

REPORT DOCUMENTATION FORM
WATER RESOURCES RESEARCH CENTER
University of Hawaii at Manoa

¹ SERIES NUMBER Special Report 09.24:92	² COWRR 05-F
³ TITLE Granular activated carbon treatment of Mililani well water: Phase II study to extend effective life of GAC, six-month progress report	⁴ REPORT DATE October 1992
	⁵ NO. OF PAGES x + 39
	⁶ NO. OF TABLES 11 ⁷ NO. OF FIGURES 10
⁸ AUTHORS Gordon L. Dugan Roger S. Fujioka L. Stephen Lau Gerald H. Takei Henry K. Gee Terra L. McParland	⁹ GRANT AGENCY Board of Water Supply City and County of Honolulu
¹⁰ CONTRACT NUMBER C09012	
¹¹ DESCRIPTORS: *water treatment, atomic absorption spectrophotometry, gas chromatography, mass spectrometry ¹¹ IDENTIFIERS: *granular activated carbon, *minicolumn carbon, DBCP, TCP, *Mililani Wells, Mililani Water Treatment Plant, Oahu, Hawaii	
¹² ABSTRACT (PURPOSE, METHOD, RESULTS, CONCLUSIONS) The aerated Mililani well water, which removed about 40% of TCP, and spiked deionized water, intended to reduce the level of natural background organics, both appeared to increase the volume of water passing through the minicolumns before breakthrough by nearly 40%. Likewise the carbon usage rates for the spiked deionized water and aerated Mililani well water decreased in comparison to untreated Mililani well water, except for the March 1992 minicolumn experiment, which was nearly the same. More minicolumn tests will need to be performed to ascertain if the March 1992 minicolumn results were reasonable or, possibly an anomaly. The minimum minicolumn carbon usage values of approximately 0.022 lb/1000 gal did not simulate field operation values which ranged from 0.135 to 0.150 lb/1000 gal; however a close correlation would not be expected. In addition, the aerated Mililani well water samples did not increase the weight of TCP and DBCP that was able to be adsorbed by the pulverized GAC. Thus, it seems apparent that background material (presumably organic or primarily organic material) may be utilizing adsorption sites. No apparent relationship existed for TC or NPOC removal before and after breakthrough. Further minicolumn experiments will be continued to substantiate the minicolumn experimental data collected to date.	

**WATER RESOURCES RESEARCH CENTER
PROJECT PERSONNEL**

**Dr. Gordon L. Dugan
Project Principal Investigator
Professor, Civil Engineering**

**Dr. Roger S. Fujioka
Co-Principal Investigator
Director, Water Resources Research Center
Professor, The School of Public Health**

**Dr. L. Stephen Lau
Co-Principal Investigator
Professor, Civil Engineering**

**Dr. Gerald H. Takei
Toxic Chemist, WRRRC**

**Mr. Henry K. Gee
Research Associate, WRRRC**

**Ms. Terra L. McParland
Graduate Research Assistant, WRRRC**

Coordinating Personnel

**Mr. Delwyn S. Oki
Project Coordinator, Phase I
Graduate Research Assistant, WRRRC
Doctoral candidate (Geology/Geophysics), UHM**

**Ms. Holly Chu
Former Graduate Research Assistant, WRRRC
(Presently completing thesis on project-related theme)**

ABSTRACT

The aerated Mililani well water, which removed about 40% of TCP, and spiked deionized water, intended to reduce the level of natural background organics, both appeared to increase the volume of water passing through the minicolumns before breakthrough by nearly 40%. Likewise the carbon usage rates for the spiked deionized water and aerated Mililani well water decreased in comparison to untreated Mililani well water, except for the March 1992 minicolumn experiment, which was nearly the same. More minicolumn tests will need to be performed to ascertain if the March 1992 minicolumn results were reasonable or, possibly an anomaly.

The minimum minicolumn carbon usage values of approximately 0.022 lb/1000 gal did not simulate field operation values which ranged from 0.135 to 0.150 lb/1000 gal; however a close correlation would not be expected. In addition, the aerated Mililani well water samples did not increase the weight of TCP and DBCP that was able to be adsorbed by the pulverized GAC. Thus, it seems apparent that background material (presumably organic or primarily organic material) may be utilizing adsorption sites. No apparent relationship existed for TC or NPOC removal before and after breakthrough. Further minicolumn experiments will be continued to substantiate the minicolumn experimental data collected to date.

EXECUTIVE SUMMARY

The herein presented report represents the second phase of the study to extend the effective life of GAC in Mililani well water.

The original laboratory and pilot plant testing of methods for reducing the target organics, EDB, DBCP, and TCP, were conducted by the Honolulu consulting firm, GMP and Associates, in 1984. Based on the results of the dynamic minicolumn filtration test, GMP projected the GAC usage rates for the prototype facilities at Mililani, Kunia, and Waipahu, which were designed, constructed, and respectively placed in service in March 1986, May 1986, and July 1987. Unfortunately, under actual field operating conditions the effective service life of the GAC was only approximately 15% of its projected designed life. The reasons for the less than expected GAC service life and practical economically feasible methods for extending the effective GAC life is the objective of the previous Phase I and the present Phase II projects.

Major finds of Phase I were:

1. Levels of target organic compounds, DBCP, EDB, and TCP, in groundwater in the Pearl Harbor aquifer of central O'ahu do not appear to be decreasing at present.
2. Based on spent carbon samples from the contactors of the GAC treatment facilities, the adsorption capacity of GAC for a particular target compound is directly related to the concentration of the compound in the influent water.
3. Inorganic cations and anions do not appear to be significantly adsorbed by GAC, however, the total organic carbon concentration of the Pearl Harbor basaltic aquifer is typically a few tenths of mg/L, which is considerably higher than the levels of DBCP, EDB, and TCP encountered at the contaminated well sites. Thus, the background organic matter may be contributing to the shortened service life of the GAC contactors.
4. Various pretreatment processes should be considered for reducing the background organic matter which may be limiting the effective treatment life of the GAC.
5. Scaling-up calculations indicated significant limitations when extrapolating results from minicolumns to prototype units.

The minicolumn testing procedure was utilized in Phase II inasmuch as it is considered a valuable means for screening GAC test within short periods of time, even though extrapolating the carbon usage rate to prototype units is limited.

Six minicolumn experiments utilizing pulverized GAC have been conducted to date which include naturally contaminated Mililani well water, deionized water spiked with DBCP and TCP (EDB not detected in Mililani well water), and aerated Mililani well water. The experiments were conducted until breakthrough occurred, based on the acceptable detection limit of 20 ng/L for DBCP and 100 ng/L for TCP. The predominate breakthrough occurred for TCP within the

time frame of the experiments, primarily because of the low levels of DBCP compared to TCP. The results showed that the spiked deionized water (intended to represent water with a lower organic carbon background than the well water) and the aerated Mililani water, with 40% of the TCP removed, appeared to increase the volumes of water passing through the minicolumns before breakthrough by nearly 40%, as well as decreasing the carbon usage rates in comparison to untreated Mililani well water. Apparently background materials (presumably organic or primarily organic materials) are competing with TCP and DBCP for GAC adsorption sites. These natural background materials are not reduced by aeration, although TCP is reduced.

Continuing minicolumn experiments are being conducted using pulverized GAC manufactured from lignite rather than a bituminous base. Results of these experiments will be presented in the final project report.

CONTENTS

ABSTRACT	v
EXECUTIVE SUMMARY	vii
INTRODUCTION	1
PROBLEM IDENTIFICATION	3
PURPOSE AND SCOPE	4
PROJECT MANAGEMENT PERSONNEL	5
MAJOR CONCLUSIONS OF RESULTS, PHASE I	5
METHODOLOGY, PHASE II	7
MINICOLUMN EXPERIMENTS	7
RESULTS AND DISCUSSION, PHASE II	11
CONCLUSIONS	21
REFERENCES CITED	21
APPENDICES	23

Figures

1. GAC Treatment Facility Sites, O'ahu, Hawai'i	3
2. Minicolumn Schematic	9
3. Schematic of System Used for Continuous Flow Aeration Experiments	10
4. Minicolumn Analysis of TCP and DBCP Concentration Using Mililani Well Water, Sept. 1992	12
5. Minicolumn Analysis of TCP and DBCP Concentration Using Mililani Well Water, Jan. 1992	13
6. Minicolumn Analysis of TCP and DBCP Concentration Using Mililani Well Water, Mar. 1992	14
7. Minicolumn Analysis of TCP and DBCP Concentration Using Autoclaved Mililani Well Water, Jan. 1992	15
8. Minicolumn Analysis of TCP and DBCP Concentration Using Deionized Water Spiked with TCP and DBCP	16
9. Minicolumn Analysis Using Aerated Mililani Well Water	17
10. Effluent TCP Concentration with Volume from Various Minicolumn Runs	18

Table

1. Comparison of Various Minicolumn Experiments and Selected
Constituent Parameters at Breakthrough 20

INTRODUCTION

In 1977, a spill of approximately 1.9 m³ (500 gal) of 1,2-dibromoethane (EDB) within 18 m (60 ft) of the Del Monte Corporation water-supply well at Kunia (2703-01) focused attention for the first time on the possibility of pesticide contamination of groundwater in Hawai'i. During the early 1980s, numerous wells located in the Pearl Harbor aquifer, O'ahu, Hawai'i were found to be contaminated with trace amounts of organic chemicals. In 1980, the Del Monte Kunia Well was the first well closed because of pesticide contamination after the discovery of 1, 2-dibromo-3-chloropropane (DBCP) and EDB in water samples. From 1982 to 1983, after the detection of DBCP or EDB in well samples, nine additional potable water wells in Central O'ahu were closed because of potential adverse health risks associated with long-term exposure to the contaminated water. Affected well sites included Mililani Wells I (2800-02, -04) and II (2859-01), Kunia Wells II (2402-01, -02), and the Waipahu Wells (2400-01, to -04). After the well closures, a third contaminant, 1,2,3-trichloropropane (TCP), was also detected in water samples at all nine of the closed wells.

DBCP is a soil fumigant first used on a significant commercial basis by Dole Company in Central O'ahu in 1959. Del Monte Corporation did not use DBCP on O'ahu except on an experimental basis (Department of Agriculture 1983). DBCP use on O'ahu by Dole Company was phased out in the 1977 planting season in response to findings of the potential health risks associated with the compound.

EDB was used in a tetraethyl lead mixture added to aviation fuels (Lau 1985). EDB was also used as a fumigant to control nematodes in pineapple fields. On O'ahu, EDB was the primary soil fumigant of Del Monte Corporation since approximately 1948. Dole Company only began using EDB on O'ahu on a significant commercial scale in 1978 after it phased out the use of DBCP in 1977 (Department of Agriculture 1983). In September 1983, the U.S. Environmental Protection Agency (EPA) announced its intent to cancel registrations of pesticide products containing EDB and ordered an emergency suspension of registrations of EDB for use as a soil fumigant. By the terms of the cancellation order, the use of EDB on pineapple fields in Hawai'i was allowed until 1 September 1984. However, use of EDB on O'ahu by pineapple growers was effectively terminated by the end of 1983.

Excluding the Del Monte Kunia Well, EDB contamination of groundwater on O'ahu is limited to the Waipahu area. EDB may have entered the groundwater as a result of use and handling by pineapple growers. The presence of large fuel pipeline leaks in the vicinity of the contamination, however, makes it difficult to identify the source of EDB in groundwater at this time.

TCP is used as a paint and varnish remover, a solvent, and a degreasing agent (U.S. EPA 1980). It also occurred as an impurity during the manufacturing process of the Shell Chemical Company product DD which was introduced in 1942. Shell DD became the primary soil fumigant of Dole Company in 1948 and was later used as a pre-plant nematicide in conjunction with DBCP. DD has not been used on pineapple fields on O'ahu since 1977.*

At the time of the well closures, no state or federal drinking water standards existed for DBCP, EDB, or TCP. Consequently, the Hawaii State Department of Health (DOH) set an interim limit of 20 ng/L for DBCP and EDB. The accepted detection limit for DBCP and EDB during the period of contaminant discovery was 20 ng/L. DOH did not have an action limit for TCP based on the assumed lesser risk associated with its consumption. Currently, EPA is proposing enforceable maximum contaminant levels (MCLs) of 50 and 200 ng/L for EDB and DBCP, respectively (Federal Register 22 May 1989, 54(97):22062-22160). DOH established, as of March 1992, stricter MCLs of 40 ng/L for EDB and DBCP and 800 ng/L for TCP.

