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Effects of Chlorine on the Toxicity of a Wastewater Treatment Facility Effluent and Impacts on Receiving Waters 54 pp

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Narragansett Bay Estuary Program

EFFECTS OF CHLORINE ON THE TOXICITY OF A WASTE WATER TREATMENT FACILITY EFFLUENT AND IMPACTS ON RECEIVING WATERS

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FOREWORD

The United States Congress created the National Estuary Program in 1984, citing its concern for the "health and ecological integrity" of the nation's estuaries and estuarine resources. Narragansett Bay was selected for inclusion in the National Estuary Program in 1984 , and the Narragansett Bay Project (NBP) was established in 1985. Narragansett Bay was designated an "estuary of national significance" in 1988. Under the joint sponsorship of the U.S. Environmental Protection Agency and the Rhode Island Department of Environmental Management, the NBP's mandate is to direct a program of research and planning focussed on managing Narragansett Bay and its resources for future generations.

The NBP will develop a draft Comprehensive Conservation and Management Plan (CCMP) by December, 1991, which will recommend actions to improve and protect the Bay and its natural resources.

The NBP has established the following seven priority issues for Narragansett Bay:

- management of fisheries
- nutrients and potential for eutrophication
- impacts of toxic contaminants
- health and abundance of living resources
- health risk to consumers of contaminated seafood
- land-based impacts on water quality
- recreational uses

The NBP is taking an ecosystem/watershed approach to address these problems and has funded research that will help to improve our understanding of various aspects of these priority problems. The Project is also working to expand and coordinate existing programs among federal, state and local agencies, as well as with academic researchers, in order to apply research findings to the practical needs of managing the Bay and improving the environmental quality of its watershed.

This report represents the technical results of an investigation performed for the Narragansett Bay Project. The information in this document has been funded wholly or in part by the United States Environmental Protection Agency through Cooperative Agreement #CX815457 to the Rhode Island Department of Environmental Management. It has been subject to the Agency's and the Narragansett Bay Project's peer and administrative review and has been accepted for publication as a technical report by the Management Committee of the Narragansett Bay Project. The results and conclusions contained herein are those of the author(s), and do not necessarily represent the views or recommendations of the NBP.

EXECUTIVE SUMMARY

EFFECTS OF CHLORINE ON THE TOXICITY OF A WASTE WATER TREATMENT FACILITY EFFLUENT AND IMPACTS ON RECEIVING WATERS

The Narragansett Bay Commission and the USEPA Environmental Research Laboratory-Narragansett, RI conducted a cooperative study during the spring and summer of 1989 to evaluate the effects of municipal waste water chlorination on both effluent and receiving waters. The specific objectives were to (1) evaluate the toxicity of a chlorinated effluent on selected test organisms, (2) determine the minimum effective residual chlorine concentrations required for adequate effluent disinfection, (3) identify concentrations of chlorine that would minimize toxicity while maintaining adequate disinfection of the waste stream, and (4) determine whether dechlorination should be recommended to mitigate toxicity in receiving waters.

The focal point of the study was the Field's Point Sewage Treatment Plant in Providence, RI. Toxicity tests were conducted, and bacterial determinations made on pre-chlorinated, chlorinated (in plant and in laboratory), and de-chlorinated effluents. Tests were also performed on two occasions on Providence River receiving waters in conjunction with dye (effluent tracing) studies. Toxicity tests used for the

effluents and receiving waters were the macroalga, Champia parvula, reproduction test, the sea urchin, Arbacia punctulata, sperm cell test and the hard-shell clam, Mercenaria mercenaria, embryo/larval development test.

Both chlorinated and un-chlorinated effluents were toxic to the three test species with chlorination having the greatest effect on the sea urchin test. Removal of chlorine (dechlorination) generally returned effluent toxicity to pre-chlorination levels. Chlorine concentrations required to produce adequate waste stream disinfection were also quite toxic to sea urchin fertilization and moderately toxic to hard-shell clam embryo/larval development.

Toxicity tests conducted on receiving waters generally showed those waters closest to the effluent discharge (highest effluent concentrations) were the most toxic. The Champia tests detected receiving water toxicity at effluent concentrations below what would be predicted based on results of pure effluent tests. This suggests sources of toxicity other than the Field's Point discharge. The hard-shell clam tests did not show any receiving water toxicity.

Although it was determined that chlorination increased the toxicity of the Field's Point effluent it is not known to what extent this added toxicity affects Providence River receiving waters. Specifically designed field studies coupled with Toxicity Identification Evaluations (TIE) procedures would be necessary to determine the distribution, duration, and toxicity of residual chlorine in the Providence River.

Introduction

The toxicity of chlorine in chlorinated waste water treatment plant effluents is perceived to be a serious problem in Rhode Island waters. The major goal of wastewater chlorination is to protect human health through disinfection. However, it also very important to minimize impacts of chlorinated discharges on marine organisms present in the receiving waters. The purpose of this project was to attempt to determine the balance of these two concerns using effluent from an area waste water treatment facility (WWTF).

The WWTF studied in this project was the Narragansett Bay Commission's Field's Point WWTF in Providence, RI. This is the largest WWTF in Rhode Island, with an average flow of 52.5 million gallons per day. This flow contributes approximately 41% of total WWTF flow into Narragansett Bay.

The goal of the study was accomplished through: 1) evaluation of chlorination practices at Field's Point WWTF and experimentation with different chlorine dosages and different combinations of disinfection and dechlorination practices; and 2) evaluation of the resultant toxicity of the chlorinated effluent and impacts on the toxicity of receiving waters by conducting acute and chronic toxicity tests. In addition, two dye studies were conducted to determine the Field's Point discharge plume characteristics, dilution factors, and limits of effluent toxicity. If necessary, based on toxicity and bacterial kill

assessments, modifications of the chlorination procedures at the WWTF may be implemented to achieve cost-effective disinfection and simultaneously, minimize receiving water impacts.

The Narragansett Bay Project approved funding to EPA's Environmental Research Laboratory, Narragansett, RI (ERL-N) to provide technical assistance to the Narragansett Bay Commission in this study. Samples were examined for toxicity using the following short-term marine toxicity tests: (1) the sea urchin (Arbacia punctulata) fertilization test, (2) the red macroalga (Champia parvula) reproduction test, and (3) the quahog (Mercenaria mercenaria) embryo/larval test. For some samples chlorine content was measured (as total residual oxidant, TRO) concurrently with toxicity testing. Testing was performed to evaluate the toxicity of the effluent, the contribution of chlorination to effluent toxicity, and the impact of post-chlorinated effluent on the toxicity of receiving waters associated with the plant. In addition, de-chlorination was evaluated as a method of reducing the toxicity of the chlorinated effluent.

An additional study was conducted by staff at ERL-N to estimate the persistence of toxic effects of sewage effluent diluted in marine waters and the relative contribution of chlorination to this persistence. Toxicity was evaluated using the sea urchin fertilization test, and chlorine content was measured concurrently. Toxicity and chlorine content were measured repeatedly on samples in order to estimate decay rates

for these parameters.

Methods

Effluent samples were collected on ten occasions between February 10 and July 26, 1989 and returned to ERL-N for toxicity testing and, when appropriate, TRO analysis. Pre-chlorinated effluent, pre-chlorinated effluent spiked with chlorine in the laboratory, post-chlorinated (in plant) effluent, and several plant-chlorinated effluents from which chlorine was chemically removed (de-chlorinated) were tested using A. punctulata or M. mercenaria immediately upon arrival at ERL-N concurrent with testing by Narragansett Bay Commission staff (at the plant) for residual bacterial content.

Receiving water samples were collected April 5 and 6, 1989 and August 18 and 19, 1989 in conjunction with a tracer-dye study (Ocean Surveys, Inc.). Pre- and post-chlorination effluent samples were collected on April 5 and August 18 and 19, 1989 to be tested concurrently. Rhodamine-WT dye was continuously fed into the chlorine contact tank at Field's Point WWTF for at least 48 hours. A small sample of the dye used in the study was screened for toxicity at ERL-N prior to use in the study, and was found to be non-toxic at concentrations which would be present in samples collected during the dye studies (Table 1). On-site transects of the Providence River were conducted by Ocean

Surveys, Inc. within the immediate area of the Field's Point WWTF outfall to determine the mixing zone, and downstream to determine the limits of minimum detectable dye concentration. Up to six stations were selected for sampling for toxicity tests starting near the Field's Point WWTF outfall, then located at intervals down the Providence River in the effluent plume (Figures 1a, 1b, 2a, 2b). A flow-through fluorometer was used to sample and record the concentrations of dye at stations in the study area. Samples were collected for toxicity testing on low slack tide, brought to the laboratory, and stored at 4°C. Samples were tested on the days following collection using A. punctulata and C. parvula in both April and August, and M. mercenaria in August only. Effluent concentrations in the receiving waters were estimated based on fluorometer readings of Rhodamine-WT dye concentrations, but no TRO measurements were performed on these samples. Chemical analyses were performed on Field's Point pre- and post-chlorination effluent samples collected on April 3, 1989 and on plume samples collected April 5, 1989 (Appendix A).

The effluent decay study was initiated using only post-chlorinated effluent sample, since pre-chlorinated samples collected to initiate this study were not toxic. A post-chlorinated effluent sample was collected from the Field's Point WWTF and shipped to ERL-N on ice. The sample was tested for toxicity and chlorine within hours of collection. The sample was then split into (2) 4 l bottles, and both subsamples were diluted with hypersaline brine so that the final concentration of

effluent was 70% and the salinity was 30°/oo. One bottle was then stored at room temperature (about 20°C), while the other was stored in a water bath in a refrigerator (about 10°C). Subsamples were taken at 4, 12, 24, 48, and 96 hr after initiation. Subsamples were tested whole for chlorine content, and were tested whole and as a series of dilutions with reconstituted seawater (hypersaline brine and deionized water) for toxicity. Decay rates for toxicity and chlorine content were calculated by regressing log-transformed measured values versus time (hours) to determine slope values. Half-lives for these processes were calculated as (log)2/slope.

Arbacia punctulata Toxicity Testing

The purpose of the sperm cell toxicity test using the sea urchin, Arbacia punctulata, was to determine the effect on fertilization of gametes exposed to test substances. The procedure consisted of exposure of freshly obtained sperm to test substances for a period of one hour, followed by the addition of sufficient number of eggs to allow high fertilization in control samples. Samples were preserved in formalin and monitored microscopically for fertilization.

In order to present data in units directly proportional to toxicity, data were also reported as toxic activity (TA) units, where TA = 50(1/EC50).

Champia parvula Toxicity Testing

The macroalga test estimated the toxicity of effluents and receiving waters to the sexual reproduction of Champia parvula. Champia tests consisted of the exposure of male and female plants together to an effluent or receiving water for two days. Fertilization occurred during this exposure period. The female plants were then placed in a control medium for a 5- to 7-day recovery period during which the cystocarps, evidence of sexual reproduction, developed. The number of cystocarps per plant was then counted, and toxicity was expressed as a significant reduction in the number of cystocarps relative to the controls.

Mercenaria mercenaria Toxicity Testing

The M. mercenaria, or quahog, test was performed following a modification of the bivalve embryo/larval test procedure described in Standard Methods sections 809 A 1, 2, and 3.b and 809 B 1.a and 1.b (4). Actual receiving water concentrations after salinity adjustments were 83.3% lower than nominal test concentrations due to additional dilution of the samples by addition of 1 ml of seawater containing M. mercenaria embryos. Fertilized M. mercenaria eggs less than two hours old were added to each of three 5 ml treatment replicates in 20 ml glass scintillation vials and allowed to incubate for 48 hours at 20°C. The treatments were then fixed using 2 ml 10% formalin in seawater and an aliquot from each treatment vial examined microscopically to determine the presence or absence of a shell.

As in the sea urchin procedure, toxicity was also reported

as toxic activity (TA) units, where TA = 50(1/EC50).

Salinity Adjustment/Statistical Analysis

All effluent and receiving water samples were adjusted up to $30^{o}/oo$ salinity using hypersaline ($100^{o}/oo$) brine made from clean filtered Narragansett Bay seawater when necessary prior to testing. Effluents were diluted following salinity adjustment using either clean Narragansett Bay seawater (ERL-N seawater system) or a $30^{o}/oo$ mixture of hypersaline brine and deionized water (brine + DI). Test results, unless otherwise stated, are presented as actual effluent concentrations after salinity adjustment. Results of effluent and receiving water toxicity tests were compared to the Brine + DI and/or Narragansett Bay seawater controls to determine statistically significant effects.

The toxicity of effluents and chlorine spike samples to A. punctulata and M. mercenaria was determined as that concentration of effluent causing a 50% reduction in fertilization (EC50) as calculated by Spearman-Karber (5) analyses. All C. parvula effluent data were subjected to one-way analysis of variance (ANOVA, $\alpha = 0.05$), then analyzed using Dunnett's Procedure (6). Receiving water toxicity results were analyzed using ANOVA ($\alpha = 0.05$) followed by T-Tests for all of the species tested.

Fecal Coliform Procedure

The coliform test used was the standard coliform most probable number (MPN) test from Standard Methods (7) sections

908 A and 908 C.

Presumptive Test: A series of fermentation tubes were inoculated with graduated quantities of the effluent samples. Lauryl tryptose broth was used in these tests. A sterile fermentation vial was added, and the tubes were incubated at 35.0 $\pm$ 0.5°C. At 24 $\pm$ 2 hr, the tubes were gently shaken and examined for gas formation, and the presence or absence of gas recorded. The formation of gas constituted a positive test for coliforms.

