problems in Richardson Bay, the San Francisco Bay Regional Water Quality Control Board requested that the Federal Water Quality Administration (now the Water Quality Office of the Environmental Protection Agency) measure the dilution of effluent from the Richardson Bay S.D. plant by the receiving waters. The dilution factors would then be used by the Board in drafting a resolution prescribing waste discharge requirements.

The Board also requested that the Water Quality Office measure nutrient concentrations and algal growth potentials (AGP) in (1) bay water from representative locations and in (2) sewage discharged from both treatment plants. AGP experiments were

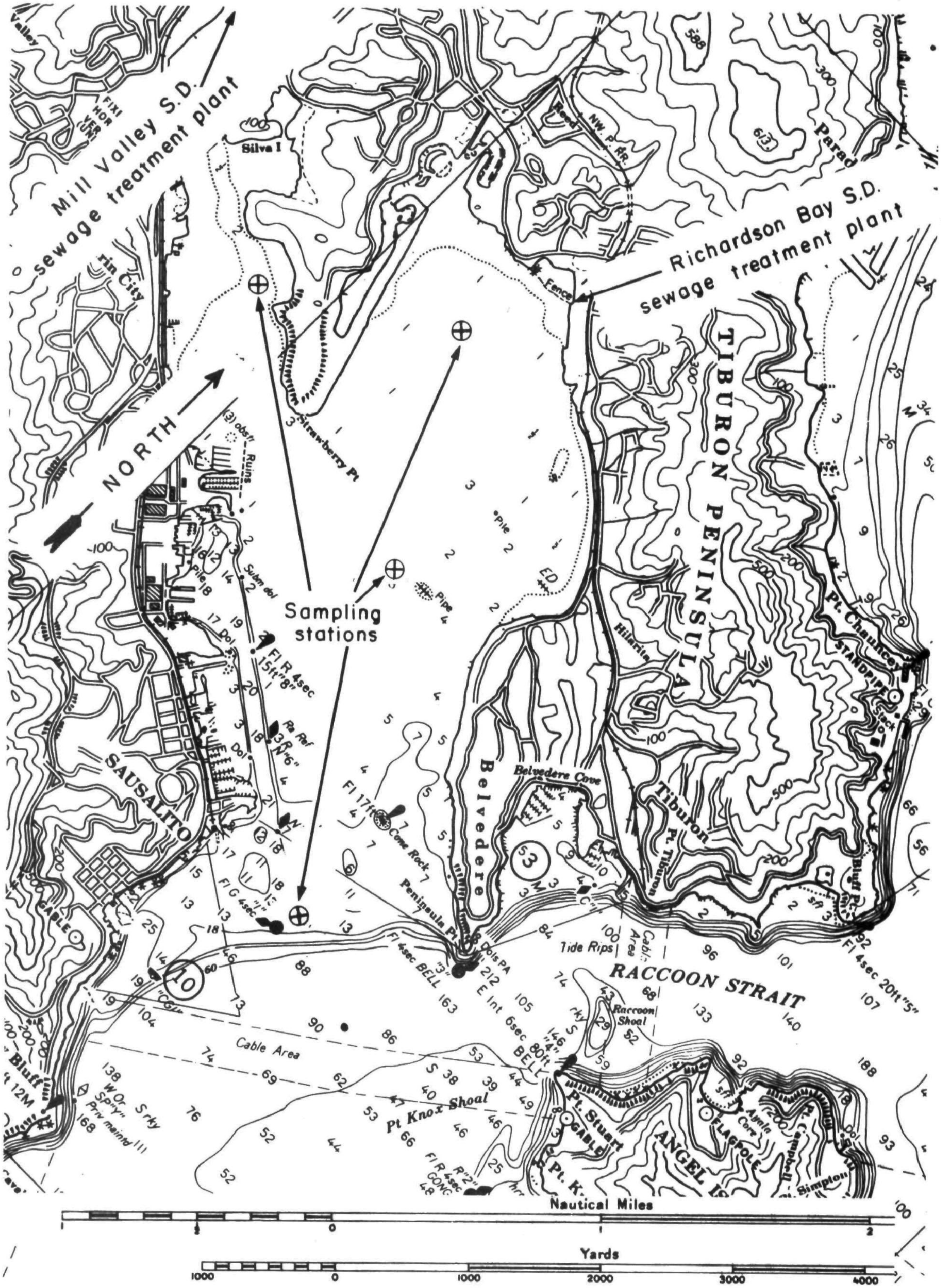

Figure 1. Richardson Bay

also to be performed on various dilutions of effluent in San Francisco Bay water in order to correlate growth stimulation effects with dilution contours.

Summary and Conclusions

Dilution of the Richardson Bay S.D. treatment plant effluent in Richardson Bay was measured with fluorescent dye. The dye was added to the effluent at continuous rate during a two week period, and its buildup in the bay was monitored daily. Although the dye field shifted with wind direction, a comparison of each day's concentration contours showed that a consistent gradient had developed after the first week and indicated a steady state condition. Effluent dilution figures were developed from steady state contours. Nutrient concentrations and algal growth potentials were measured in both the effluent and receiving water to relate dilution to eutrophication.

The following conclusions were drawn from this study:

1. Low dilutions are limited to a narrow band in the vicinity of the Richardson Bay S.D. outfall. Dilutions of less than 100:1 persist in a band extending 50 to 100 feet from the water's edge at high slack water and from 1000 to 2000 feet along the shore in either direction from the outfall. Dilutions of less than 10:1 occur within 25 feet of the discharge point. Beyond 100 feet from the water's edge the effluent disperses rapidly, with dilutions of 500:1 occurring within 300 feet of the outfall and 1000:1 within 1500 feet. The width, length and orientation of the low dilution field are strongly affected by the general wind direction.

2. Flushing takes place rapidly within the portion of Richardson Bay studied. All dye was removed from the bay within a week after the injection has been discontinued.