The immediate response to the well closures by the Honolulu Board of Water Supply (BWS) was to increase production at other well sites less affected by contamination. In the Mililani area, however, Mililani Wells I, Pumps 1 (2800-01) and 3 (2800-03) remained open despite evidence of trace amounts of DBCP since no other wells were available to serve the area. In addition, uncontaminated water was delivered to the Mililani area in water trucks.

A number of studies were conducted to identify the best practicable treatment technology to reduce contaminant concentrations to below detectable levels (Dugan et al. 1984; Oshiro 1986; GMP Associates, Inc. 1984). Dugan et al. (1984) conducted a series of laboratory bench-scale experiments in which EDB and/or DBCP-spiked water was treated by passing various quantities through different types of GAC. Oshiro (1986) studied thin film volatilization and heat volatilization as possible treatment alternatives. GMP Associates, Inc. (1984) examined granular activated carbon (GAC), packed tower air stripping, and cooling tower treatment. In spite of its greater capital cost, GAC treatment was recommended because it provided (1) improved performance and comparable operational costs relative to that attained with air stripping, (2) performance stability under varying influent conditions, (3) operational ease and reliability, (4) enclosed treatment, and (5) no air emissions (GMP Associates, Inc. 1984).

Based on the recommendations of the GMP Associates, Inc. (1984) study, BWS installed GAC treatment facilities at Mililani, Kunia, and Waipahu (Fig. 1). The treatment plants at Mililani, Kunia, and Waipahu were respectively placed in service in March 1986, May 1986, and July 1987.

*Honolulu Advertiser, 6 October 1983.

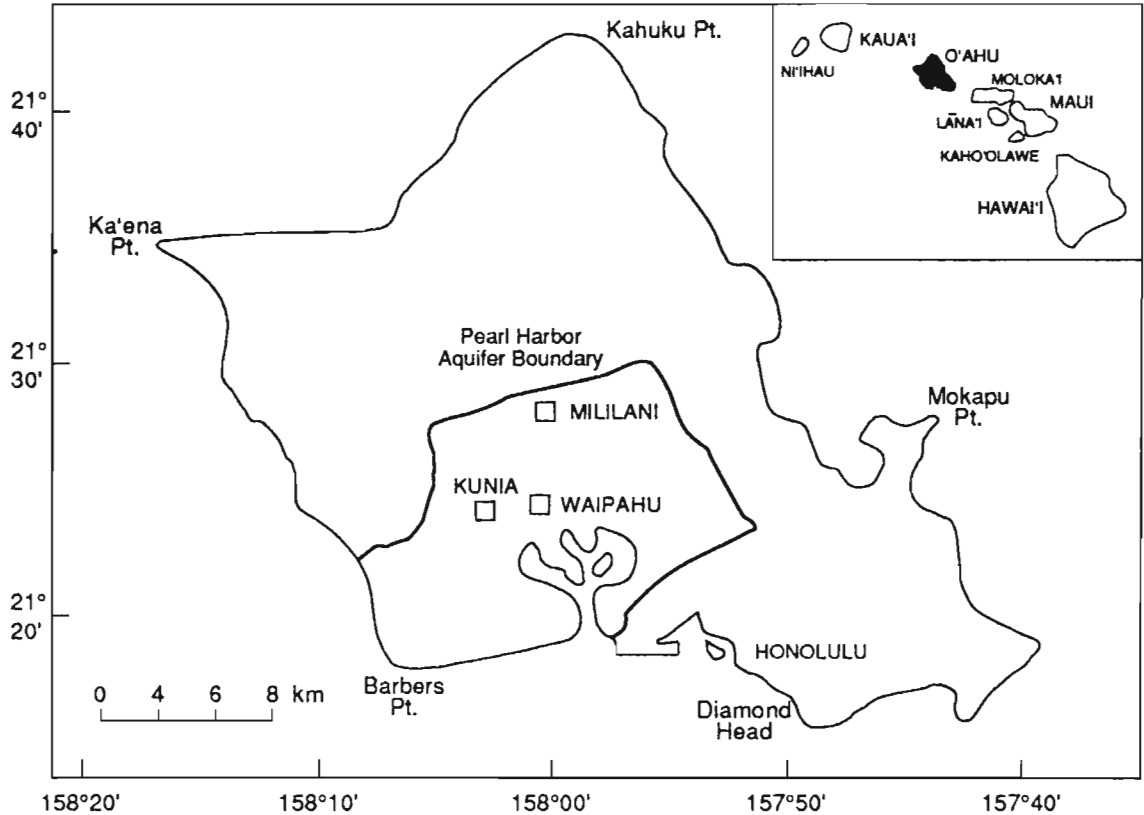


Figure 1. GAC treatment facility sites, O'ahu, Hawai'i

PROBLEM IDENTIFICATION

Original operational cost estimates for the GAC treatment plants at Mililani and Waipahu were based on assumed carbon requirements of 0.0028 and 0.0043 kg/m^3 (23 and 36 lb/mil gal), respectively (GMP Associates, Inc. 1984). Original carbon requirements were estimated based on breakthrough of TCP from laboratory minicolumns. Operational experience to December 1990, however, indicates actual carbon usage rates of approximately 0.016 and 0.018 kg/m^3 (135 and 150 lb/mil gal) for Mililani and Waipahu, respectively. The actual carbon usage rate represents the ratio of carbon quantity to volume of water treated between successive carbon replacements. The GAC in the contactors are typically changed upon breakthrough of target organic compounds. Because actual carbon usage is significantly greater than originally predicted, operational costs are much greater than anticipated.

PURPOSE AND SCOPE

Based on a desire to reduce operational costs associated with their GAC facilities, BWS contracted the University of Hawaii Water Resources Research Center (WRRC) in May 1990 to address the problem of extending the effective life of GAC used for the removal of target organic chemicals from well water in Central O'ahu. The scope of the study was to obtain the basic information necessary to understand the problem so that potentially, based on economic considerations, corrective measures could be taken to extend the life of the GAC.

The results reported herein represent the results obtained for the first six months of the second year (Phase II) of the project originally entitled "Evaluative Study to Extend the Effective Life of the GAC used to Treat Mililani Well Water, Phase I." The title of the Phase II portion of the study changed slightly, as can be noted on the title page.

The project objectives for the Phase I portion of the evaluation study were:

1. Examine the operations of the GAC facilities at the Mililani, Waipahu, and Kunia well sites.
2. Employ and train a toxic chemist to effectively and reliably assay for the various target organic chemicals of importance in the well waters and GAC.
3. Conduct physical, chemical, and biological tests to characterize the influent water, effluent water, and GAC in various stages of operation.
4. Test and characterize the spent carbon to determine its total sorptive capacity to extend the life of the GAC.

The Phase I portion of the project was initially a 12-mo project, commencing on 1 May 1990; however, a four-month no-cost extension moved the completion date to 31 August 1991. A six-month progress report (Oki et al. 1991a) and a Phase I completion report (Oki et al. 1991b) presented the results of the Phase I study.

The Phase II portion of the study was established as a 12-mo project, officially starting on 15 October 1991; however, the project activities were maintained in the interim period between the end of Phase I (31 Aug. 1991) and the start of Phase II.

The project objectives for Phase II basically reflected those of Phase I, except that a toxic chemist was hired and trained, and the toxic chemistry laboratory was upgraded during Phase I. In addition to continuing the basic objectives of Phase I, a greater emphasis was placed on (1) ascertaining the effects of non-target compounds, total organic carbon, humic acids and other naturally occurring organics which potentially could limit the effective life of the GAC; and (2) studying the effectiveness of pretreatment methods.

PROJECT MANAGEMENT PERSONNEL

The research project requires multidisciplinary expertise and is accomplished by a number of coordinated activities. Project personnel, consisting of researchers in the fields of engineering, chemistry, and microbiology, are listed at the front of the report. Overall responsibility for the project is vested with the principal investigator.

MAJOR CONCLUSIONS OF RESULTS, PHASE I

Several new instruments were purchased to enhance the capabilities of the Toxic Chemistry Laboratory for the Phase I portion of the the project, in addition to hiring an experienced and academically trained toxic chemist. A considerable amount of time was required for the toxic chemist to be trained and, in turn, to train other personnel in the operation of the newly acquired sophisticated instruments. As with most situations with highly technical instruments a certain amount of "shake-down" was required. The major items of equipment include: a gas chromatograph mass spectrometer, atomic absorption spectrophotometer with graphite furnace, total organic carbon (TOC) analyzer, ion chromatograph, and high performance liquid chromatograph.

The principal findings of Phase I by Oki and associates (1991) are herein summarized.

Levels of target organic compounds DBCP, EDB, and TCP in groundwater in the Pearl Harbor aquifer of Central O'ahu do not appear to be decreasing significantly at present. In fact, based on the analysis of spent GAC samples from contactors at the Waipahu treatment facility, DBCP which was previously undetected at the Waipahu wells now appears to be occurring at low levels (few ng/L) in groundwater near Waipahu. This discovery does not necessarily preclude the possibility that DBCP has been present for a number of years near Waipahu. However, it does seem to indicate that the plume of DBCP contamination in the aquifer is moving slowly. Because recovery of the aquifer from such contamination may take many years, the need for continued treatment of the groundwater seems likely. Furthermore, recent EPA reports regarding the carcinogenicity of TCP may support the continued use of GAC and/or other high-level treatments of groundwater.

Based on analysis of spent carbon samples collected from contactors at Mililani, Kunia, and Waipahu, it is apparent that the adsorptive capacity of the GAC for a particular target compound is directly related to the concentration of that compound in the influent water. At Mililani, for instance, where TCP in the influent occurs at levels of about 2 000 ng/L, the spent

carbon contains TCP at levels of up to 400 mg/kg. At Waipahu where TCP in the influent occurs at levels of about 200 ng/L, the spent carbon contains TCP at levels of about 40 mg/kg.

Various organic or inorganic compounds present in the groundwater could be responsible for occupying adsorption sites on the GAC, thus making fewer sites available for adsorption of target compounds. Results of this study indicate that naturally occurring background organic matter in groundwater exists at concentrations which are two to three orders of magnitude greater than concentrations of TCP, which is typically the target organic compound found at the greatest concentrations. Thus, naturally occurring background organics could play a significant role in determining the effective life of the GAC.

Results of this study seem to indicate that inorganic cations and anions are not significantly adsorbed by the GAC. However, the behavior of compounds such as silica relative to GAC has not been established with certainty to date.

In addition to chemical effects, bacterial growth may also play a role in the adsorption of target organic compounds. Although bacteria were isolated from spent GAC samples, subsequent scanning electron microscope (SEM) analysis did not reveal a significant microbiological flora other than some suspected slime layer that might inhibit adsorption.

Specific results and conclusions from Phase I include:

1. The ultrasonic solvent extraction method developed for this study appears to be the most effective at desorbing target organic compounds from spent GAC samples, compared to other techniques.
2. TOC levels in groundwater samples from the Pearl Harbor basaltic aquifer are typically a few tenths of mg/L which is considerably higher than the levels of DBCP, DCP, EDB, and TCP encountered at the contaminated well sites. Thus, the background organic matter may be contributing to the shortened service life of the GAC contactors.
3. TOC and infrared analyses indicate the presence of background organic compounds in groundwater. Further research is necessary to characterize the nature of the background organics, particularly humic acids.
4. The presence of background organic matter in groundwater suggests that different operational strategies could enhance the effective service life of GAC. For instance, lag contactors kept off-line until needed may avoid preloading the GAC in the lag contactor with background organic matter. Minicolumn studies could assess the effectiveness of different GAC treatment facility operation modes.
5. Various pretreatment processes, including ozonation, ultrafiltration, or aeration, should be considered in examining the possible strategies for enhancing the effective life of the GAC.

METHODOLOGY, PHASE II

A major problem in determining the effective life of GAC under various conditions and potential pretreatment options is the time required for breakthrough of target organics. The target organics for Mililani well water are presently considered DBCP and TCP. When the GAC contactors were initially designed the effective life of GAC under the operating conditions envisioned by the BWS was upward to two-years (GMP Associates, Inc. 1984), whereas actual operating conditions at the Mililani, Kunia, and Waipahu GAC treatment facilities have shown that the GAC requires replacement approximately every six months. It is suspected that background organics are competing for the adsorption sites with the target organics.