Confirmed Test: Samples from all tubes showing gas production were transferred aseptically to a fermentation tube containing brilliant green lactose bile broth and incubated for about 24 hr at 35.0 $\pm$ 0.5°C. Gas formation constituted a positive Confirmed Test.

Fecal Coliform Test: This test differentiates between coliforms of fecal origin and coliforms from other sources. Samples from all positive tubes were transferred to EC Medium and incubated at 44.5 $\pm$ 0.2°C for 24 $\pm$ 2 hr. Gas production within 24 hr was a positive reaction indicating fecal origin. Fecal coliform densities were calculated as the combination of positive tubes in each treatment and recorded in terms of the MPN index. The MPNs for a variety of results are given in Standard Methods Tables 908:I and 908:II. The permit limit for coliforms in Field's Point effluent is 200 MPN.

Total Residual Oxidant Procedure

Total residual oxidant determinations were made by amperometric back titration using a Fisher-Porter series 17T2000 instrument following Standard Methods (8) section 408C. Results were reported as chlorine equivalents or total residual oxidant, mg/l. Detection limit was about 0.02 mg/l.

Effluent Chlorination and Dechlorination Procedures

Pre-chlorinated effluent samples were chlorinated with reagent grade sodium hypochlorite (100 ppm stock) and referred to as pre-chlorinated/spike samples. Samples were mixed for fifteen minutes before TRO measurements were taken. Dechlorination of effluent samples was accomplished by adding sodium thiosulfate.

Results and Discussion

Arbacia punctulata

Pre-chlorinated effluent was toxic on each of seven days tested in February and April, 1989. The EC50 values ranged from 14.7% to 37.5% effluent (Table 2), with a mean value of 23.8% effluent. Post-chlorinated effluent samples were about 7 times more toxic, with EC50 values ranging from 2.9% to 4.1% effluent (mean EC50 = 3.4% effluent). The TRO values for post-chlorinated effluent samples ranged from 0.78-1.68 mg/l. Chlorinated effluent samples (WWTF or laboratory) with similar TRO content had similar toxicity and toxicity increased in proportion to added chlorine. For all samples, whether chlorinated at the WWTF or in the laboratory (n=26, Figure 3), toxic activity of

the effluent was statistically correlated with TRO and was described by the relationship:

$$TA = 11.9(TRO) + 2.3 \quad (r^2 = 0.89)$$

Toxicity increased approximately 1.5 times with each TRO increase of 0.54 mg/l. Conversely, dechlorination reduced toxicity. When dechlorination eliminated TRO, toxicity of the post-chlorinated-dechlorinated effluent was similar to that of the pre-chlorinated effluent (Table 2).

Receiving water samples collected April 5 produced effects in toxicity tests ranging from 99.7% fertilization (non-toxic) at station 6 to 1.0% fertilization (complete toxicity) at station 2 (Table 3, Figure 1). Estimated effluent concentrations based on dye concentrations in the samples collected April 5 ranged from 0.4% to 31.8% effluent, and generally increased toxicities were observed in samples with higher concentrations of effluent. Effluent diluted in the laboratory appeared to be more toxic than effluent in the receiving waters (Tables 3 and 4, Figure 4). This apparent decrease in toxicity of the effluent in receiving waters relative to laboratory results may be due to decay in the toxicity of the effluent over time and/or upon contact with Providence River water.

Estimated effluent concentrations in receiving waters collected April 6 ranged from 1.3% in sample from Station 1 to 66.8% in sample from Station 2 (Table 3, Figure 2). Fertilization in samples collected April 6 averaged from 97.0% in water from Station 4 to 0.0% in water from Station 2. Again,

toxicity tended to increase with increased effluent concentration.

Fertilization in receiving waters collected August 18 averaged from 0.0% in water from Station VP11 to 99.6% in water from Stations VP4 and VP5 (Table 5). Receiving water effluent concentrations ranged from 1.0% at Station VP4 to 32.8% at Station VP11. Again, receiving waters tended to be less toxic than would be predicted from the results of laboratory diluted effluent tests (Figure 5). The EC50 for laboratory diluted effluent was 8.38% (Table 4), whereas an approximate EC50 for the effluent in the receiving water was 15%.

Receiving waters and post-chlorinated effluent collected August 19 were less toxic than on the previous day (Table 5). This was probably due to chlorine decay in the samples, which were not tested until August 21. Once again, however, the receiving waters were less toxic than would be predicted by laboratory effluent tests (Figure 6). The EC50 for the laboratory diluted effluent was 23.47% (Table 4), whereas the EC50 for effluent in the receiving waters was greater than 32.5%.

Champia parvula

Pre-chlorinated effluent from Field's Point collected April 5 was highly toxic to Champia, with a reduction of cystocarps evident at 1.25% effluent, the lowest concentration tested (Table 6). The chlorinated effluent collected from Field's Point the same day was slightly less toxic, with a no observed effect

concentration (NOEC) of 1.25% effluent and a lowest observed effect concentration (LOEC) of 2.50% effluent. Both effluents caused total cessation of cystocarp production at 10.0%.

Pre-chlorinated effluent from Field's Point collected August 18 was again toxic to Champia. Cystocarp reduction was evident at 1.25% effluent, the lowest concentration tested (Table 6). Post-chlorinated effluent was also toxic at 1.25%, the lowest concentration at which this effluent was tested. Post-chlorinated effluent collected August 19 was more toxic than the pre-chlorinated effluent, with NOECs in the two effluents of <1.25% and 5.0%, respectively (Table 6). However, similar cystocarp production was observed at similar concentrations of the two effluents. The results of effluent tests conducted in April and August indicate that chlorine in this effluent does not appear to be a major cause of toxicity to Champia.

All of the receiving waters tested on both days in April caused significant reductions in cystocarps produced (Table 3). No cystocarps were produced in water from Station 2 on either collection day. Water from Station 3 was similarly toxic, with fewer than one cystocarp produced per plant on both days. Cystocarp production in the remaining samples averaged from 0.2 to 7.0 per plant.

Receiving water samples collected from stations VP7, VP9, and VP11 on August 18 were toxic to Champia (Table 5). Less than one cystocarp per plant was produced in water collected from all three of these stations on this day. Receiving water samples

collected from stations VP20 and VP21 on August 19 were also toxic, with mean cystocarps produced per plant of 0.8 and 7.5, respectively (Table 5).

The NOEC of the chlorinated effluent sample collected April 5 was 1.25%, while the LOEC was 2.50% (Table 6); thus, receiving waters collected on this day with estimated effluent concentrations $\geq$2.50% would be expected to cause toxicity to Champia if no other toxicants were already present in the receiving water (Figure 7). In fact, every receiving water sample with estimated effluent concentration $\geq$2.5% was toxic to Champia. However, samples from Stations 5 and 6 collected April 5 caused toxicity to Champia, although estimated effluent concentrations in these samples were 1.6%, and 0.4%, respectively. Generally, the receiving water samples collected on these two days proved to be more toxic than would be predicted by the effluent tests, indicating that perhaps the receiving water toxicity observed was caused in part by some other toxicant(s) present in the Providence River.

The NOECs of the post-chlorinated effluents collected August 18 and August 19 were both <1.25% (Table 6). Therefore, again assuming no other toxicants were present in the receiving water, samples with greater than 1.25% effluent concentration would be expected to cause toxicity to Champia (Figures 8 and 9). In contrast to the April tests, however, toxicity was not observed in samples with 1.4 - 4.6% effluent. As in the sea urchin tests, apparent decrease in toxicity may have been due to decay of the

effluent over time or upon contact with Providence River water.

Mercenaria mercenaria

Pre-chlorinated effluent was toxic on each of the three days tested in July, 1989. The EC50 values ranged from 41.28% to 50.39% effluent (Table 7), with a mean value of 45.26% effluent. Post-chlorinated effluent samples were more toxic than pre-chlorinated samples on all three days, with EC50 values ranging from 27.22% to 39.75% effluent (mean EC50 = 31.95% effluent). The TRO values for post-chlorinated effluent samples were 0.57 mg/l on July 24 and 0.37 on July 26. Total residual oxidant was not measured on July 13. As in the previous sea urchin tests, chlorinated effluent samples (WWTF or laboratory) with similar TRO content were similarly toxic and toxicity increased in proportion to added chlorine. For all samples for which TRO was measured, whether chlorinated at the WWTF or in the laboratory (n=13, Figure 10), toxic activity of the effluent was significantly correlated statistically with TRO and was described by the relationship:

$$TA = 1.97(TRO) + 0.928 \quad (r^2 = 0.80)$$

Toxicity increased approximately 1.5 times with each increase of 0.76 mg/l TRO. Dechlorination reduced the toxicity of chlorinated effluent to approximately the level of pre-chlorinated effluent, with a mean EC50 of 46.13% in de-chlorinated samples.

No receiving water tested during the August dye study was

toxic to Mercenaria (Table 5). This result was to be expected, since no effects were observed in concentrations of 29.2% or less in post-chlorinated effluents collected August 18 or August 19 (Table 8); the highest effluent concentration in any receiving water tested using the quahog was 27.3% (Table 5). Pre- and post-chlorinated effluents collected August 19 were similarly toxic. The apparent loss of toxicity in the post-chlorinated effluent relative to the pre-chlorinated effluent was probably due to decay of chlorine in the chlorinated effluent between collection on August 19 and testing on August 21 (Table 8).

Fecal Coliforms

The geometric means of the highest TRO concentration allowing unacceptable ($\geq$200 MPN/100 ml) coliform levels and the lowest TRO concentration causing acceptable (<200 MPN/100ml) coliform kills (analogous to lowest observed effect concentration and no observed effect concentration, respectively, in chronic toxicity tests) were taken in order to generate an estimate of the concentration necessary to achieve an acceptable coliform kill (Tables 9, 10, and 11). The coliform MPNs corresponding to these TRO concentrations were also calculated. The TRO concentration geometric means calculated for the nine test days were similar, ranging from 0.7 mg/l on February 14 and February 15 to 1.2 mg/l on February 13 and April 6 (Table 11). The mean value for all nine days was 0.90 $\pm$ 0.19 mg/l TRO. Coliform geometric means ranged from 53 MPN/100 ml on July 24 at 0.94

mg/l TRO to 225 MPN/100 ml on April 6 at 1.2 mg/l TRO. The mean coliform over nine days was 158.2 $\pm$ 67.7 MPN/100 ml. Post-chlorinated effluent and pre-chlorinated/spiked effluents with similar TRO concentrations yielded similar coliform MPNs.

The logs of the fecal coliform MPNs versus TRO concentration in the post-chlorinated effluents were plotted and a linear regression was performed on the resultant data (Figure 11). Log(MPN) was statistically correlated with TRO, as described by the relationship:

$$\text{Log(MPN)} = -3.41(\text{TRO}) + 8.44 \qquad (r^2 = 0.65)$$

A reduction of MPN by 0.5 times was predicted with each increase in TRO of 0.203 mg/l.

Decay Study

Initial measurements of the effluent samples collected from the Field's Point WWTF on July 24, 1989 indicated that while the pre-chlorinated effluent sample was not toxic at the highest tested concentration (70%), the post-chlorinated effluent had a total residual oxidant content of 0.72 mg/l and an EC50 of 2.76% effluent (Table 12). Upon dilution of the post-chlorinated effluent with brine, the chlorine content was 0.47 mg/l.

By 24 hr post-initiation, toxicity was reduced by about 12x and 6x under warm and cold storage conditions, respectively, while chlorine content was reduced by about 8x and 3x, respectively. Samples stored at warm or cold temperatures were non-toxic and chlorine was undetectable by 96 hr. These data

were used to calculate decay rates and half-lives for each process at each temperature. At about 20°C, toxicity was reduced by one-half (half-life, t1/2) in about 12.6 hr while TRO content was similarly reduced in about 8.2 hr (Table 13). At about 10°C, the half-lives for toxicity and TRO content were 19.3 and 17.7 hr, respectively.

The decay of toxicity was concurrent with TRO decay; at each temperature, slopes for both processes were not significantly different (Figures 12 and 13). Rates for both processes were temperature dependent, increasing with increasing temperature. Toxicity was correlated with the TRO content generated by the chlorination process (Figure 14, $n = 6$, $r^2 = 0.859$).

Conclusions

The results of this study indicate that both the pre- and post-chlorinated Field's Point effluents were usually quite toxic to Arbacia punctulata, Champia parvula, and to a lesser extent, Mercenaria mercenaria. Some of the receiving waters associated with the outfall were toxic to Arbacia and Champia, but no receiving water was toxic to Mercenaria. It was determined that residual chlorine in effluents can be a major cause of toxicity to the sea urchin and quahog, although not to Champia. However, it has not been definitively shown that residual chlorine in the Providence River receiving water poses a substantial environmental problem. Additional studies would be necessary to

determine the distribution, duration and toxicity of chlorine in the river. However, from the results of these effluent toxicity tests, we believe that it is unlikely that, due to the degree of dilution at the outfall, any perceivable effects to the quahog population are caused by Field's Point WWTF effluent. However, further study would be necessary to determine possible effects of bioaccumulation of toxicants in shellfish in the Providence River and upper Narragansett Bay.

