Chapter 6

# AN ANALYSIS OF POTENTIAL ENVIRONMENTAL IMPACTS OF GRAYWATER DISCHARGE UPON WATER QUALITY IN SAN FRANCISCO BAY

Nicole Somorjai

## Introduction

Various types of pollutants, including industrial and household wastes, have found their way into San Francisco Bay. One form of waste from both households as well as houseboats and live-aboard boats is graywater, a wastewater consisting of kitchen, bath and shower wastes. It affects water quality by introducing coliform bacteria, toxic soap residues, varying concentrations of biochemical oxygen-demanding substances (BOD), suspended solids such as oil and grease, and biostimulatory substances such as nitrogen and phosphorus (BCDC, 1985). The type of impact graywater pollution has on the Bay is as yet unknown, although the California Regional Water Quality Control Board (RWQCB) believes that vessel graywater wastes are of concern in crowded areas such as marinas and harbors (RWQCB, 1981). This report will evaluate the effects of graywater discharge generated by houseboats and live-aboards on the water quality of San Francisco Bay by examining analyses of water samples taken from houseboat berths in the Berkeley marina.

## The Scope of the Problem

In 1984, the Bay Conservation and Development Commission (BCDC) did a mail survey on live-aboard boat use in 74 Bay Area marinas. They received responses from 41 of the marinas, out of which 18 indicated the presence of live-aboards (BCDC, 1985). The total number of live-aboard vessels was estimated to be 260. In 1983, a survey of 66 marinas by Bay Area Boaters reported that 1,033 boats out of a total of 16,295 possible berths might be live-aboard boats (BCDC, (1985). Out of approximately 19,000 berths existing today and presently under construction, it is estimated that there might be 380 to 1,140 live-aboards in the Bay (BCDC, 1985).

Currently, there are 12 houseboats and 40 live-aboards berthed in the Berkeley marina. No graywater should be discharged from these vessels into the Bay because each vessel is hooked up to a pumpout station located at the marina into which any possible waste discharge is pumped from holding tanks on board the vessels (Worden, 1985, pers. comm.).

The RWQCB staff recently completed a study of vessel waste discharge in the San Francisco Bay Area (RWQCB, 1981). They found that as a result of BCDC regulations, pumpout facilities for vessel holding tanks are located throughout the area, but several of them are rarely used due to poor location and/or high user fees.

BCDC has a Bay Plan policy on houseboats, recently put into effect, that suggests that houseboats be permitted in some parts of the Bay provided that they do not adversely affect the ecology of the Bay, do not cause a harmful amount of sedimentation, and are either connected to a shoreline sewage treatment system or have on-board treatment facilities acceptable to public health and water quality control agencies.

Prior to 1972, vessel wastes were not regulated and could be discharged overboard without treatment. The U.S. Congress, in 1972, enacted the Federal Water Pollution Act Amendments (Public Law 92-500). These amendments characterized vessels as pollution sources and required that marine sanitation devices (MSD's) be installed on board vessels. MSD's collect wastes and either treat and dispose of the wastewaters or retain them for shoreside disposal. There is, however, at the present time, no regulation addressing graywater discharge into in San Francisco Bay.

Water Circulation in San Francisco

San Francisco Bay is one of the largest estuarine systems in the world. The system includes the Central Bay, South San Francisco Bay, and San Pablo Bay, and connects with the Pacific Ocean at the Golden Gate. To the north and northeast it extends through Carquinez Strait to Suisun Bay and the Delta. The total surface area of the San Francisco Bay system is approximately 1,220 square kilometers and the mean depth is about 5 meters referenced to mean lower low water (Cheng and Gartner, 1985). Each embayment within the Bay is dominated by a wide expanse of shoal areas which surround deep and narrow ship channels. Narrow straits, which are frequently areas of higher currents, are the natural transitions from one embayment to the next.

Water circulation in San Francisco Bay is driven primarily by the tides which flow into the Bay from the Pacific Ocean through the Golden Gate (Cheng and Gartner, 1985), and by the winds. Circulation in the open Bay provides adequate dispersal of pollutants (Cheng and Gartner, 1985); however, this may not be the case in enclosed marinas.