It has been demonstrated that aeration alone effectively removes the volatile target organics EDB, DBCP, and TCP (GMP Associates 1984; Dugan et al. 1984). A prototype aeration tower, using Mililani well water and operated by the BWS in 1983, proved this. However, the attraction of using GAC is its effectiveness in removing at least a high percentage of most organics. Nevertheless in the operation of the GAC facilities, which were established to remove the organics of initial concern, EDB and DBCP, and later TCP, this high adsorption efficiency of all organics may be its operational downfall.

Preliminary economic analysis by BWS personnel have indicated that it is more economical to continue to replace the GAC approximately every six-months than to replace the GAC facilities with aeration units, based on amortized capital costs and operational expenses. Consequently, the present portion of the study (Phase II) is based on the premise that the GAC facilities will continue to be operated and expanded as necessary, and that efforts to extend the life of the GAC should concentrate on removing background organics (including target organics), adjusting operational procedures, and/or using different types of GAC.

MINICOLUMN EXPERIMENTS

The minicolumn procedure basically incorporates a small amount (~50 mg) of powdered activated carbon (PAC), placed in a small container and subjected to a high volume of flow per unit mass of GAC (~0.002 mL/min-mg of activated carbon) under high pressure (up to and occasionally over 200 psi). However, for this situation, the GAC that was used in the Mililani, Kunia, and Waipahu GAC treatment facilities was pulverized to powdered size (200 × 325 mesh) for use in the minicolumn experiments, in order to keep the source of activated carbon the same.

A schematic of the minicolumn is shown in Figure 2. The minicolumn procedure definitely has its limitations in terms of transferring its results to prototype fullscale operations. These limitations were indicated in scaling-up calculations presented in the Final Phase I report (Oki et al. 1991). Pilot-scale columns using GAC, rather than pulverized GAC, and operating at lower pressure, are needed for scaling-up projections to prototype field operations. Nevertheless, the minicolumn procedure is considered to be a valuable means for screening GAC tests within relatively short periods of time.

During the minicolumn experiments, numerous pump failures occurred. Pump seals would break down after relatively short continuous use, apparently because of the high pressure used. The primary problem was to find a pump that could be maintained at a continuous high pressure without leaking. Several pumps were tried and sent back to the manufacturer for replacement and/or repair when they failed to meet their advertised operational specifications. Finally, a relatively expensive high performance single-piston, liquid pump was obtained which performed satisfactorily with minimal maintenance. Based on the apparent proven success of the new high performance pump, a second identical pump was purchased to serve as a backup and/or be available to conduct concurrent experiments.

Six pulverized GAC minicolumn experiments have been conducted and the results compared, when applicable, to experiments by GMP Associates, Inc. (1984). The six minicolumn experiments included, (1) naturally contaminated Mililani well water, (2) deionized water (18 μcm) spiked with DBCP and TCP, and (3) aerated Mililani well water. Autoclaved water samples were prepared to simulate boiling conditions which are known to rapidly decrease the concentration of volatile organics. The spiked deionized water was tested for baseline purposes to determine the adsorption of TCP and DBCP by the pulverized GAC in the minicolumn without the interferences of background organic matter, which is suspected of competing with the target organics for activated carbon adsorption sites. The use of aerated Mililani well water was to determine whether the removal of a portion of the volatile organics by this pretreatment would increase the effective life of the pulverized GAC.

Although numerous aeration configurations and operational modes could be explored, the aeration experiments were limited to three basic types: two of which were batch systems, the other, a continuous system. Operational parameters were varied for the three types. One of the batch aerators was a 2 000-mL beaker stirred at varying detention times and speed. The second batch system utilized diffused air to induce volatilization. The continuous system consisted of a sustained water flow and diffused air for volatilization (Fig. 3). The batch diffused aeration system used the same aeration apparatus (Fig. 3) as the continuous-flow, diffused-air system, except that water was not pumped in or allowed to flow out.

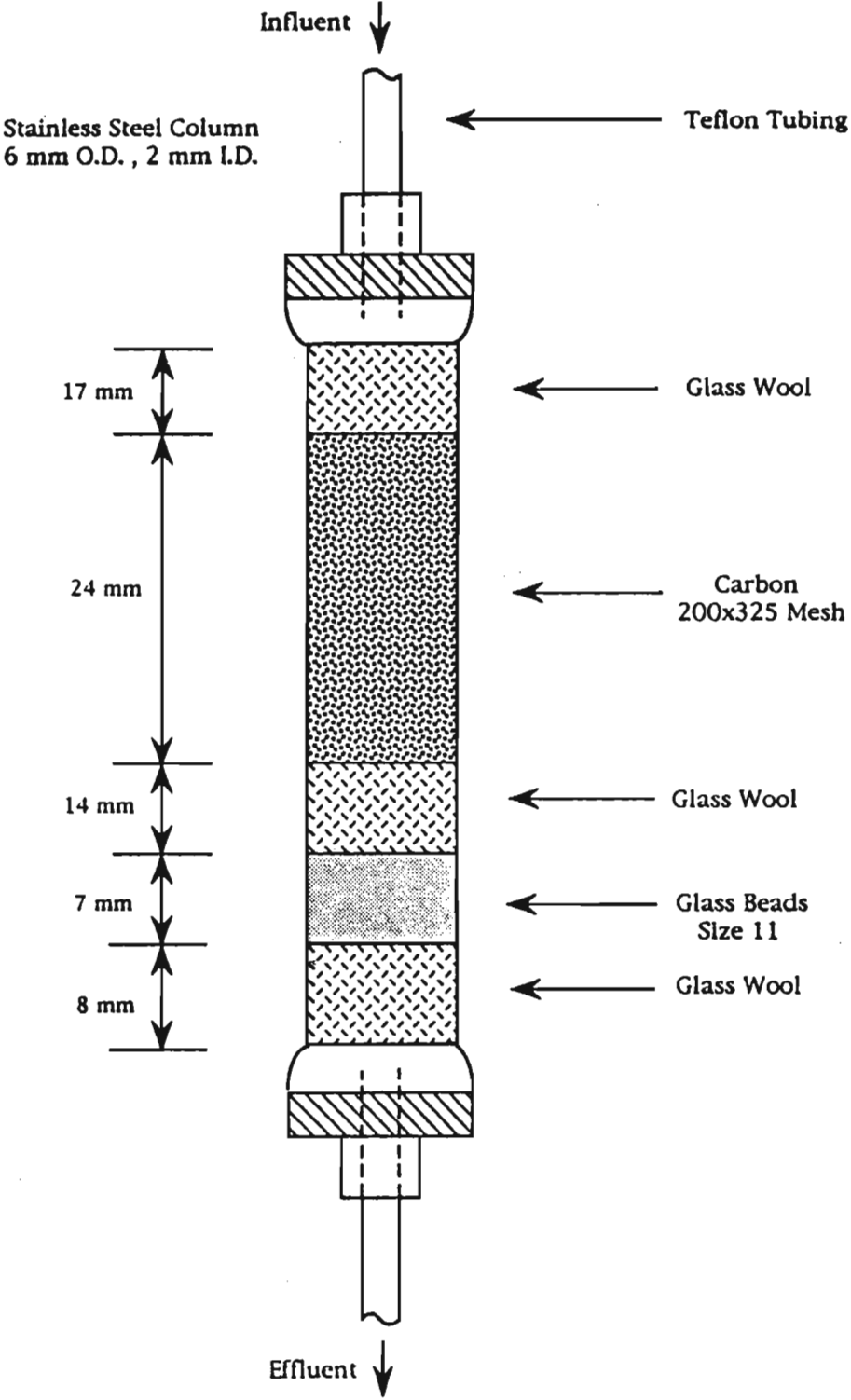


Figure 2. Minicolumn schematic

Aeration Column

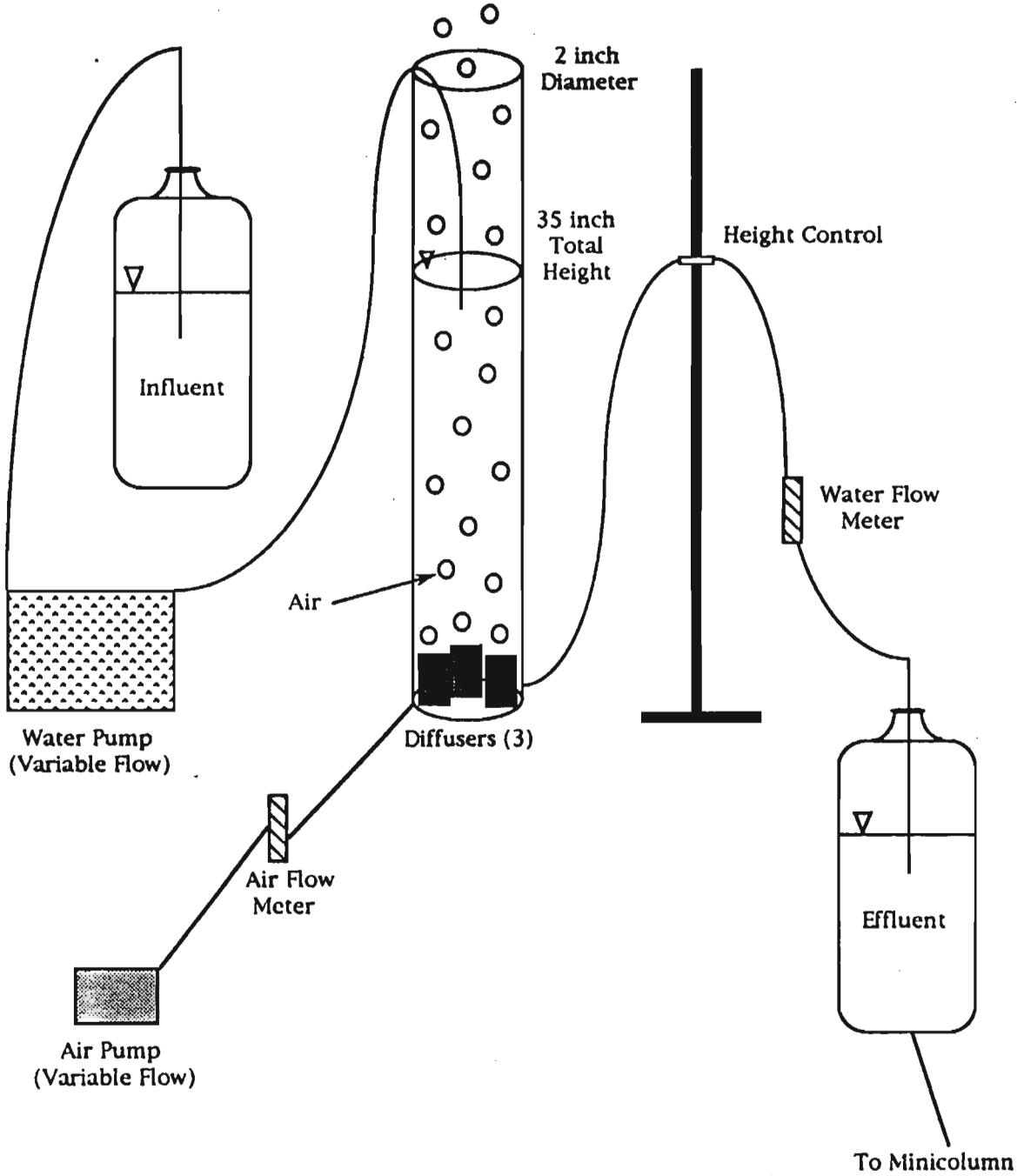


Figure 3. Schematic of system used for continuous flow aeration experiments

The operational parameters for the batch diffused air system were varying air flow, water depth, and detention times, while the continuous system used the same parameters plus various influent/effluent flow rates. The various operational conditions, together with the percentage reduction of TCP and DBCP, for mechanical aeration, batch aeration and continuous flow aeration are shown respectively in Appendix Tables A.1, A.2, and A.3. The minicolumn experiment with aerated Mililani well water utilized the continuous flow system under the following parameters: water height 19 in. (483 mm), air flow 2124 mL/min, water flow 28 mL/min, and detention time 35 min. It should be noted here that aeration was purposely adjusted so that 100% removal of TCP and DBCP did not occur. This procedure was followed so that an identifiable concentration in the effluent could be measured when the pulverized GAC adsorption sites were saturated during the subsequent minicolumn test.

The water was intended to be pumped through the minicolumns at approximately 1 mL/min; however, the overall average pumped flow ranged from <0.2 to >0.8 mL/min, with an overall average of slightly >0.5 mL/min, which equals a 10 sec empty bed contact time. A brief description of laboratory experimental methods involving carbon preparation, packing of the pulverized GAC column, preparation of the spiked deionized water influent, analysis of the pulverized GAC column influent and effluent, and gas chromatography can be found respectively in Appendix Tables B.1, B.2, B.3, B.4, and B.5.