The shapes of effluent toxicity response curves for effluent diluted in the laboratory and effluent in the receiving waters were usually similar on a particular day, but the two curves were offset from each other. The curves generally predicted that effluent diluted in the receiving water would be less toxic than effluent diluted in the laboratory. We believe that this disparity is at least partly due to the degradation of the effluent toxicity over time, as shown in the decay study.

The balance of coliform kill versus toxicity to the test species was determined. The concentration of residual chlorine required to cause an acceptable fecal coliform kill in the effluent was found to be about 1 mg/l. Effluent with this TRO concentration can be expected to have an EC50 of about 3.52% in the sea urchin test and an EC50 of about 17.25% in the quahog test. Dechlorination was found to be effective in reducing the toxicity of chlorinated effluent to A. punctulata and M. mercenaria to that of pre-chlorinated effluent. Therefore, dechlorination could be a solution to the problem of striking an

acceptable balance between adequate chlorine disinfection and significant toxicity of chlorine residuals in receiving waters. Further research is needed to ascertain which dechlorination procedure produces the lowest effluent toxicity, and is economically feasible.

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Table 1: Results of the Arbacia punctulata fertilization test conducted on a sample of the rhodamine-WT dye used in the Providence River dye study.

Sample Description	Dye Concentration (μg/l)	Fertilization (%)
Narr. Bay	0.0	94.0 $\pm$ 7.0
Rhodamine Dye	0.5	94.0 $\pm$ 1.7
	5.0	94.7 $\pm$ 3.1
	50.0	97.7 $\pm$ 1.2
	500.0	96.0 $\pm$ 1.7

No toxicity was observed.

Table 2: Results of Arbacia punctulata fertilization tests conducted on samples associated with the Field's Point WWTF.

Collection Date Sample Description	Toxicity EC50, (% Effluent)	Total Residual Oxidant (measured, mg/l)
February 10, 1989		
Pre-Cl	14.7	0
Pre-Cl, spiked	2.9	1.26
February 13, 1989		
Pre-Cl	32.1	0
Pre-Cl, spiked	6.3	0.37
Pre-Cl, spiked	2.7	0.82
Pre-Cl, spiked	1.6	2.07
February 14, 1989		
Pre-Cl	17.3	0
Pre-Cl, spiked	6.9	0.27
Pre-Cl, spiked	4.1	0.77
Pre-Cl, spiked	1.6	2.07
February 15, 1989		
Post-Cl	3.2	1.16
Pre-Cl, spiked	3.1	1.22
April 3, 1989		
Pre-Cl	37.5	0
Pre-Cl, spiked	3.1	1.52
Pre-Cl, spiked, dechlorinated	15.1	0.34
Post-Cl	2.9	1.68
Post-de-Cl	25.3	0.26
April 5, 1989		
Pre-Cl	15.2	0
Pre-Cl, spiked	3.1	0.94
Pre-Cl, spiked, dechlorinated	17.7	0
Post-Cl	4.1	0.78
Post-de-Cl	19.9	0
April 12, 1989		
Pre-Cl	26.2	0
Pre-Cl, spiked	6.8	0.44
Pre-Cl, spiked	4.2	0.80
Pre-Cl, spiked	3.9	1.55

Table 3: Estimated effluent concentrations in receiving waters and toxicities to Champia parvula and Arbacia punctulata during the April, 1989 Providence River dye study.

Station	Estimated Effluent (%)*	C. parvula cystocarps (no.)	A. punctulata fertilization (%)
April 5, 1989 Samples			
Narr. Bay	0.0	19.0 ± 4.9	96.0 ± 1.7
Br + DI	0.0	22.7 ± 4.7	------
1	6.5	------	98.7 ± 1.5
2	31.8	0.0 ± 0.0 **	1.0 ± 1.0 **
3	6.4	0.0 ± 0.0 **	52.3 ± 4.0 **
4	2.6	5.7 ± 2.7 **	99.3 ± 1.2
5	1.6	1.8 ± 0.7 **	97.7 ± 0.6
6	0.4	7.0 ± 2.3 **	99.7 ± 0.6
April 6, 1989 Samples			
Narr. Bay	0.0	18.9 ± 7.2	98.0 ± 1.0
Br + DI	0.0	14.2 ± 0.7	97.0 ± 1.7
1	1.3	2.5 ± 2.7 **	91.3 ± 3.5
2	66.8	0.0 ± 0.0 **	0.0 ± 0.0 **
3	12.4	0.2 ± 0.2 **	72.7 ± 1.5 **
4	6.3	0.7 ± 0.8 **	97.0 ± 2.0
5	3.1	0.3 ± 0.1 **	96.0 ± 2.0

* Percent effluent corrected for salinity adjustments.
** Significantly lower than the controls.

Table 4: Toxicity of pre- and post-chlorinated Field's Point effluent to Arbacia punctulata during the April and August Providence River dye studies.

Date/ Concentration (%)	Percent Fertilized	
	Pre-Chlorinated	Post-Chlorinated
April 5, 1989		
Narr. Bay	93.9 ± 2.6	96.0 ± 1.7
Brine + DI	80.0 ± 4.0	------
0.55	74.3 ± 11.7	80.3 ± 9.2
1.1	75.6 ± 4.7	90.0 ± 4.3
2.2	72.0 ± 1.7	82.9 ± 14.7
4.4	71.0 ± 1.7	16.3 ± 4.9 *
8.8	67.0 ± 8.5	2.6 ± 4.6 *
17.5	38.9 ± 10.3 *	------
35.0	0.3 ± 0.5 *	------
	EC50 = 15.15% (14.13 - 16.25)	EC50 = 4.12% (3.95 - 4.29)
August 18, 1989		
Narr. Bay	99.6 ± 0.5	99.6 ± 0.5
Brine + DI	99.3 ± 0.5	99.3 ± 0.5
4.4	------	98.0 ± 0.0
8.8	------	43.6 ± 8.0 *
17.5	------	0.0 ± 0.0 *
35.0	99.0 ± 1.0	------
70.0	92.6 ± 2.0 *	
	EC50 = Not Calculable	EC50 = 8.38% (8.04 - 8.73)
August 19, 1989		
Narr. Bay	96.6 ± 1.5	96.6 ± 1.5
Brine + DI	94.9 ± 1.0	94.9 ± 1.0
2.2	------	95.6 ± 2.5
4.4	------	92.0 ± 1.0
8.8	91.0 ± 2.0	91.0 ± 6.5
17.5	85.3 ± 5.6 *	68.0 ± 6.0 *
35.0	85.6 ± 3.5 *	26.3 ± 12.0 *
70.0	80.0 ± 0.0 *	0.0 ± 0.0 *
	EC50 = Not Calculable	EC50 = 23.47% (22.22 - 24.80)

* Significantly less than control.

Table 5: Receiving water toxicities and estimated effluent concentrations during the August, 1989 Providence River dye study.

Station	Effluent Conc.* (approx. %)	C. parvula cystocarps (no.)	A. punctulata fertilization (%)	M. mercenaria % with shell
August 18, 1989 Samples				
Narr. Bay	0.0	17.9 ± 3.1	99.6 ± 0.5	78.0 ± 32.9
Brine + DI	0.0	11.0 ± 3.2	99.3 ± 0.5	83.3 ± 10.7
VP4	1.0	9.8 ± 2.3	99.6 ± 0.5	95.0 ± 1.0
VP5	2.4	9.8 ± 2.3	99.6 ± 0.5	94.0 ± 1.7
VP7	9.3	0.4 ± 0.3 **	99.0 ± 1.0	97.3 ± 1.5
VP9	14.7	0.0 ± 0.0 **	57.6 ± 6.0 **	95.3 ± 2.1
VP11	32.8	0.0 ± 0.0 **	0.0 ± 0.0 **	90.0 ± 4.4
August 19, 1989 Samples				
Narr. Bay	0.0	20.6 ± 6.4	96.6 ± 1.5	95.0 ± 2.6
Brine + DI	0.0	14.6 ± 3.0	94.9 ± 1.0	91.7 ± 5.8
VP19	4.6	9.8 ± 1.4	97.6 ± 0.5	95.7 ± 2.3
VP20	32.5	0.8 ± 0.4 **	69.6 ± 10.5 **	94.3 ± 2.3
VP21	14.0	7.5 ± 1.8 **	98.3 ± 1.1	91.0 ± 5.6
VP24	1.5	12.3 ± 3.5	98.0 ± 2.6	92.7 ± 4.9
VP25	1.4	14.0 ± 3.4	98.6 ± 0.5	96.0 ± 3.0

* Percent effluent corrected for salinity adjustments. Effluent concentrations in M.mercenaria test are approximately 83.3% of nominal concentrations.

** Significantly reduced relative to the controls.

Table 6: Cystocarps produced by Champia parvula plants exposed to Field's Point pre- and post-chlorinated effluent during the April and August Providence River dye studies.

Effluent Concentration (%)	Cystocarps Produced	
	Pre-chlorinated	Post-chlorinated
April 5, 1989		
0.00	43.8 ± 16.7	43.8 ± 16.7
1.25	24.3 ± 8.4 *	33.5 ± 17.1
2.50	20.2 ± 6.2 *	19.5 ± 5.5 *
5.00	6.0 ± 2.3 *	4.7 ± 3.8 *
7.50	1.1 ± 0.4 *	0.1 ± 0.2 *
10.00	0.0 ± 0.0 *	0.0 ± 0.0 *
August 18, 1989		
0.00	17.9 ± 3.1	17.9 ± 3.1
1.25	9.5 ± 0.4 *	11.5 ± 2.3 *
5.00	9.0 ± 1.0 *	-----
7.50	-----	4.1 ± 1.6 *
10.00	1.2 ± 0.9 *	2.1 ± 0.7 *
August 19, 1989		
0.00	43.8 ± 16.7	43.8 ± 16.7
1.25	16.6 ± 1.3	13.2 ± 4.4 *
5.00	15.6 ± 3.3	11.4 ± 0.5 *
10.00	5.9 ± 2.8 *	6.5 ± 0.8 *

* Significantly lower than the control.

Table 7: Results of *Mercenaria mercenaria* toxicity tests conducted on post-chlorinated and pre-chlorinated (Cl spiked) effluents from Field's Point WWTF.

Sample Description	EC50 (95% Conf. Interval) % Effluent	Total Residual Oxidant, mg/l
July 13, 1989		
Pre-Cl	50.39 (47.73 - 53.19)	0.0
Post-Cl	28.87 (27.75 - 30.03)	---
Post-de-Cl	56.09 (52.22 - 60.25)	0.0
Pre-Cl, Spiked	14.91 (14.33 - 15.52)	1.43
Pre-Cl, Spiked	27.23 (26.10 - 28.41)	0.89
July 24, 1989		
Pre-Cl	41.28 (40.60 - 41.97)	0.0
Post-Cl	27.22 (25.92 - 28.58)	0.57
Post-de-Cl	40.61 (39.87 - 41.37)	0.0
Pre-Cl, Spiked	14.33 (13.66 - 15.02)	1.37
Pre-Cl, Spiked	18.01 (17.28 - 18.77)	0.92
Pre-Cl, Spiked	35.12 (33.85 - 36.43)	0.37
July 26, 1989		
Pre-Cl	44.10 (43.09 - 45.13)	0.0
Post-Cl	39.75 (38.96 - 40.56)	0.37
Post-de-Cl	41.69 (41.26 - 42.13)	0.0
Pre-Cl, Spiked	11.21 (10.70 - 11.74)	1.19
Pre-Cl, Spiked	16.58 (15.77 - 17.44)	0.77
Pre-Cl, Spiked	33.18 (31.96 - 34.43)	0.37

Table 8: Toxicity of pre- and post-chlorinated effluent samples collected during the August, 1989 Providence River dye study to Mercenaria mercenaria.

Date/ Concentration (%)	Percent Larvae with Shells	
	Pre-chlorinated	Post-chlorinated
August 18, 1989		
Narr. Bay (0.0)	78.0 ± 32.9	78.0 ± 32.9
Brine + DI (0.0)	83.3 ± 10.7	83.3 ± 10.7
7.3	------	93.7 ± 6.7
14.6	------	93.7 ± 5.8
29.2	93.3 ± 3.8	82.7 ± 6.1
58.3	20.3 ± 7.6 *	0.0 ± 0.0 *
EC50 =	47.63 (46.42 - 48.89)	41.13 (40.71 - 41.55)
August 19, 1989		
Narr. Bay (0.0)	95.0 ± 2.6	95.0 ± 2.6
Brine + DI (0.0)	91.7 ± 5.8	91.7 ± 5.8
14.6	89.0 ± 4.6	------
29.2	93.0 ± 3.6	96.7 ± 2.3
58.3	13.3 ± 1.5 *	17.7 ± 12.5 *
EC50 =	43.33 (42.45 - 44.21)	45.23 (44.23 - 46.26)

* Significantly different from the controls.

Table 9: Most probable number (MPN) of fecal coliform in Field's Point pre-chlorinated/Cl spiked and post-chlorinated effluent. Arbacia punctulata was tested concurrently.