The effects of waste loads on the Bay depend on the amount of pollutants and their dispersal by tidal flows and freshwater inflows. Although the rates of pollutant discharge can be controlled, and tidal flows can be predicted, freshwater inflows into the Bay are subject to uncontrolled and wide annual variation depending on seasonal or catastrophic events.

It is through the ebb and flow of the tide, however, by which effluents present in the Bay eventually are carried out to sea, or become dilute enough that their effects on aquatic life become negligible. In enclosed marina basins, where circulation is limited, pollutant dispersal is at a minimum. Thus, as the concentration of wastewater loads increases, there may be an adverse affect on water quality in marina waters. Marinas which are not as sheltered from tidal flows, on the other hand, have better mixing and lower concentrations of effluents from waste discharge. Consequently, the major concern in evaluating the possible impacts of graywater discharge on San Francisco Bay is the enclosed marinas with restricted circulation.

Parameters of Graywater

There are a number of parameters that are important to consider in assessing impacts of waste discharge on water quality. These are: (1) the presence or absence of coliform bacteria; (2) the amount of dissolved oxygen; (3) the amount of suspended solids; (4) the amount of plant nutrients dissolved; (5) the pH of the water; and (6) the temperature of the water.

Coliform bacteria are found in the intestinal tract and are harmless to humans. An individual excretes between 100 billion and 400 billion coliform bacteria per day (Titcomb and Bartley, 1979). Coliforms are important because they are used to indicate the possible presence of pathogenic organisms in waste materials. Pathogenic, or disease-carrying organisms, originate in humans who are infected with disease or who are carriers of a specific disease. The absence of coliform organisms is considered an indication that the water is free from disease-producing organisms.

Biochemical oxygen demand (BOD), measures the amount of dissolved oxygen (DO) consumed by decomposer organisms in wastewater. When high amounts of DO are consumed by these organisms, there is increased competition for the remaining DO and concentrations may sink below the tolerance levels for other organisms in the Bay.

Suspended solids are materials that either float on the surface of, or are in suspension in, wastewater. They affect fish and fish food populations by either killing them or reducing their growth rate and resistance to disease (Titcomb and Bartley, 1979).

Nitrogen, a nutrient naturally occurring in water, when combined with phosphorus, contributes to aquatic enrichment and the consequent growth of algae. Phosphorus is necessary for the growth of algae and other organisms. Too much algal growth, however, can limit the reproduction of certain kinds of fish and other aquatic life by depleting the dissolved oxygen supply. Effluents from wastewater treatment, high in nutrients, cause enrichment and increase phosphate concentrates when discharged into natural surface waters (Titcomb and Bartley, 1979).

An important factor in the chemical and biological systems of natural waters is the pH, which is a measure of the concentration of hydrogen ions in water. Wastewater effluents discharged into natural waters are required to have a pH within the range of 6.5 to 9.0 needed by the marine life present. This pH range has been shown to provide adequate protection for the life of both freshwater fish and bottom dwelling invertebrate fish food organisms (Titcomb and Bartley, 1979). Beyond this range, fish suffer adverse behavioral effects which increase in severity as time and degree of deviation increases, until lethal levels are reached (Titcomb and Bartley, 1979). Test results indicate that the pH of graywater waste usually falls in the range of about 6.0 to 9.0, a range safe for aquatic life.

The addition of graywater to the waste stream is expected to increase the temperature of the wastewater (Titcomb and Bartley, 1979). Temperatures above 100$^{o}$F are considered to be hazardous to marine life (RWQCB, 1982).

Kitchen or galley wastes, including fats, oils and grease, contribute mostly suspended solids to the aquatic environment into which they drain. Limits for grease discharge into natural waters have been established for shoreside sources, but shipboard discharges remain unregulated (Titcomb and Bartley, 1979).