RESULTS AND DISCUSSION, PHASE II

The influent and effluent concentrations of TCP and DBCP from the minicolumn experiments for the three Mililani well water samples, autoclaved Mililani well water, deionized water spiked with TCP and DBCP, and aerated Mililani well water are presented respectively in Appendix Tables C.1, C.2, C.3, C.4, C.5, and C.6. Also presented in these tables are the total volume of water to breakthrough, weights of TCP and DBCP to breakthrough, and the total carbon usages in lb/1000 gal. Breakthrough was considered to be at the acceptable detection limit, 20 ng/L for DBCP and 100 ng/L for TCP. Figures 4 through 9 are respective graphical representations of Appendix Tables C.1 through C.6. The increased breakthrough volume of TCP for the spiked deionized water and aerated Mililani well water (Figs. 7, 8) is quite apparent. Generally, no breakthroughs occurred for DBCP within the time frame of the experiments, primarily because of the low levels of DBCP concentrations compared to those of TCP. A clearer indication of the increased breakthrough volume for the pretreated aerated Mililani well water can be seen in Figure 10.

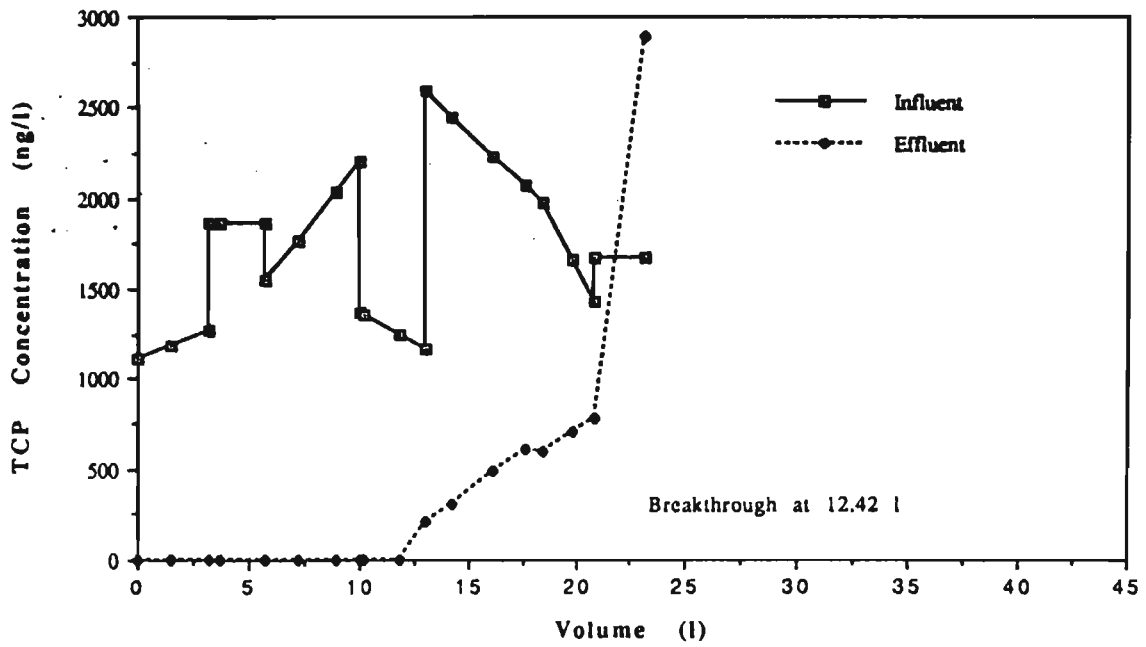


Figure 4.1. TCP concentration with volume through minicolumn

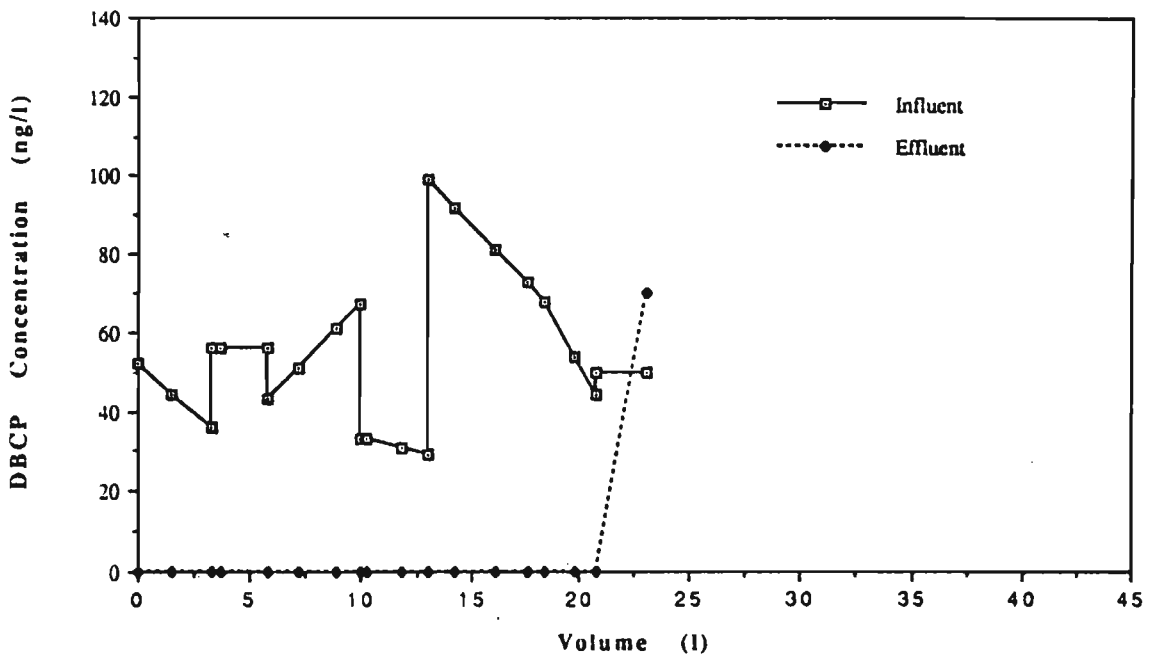


Figure 4.2. DBCP concentration with volume through minicolumn

Figure 4. Minicolumn analysis of TCP and DBCP concentration using Mililani well water, Sept. 1992

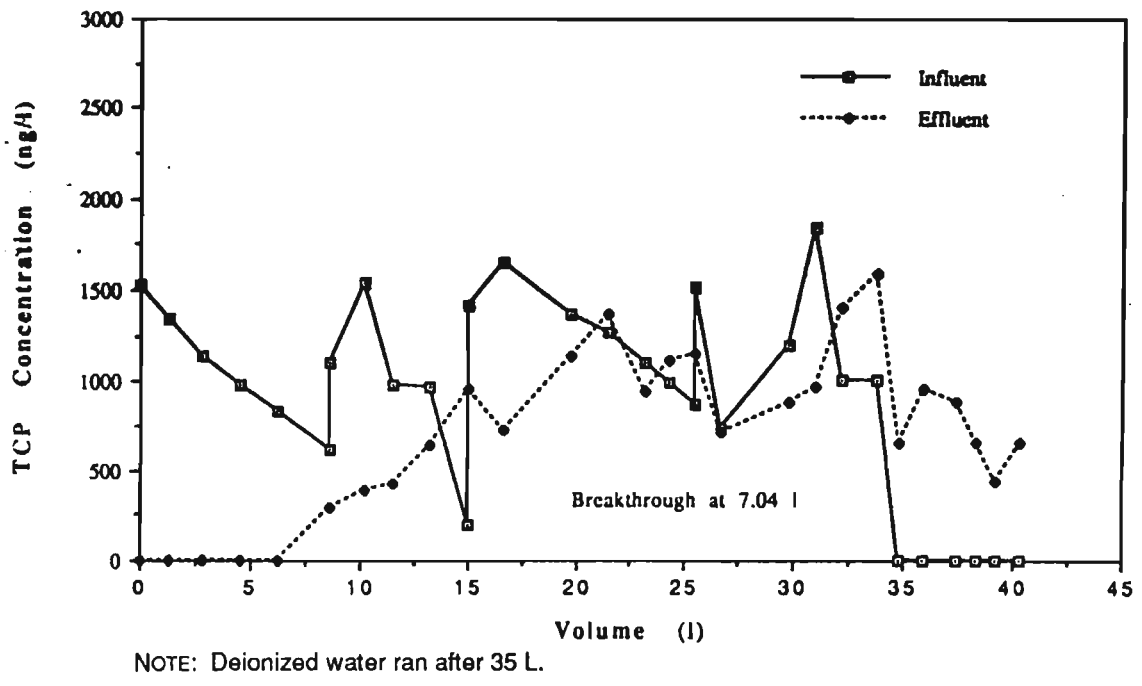


Figure 5.1. TCP concentration with volume through minicolumn

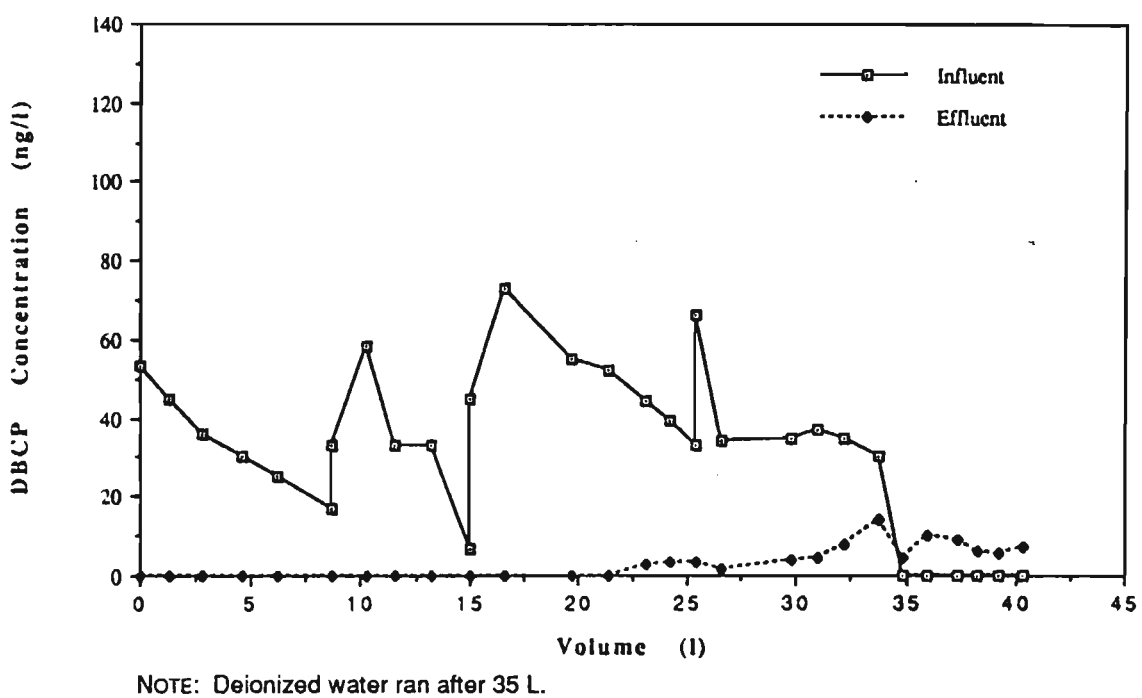


Figure 5.2. DBCP concentration with volume through minicolumn

Figure 5. Minicolumn analysis of TCP and DBCP concentration using Mililani well water, Jan. 1992