Collection Date	Total Residual Oxidant (measured, mg/l)	Fecal Coliform (MPN)
February 13, 1989	0.00	≥1600 *
	0.40	≥1600 *
	0.88	≥1600 *
	1.50	<2
	2.20	2
February 14, 1989	0.00	≥1600 *
	0.30	≥1600 *
	1.10	30
	1.50	17
	2.20	4
February 15, 1989	0.00	≥1600 *
	0.50	900 *
	0.95	13
	1.50	11
	2.10	2
April 3, 1989	0.50	1600 *
	0.70	500 *
	1.10	80
	1.60	30
	1.90	17
Post-Cl Effluent	1.65	17
April 6, 1989	0.45	3500 *
	0.70	1300 *
	1.00	1700 *
	1.40	30
	1.90	70
Post-Cl Effluent	1.00	2100 *
April 12, 1989	0.55	350 *
	0.80	90
	1.10	240 *
	1.55	<2
	1.95	<2
Post-Cl Effluent	1.60	23

* Above permit limit.

Table 10: Most probable number (MPN) of fecal coliform in Field's Point pre-chlorinated/Cl spiked and post-chlorinated effluent. Mercenaria mercenaria was tested concurrently.

Collection Date	Total Residual Oxidant (measured, mg/l)	Fecal Coliform (MPN/100 ml)
July 24, 1989	0.55	80
	1.00	130
	1.50	14
Post-Cl Effluent	2.70	21
July 26, 1989	0.50	900[a]
	1.00	130
	1.50	50
Post-Cl Effluent	2.10	11

[a] Over permit limit of 200 MPN/100 ml.

Table 11: Summary TRO and fecal coliform data from Field's Point WWTF.

Collection Date	Acceptable TRO/ Fecal Coliform Range*	Geometric Mean
February 13, 1989		
TRO	0.88 - 1.50 mg/l	1.2 mg/l
Coliform	≥1600 - <2 MPN	56 MPN
February 14, 1989		
TRO	0.30 - 1.10 mg/l	0.7 mg/l
Coliform	≥1600 - 30 MPN	219 MPN
February 15, 1989		
TRO	0.50 - 0.95 mg/l	0.7 mg/l
Coliform	900 - 13 MPN	108 MPN
April 3, 1989		
TRO	0.70 - 1.10 mg/l	0.9 mg/l
Coliform	500 - 80 MPN	200 MPN
April 6, 1989		
TRO	1.00 - 1.40 mg/l	1.2 mg/l
Coliform	1700 - 30 MPN	225 MPN
April 12, 1989		
TRO	0.55 - 0.80 - 1.10 mg/l	0.82 mg/l
Coliform	350 - 90 - 240 MPN	196 MPN
July 24, 1989		
TRO	0.55 - 1.00 - 1.50 mg/l	0.94 mg/l
Coliform	80 - 130 - 14 MPN	53 MPN
July 25, 1989		
TRO	0.50 - 1.10 mg/l	0.74 mg/l
Coliform	500 - 70 MPN	187 MPN
July 26, 1989		
TRO	0.50 - 1.00 - 1.50 mg/l	0.91 mg/l
Coliform	900 - 130 - 50 MPN	180 MPN
	Overall TRO	0.90 ± 0.19 mg/l
	Overall Coliform	158.2 ± 67.7 MPN

* Highest TRO causing an unacceptable coliform level - lowest TRO causing an acceptable coliform level and associated fecal coliform MPNs.

Table 12: Toxicity and measured TRO of post-chlorinated effluent collected on July 24, 1989. Samples with less than 0.02 mg/l TRO were below detection (ND). Samples were not retested after toxicity (EC50, % effluent) or TRO (mg/l) were no longer measurable (NT).

	10°C Storage		20°C Storage	
Time after Initiation	TRO (mg/l)	EC50 (% eff.)	TRO (mg/l)	EC50 (% eff.)
100% fresh effluent				
0 hr	0.72	2.76	----	----
70% effluent				
0.5 hr	0.47	NT	----	----
4 hr	0.37	5.97	0.31	>20.00
12 hr	NT	7.30	NT	11.20
24 hr	0.16	16.90	0.06	32.50
48 hr	0.07	18.80	ND	51.80
96 hr	ND	>70.00	NT	>70.00

Table 13: Calculated half-life values and statistics on decay regression lines for toxicity and TRO of effluent collected on July 24, 1989.

20°C Storage

Toxicity

$t1/2 = 12.6$ hr

$\log(TA) = \text{time}(-0.05511) + 2.29$

$n = 5$

$r^2 = 0.85$

Total Residual Oxidant

$t1/2 = 8.2$ hr

$\log(TRO) = \text{time}(-0.08458) - 0.79$

$n = 3$

$r^2 = 0.99$

10°C Storage

Toxicity

$t1/2 = 19.3$ hr

$\log(TA) = \text{time}(-0.03598) + 2.43$

$n = 5$

$r^2 = 0.78$

Total Residual Oxidant

$t1/2 = 17.7$ hr

$\log(TRO) = \text{time}(-0.03927) - 0.81$

$n = 4$

$r^2 = 0.99$

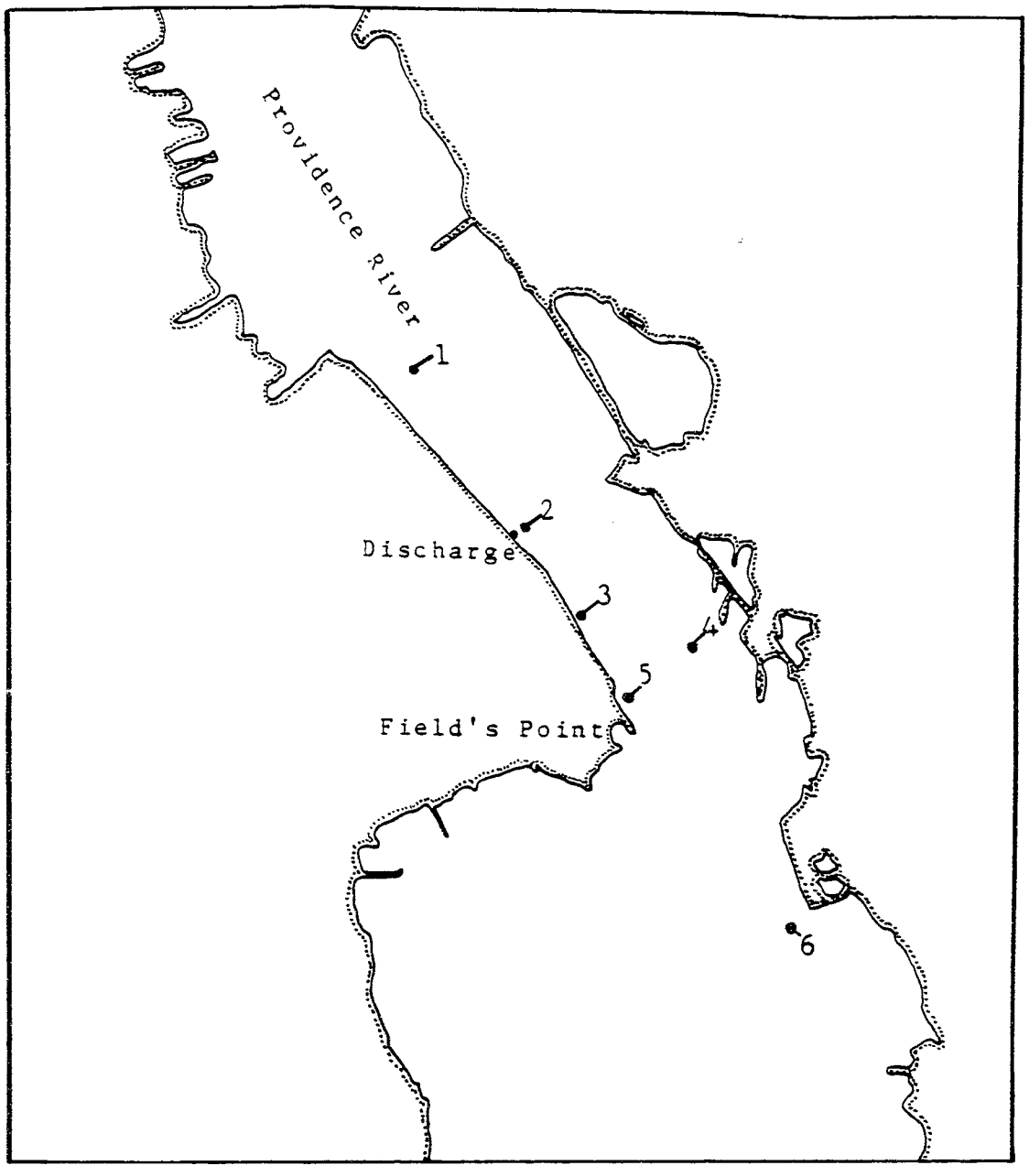


Figure 1a. Stations sampled during the Providence River dye study, 4/5/89.

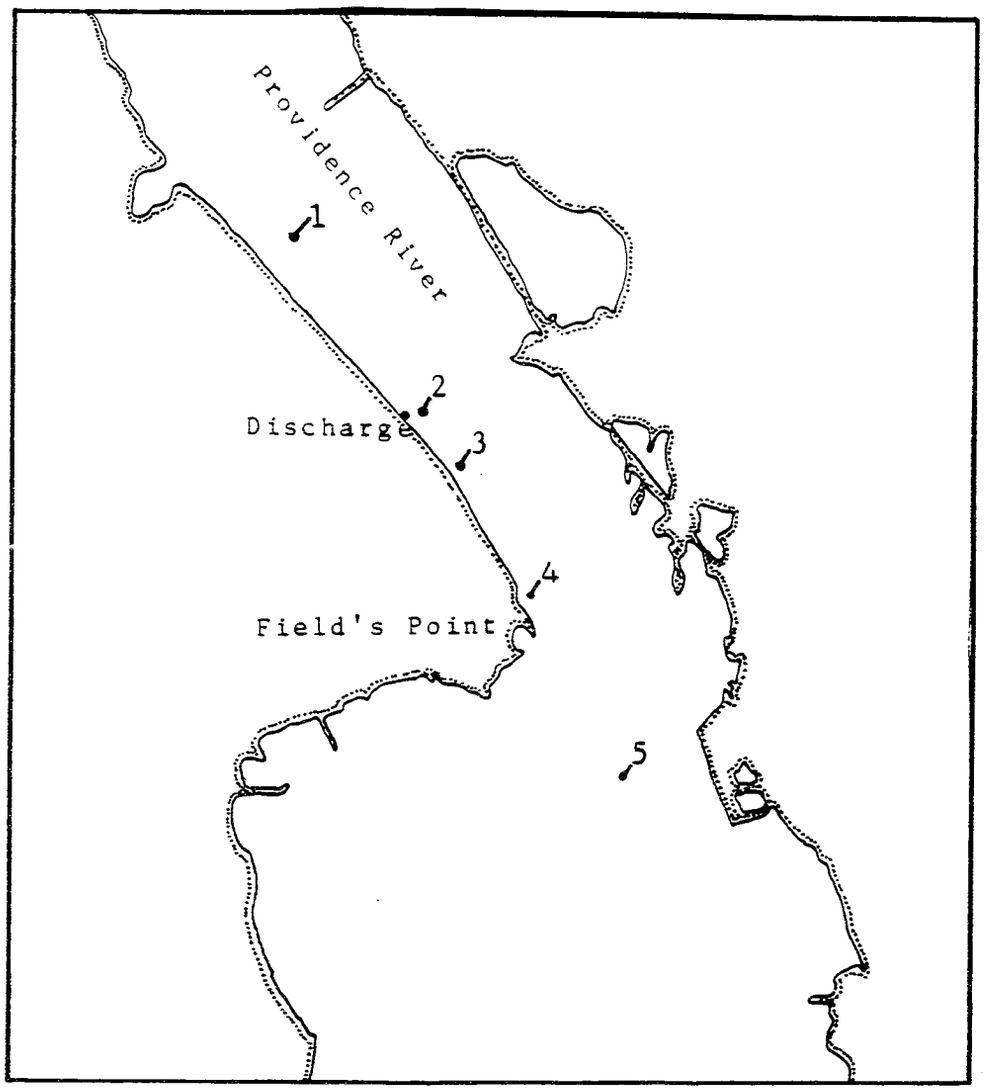


Figure 1b. Stations sampled during the Providence River dye study, 4/6/89.