Laundry wastewater from the total cycle of a typical load contains 425 ppm detergents, 140 ppm total organic carbon (amount of organic matter present in water), 430 ppm chemical oxygen demand (oxygen demand of inorganic matter), 180 ppm BOD, 1200 ppm total solids (suspended and dissolved solids), 150 ppm suspended solids, and 100 ppm oil and grease (Titcomb and Bartley, 1979). Average laundry wastes contain approximately 0.007 pounds per capita per day BOD and 0.009 pounds per capita per day suspended solids; average total phosphorus loadings from detergents range from 1.7-20 grams per capita per day to 2.9 gpcd (Titcomb and Bartley, 1979).

Shower wastes consist of approximately 40 mg/liter BOD (Titcomb and Bartley, 1979) and minor amounts of soap. This form of wastewater, however, is considered to have a minor effect on water quality when compared to the effects of kitchen and laundry wastes.

Water Quality Standards

The RWQCB has set water quality standards for the Bay. These standards require that the water temperature should not exceed 100$^{O}$F (or 38.1$^{O}$C); the pH shall not be below 6.5 or above 8.5; the dissolved oxygen level should not be below 5.0 mg/L, and the amount of plant nutrients, ammonia and organic nitrogen, must not exceed 0.4 mg/L (RWQCB, 1982). Standards for total suspended solids, BOD and other parameters were also set but are not included in this report because data were not collected for these parameters.

Graywater Flow Rates

Alhtough the chemical composition of graywater is important, the variability of graywater flow rates causes significant daily fluctuation in composition. It seems likely that the amount of graywater discharged would be greatest during the early morning, mid-day and evening hours when the amounts of shower and kitchen wastes would be most concentrated.

Graywater flow rate is measured in gallons per capita per day (gpcd) and is a measure of the amount of graywater produced by one person in a 24-hour period. Table 1 lists the various loads of laundry, shower and galley wastewater, which are about 10 gpcd, 24-30 gpcd, and 10-20 gpcd, respectively, as well as 5 gpcd miscellaneous graywater. Diet, personal habits, seasonal changes, total water usage, and availability of facilities, are all factors which could affect the variability of vessel graywater waste loads. Weather, tide conditions and location of the site of data collection could also affect the reported waste load concentrations.

Methods

Samples of Bay water were collected at docks J and E, around houseboat berths, in the Berkeley Marina on two different occasions (Figure 1). Two samples were collected on February 10 at high tide and two samples were collected on February 22 at high-low tide. All samples were collected in the early afternoon, between 12:30 and 1:30 P.M. It was raining during both these days and had been raining continuously on the days prior to sample collection.

| Source | Flow Rate (gpcd) |
|---|---|
| Laundry | 10 |
| Galley | 20 |
| Shower | 24-30 |
| Miscellaneous | 5 |
| Total Graywater | 59-65 |

Table 1. Graywater Flow Rate Contributions by Source
Source: Titcomb and Bartley, 1979

The samples were stored in small glass jars which were rinsed several times with the sample water before the water was actually collected. Water quality tests were then conducted both in the field and in the laboratory; however, only some of the important parameters were tested due to laboratory restrictions. Temperature, pH and dissolved oxygen were tested at the time of the sample collection. Temperature and DO were measured with a portable Leeds and Northrup dissolved oxygen meter. The pH was measured using a "pH Master" meter.

The tests performed in the laboratory consisted of salinity tests using a self-contained conductivity meter (YSI MOdel 131), Kjeldahl tests for organic nitrogen (nitrate + nitrite) and acidimetric tests for the determination of ammonia (nutrient nitrogen). Tests for these specific parameters were done for the following reasons: Conductivity is an indication of salinity; the amount of salinity determines the availability of nutrients (ammonia and organic nitrogen) for such organisms as phytoplankton, benthic algae and vascular marsh plants (Conomos, 1979). Each test was conducted in accordance with Standard Methods (APHA, 1975).

## Results

All the test results are within the RWQCB standards and are summarized in Table 2. The test data show that there was little variation in the temperature of the marina water around the houseboat berths, the range being from 13.6°C-13.8°C. The pH ranged from 7.5 to 8.0. The dissolved oxygen concentration levels, ranging from 10.3 ppm - 11.3 ppm, were relatively high, as were the salinity values which ranged from 24.4 o/oo - 25.1 o/oo. Neither ammonia nor organic nitrogen was detected. No data were collected for coliform bacteria, suspended solids, phosphorous, and BOD concentration levels. Bits of floating solid particles were observed at the time of sample collection.