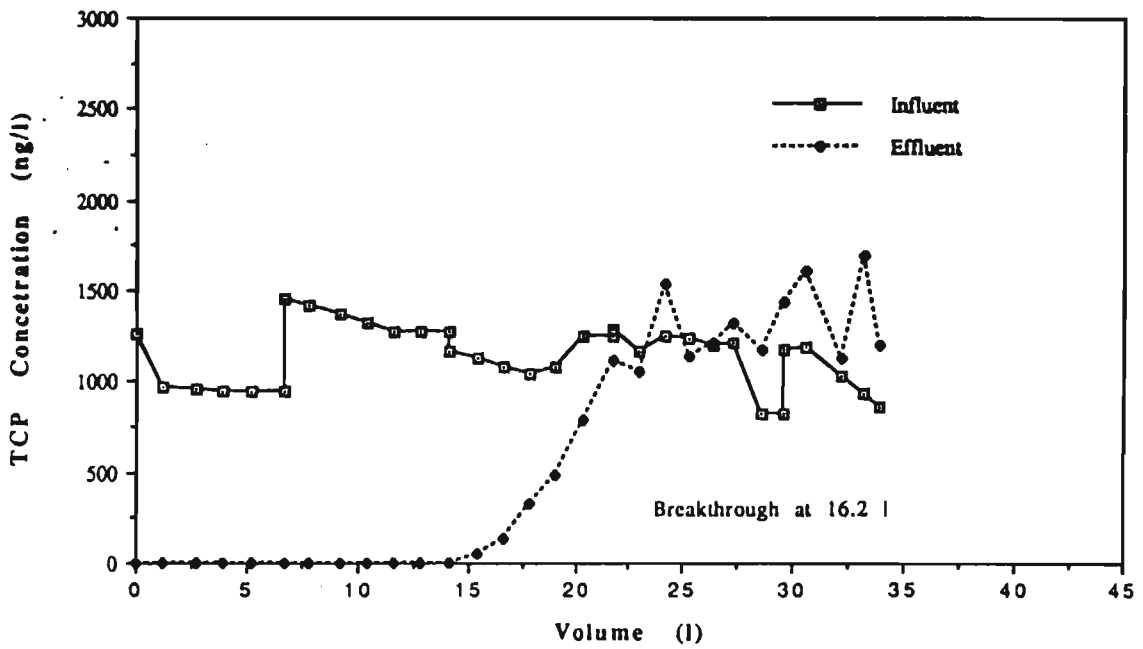


Figure 6.1. TCP concentration with volume through minicolumn

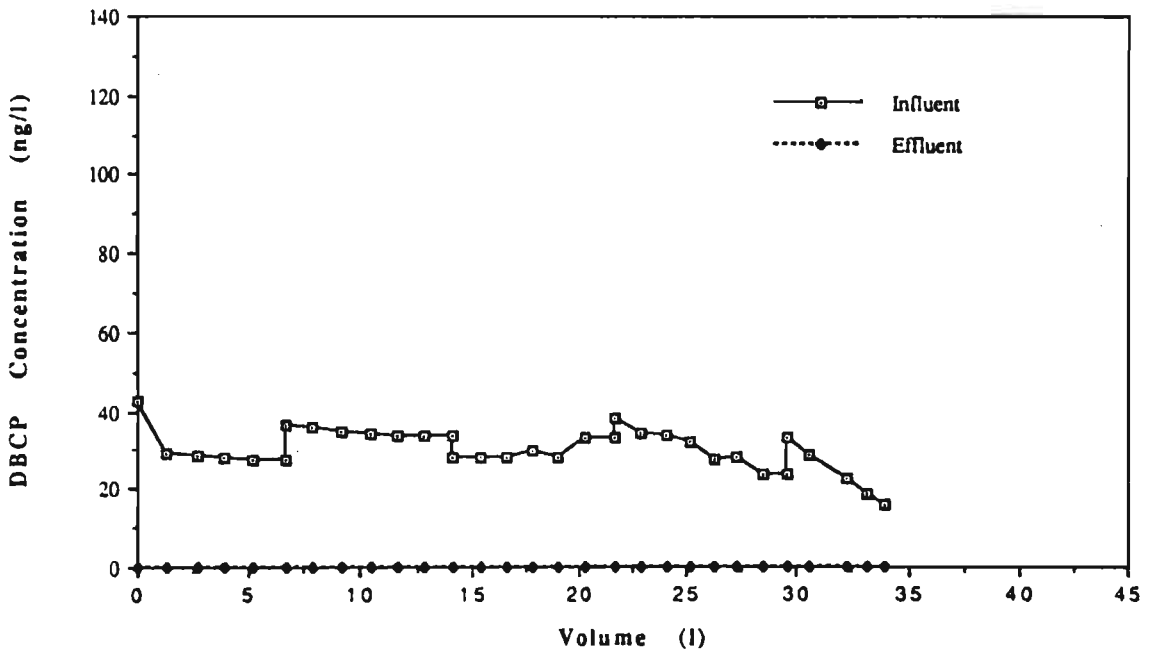


Figure 6.2. DBCP concentration with volume through minicolumn

Figure 6. Minicolumn analysis of TCP and DBCP concentration using Mililani well water, Mar. 1992

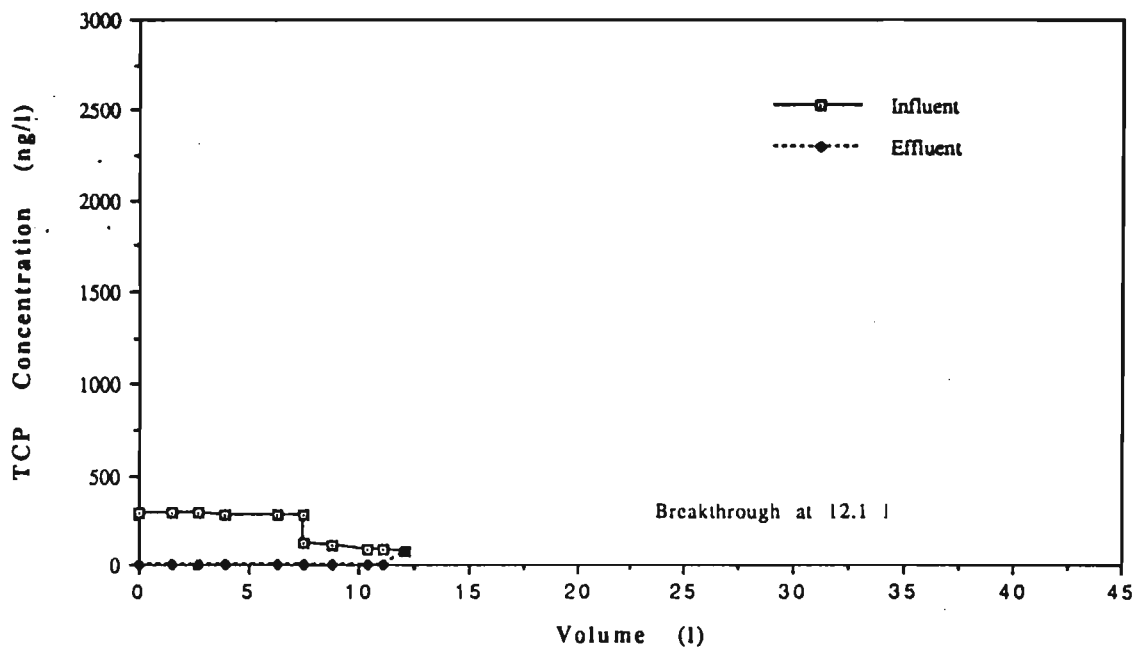


Figure 7.1. TCP concentration with volume through minicolumn

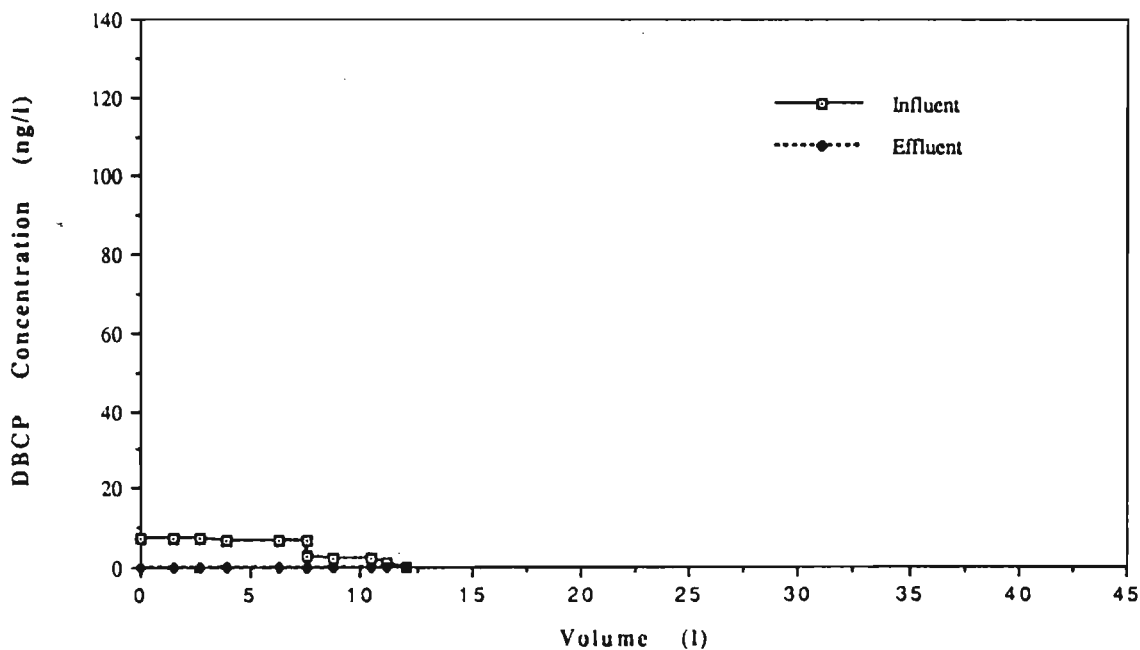


Figure 7.2. DBCP concentration with volume through minicolumn

Figure 7. Minicolumn analysis of TCP and DBCP concentration using Autoclaved Mililani well water, Jan. 1992