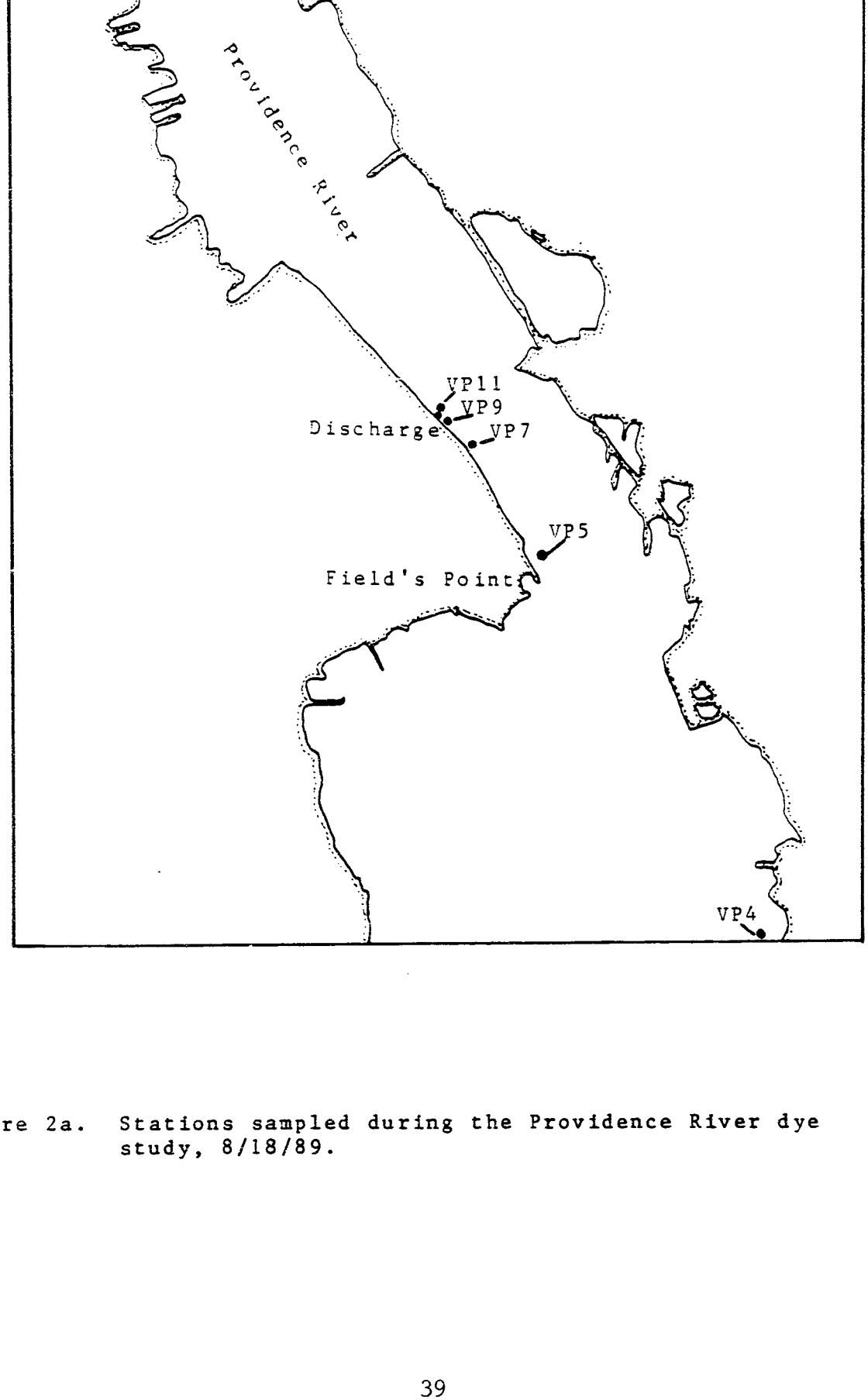


Figure 2a. Stations sampled during the Providence River dye study, 8/18/89.

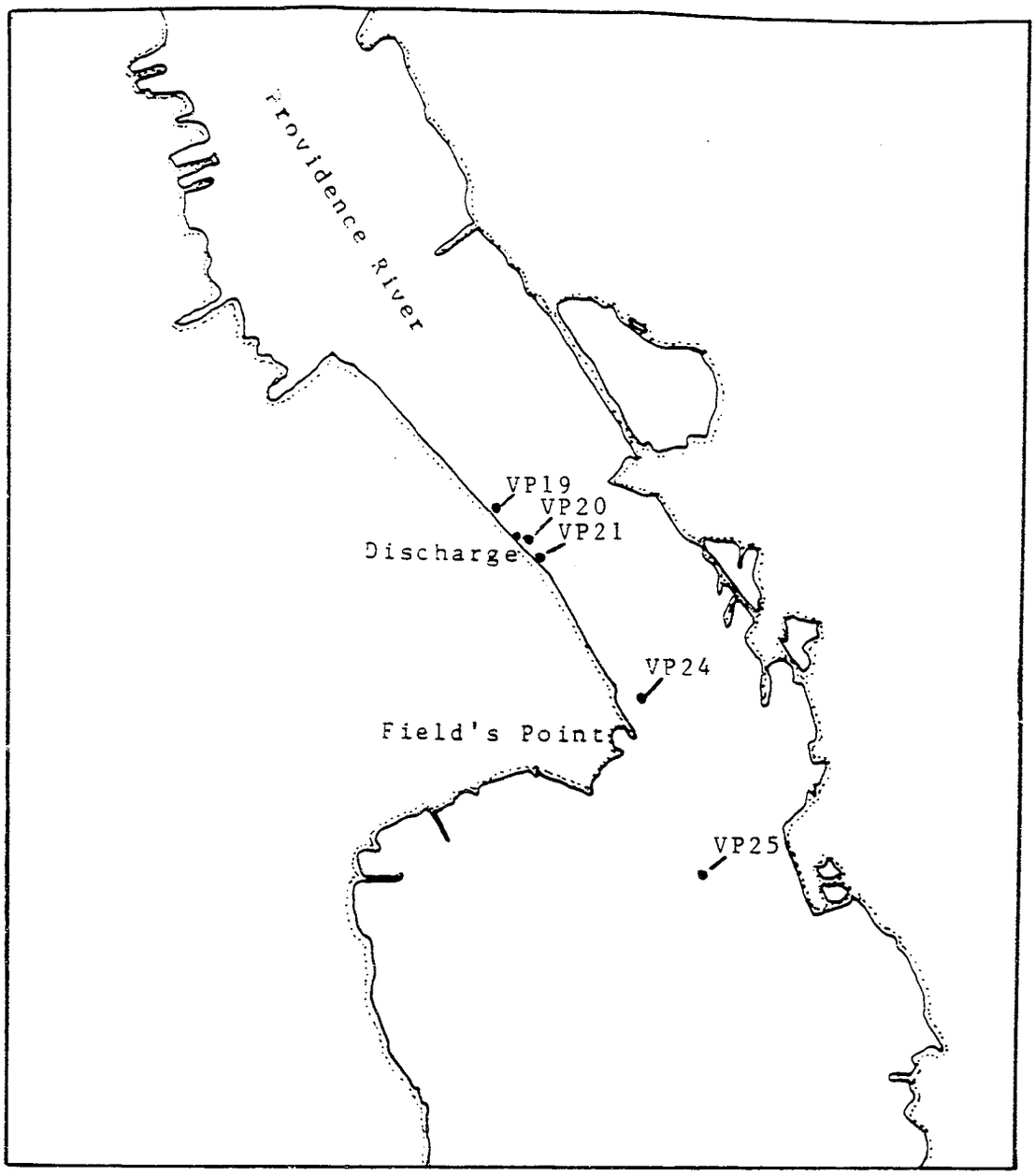
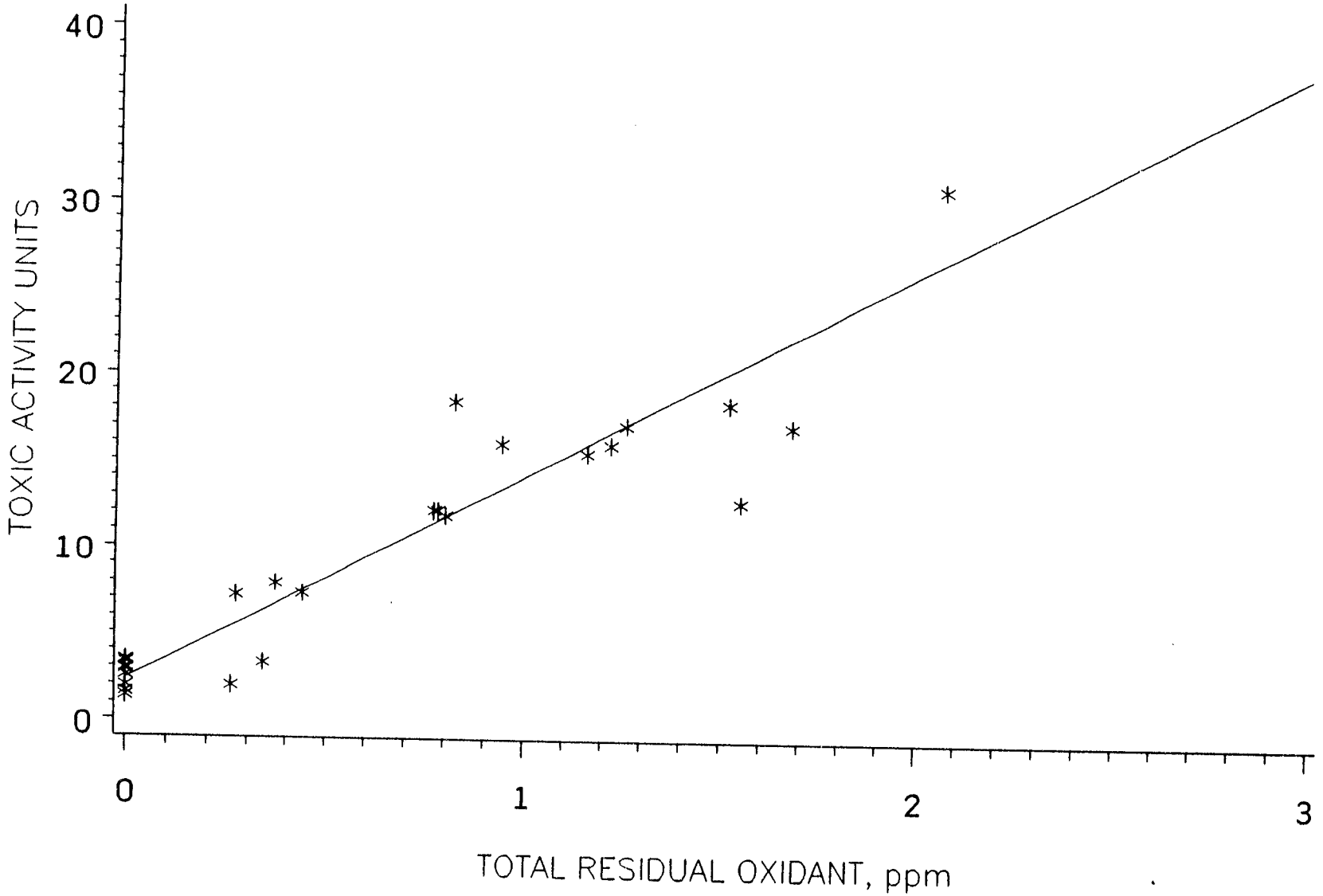


Figure 2b. Stations sampled during the Providence River dye study, 8/19/89.

TOXICITY TO A.PUNCTULATA vs. CHLORINE

in FIELDS POINT EFFLUENT

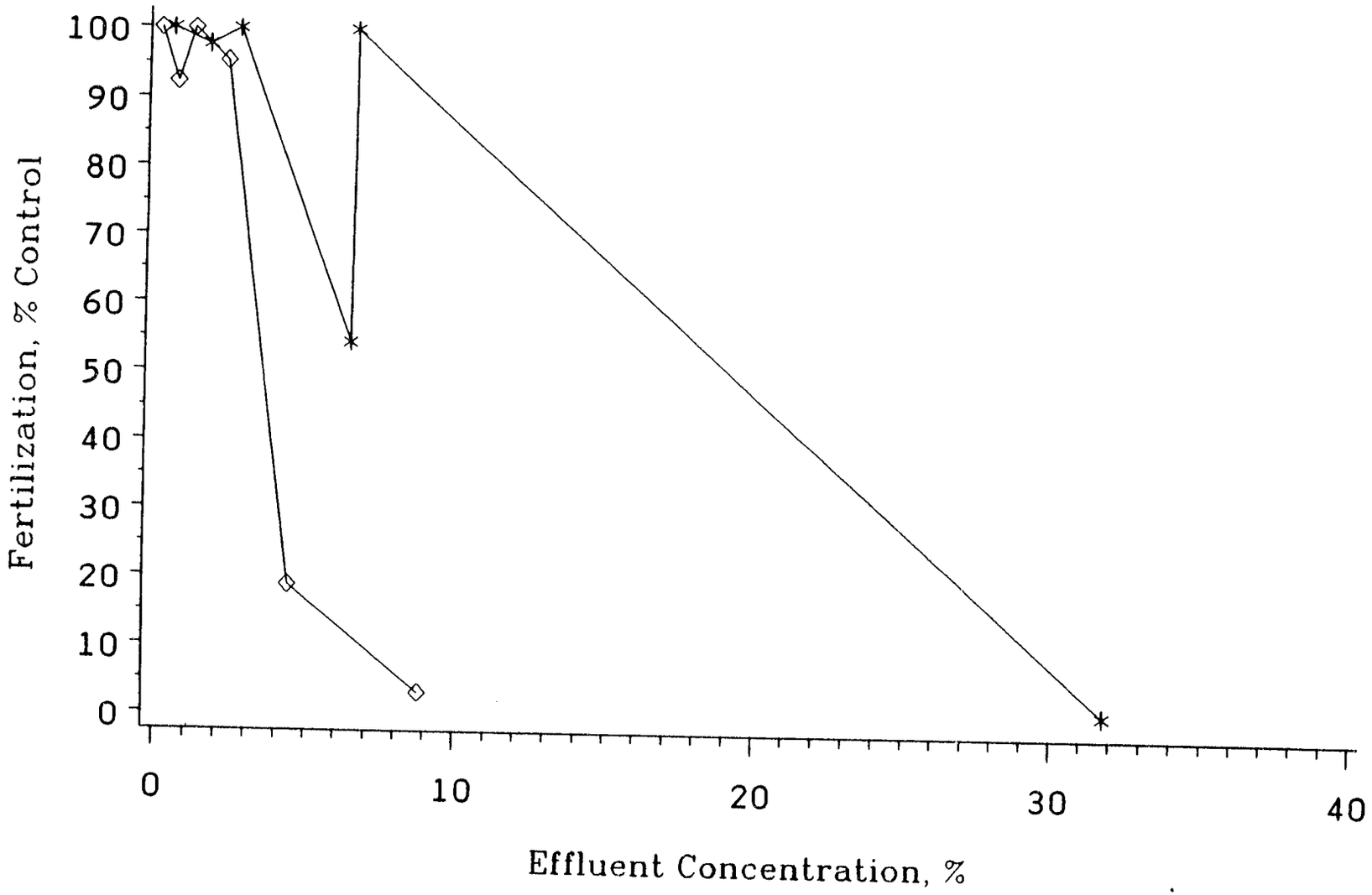


POSTCHLORINATED EFFLUENT and PRECHLORINATED EFFLUENT, Cl SPIKED

FIGURE 4:

Toxicity vs. Effluent Concentration, 4/89

Arbacia punctulata

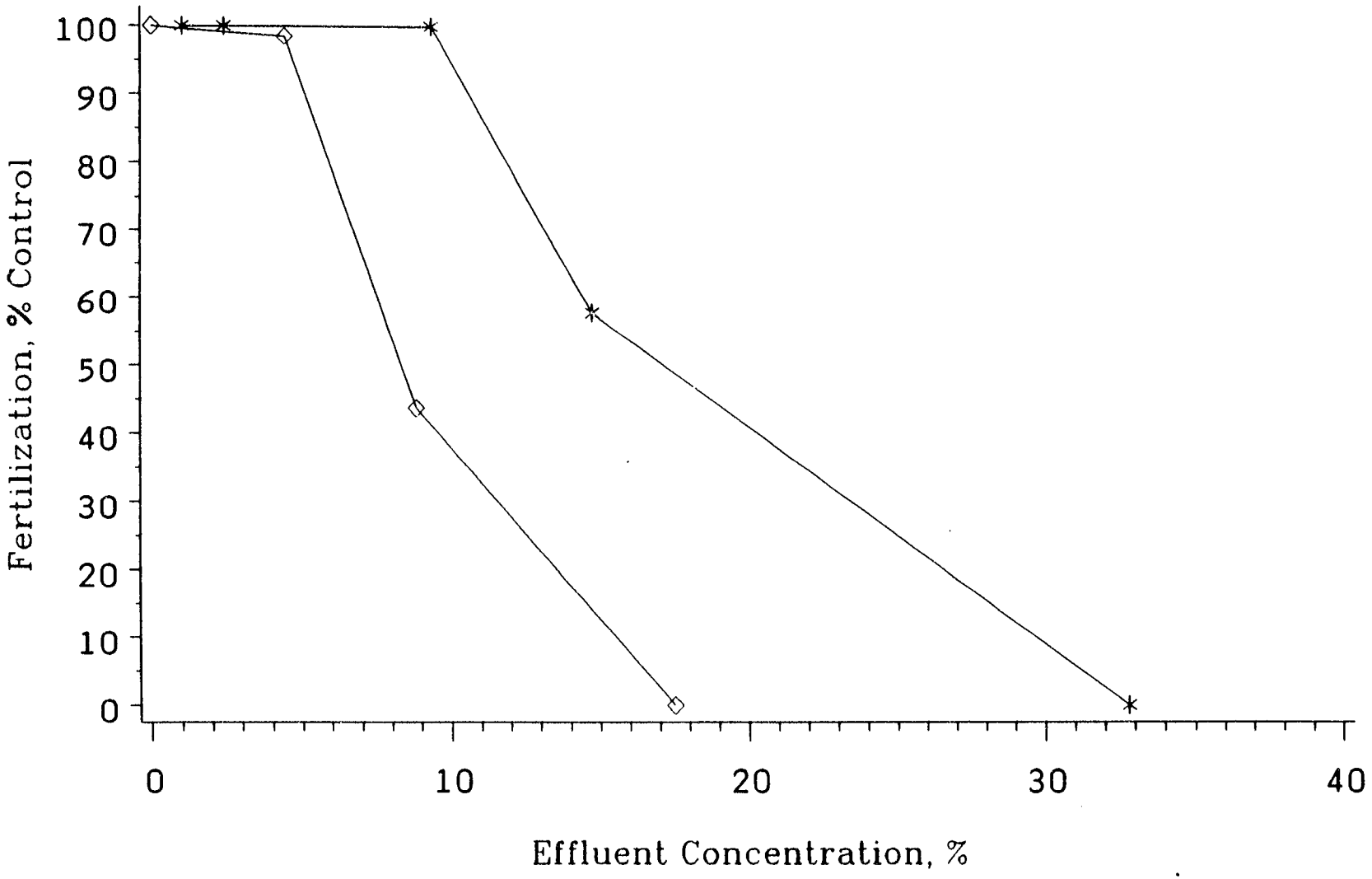


◇ WHOLE EFFLUENT, DILUTED IN THE LABORATORY
* EFFLUENT IN RECEIVING WATER

FIGURE 5:

Toxicity vs. Effluent Concentration, 8/18/89

Arbacia punctulata

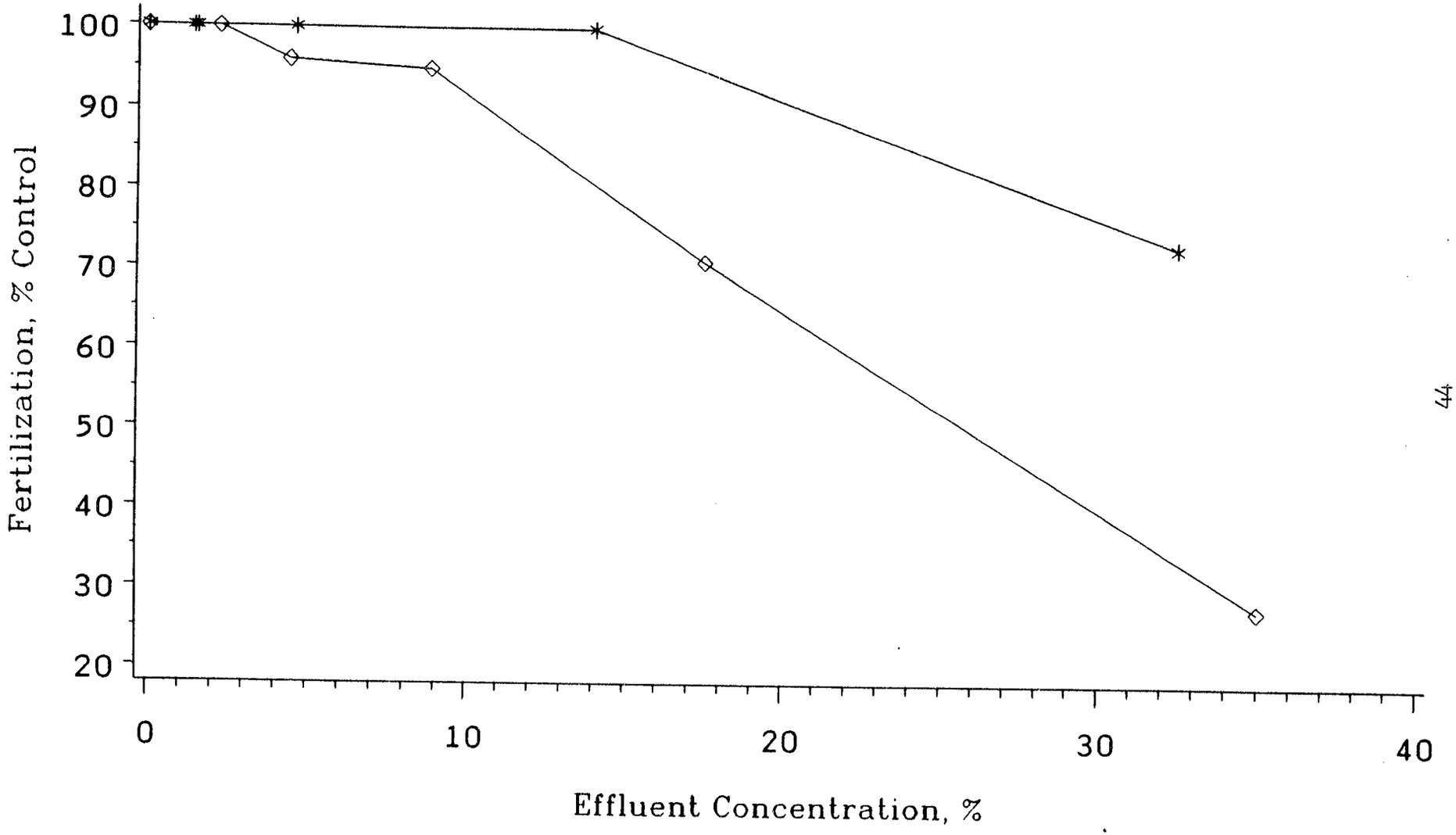


◇ WHOLE EFFLUENT, DILUTED IN THE LABORATORY
* EFFLUENT IN RECEIVING WATER

FIGURE 6:

Toxicity vs. Effluent Concentration, 8/19/89

Arbacia punctulata



◇ WHOLE EFFLUENT, DILUTED IN THE LABORATORY
* EFFLUENT IN RECEIVING WATER

FIGURE 7:

Toxicity vs. Effluent Concentration, 4/89

Champia parvula

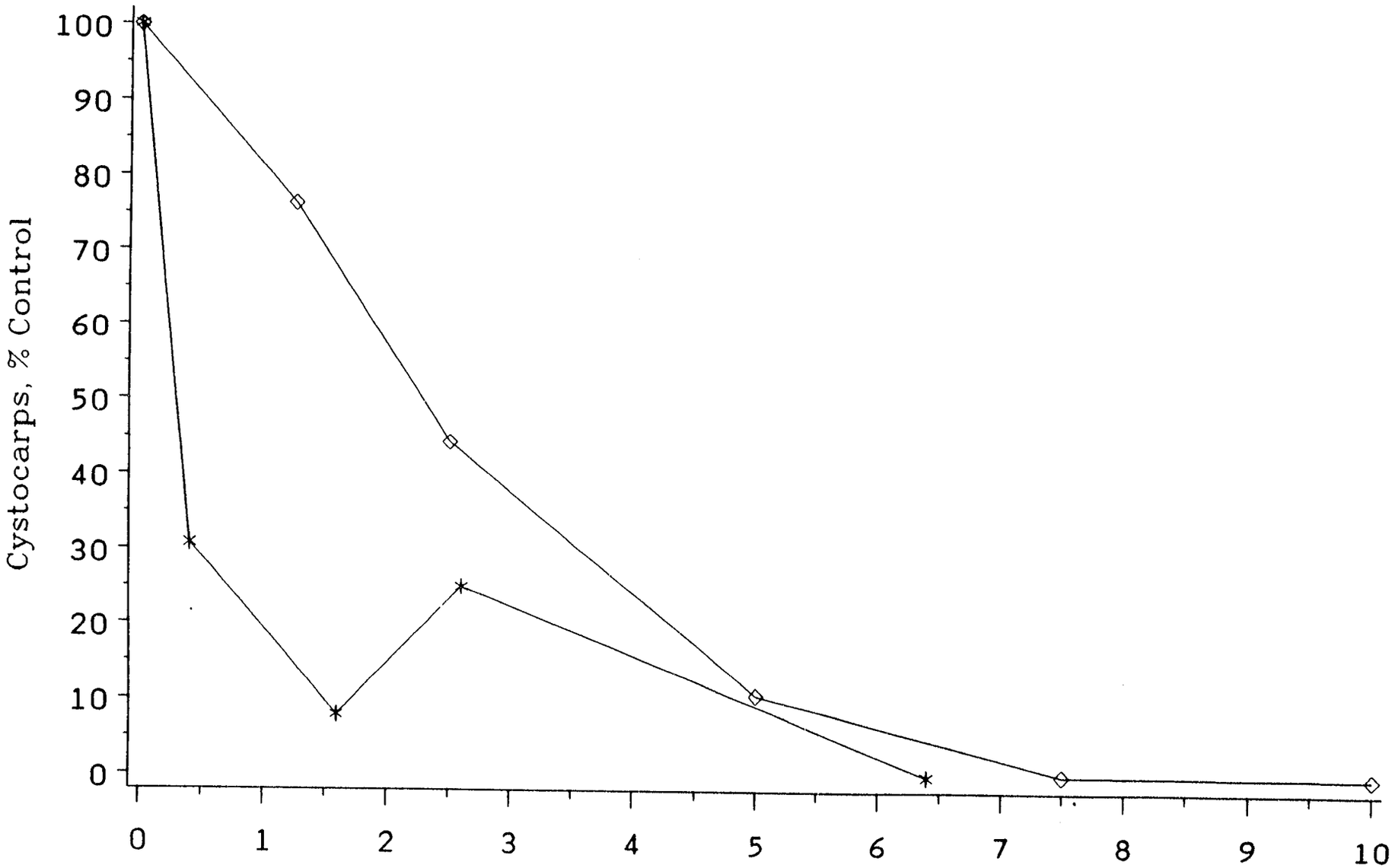


FIGURE 8:

Toxicity vs. Effluent Concentration, 8/18/89

Champia parvula

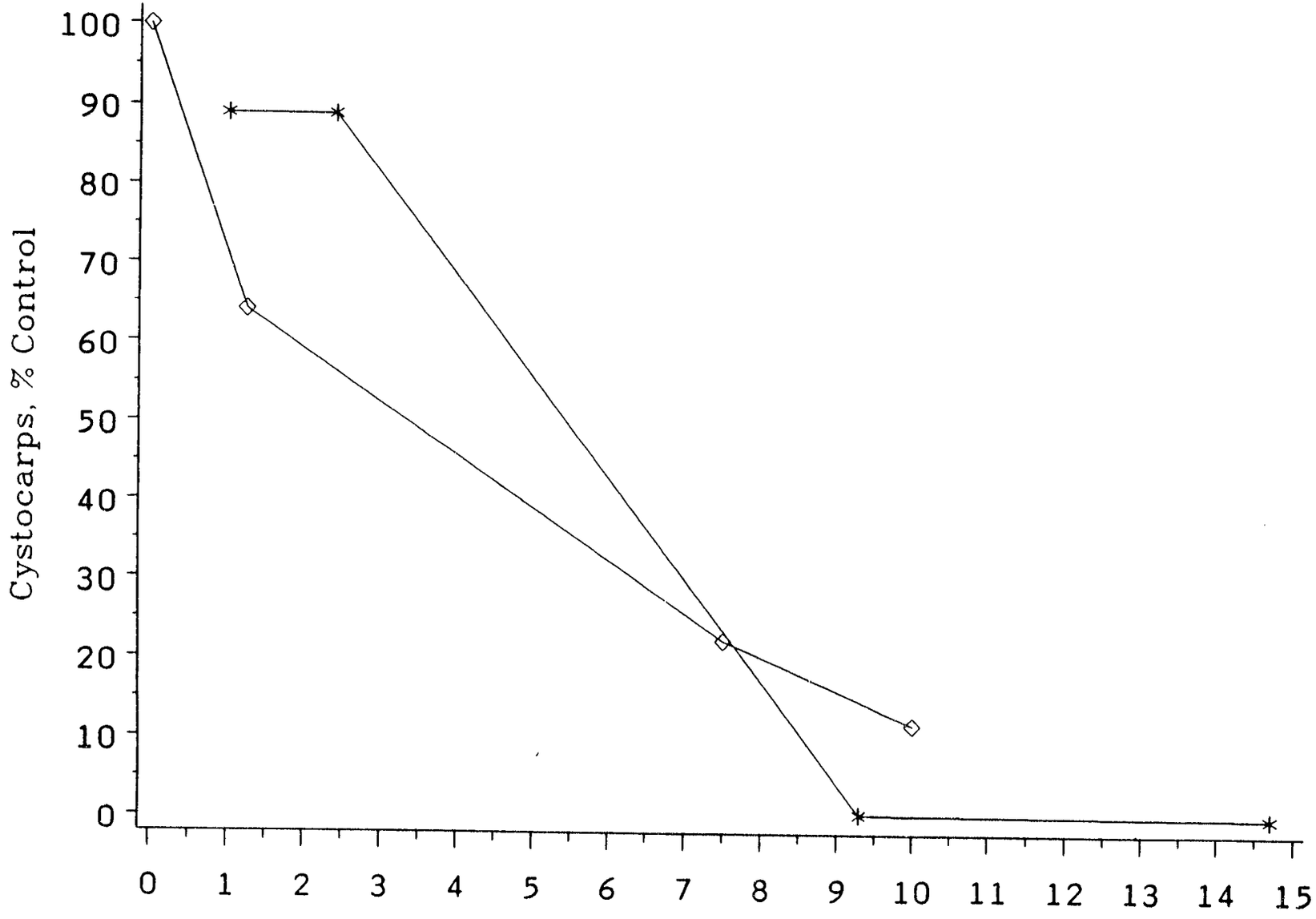


FIGURE 9:

Toxicity vs. Effluent Concentration, 8/19/89

Champia parvula

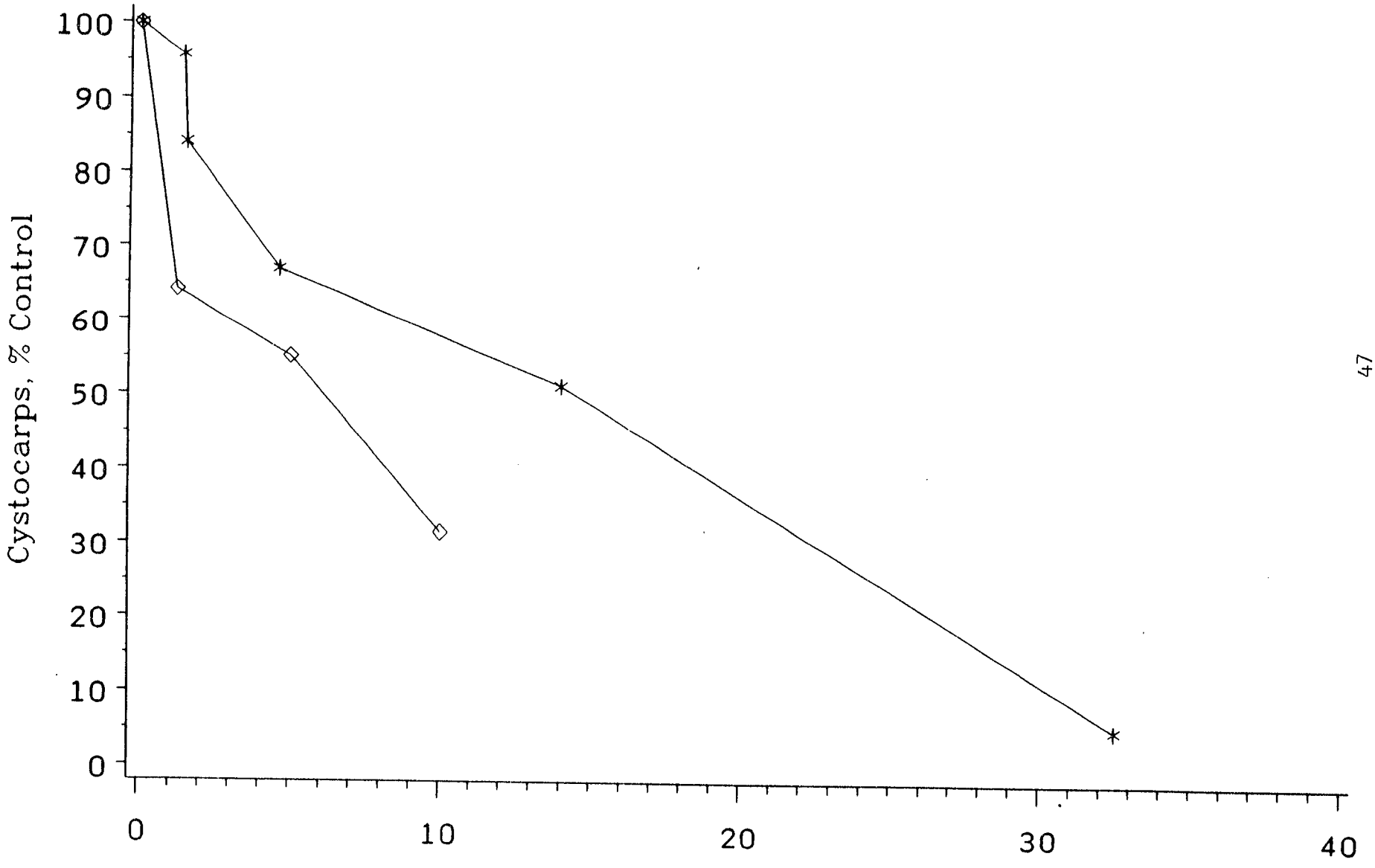
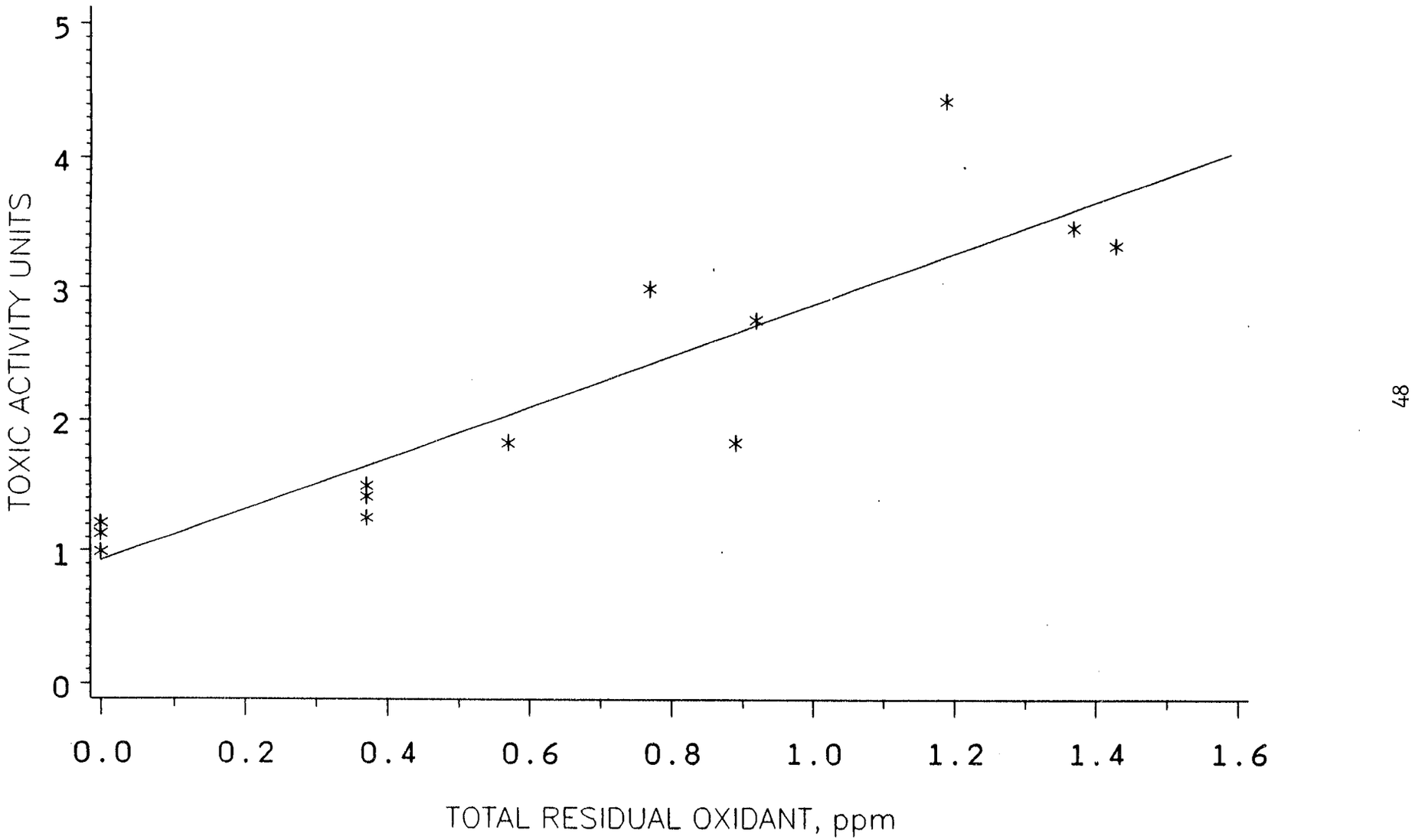


FIGURE 10:

TOXICITY TO M.MERCENARIA vs. CHLORINE

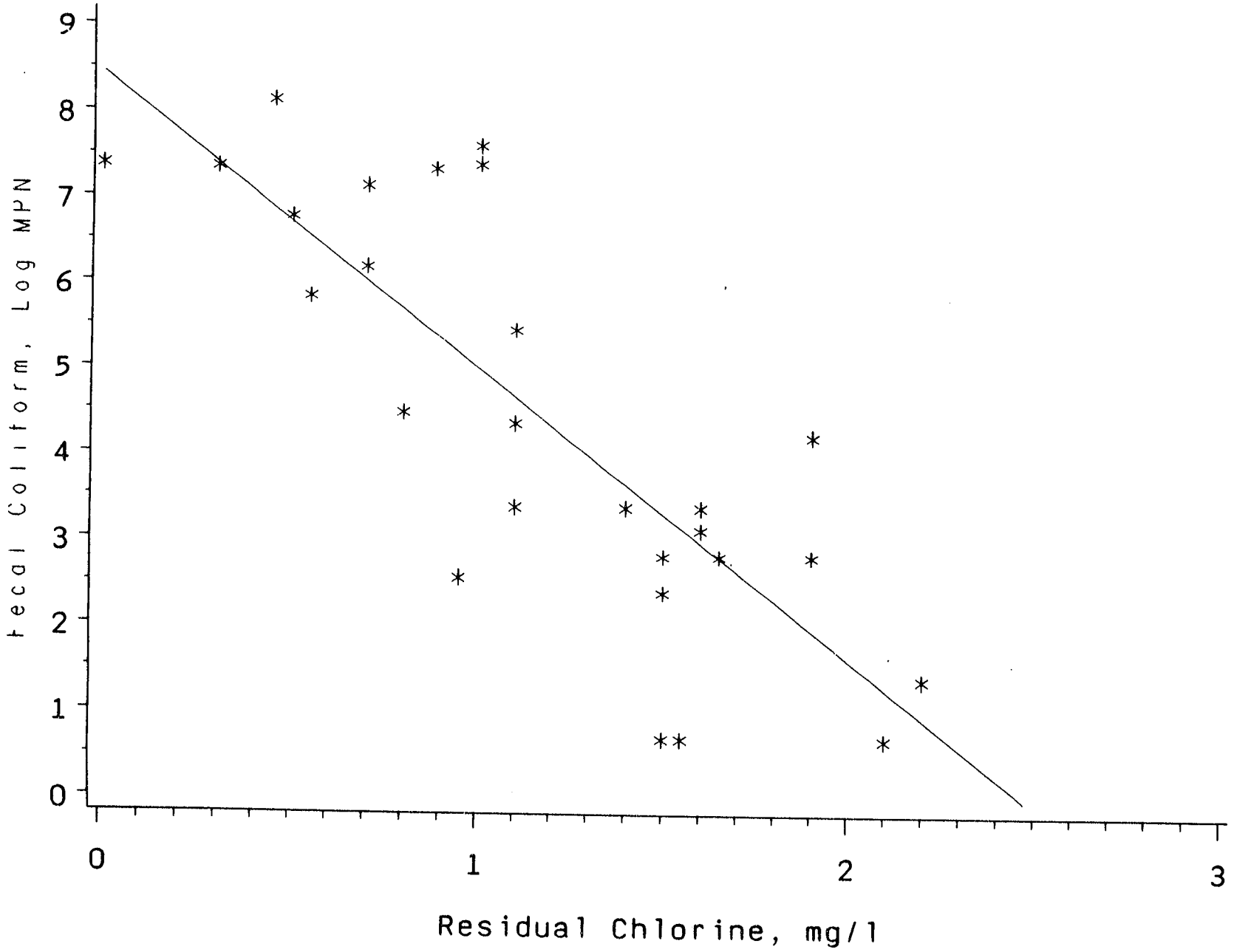
in FIELDS POINT EFFLUENT



POSTCHLORINATED EFFLUENT and PRECHLORINATED EFFLUENT, CI SPIKED

FIGURE 11:

Fecal Coliform Kill vs. Residual Chlorine



APPENDIX A

The University of Rhode Island Graduate School of Oceanography
Narragansett Bay Campus, Narragansett, RI 02882-1197

MEMORANDUM

April 17, 1989

TO: Steve Schimmel, EPA

FROM: J. G. Quinn and R. Kango, GSO

Subject: Analyses of samples from the Fields Point chlorination study.

Enclosed are the results of our analyses from this study. The pre-chlorinated samples (#122-4/3/89 and #124-4/5/89) are similar in composition to the previous pre-chlorinated sample (# 102) collected on 2/14/89. They all have relatively high concentrations of the following halocarbons: methylene chloride, 1,1,1-trichloroethane, trichloroethene, and tetrachloroethene. The post-chlorinated sample (#123-4/3/89) was also similar to the previous post-chlorinated sample (#103-2/14/89), but this time it contained 4.5 ppb of vinyl chloride. We tried to analyze the samples that were chlorinated at your laboratory, but we had major difficulties with our Hall Detector due to the complex products formed in the chlorination reaction. The only one that we could analyze was the 0.4 ppm hypochlorite sample and the results indicated that vinyl chloride was formed during this reaction as we had previously indicated in our memo of March 9th. Because of the detector problems encountered with the analyses of chlorinated samples, we will not be able to analyze any more of these samples at the present time. (I just finished paying $3200 to fix the instrument and now we have new problems to solve). We would like to study the formation of vinyl chloride during this reaction, but we will have to find a way to prevent contamination of our GC detector before we do.

We also analyzed samples collected from the Providence River on 4/6/89. Sample 2 was collected at the Fields Point outfall and had the highest concentration of all components (including 6.4 ppb vinyl chloride). It contained many of the components found in the post-chlorinated samples from the Fields Point plant. In general, the levels of major halocarbons decreased with distance from the outfall to station 6. We are still working with this data and will send you our results, if we find anything interesting.

Please send me the results of your analyses when they are finished. Also, what are your plans for future studies?

JGQ/d
Enc.

Graduate School of Oceanography
University of Rhode Island

SAMPLE NAME: pre and post chlorinated LOCATION: Fields point

DATE RECEIVED: 4/3/89 DATE ANALYZED: 4/3/89

ANALYST: RAK

COMPOUND	SAMPLE CONCENTRATION (ppb)					
	OGL # 122	OGL # 123	OGL #	OGL # 124	OGL # 125	OGL #
HALL DETECTOR	pre-chlorinated	post-chlorinated		pre-chlorinated	0.4 ppm Hypo-	
VINYL CHLORIDE		4.5			2.3	
1,1-DICHLOROETHENE						
METHYLENE CHLORIDE	3.5	3.7		16.3	7.6	
TRANS-1,2-DICHLOROETHENE						
1,1-DICHLOROETHANE	0.4	0.2		0.2		
CHLOROFORM	1.7	2.9		3.2	1.0	
1,1,1-TRICHLOROETHANE	10.9	12.6		16.0	7.1	
CARBON TETRACHLORIDE						
1,2-DICHLOROETHANE	0.4					
TRICHLOROETHENE	12.0	11.3		17.8	10.1	
1,2-DICHLOROPROPANE						
BROMODICHLOROMETHANE		0.7				
2-CHLOROETHYLVINYL ETHER						
CIS-1,3-DICHLOROPROPENE						
TRANS-1,3-DICHLOROPROPENE	1.2	1.5		0.8	1.0	
1,1,2-TRICHLOROETHANE						
TETRACHLOROETHENE	5.2	4.4		6.0	3.0	
DIBROMOCHLOROMETHANE						
CHLOROBENZENE						
BROMOFORM						
1,1,2,2-TETRACHLOROETHANE						
1,3-DICHLOROBENZENE						
1,4-DICHLOROBENZENE	1.9	1.8		2.2	1.1	
1,2-DICHLOROBENZENE				0.1		
PID DETECTOR						
METHYL -T- BUTYL ETHER	4.8	5.3		4.6	2.9	
BENZENE	0.1			0.1		
TOLUENE	0.2	0.3		0.5	0.4	
ETHYLBENZENE						
M,P-XYLENE	1.5	0.5		2.8	1.8	
O-XYLENE	1.5	0.3		1.2	0.7	

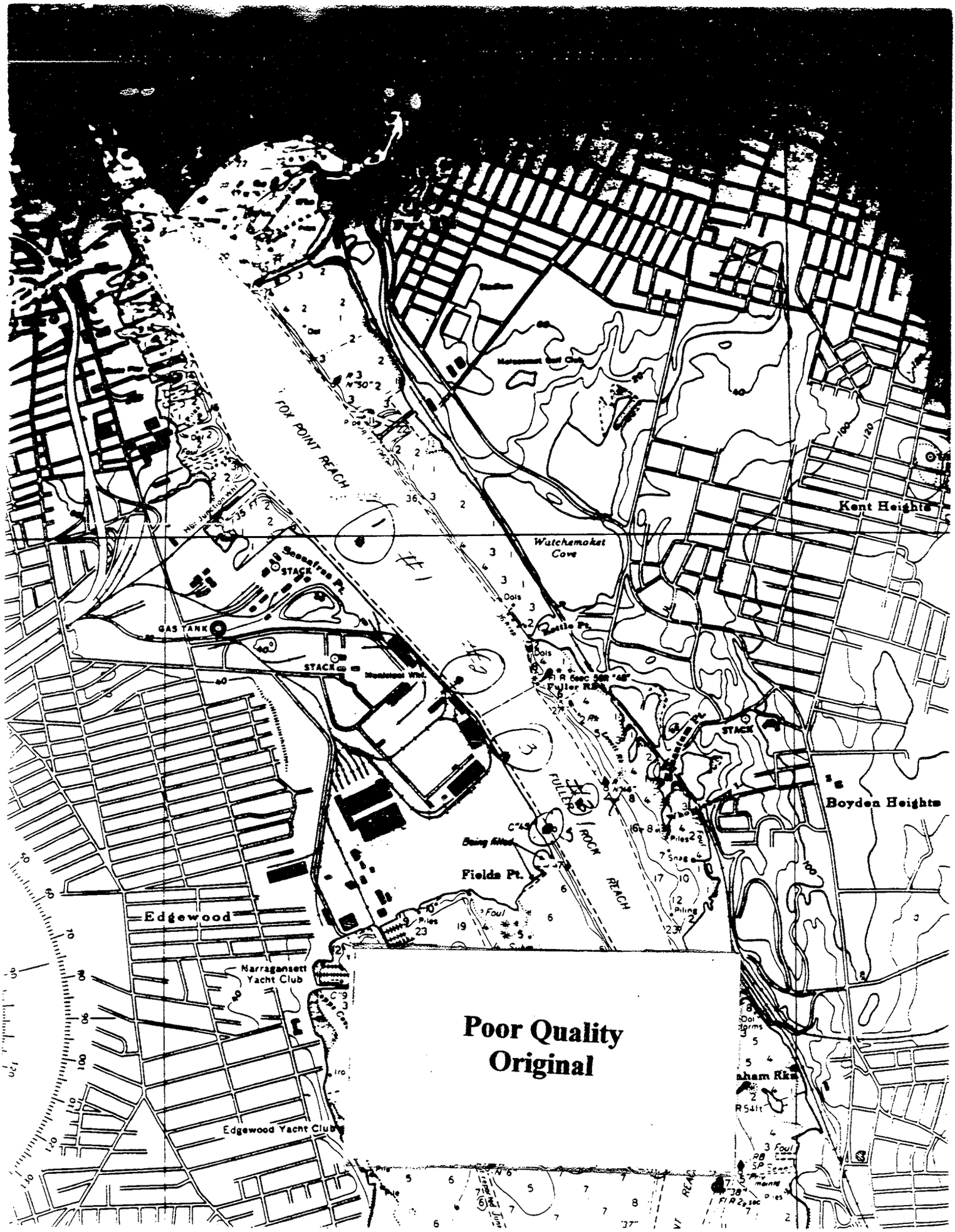
Graduate School of Oceanography
University of Rhode Island

SAMPLE NAME: Pro River samples LOCATION: Providence River

DATE RECEIVED: 4/6/89 DATE ANALYZED: 4/10/89

ANALYST: RAK

COMPOUND	SAMPLE CONCENTRATION (ppb)					
	OGL # 129	OGL # 130	OGL # 131	OGL # 132	OGL # 133	OGL #
HALL DETECTOR	#1	#2	#3	#4	#5	
VINYL CHLORIDE		6.4	1.8			
1,1-DICHLOROETHENE			0.1			
METHYLENE CHLORIDE	1.8	14.6	2.7	1.2	1.6	
TRANS-1,2-DICHLOROETHENE	0.1			0.1		
1,1-DICHLOROETHANE		0.1				
CHLOROFORM	0.3	0.6	0.5	0.1	0.1	
1,1,1-TRICHLOROETHANE	0.7	6.1	1.2	0.2	0.2	
CARBON TETRACHLORIDE						
1,2-DICHLOROETHANE					0.1	
TRICHLOROETHENE	0.7	5.2	1.2	0.3	0.3	
1,2-DICHLOROPROPANE						
BROMODICHLOROMETHANE		0.2				
2-CHLOROETHYLVINYL ETHER						
CIS-1,3-DICHLOROPROPENE		0.1				
TRANS-1,3-DICHLOROPROPENE	0.1	0.6	0.2			
1,1,2-TRICHLOROETHANE						
TETRACHLOROETHENE	0.2	0.8	0.2	0.1	0.1	
DIBROMOCHLOROMETHANE						
CHLOROBENZENE						
BROMOFORM						
1,1,2,2-TETRACHLOROETHANE						
1,3-DICHLOROBENZENE						
1,4-DICHLOROBENZENE	0.2	0.4	0.2	0.1	0.1	
1,2-DICHLOROBENZENE		0.4				
PID DETECTOR						
METHYL -T- BUTYL ETHER	0.7	2.5	1.1	0.4	0.9	
BENZENE				0.2	1.2	
TOLUENE	0.4	0.4	0.8	0.7	2.6	
ETHYLBENZENE	0.1		0.1	0.1	0.4	
M,P-XYLENE	0.2	0.2	0.4	0.3	1.6	
O-XYLENE	1.7	0.1	0.2	0.2	1.0	



FOX POINT REACH
Watchemoket Cove
Kent Heights
GAS TANK
STACK
Fuller Rk
FULLER ROCK REACH
Boyden Heights
Being filled
Fields Pt.
Edgewood
Narragansett Yacht Club
Iron stake
Edgewood Yacht Club
Pomham Rks
Dol Platforms
Piles
Piling
Subm pile
Foul