## Discussion of Test Results

In the winter, an increased Delta outflow controls the salinity distribution in the Bay and slightly lowers the surface salinities of coastal waters. The cold (10°C) water of this Delta outflow lowers

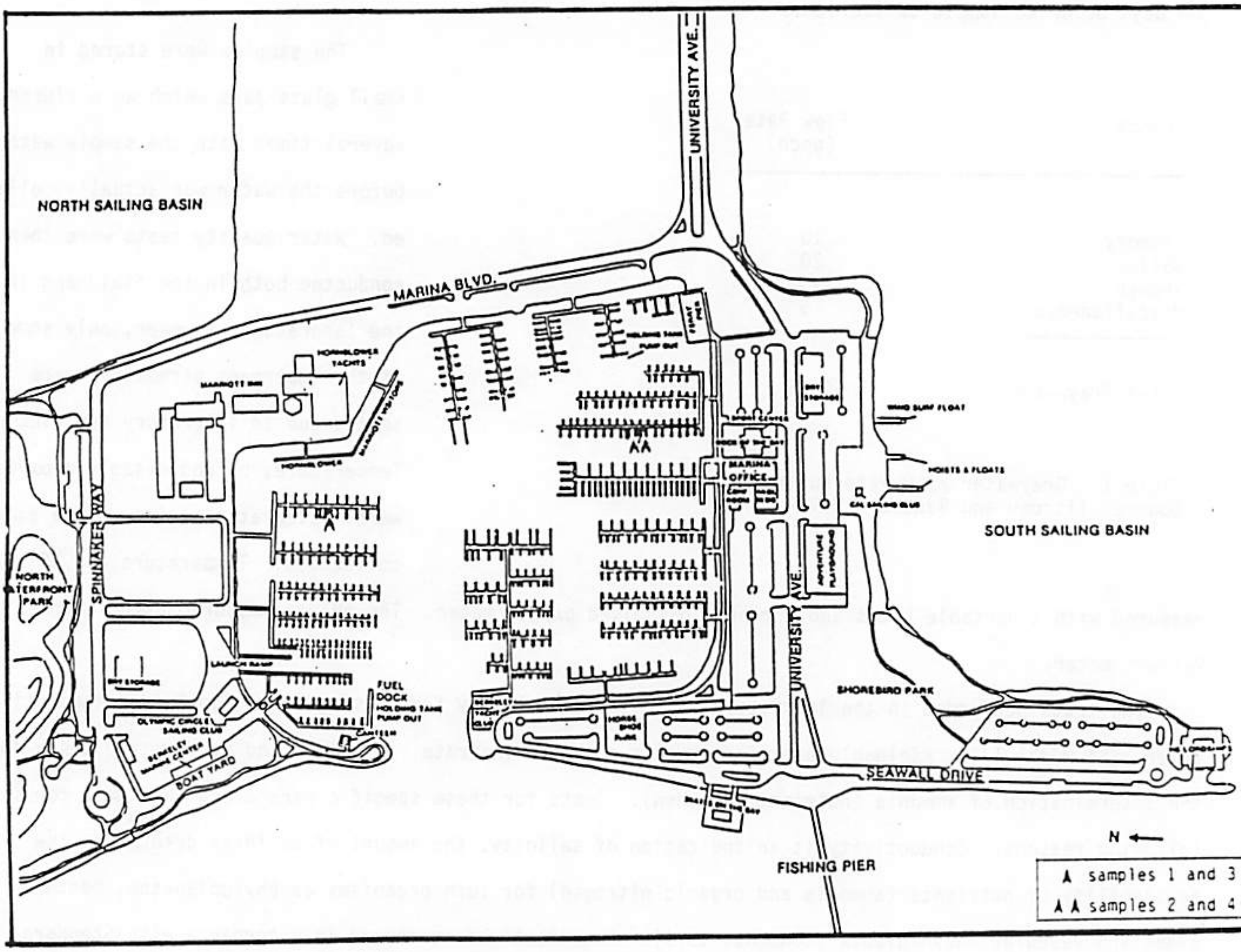


Figure 1. Berkeley Marina, Location of Sample Sites.
Source: Worden, 1986.

ambient Bay-water temperatures (Conomos, 1979). In summer, however, a decreased Delta outflow does not noticeably depress salinity, but the water temperatures are $10^{0}C$ warmer than in winter (Conomos, 1979).