3. Effluent concentrations of 0.5 to 1.0% in San Francisco Bay water did not noticeably stimulate algal growth in laboratory experiments. However, a 5% effluent solution in bay water produced an 8-fold increase in growth over unspiked bay water, and in pure effluent the increase in growth over bay water was more than 100-fold.

4. Nutrient analyses showed the total nitrogen concentration in the Mill Valley S.D. effluent was 4 times the concentration in the Richardson Bay S.D. plant effluent, although neither nitrogen nor phosphorous levels in the waters of Richardson Bay showed any significant areal variation.

Dye Tracer Study

Dilution factors were determined by introducing a dye tracer to the Richardson Bay S. D. waste water treatment plant effluent and measuring its concentration in Richardson Bay. Measurements made daily at the same stage of tide documented the buildup until it approached a steady state level. Tracer concentrations were plotted, joined into isopleths (lines of equal concentration), and then converted to dilution contours on the basis of the average effluent flow rate.

Fluorescent dye (Rhodamine WT) was introduced into the plant discharge line downstream from the chlorination chamber at a rate of 10 milliliters per minute for a period of 14 days. The plant discharge rate during this period averaged 0.216 mgd, making the dye concentration in effluent approximately 2 X 104 ppb.

Dye concentrations in Richardson Bay were monitored from a research vessel during higher high slack water each day from October 27 through November 9, and during lower low slack water on November 3, 5 and 8. Background runs were made at both high and low slack waters prior to the dye release, and on November 16, a week after terminating the release, to check for persisting concentrations. Continuous measurements made by standard fluorometeric methods were recorded on a strip chart. Vessel locations were pinpointed frequently by cross bearings or fixes on convenient landmarks. Monitoring cruises, which followed roughly the same routes each day, were timed to begin 45 minutes before slack water and end 45 minutes after.

On the 12th day of the release, November 7, aerial photographs were taken of the visible dye that persisted in a band along the shoreline near the outfall, while discrete samples were taken from a small skiff to relate dye concentration to color intensity in the photographs.