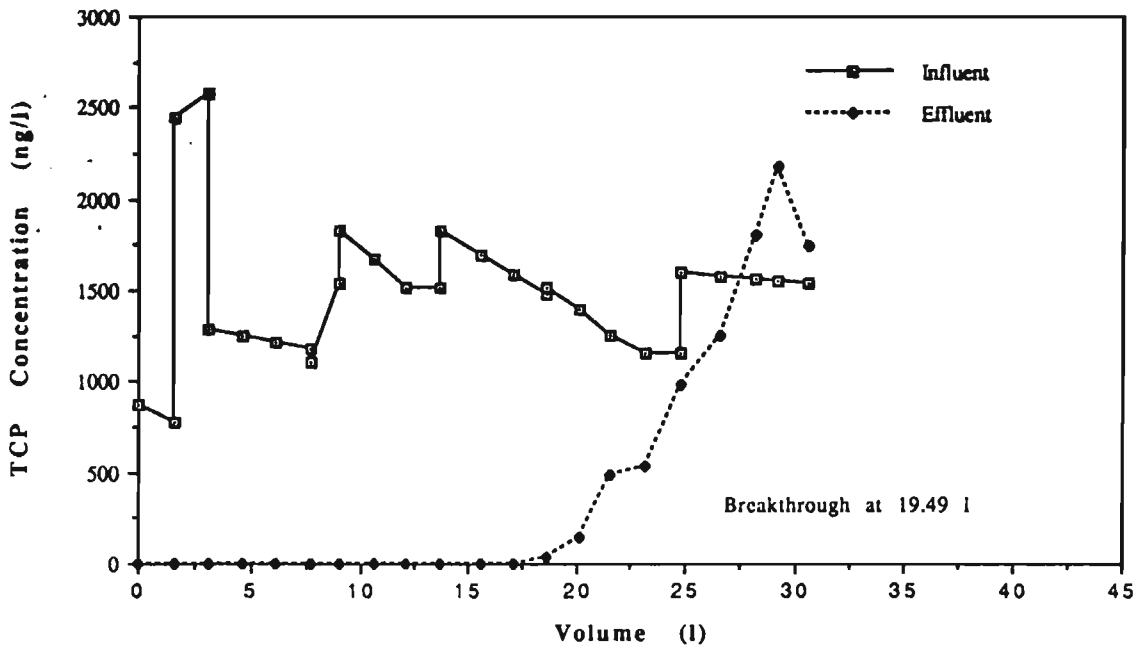


Figure 8.1. TCP concentration with volume through minicolumn

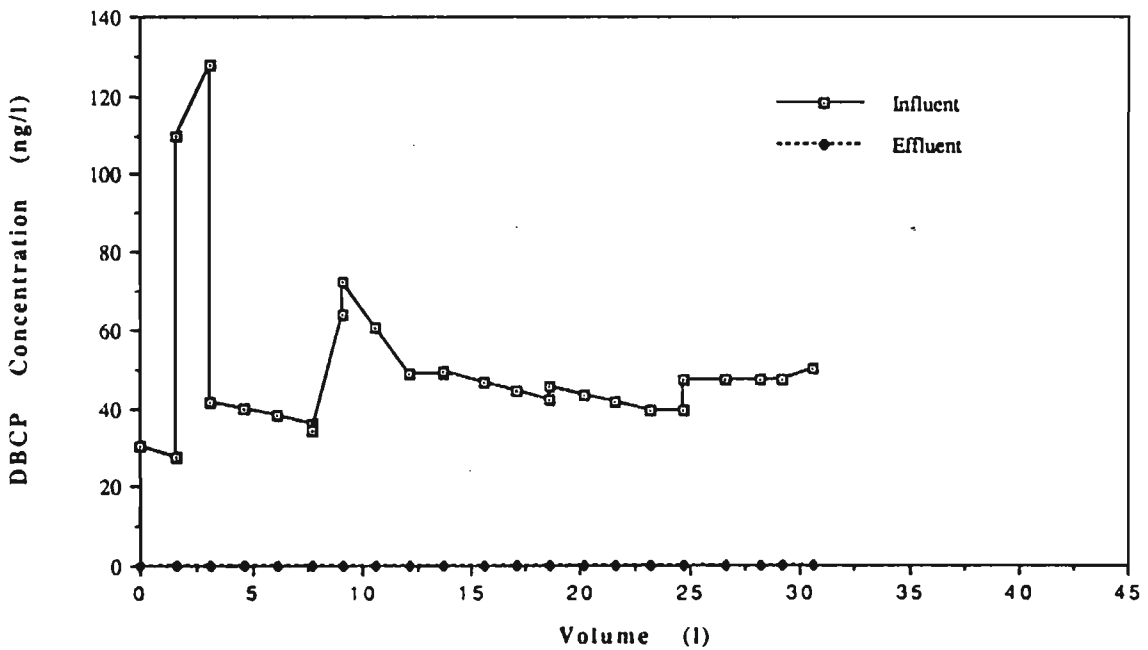


Figure 8.2. DBCP concentration with volume through minicolumn

Figure 8. Minicolumn analysis of TCP and DBCP concentration using deionized water spiked with TCP and DBCP

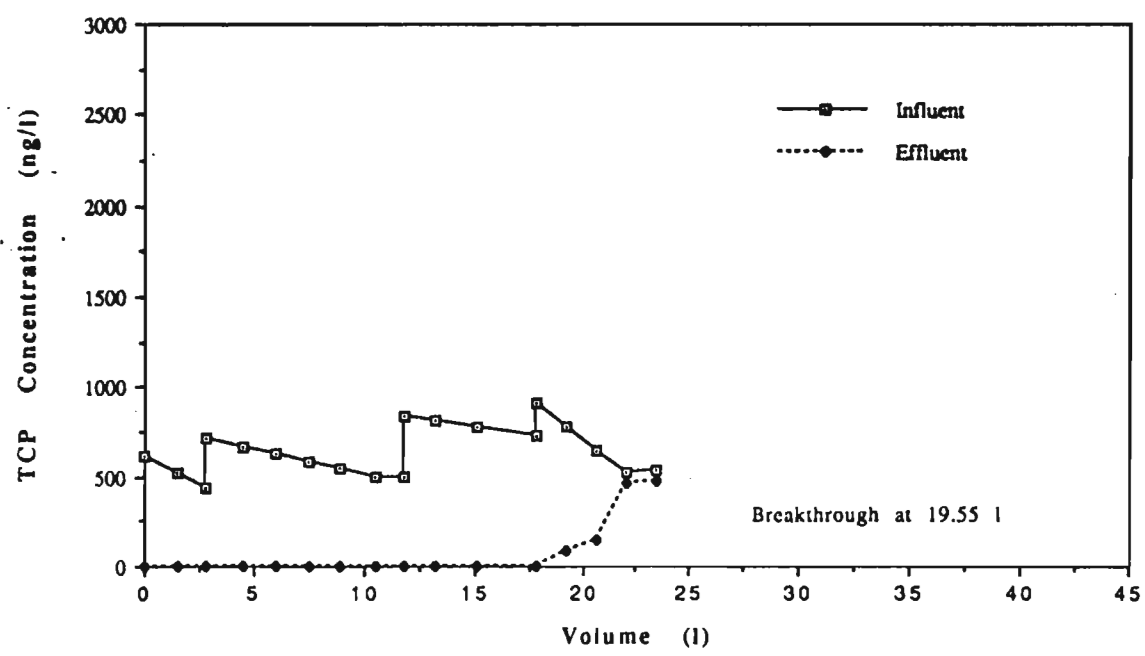


Figure 9.1. TCP concentration with volume through minicolumn

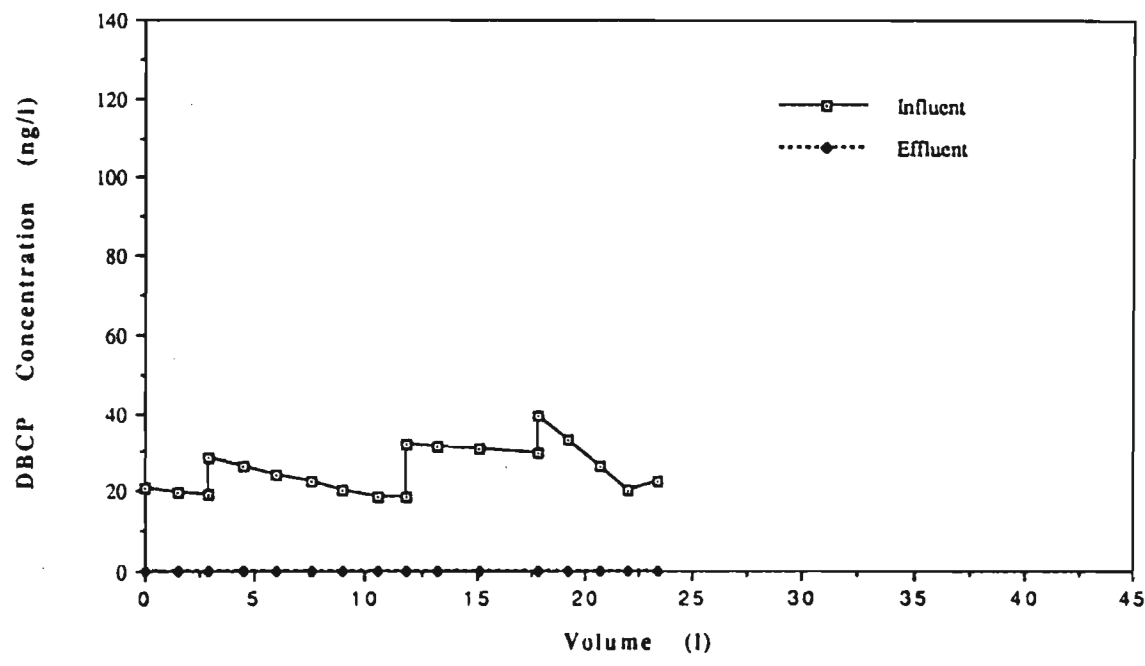


Figure 9.2. DBCP concentration with volume through minicolumn

Figure 9. Minicolumn analysis using aerated Mililani well water

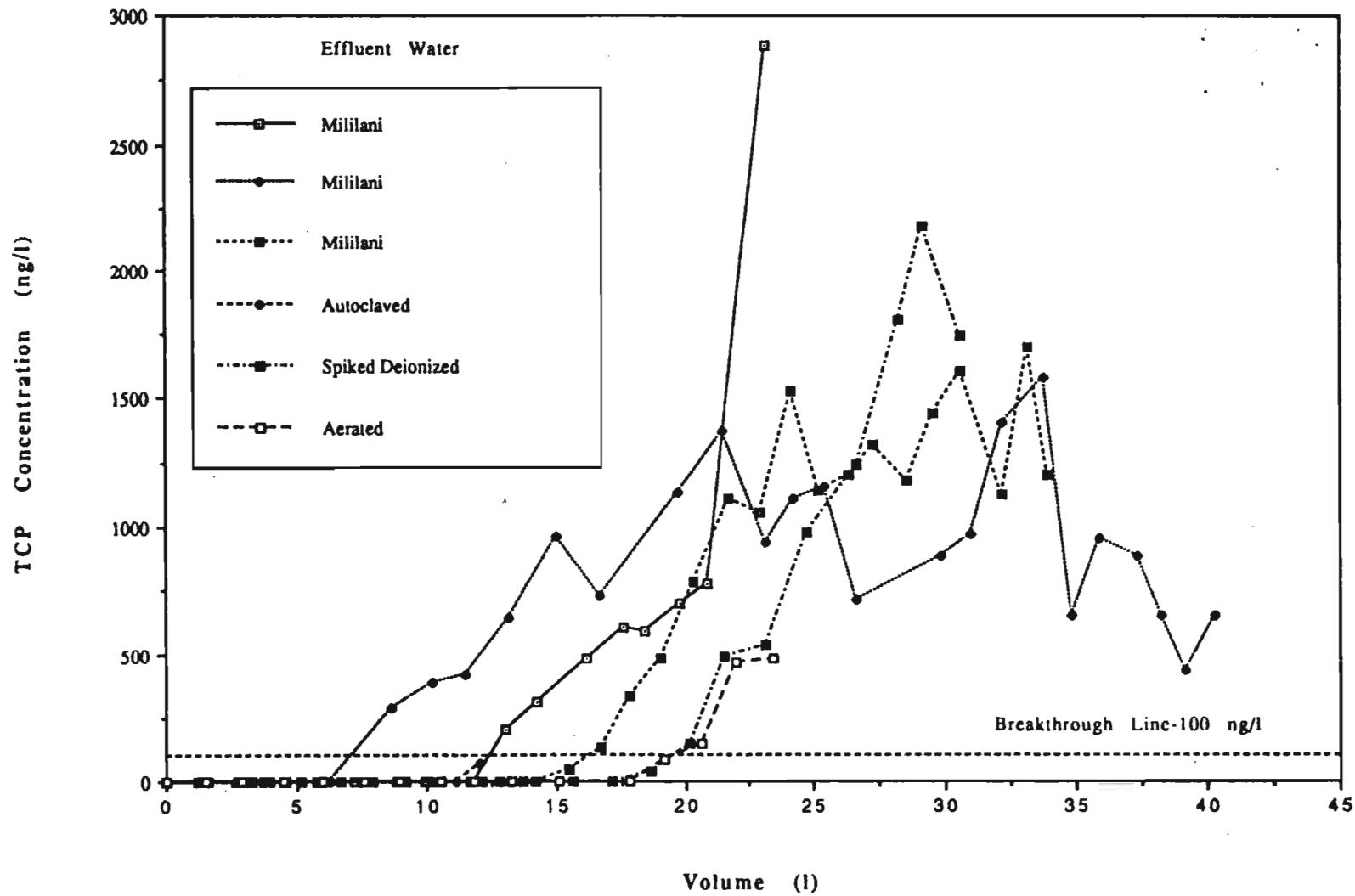


Figure 10. Effluent TCP concentration with volume from various minicolumn runs

The analyses for total carbon (TC) and nonpurgable organic carbon (NPOC) for the various minicolumn tests with specific dates or periods of time are tabulated in Appendix Table D.1. The high values of TC and NPOC, nearly 75 and 69 mg/L, respectively, in Appendix Table D.1 for the spiked deionized water were the result of methanol in which TCP and DBCP were prepared. Apparently, methanol is not adsorbed by activated carbon or purged off at pH 2 and remains in the water samples as NPOC. The TC values found in Mililani well water are equal or lower than the other sites on the island of O'ahu and NPOC concentrations are not significantly higher. The data of Appendix Table D.1 does not appear to show a correlation between increased detention times and increased TC or NPOC removals, nor does there appear to be a relationship between increased water heights and TC or NPOC removals.

A comparison of the previously discussed six minicolumn experiments and the primary pesticide constituent parameters measured at breakthrough (in this case, TCP), together with the results from the previous GMP Associates, Inc. (1984) study, are presented in Table 1. Even though the concentrations are different it is still evident that the spiked deionized water and the aerated Mililani well water resulted in a higher volume of flow through water and a lower carbon usage (lb/1000 gal); however, the third Mililani well water minicolumn experiment (March 1992) also had a low carbon usage that was essentially as low as both the spiked deionized water and aerated Mililani well water and slightly lower than the GMP Associates, Inc. value, the latter of which helped form the basis for the design of the present GAC facilities at Mililani, Kunia, and Waipahu.