It is unclear as to why the laboratory tests performed for this report did not detect the presence of the plant nutrients, $NH_3$ and organic nitrogen. In the northern part of the Bay, the area closest to the test site, nutrient supply is dominated by Delta outflow and exchange with the ocean. Concentrations of these nutrients are higher in winter than in the summer, due to the presence of additional organic nitrogen and ammonia by local stream inflow (Conomos, 1979).

The high DO levels shown in Table 2, levels which indicate no cause for concern about effects on wildlife, could be accounted for by the fact that DO concentration levels tend to be higher in winter than in summer, due in part to a greater solubility of oxygen in colder water. Dissolved oxygen is biologically reactive and is influenced by oxygen exchange across the water surface, photosynthesis, respiration by plants and animals, decomposition of organic matter by bacteria and by chemical oxidation,

| Sample | Date of Collection | Temperature ($^{o}C$) | pH | DO (ppm) | Salinity (o/oo) | $NH_3$ (mg/l) | $NO_3$+$NO_2$ (mg/l) |
|---|---|---|---|---|---|---|---|
| RWQCB Standards | --- | 38.1 | 6.5-8.5 | 5.0 | | 0.4 | 10.0 |
| 1 | February 10, 1986 | 13.8 | 8.0 | 10.7 | 24.8 | 0.0 | 0.0 |
| 2 | February 10, 1986 | 13.7 | 7.6 | 11.2 | 24.4 | 0.0 | 0.0 |
| 3 | February 22, 1986 | 13.7 | 7.9 | 11.3 | 24.5 | 0.0 | 0.0 |
| 4 | February 22, 1986 | 13.6 | 7.5 | 10.3 | 25.1 | 0.0 | 0.0 |
| | average values: | 13.7 | 7.8 | 10.9 | 24.7 | | |

note: no specific standards were found for salinity

Table 2. Water Sample Test Data and RWQCB Standards (RWQCB, 1982).

advection and diffusion (Conomos, 1979). Low DO concentrations are thus more likely to be important considerations during the summer or fall when large amounts of plant growth and decay occur.

The data show that the pH range, as well as the water temperature range, are safe for marine life. Changes in pH are directly related to changes in water temperature. Thus, as the water temperature becomes 10$^{o}$C warmer during the summer than in the winter, pH values for the summer would tend to drop by 0.1 (Conomos, 1979). The pH values in summer would also tend to be higher than those in winter due to increased photosynthesis, respiration and mineralization.

Water temperature, salinity and pH data from the present study can be compared with data collected in a USGS study (Conomos, 1979) for the station closest to the Berkeley Marina test site. Averaged data for winters from 1969-1977 yield a water temperature of 10$^{o}$C, a salinity value of 26 o/oo (per mille), and a pH of 8.1 (Conomos, 1979). The average values for each parameter of all four samples shown in Table 2 yield a water temperature of 13.7$^{o}$C, a salinity value of 24.7 o/oo, and a pH of 7.8. Thus, the difference between values for the parameters are 3.7$^{o}$C in water temperature, 1.3 o/oo in salinity, and o.3 in the water pH, in each case a negligible amount.

The differences between the data in Table 2 and the data collected by the U.S. Geological Survey could be attributed to the difference in site location, weather conditions, or variability of tidal mixing, as well as the fact that the data collected for this report were representative of graywater test samples, whereas the U.S. Geological Survey test samples were of Bay water in general. Unfortunately, since no other results of graywater studies in San Francisco Bay were available for comparison, it is difficult to use a comparison of data from another locality to account for the accuracy of the data in Table 2. The accuracy of the data could, however, be determined by repeated samplings at the same test site.