Data Analysis

Fluorometer measurements were tabulated from the recorder strip charts at points identified by location fixes and at intermediate points where abrupt concentration changes occurred. A computer program was written to convert fluorometer units to parts of dye per billion parts of water, to subtract background and to correct the dye concentration for temperature effects. The cruise track for each day and all location fixes were plotted on individual work charts of Richardson Bay and the dye concentrations then plotted at the appropriate points.

Isopleths were plotted for as many concentrations as possible, and the completed charts then compared in chronological order to study trends. The 200, 40, 20 and 1 ppb isopleths that best reflected steady state concentrations were selected from the work chart and transferred to another chart for final presentation. The first three of these concentrations correspond to dilution factors of 100:1, 500:1 and 1000:1, respectively, and 1 ppb contour represents the limit of detectable dye over background. Background levels varied between 0.3 and 0.8 ppb, depending upon tidal stage and the location of measurement.

The orientation of the dye field was strongly affected by wind velocity. Even at high tide, the water in upper Ricardson Bay is only a few feet deep (Figure 1) and therefore highly responsive to wind effects. As the dye-tagged effluent entered the receiving water it was quickly mixed by wave action and the mixture pushed against the shoreline by the wind. This created a hydraulic gradient which carried the dilute effluent along the shoreline and eventually back into the bay. As the direction of the wind changed, the location of the effluent field and its bayward route changed accordingly.

A steady state condition which might, therefore, be described as "shifting" was evidently reached near the end of the first week of the dye release. On November 1 and 2, when the wind was from the southeast, the dye concentrated to the west of the outfall. The wind then shifted to the southwest, and from November 3, to the end of the release period the dye concentrated to the east of the outfall. The contours drawn for November 3 through 8 show a similar distribution for each day, with no further buildup.

Figure 2 shows the dilution contours measured during higher high slack on November 7. This date was selected for display because of the coincident aerial photographs and discrete samples. Figures 3 and 4 show the visible band of dye extending along the shoreline from the release point. The red color provides a rough quantitative measure of concentration since a dilution of 400:1 or less is visible, and the distinct edge of color implies a steep concentration gradient. In Figure 4 varying concentrations indicated by the different shades of red are distinguishable, representing dilutions ranging from 7:1 to 400:1.