The data clearly shows that the small minicolumns using pulverized GAC at high flow rates and pressure cannot be directly compared to the prototype GAC facilities already in operation, which is in agreement with the scaling-up calculations (laboratory to prototype units) presented in the final Phase I report (Oki et al. 1991). Even though approximately eight years separated the GMP (1984) minicolumn tests from the minicolumn tests reported here, and although GMP used commercial powdered activated carbon where the project minicolumns used pulverized GAC, the estimated carbon usage results were relatively in the same range. However, GMP (1984) assumed that the minicolumn method can be used to make "...relatively accurate estimates of carbon usage for a full scale plant..." Consequently, the results for GMP's prototype at the Mililani GAC treatment facility were based on their minicolumn results of carbon usage of 0.023 lb/1000 gal (GMP 1984). However, the minicolumn experiments are useful for obtaining comparative values for various operating parameters or using different sources of activated carbon, in a relatively short period of time. Nevertheless, if time permits, the use of larger columns, possibly using field size GAC should prove to be of value in attempting to simulate expected actual field operating conditions.

TABLE 1. COMPARISON OF VARIOUS MINICOLUMN EXPERIMENTS AND SELECTED CONSTITUENT PARAMETERS AT BREAKTHROUGH

INFLUENT (Date)	TCP BREAKTHROUGH		DBCP BREAKTHROUGH		CARBON USAGE (lb/1000 gal)	TCP TO BREAK- THROUGH (ng)	DBCP TO BREAK- THROUGH (ng)	TOTAL TCP (ng)	TOTAL DBCP (ng)
	Volume (L)	Days	Volume (L)	Days					
GMP-Mililani (March 1984)	18.1	*	>27.3	>20	0.023	42250	*	68250	*
Mililani (September 1991)	12.425	11	23.125	17	0.0335	19616	592	40520	1309
Mililani (January 1992)	7.042	6	23.12	15	0.0543	7692	246	38444	1364
Mililani (March 1992)	16.202	13	>33.93	>28	0.0221	18934	514	38594	1021
Mililani Autoclaved (March 1992)	12.095	13	>12.095	>13	0.0347	2565	61	2565	61
Spiked Deionized (April 1992)	19.493	13	>30.56	>21	0.0215	29429	995	45092	1486
Aerated Mililani (May 1992)	19.554	14	>23.43	>16	0.0214	13103	513	15215	598

*Not provided or determined.

CONCLUSIONS

The aerated Mililani well water, from which 40% of TCP was removed, and spiked deionized water, both appeared to increase the volumes of water passing through the minicolumns before breakthrough by nearly 40%. Furthermore, the carbon usage rates for the spiked deionized water and aerated Mililani well water decreased in comparison to untreated Mililani well water. However, one of the three Mililani water samples, the March 1992 one, gave rise to a carbon usage rate which was similar to those for spike deionized and aerated Mililani waters. More minicolumn tests will be performed to ascertain whether the March 1992 minicolumn results were reasonable or possibly anomalous.

The lowest minicolumn carbon usage values of approximately 0.022 lb/1000 gal did not simulate field operation values which ranged from 0.135 to 0.150 lb/1000 gal. However, a close correlation would not be expected considering the problems and difficulties in scaling-up minicolumn parameters to full-scale operations. In addition, the aerated Mililani well water samples did not increase the weights of TCP and DBCP that were able to be adsorbed by the pulverized GAC. Apparently, background materials (presumably organic or primarily organic materials) are competing with TCP and DBCP for the GAC adsorption sites and are occupying them. These natural background materials are not reduced by aeration, although TCP is reduced. No apparent relationship exists for TC or NPOC removal before and after breakthrough. Further minicolumn experiments will be continued to solidify the minicolumn experimental data collected to date.

REFERENCES CITED

- Department of Agriculture. 1983. Preliminary report on soil sampling for EDB on Oahu. Pesticides Branch, Division of Plant Industry, State of Hawaii, Honolulu, Hawaii.
- Dugan, G.L.; Gee, H.K.; Oshiro, K.M.; and Lau, L.S. 1984. Activated carbon adsorption of low concentration organic pesticides in water. *Tech. Rep.* No. 166, Water Resources Research Center, University of Hawaii at Manoa, Honolulu, Hawaii. 53 p.
- GMP Associates, Inc. 1984. Treatment study for ground water supply final report. Prepared for Board of Water Supply, City and County of Honolulu (August).
- Lau, L.S. 1985. Subsurface water quality: Organic chemical contamination of Oahu groundwater. Special Rep. 7.0:85, Water Resources Research Center, University of Hawaii at Manoa, Honolulu, Hawaii.

- Oki, D.S.; Dugan, G.L.; Fujioka, R.S.; Gee, H.K.; Lau, L.S.; and Takei, G.S. 1991*a*. Evaluative study to extend the effective life of the GAC used to treat Mililani well water, Phase I. Six month progress report, prepared for Board of Water Supply, City and County of Honolulu, by Water Resources Research Center, University of Hawaii at Manoa, Honolulu. 43 p.
- Oki, D.S.; Dugan, G.L.; Fujioka, R.S.; Gee, H.K.; Lau, L.S.; and Takei, G.S. 1991*b*. Evaluative study to extend the effective life of the GAC used to treat Mililani well water, Phase I. Draft final report, prepared for Board of Water Supply, City and County of Honolulu, by Water Resources Research Center, University of Hawaii at Manoa, Honolulu (October). 79 p.
- Oshiro, K.M. 1986. "Treatment of groundwater contaminated by EDB and DBCP by volatilization." Master's thesis (Civil Engineering), University of Hawaii at Manoa, Honolulu.
- U.S. Environmental Protection Agency. 1980. 1,2,3-trichloropropane health and environmental effects. No. 169 in Carcinogen Assessment Group List of Carcinogens, 30 April 1980, Carcinogen Assessment Group, Office of Health and Environmental Assessment, Office of Research and Development, Washington, D.C. 7 p.

APPENDIX CONTENTS

B.1.	CARBON PREPARATION.....	28
B.2.	PACKING THE PAC COLUMN	29
B.3.	PREPARATION OF SPIKED DEIONIZED WATER INFLUENT	30
B.4.	ANALYSIS OF GAC COLUMN INFLUENT AND EFFLUENT	31
B.5.	GAS CHROMATOGRAPHY	32

Tables

A.1.	Mechanical Aeration Experiments of Primary Pesticide Constituents	25
A.2.	Batch Aeration Experiments at Varying Air Flow Rates, Detention Times, and Column Water Heights	26
A.3.	Continuous Flow Aeration Experiments at Varying Ratios of Air to Water Flow Rates and Varied Detention Times and Water Heights	27
C.1.	Mililani Well Water Analysis by Minicolumn, September 1991	33
C.2.	Mililani Well Water Analysis by Minicolumn, January 1992	34
C.3.	Mililani Well Water Analysis by Minicolumn, March 1992	35
C.4.	Autoclaved Mililani Well Water Analysis by Minicolumn	36
C.5.	Deionized Water Spiked with TCP and DBCP Analysis by Minicolumn	37
C.6.	Aerated Mililani Well Water Analysis by Minicolumn	38
D.1.	Summary of Carbon Analysis Data from Minicolumn Experiments (Influent and Effluent)	39

APPENDIX TABLE A.1. MECHANICAL AERATION EXPERIMENTS
OF PRIMARY PESTICIDE CONSTITUENTS

SAMPLE DETENTION TIME (hr)	% REDUCTION		RELATIVE SPEED OF MIXING†
	TCP	DBCP	
0.5 C*	32.1	37	5
0.5 C	25	19.7	5
0.5 C	17.8	9.1	5
0.5	38.5	37.4	5
0.5	5
0.5	54.7	48.1	5
1	52.8	56.2	5
1	32.8	20.6	5
1	54.9	42.6	5
2 C	46.6	45.3	5
2 C	8.5	0	5
2 C	47.6	57.8	5
2 C	47.8	56.1	2
2 C	56.1	24	8
2	56.5	55.8	5
2	65.2	58.7	5
2	54.7	50.8	5
2	43.2	53	2
2	73.6	73.7	2
2	36.3	49.7	8
2	61.9	52.7	8
5 C	41.1	40.6	5
5 C	8.5	0	5
5 C	53.6	55.9	5
5	81.9	83.2	5
5	80.3	71.5	5
5	83.2	75.7	5

*Control; no stirring.

†Minimum speed setting 2 = 58 rpm.

APPENDIX TABLE A.2. BATCH AERATION EXPERIMENTS AT VARYING AIR FLOW RATES, DETENTION TIMES, AND COLUMN WATER HEIGHTS

AIR FLOW (mL/min)	DETENTION TIME (hr)	WATER HEIGHT (in.)	% REDUCTION		WATER TEMPERATURE (°C)
			TCP	DBCP	
400	0.167	19	0	0	20
400	0.5	19	52.09	42.06	20
400	1	19	24.25	0	20
400	2	19	5.59	13.36	19.75
400	0.33	13.5	17.888	0	20
400	1	13.5	43.14	29.61	20.25
400	2	13.5	40.336	6.09	20
2124	0.33	13.5	62.2	50.27	19.75
2124	1	13.5	84.54	65.57	19.875
2124	2	13.5	93.55	66.48	19
2124	5	13.5	99.93	100	20
400	0.33	13.5	0	0	21
400	1	13.5	17.3	0	21.5
400	2	13.5	61.43	39.82	20.25
400	5	13.5	76.29	25.08	21.5
2124	0.33	19	28.27	21.27	20.5
2124	1	19	78.53	58.52	20.5
2124	2	19	80.41	11.09	20.5
2124	3.5	19	99.99	99.99	20.5
2124	0.33	8	52.52	9.45	21.25
2124	1	8	87.48	54.73	21.25
2124	2	8	97.79	77.79	21
2124	1.5	8	93.95	69.91	21.25
400	0.33	8	51.62	51	20
400	1	8	50.07	30.03	20
400	2	8	77.68	63.59	20
400	2.5	8	75.28	41.19	20

APPENDIX TABLE A.3. CONTINUOUS FLOW AERATION EXPERIMENTS AT VARYING RATIOS OF AIR TO WATER FLOW RATES AND VARIED DETENTION TIMES AND WATER HEIGHTS

AIR:WATER (mL/min:mL/min)	DETENTION TIME (hr)	WATER HEIGHT (in.)	% REDUCTION		WATER TEMPERATURE (°C)
			TCP	DBCP	
106.2:1	34.75	13.5	54.8	49.07	20
20:01	34.75	13.5	55.2	62.7	19
20:01	34.75	13.5	20.12	20.88	20
106.2:1	34.75	13.5	37.47	8.06	20.75
106.2:1	34.75	13.5	50.5	38.1	20
20:01	34.75	13.5	36.25	36.31	19.75
0	34.75	13.5	6.61	13.99	19
20:01	10.3	8	37.2	50.4	19.5
106.2:1	10.3	8	23.3	0	19.5
106.2:1	65.21	19	53.63	23.74	19.75
20:01	65.21	19	8.71	0	19.75
106:1	34.75	13.5	72.05	65.15	21.5
106:1	34.75	13.5	65.88	63.67	21.5
177:1	34.32	8	79.41	73.6	22
33.3:1	34.32	8	55.93	57.12	22
75.9:1	34.93	19	42.58	39.5	21
14:01	34.32	19	8.8	20.13	21.5
75.9:1	34.93	19	43.77	32.89	21.5
75.9:1	34.93	19	68.6	20.05	20.5
75.9:1	34.93	19	35.8	13.49	21
43.3:1	34.67	33	26.5	15.4	20.25
8:01	34.67	33	54.71	54.83	20.25
75.9:1	34.93	13.5	56.21	42.51	20
75.9:1	34.93	19	39.93	26.3	19.5
106.2:1	84.94	33	60.29	47.65	19.5
20:01	84.94	33	48.08	46.14	19.5
75.9:1	34.93	19	52.86	37.57	21

APPENDIX B.1. CARBON PREPARATION

1. The granular activated carbon (GAC) was obtained from bags stored for future replacement at the Mililani Treatment Plant site. Only the most recent sampling information can be provided. The Calgon GAC Filtrasorb 400 (F-400), lot #2119-N, was collected on 24 February 1992, stored in an opaque glass container, and placed in a desiccator in the Water Resources Research Center's chemistry laboratory.
2. The GAC was placed in a blender with the grinding attachment set on low speed for approximately 5 min. The carbon was then shaken through an ASTM sieve size 200 and retained on size 325 as pulverized granular activated carbon (PGAC). Deionized water was poured through the sieves to eliminate fine-sized material. The oversized carbon was returned to the grinder for further crushing until the required quantity was obtained.
3. The 200 × 325 size carbon was placed in a 500-mL beaker, filled with deionized water, and stirred. The particles were allowed to settle for 15 min. Then the supernatant was drained off in a procedure that was repeated until no particles could be removed from the solution.
4. The beaker was placed in a 105°C oven overnight and covered with aluminum foil perforated with small holes in the top for evaporation. The washing procedure outlined in step 3 was repeated. The beaker was again placed in the 105°C oven for several hours until dry, after which the beaker was placed in a 180°C oven for 2 hr and slowly cooled in a desiccator.
5. This carbon sample was transferred to an opaque 50 mL glass bottle with a teflon-lined cap, and then stored in a desiccator kept in darkness.