## Conclusion and Recommendations

The results indicate that graywater discharge does not pose a problem in the Berkeley marina. Most, if not all, of the graywater wastes from houseboats are discharged into holding tanks which are hooked up to pump-out stations and holding facilities. Any graywater which may find its way into the marina water is likely not to be a cause for concern, as indicated by the test results (Table 2). In summer, however, the number of populated houseboats may be greater than when these tests were taken. Thus, there may be larger amounts of graywater discharged into marina waters because more people are more likely to be living on boats. Additionally, at another time of day, perhaps early in the morning when most of the waking-up activity would occur on a houseboat, or at another time of year with less rainy weather, the data might also show higher levels of graywater discharge.

It is worthwhile to note that, due to the location of the Berkeley marina across from the Golden Gate, there would tend to be more tidal circulation to dissipate any discharge than in a marina in more sheltered areas of the Bay. Therefore, for an understanding of the overall impact of graywater on the Bay, it would seem necessary to analyze any graywater which might be emitted into the more sheltered marinas.

Graywater could have potential for damaging the water quality of the Bay. At the present time, however, there are not enough data to make a more conclusive assessment of the impact of graywater discharge on Sin Francisco Bay. It is thus recommended that enclosed marina basins be monitored by counting the number of houseboats and live-aboards, and by measuring the amount of graywater waste discharged per day. The actual measurement of graywater wastes could be done by monitoring each vessel for the number of showers taken, the number of times dishes are washed, as well as how many times laundry is done. The number of individuals per vessel and the gallons of water used in washing dishes, doing laundry and taking showers should also be recorded. It is the amount of graywater discharged which is important to the water quality of the Bay, especially in marinas lacking pump-out facilities or having little tidal circulation.

In addition, in order to establish definitively the minimum concentrations of impurities or toxic materials for the Bay, a set of control experiments is recommended. So as not to degrade the quality of the Bay itself, one could simulate the environment in the Bay. A tank could be filled with Bay water and then a steady flow of this water could be established into which some fish and algae would be introduced. Over appropriate time intervals, specific amounts of graywater waste material could be artificially added to the tank. With each addition, waste concentration measurements could be taken until these measurements reached levels harmful to the fish and algae in the tank. Thus, by monitoring enclosed marina basins and by performing controlled experiments in the laboratory, it would be possible to assess what minimum amount of graywater waste would prove toxic to the water quality of San Francisco Bay.

## REFERENCES CITED

American Public Health Association (APHA), 1975. Standard Methods for the Examination of Water and Wastewater, 14th edition; Washington D.C., American Public Health Association, 1193pp.

Cheng, R.T. and J.W. Gartner, 1985. Tides, Tidal and REsidual Currents in San Francisco Bay, California. Results of Measurements, U.S. Geological Survey Water Resources Investigations, Open-File Report 84-4339, 1979-1980, 72pp.

Conomos, T.J., 1979. Properties and circulation of San Francisco Bay waters. In Conomos, T.J., ed., San Francisco Bay: The Urbanized Estuary; AAAS, Pacific Division, San Francisco, California, pp. 115-42.

Fischer, H.B., E.J. List, R.C.Y. Koh, J. Imberger, and N.H. Brooks, 1979. Mixing in Inland and Coastal Waters; New York City, Academic Press, 503pp.

Regional WAter Quality Control Board (RWQCB), 1981. Vessel Waste Discharge Survey, San Francisco Bay Region; Oakland, California, 30pp.

_____, 1982. Water Quality Control Plan, San Francisco Bay Basin (2), San Francisco Bay Region; Oakland, California, 68pp.

San Francisco Bay Conservation and Development Commission (BCDC), 1983. Water Quality Issues in Richardson Bay, California. Unpublished Report, San Francisco, California, 57pp.

_____, 1985. Houseboats and Live-Aboard Boats. Unpublished report, San Francisco, California, 77pp.

Titcomb, A.N. and C.B. Bartley, 1979. Disposal of Vessel Wsates: Shipboard and Shoreside Facilities - Phase Two Graywater, No. MA-RD-930-79056; Environmental Protection Agency, Washington, D.C., 83pp.

Worden, Bill, Berkeley Marina Supervisor and Harbormaster, Berkeley Marina. Personal communication, 1985.