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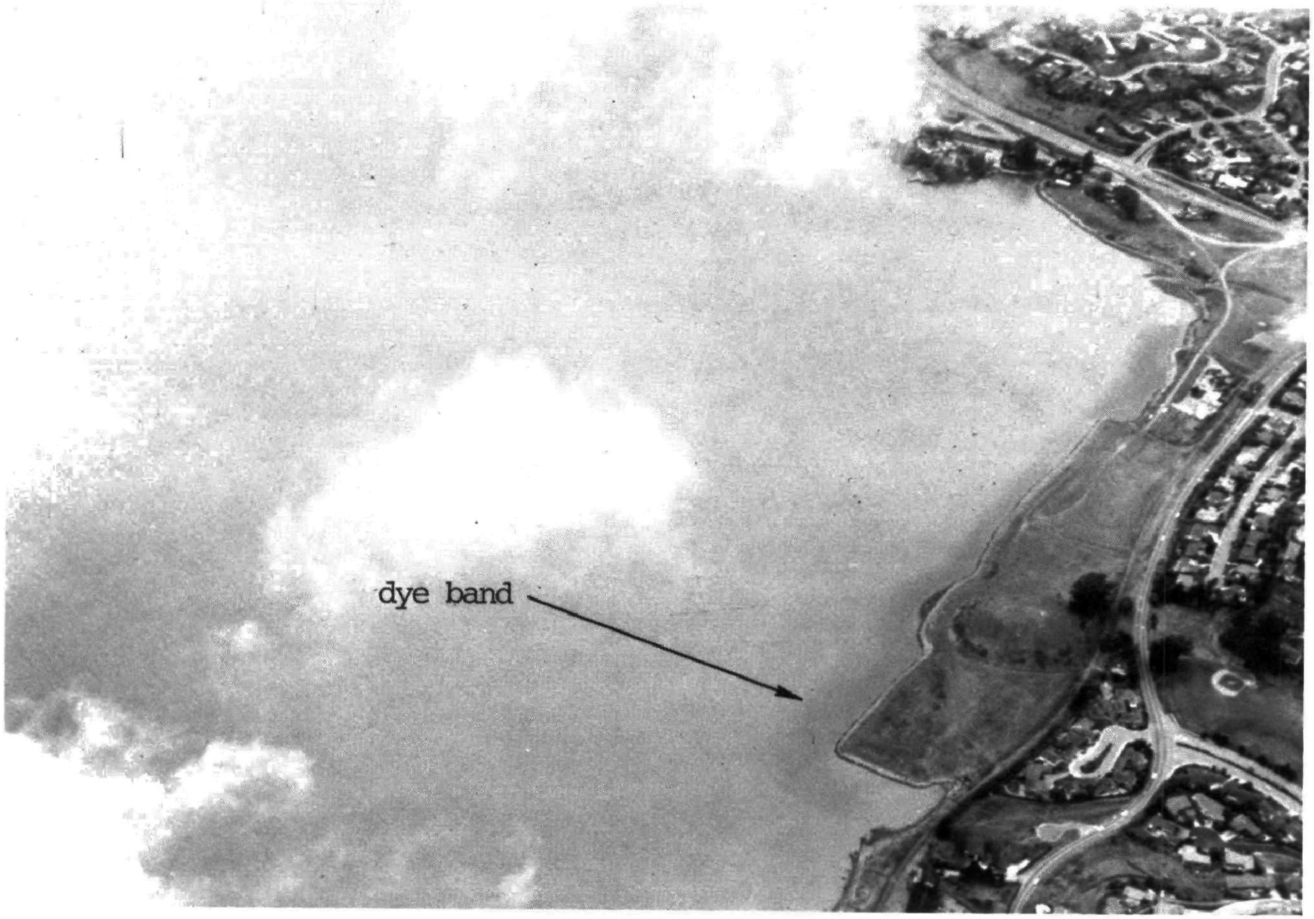

Figure 3. Aerial View of Visible Dye Field on November 7, 1970

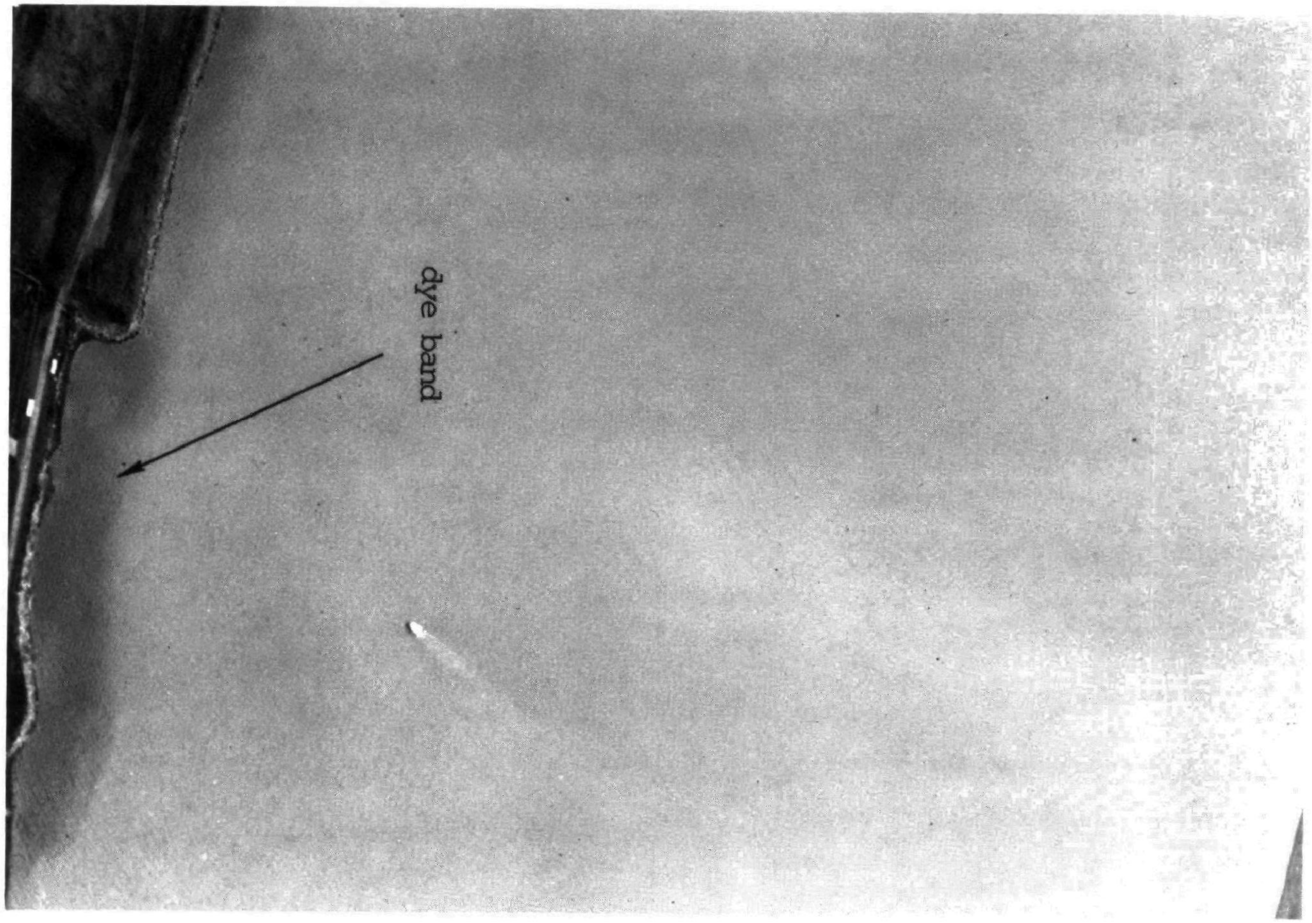

Figure 4. Color Gradations in Visible Dye Field

Figure 5 shows the dilution contours measured during low slack on the evening of November 8. The monitoring area was limited because of depth, and darkness prevented observation of visibly red areas.

Algal Growth Potential and Nutrients

On November 2, samples for nutrient and AGP analyses were collected from four locations in Richardson Bay and from the two waste water treatment plants. The bay samples were taken near the predicted time of higher high slack water from the following points shown in Figure 1:

1. Entrance to Richardson Bay, 43 minutes before higher high slack. Since the tide was still flooding, the sample was probably not affected by either of the treatment plants.

2. Center of Richardson Bay abeam the north end of Belvedere Island, 31 minutes before slack. Water at this location would be subject to the effects of both treatment plants.

3. East side of Strawberry Point about 3000 feet from the Richardson Bay S.D. plant, 21 minutes before slack. This sample should be affected primarily by the Richardson Bay S.D. plant.

4. West side of Strawberry Point about 2000 feet upstream from Kappas Yacht Harbor, 39 minutes after slack. This sample should be affected primarily by the Mill Valley plant, although wastes from nearby houseboat communities could have an additional effect.

The amounts of algal growth under laboratory conditions in the above samples and in San Francisco Bay water spiked with different amounts of effluent from each of the plants are listed in Table 1.

Growth measurement was calculated from the intensity of fluorescent light emitted by extracted chlorophyll a in an acetone solution. Increases as a function of percent effluent added are shown in Figure 6. The responses appear to be curvilinear and therefore no regression equations have been calculated from the results. Nutrient values from the water samples are listed in Table 2.

Figure 5. Dilution Contours in Richardson Bay at Lower Low Slack Water on November 8, 1970

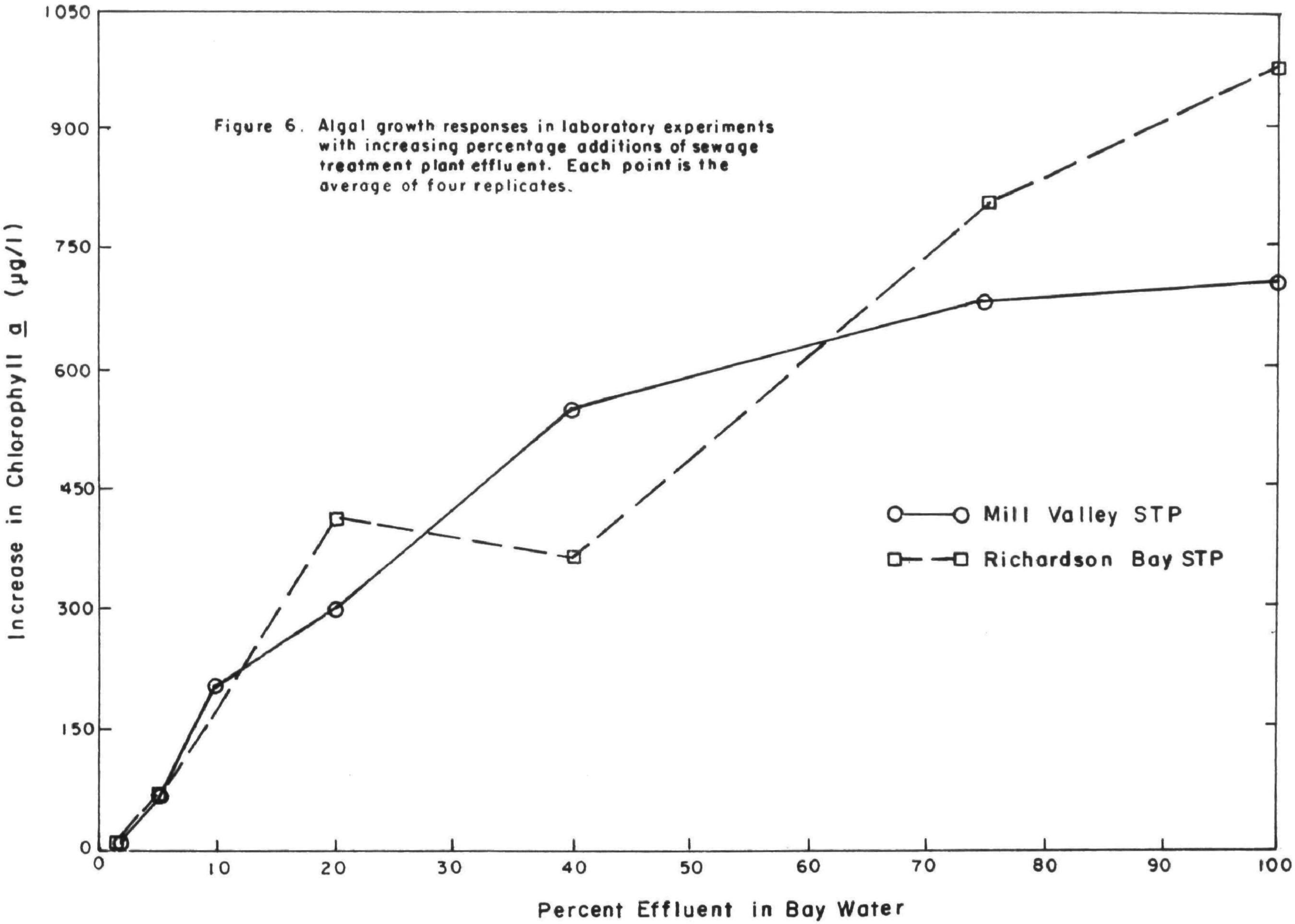

Figure 6. Algal growth responses in laboratory experiments with increasing percentage additions of sewage treatment plant effluent. Each point is the average of four replicates.

TABLE 1. ALGAL GROWTH RESPONSES IN LABORATORY CONDITIONS

S. F. Bay water with additions of Mill Valley STP effluent

Percent effluent	0	0.5	1.0	5.0	10	20	40	75	100
Increase in chl. a (ug/l)	8.0	10.7	9.7	58.2	199	300	550	683	703
Maximum chl. a (ug/l)	9.0	12.2	11.2	59.7	200	302	553	686	707
Growth rate/day	0.79	0.76	0.87	1.30	1.12	0.45	0.45	0.72	0.81

S. F. Bay water with additions of Richardson Bay STP effluent

Percent effluent	0	0.5	1.0	5.0	10	20	40	75	100
Increase in chl. a (ug/l)	8.0	10.2	12.9	60.8	173	416	364	796	972
Maximum chl. a (ug/l)	9.0	11.7	14.4	62.3	174	418	366	799	975
Growth rate/day	0.79	0.85	0.80	1.13	1.44	1.37	0.59	1.05	0.98

Richardson Bay samples without effluent addition

	San Francisco Bay	North end Belvedere	East of Saddle	West of Saddle
Increase in chl. a (ug/l)	8.0	5.2	3.8	4.9
Maximum chl. a (ug/l)	9.0	6.2	6.4	6.4
Growth rate/day	0.79	0.67	0.48	0.74

TABLE 2. NUTRIENT CONCENTRATIONS IN RICHARDSON BAY WATER AND EFFLUENT (mg/l)

Location	NH_3-N	Org-N	NO_3-N	Total N	PO_4-P	Total P
Abeam No. end of Belvedere Island	0.25	0.62	0.01	0.88	0.08	0.10
East of saddle on Strawberry Pt.	--	0.89	0.01	1.15	0.11	0.16
West of saddle on Strawberry Pt.	0.25	0.71	0.04	1.00	0.11	0.15
Buoy 2 at entrance to Richardson Bay	0.22	0.76	0.04	1.02	0.08	0.14
Richardson Bay S.D.	0.45	9.7	1.5	11.7	9.0	10.5
Mill Valley S.D.	21.1	24.5	1.20	46.8	0.92	4.80

Discussion

The movement of the dye both during and after the release period indicated that most of the volume of water in the portion of the bay studied was replaced every tidal cycle. During the release period, a steady state condition was reached when a narrow band of high concentration developed along the shoreline in the vicinity of the outfall. Beyond the outer boundary of the band a steep concentration gradient indicated a limited area of mixing, and beyond this point the water at high tide could only consist of replacement from the outer bay. After termination of the release, the visible band of red disappeared within one day, and within a week only background levels could be detected with the fluorometer.

For both treatment plants, the 0.5% and 1.0% additions of effluent did not cause growth statistically higher than the 0% controls (San Francisco Bay water). However, the 5.0% addition of the Richardson Bay STP effluent increased chorophyll a concentration almost 8-fold over that found in the control, or from approximately 8 to 60 ug/l. In general, increasing or higher percentage addition of effluent to the bay water gave higher algal growth, with 100% effluent response more than 100 times that of the controls.

Analyses of effluent samples showed the ammonia concentration from the Mill Valley plant to be more than 40 times that of the Richardson Bay plant, and the total nitrogen concentration to be more than four times higher. This disparity may be caused by the method in which the centrate from the sludge dewatering process is disposed. Phosphate concentrations were reversed; Mill Valley effluent showed on 0.92 mg/l of PO_4-P/l compared to 9.0 mg/l from the Richardson Bay plant.

Nutrient levels in the four bay samples were almost identical (0.88 - 1.15 mg/l total nitrogen and 0.10 - 0.15 mg/l total phosphorous). This similarity could be at least partly attributed to the high dilution occurring at flood tide. It should be noted that there was no statistical difference in the algal bioassay responses among the four samples.

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