APPENDIX B.2. PACKING THE PAC COLUMN

The column used in the experiment was a stainless steel column (0 = 2 mm ID × 70 mm ht) which was previously rinsed with acetone, dried in an oven at 105°C, and cooled to room temperature. The mass of this empty steel column was measured. An approximate amount of the packing materials—glass wool, glass beads (sz. 11), and pulverized GAC (200 × 325 mesh)—were also measured in separate containers before packing. A sample amount of the packing materials and the order in which these were placed in the column are shown in Figure 2. The glass wool at the bottom was tightly packed by pushing the end of the steel rod against it at the bottom of the column. The glass beads being breakable were packed by evenly tapping the column against the table top. A layer of glass wool at the top of the beads was gently packed to prevent the glass beads from breaking into smaller pieces. Then, the pulverized GAC was added in fractions tapping the column evenly at a time until the desired bed height was attained. The small piece of glass wool at the top of the carbon was just loosely packed. The actual mass of each of the materials packed in the column was measured and their corresponding height in the column were determined.

APPENDIX B.3. PREPARATION OF SPIKED DEIONIZED WATER INFLUENT

The influent was 18 mega-ohm deionized water spiked with a known concentration and volume of TCP and DBCP. The TCP and DBCP spiking solutions were first prepared by diluting 1 mL of each of the stock solutions (TCP 3.56 mg/mL, DBCP 92 µg/mL) in individual 100-mL volumetric flask with methanol. For an 8-L influent stock, an aliquot of the spiking solution (0.8 mL TCP, 1.0 mL DBCP) was transferred into a 1-liter volumetric flask and diluted to volume with DI water. The solution was further diluted to 8 liters in a 10-L nalgene jar and was mixed well by shaking for about 3 min. The TCP and DBCP concentrations were measured on the time the influent was prepared and analyzed again before the influent was consumed. This 8-L influent which lasted for four nights had an initial concentration of 1,500 ng/L TCP and 45 ng/L DBCP by GC analysis. The influent TCP and DBCP concentrations were kept at a range of 1,200 to 2,500 ng/L TCP and 30 to 90 ng/L DBCP similar to the concentration levels of these target compounds in the Mililani influent.

APPENDIX B.4. ANALYSIS OF GAC COLUMN INFLUENT AND EFFLUENT

A. Carbon Analysis

The column influent and effluent were analyzed for TOC using a Shimadzu model TOC-5000 Total Carbon Analyzer.

One hundred ml of the influent and effluent were separately collected in 125-ml erlenmeyer flasks which were thoroughly rinsed first with the water to be analyzed. For good results, the effluent to be analyzed must be freshly collected from the column to avoid contamination from exposure to the air during the collection. The TC sample was analyzed first followed by analysis for the TOC or, specifically, the NPOC analysis of the sample was undertaken. In the NPOC analysis the carbon dioxide from the carbonate and the bicarbonate ions were removed first by acidifying the solution with 2 M HCL to pH 2 and then purging it with ultra-pure air for at least 15 min. The sample was analyzed for NPOC at least once before and after TCP breakthrough in the column.

B. Pesticide Analysis of Column Influent and Effluent

The concentrations of target compounds, TCP and DBCP of the influent and effluent, were analyzed on the day the influent was prepared and were periodically checked for changes in concentration. At each water change, the new influent water concentration was also determined. The effluent was likewise monitored regularly to detect the breakthrough of TCP, and possibly DBCP, to determine whether the column had already reached the saturation or desorption point.

CODISTILLATION. Six hundred mL of the influent of effluent were placed in a 1-liter round bottom boiling flask with 24/40 ground joint. Ten ml of hexane and few grains of boiling chips were added to the flask. The boiling flask was attached to a Barret distilling receiver, which was connected to an Allihn condenser. The solution was heated with a heating mantle to distill over the hexane and associated desorbed organic compounds. The recovered hexane was dried over anhydrous sodium sulfate. Five μ l of the extract were injected into the GC with an electron capture detector (ECD) for pesticide analysis.

APPENDIX B.5. GAS CHROMATOGRAPHY

The column effluent and influent were analyzed for pesticides using a Hewlett Packard model 5700A gas chromatograph equipped with a nickel 63 electron capture detector. One J & W Scientific DB-624 megabore capillary column (0 = 0.53 mm ID × 75 m) was installed in the gas chromatograph. Injector and detector temperatures were set respectively at 250°C and 300°C. Oven temperature was set at 135°C for TCP and DBCP analysis. Carrier gas is 95% argon and 5% methane maintained at a flow rate of 35 mL/min. at 4.1 bar (60 psi). Chromatograms were plotted on a Hewlett Packard model 3390A integrator.

APPENDIX TABLE C.1. MILILANI WELL WATER ANALYSIS BY MINICOLUMN, SEPTEMBER 1991

Data reduction for column packed 09/05/91
 Total C = 50.0 mg, 200 × 325 C, 2.5 cm bed ht
 MILILANI INFLUENT

DATE	VOLUME (mL)	TCP (ng/L)		DBCP (ng/L)	
		Infl.	Effl.	Infl.	Effl.
09/06/91	0	1116	--	52	--
09/07/91	1530	<i>1189</i>	0	44	0
09/09/91	1710	1271	0	36	0
09/09/91	0	<i>1866</i>	--	56	--
09/09/91	490	<i>1866</i>	0	56	0
09/10/91	2030	1866	0	56	0
09/10/91	0	1552	--	43	--
09/11/91	1425	<i>1771</i>	0	51	0
09/12/91	1720	2035	0	61	0
09/13/91	1070	2199	0	67	0
09/13/91	0	1371	--	33	--
09/13/91	270	<i>1352</i>	0	33	0
09/17/91	1570	<i>1244</i>	0	31	0
09/18/91	1240	1159	203	29	0
09/18/91	0	2583	--	99	--
09/19/91	1190	<i>2447</i>	308	92	0
09/20/91	1920	<i>2228</i>	478	81	0
09/21/91	1430	<i>2065</i>	604	73	0
09/21/91	810	1973	588	68	0
09/22/91	1430	<i>1654</i>	697	54	0
09/23/91	1000	1431	774	44	0
09/23/91	0	1672	--	50	--
09/24/91	2290	<i>1672</i>	2886	50	70

Total volume of water to breakthrough = 12 400 mL

TCP to breakthrough = 19 616 ng

DBCP to breakthrough = 592 ng

Total C usage = 0.0335 lb/1000 gal

NOTE: Calculated values in *italics*; "not measured" indicated by dashes (--).

APPENDIX TABLE C.2. MILILANI WELL WATER ANALYSIS BY MINICOLUMN, JANUARY 1992

Data reduction for column packed 01/23/92

Total C = 50.1 mg, 200 × 325 C, 1.9 cm bed ht

MILILANI INFLUENT

DATE	VOLUME (mL)	TCP (ng/L)		DBCP (ng/L)	
		Infl.	Effl.	Infl.	Effl.
01/27/92	0	1529	0	53	0
01/28/92	1340	<i>1342</i>	0	45	0
01/29/92	1475	1136	0	36	0
01/30/92	1726	982	0	30	0
01/31/92	1650	834	0	25	0
02/01/92	--	--	--	--	--
02/02/92	2459	613.5	289	17	0
02/02/92	0	1096	--	33	--
02/03/92	1570	1539	390	58	0
02/04/92	1332	981	419	33	0
02/05/92	1645	963	646	33	0
02/06/92	1793	199	959	7	0
02/06/92	0	1410	--	45	--
02/07/92	1680	1649	729	73	0
02/08/92	--	--	--	--	--
02/09/92	3050	<i>1366</i>	<i>1132</i>	55	0
02/10/92	1725	1274	1370	52	0
02/11/92	1675	<i>1103</i>	938	44	2.7
02/12/92	1102	991	1110	39	3.3
02/13/92	1200	869	1155	33	3.6
02/13/92	0	1508	--	66	--
02/14/92	1200	738	712	34	1.9
02/15/92	--	--	--	--	--
02/16/92	3185	<i>1200</i>	880	35	3.7
02/17/92	1133	1839	967	37	4.7
02/18/92	1230	<i>1000</i>	1406	35	8.1
02/19/92	1593	<i>1000</i>	1582	30	14
02/20/92	1044	--	652	--	4.3
02/21/92	1095	0	954	0	10.2
02/22/92	1445	--	880	--	9.1
02/23/92	910	--	654	--	6.3
02/24/92	935	--	435	--	5.4
02/25/92	1130	--	648	--	7.3

Total volume of water to breakthrough = 7 042 mL

TCP to breakthrough = 7 692 ng

DBCP to breakthrough = 246 ng

Total C usage = 0.0543 lb/1000 gal

Begin tap water influent

NOTE: Calculated values in *italics*; "not measured" indicated by dashes (--).

APPENDIX TABLE C.3. MILILANI WELL WATER ANALYSIS BY MINICOLUMN, MARCH 1992

Data reduction for column packed 03/08/92

Total C = 50.2 mg, 200 × 325 C, 3.3 cm bed ht

MILILANI INFLUENT

DATE	VOLUME (mL)	TCP (ng/L)		DBCP (ng/L)	
		Infl.	Effl.	Infl.	Effl.
03/09/92	0	1255.6	--	42.8	--
03/10/92	1245	966.2	0	29.1	0
03/11/92	1470	<i>956.04</i>	0	<i>28.54</i>	0
03/12/92	1200	<i>947.74</i>	0	<i>28.08</i>	0
03/13/92	1250	939.1	0	27.6	0
03/14/92	1500	<i>939.1</i>	0	27.6	--
03/14/92	0	1452.6	--	36.4	--
03/15/92	1200	<i>1410.1</i>	0	35.7	0
03/16/92	1320	<i>1363.4</i>	0	<i>34.94</i>	0
03/17/92	1220	<i>1320.2</i>	0	<i>34.23</i>	0
03/18/92	1255	1275.7	0	33.5	0
03/19/92	1180	<i>1275.7</i>	0	33.5	0
03/20/92	1320	<i>1275.7</i>	0	33.5	0
03/20/92	0	1161.4	--	27.8	--
03/21/92	1310	<i>1119.4</i>	44.3	27.8	0
03/22/92	1200	<i>1080.9</i>	135.6	27.8	0
03/23/92	1155	1043.8	332	29.9	0
03/24/92	1240	1071.8	481.2	28.2	0
03/25/92	1285	1250.4	781.1	33.1	0
03/26/92	1380	<i>1250.4</i>	1107.1	<i>33.1</i>	0
03/26/92	0	1284.2	--	38.3	--
03/27/92	1180	1164.3	1050.6	34	0
03/28/92	1200	<i>1250.2</i>	1531	<i>33.82</i>	0
03/29/92	1100	<i>1234.5</i>	1137	<i>31.74</i>	0
03/30/92	1100	<i>1202</i>	1205.4	<i>27.45</i>	0
03/31/92	940	<i>1205.4</i>	1318.4	27.9	0
04/01/92	1270	825.7	1177.9	23.5	0
04/02/92	1000	825.7	1442.1	23.5	0
04/02/92	0	1173.8	--	32.8	--
04/03/92	1073	1179.8	1603	28.8	0
04/04/92	1615	<i>1025</i>	1120.6	<i>22.37</i>	0
04/05/92	950	<i>933.98</i>	1698.3	<i>18.59</i>	0
04/06/92	750	862.1	1201.2	15.6	0

Total volume of water to breakthrough = 16 202 mL

TCP to breakthrough = 18 934 ng

DBCP to breakthrough = 514 ng

Total C usage = 0.0221 lb/1000 gal

NOTE: Calculated values in *italics*; "not measured" indicated by dashes (--).

APPENDIX TABLE C.4. AUTOCLAVED MILILANI WELL WATER ANALYSIS BY MINICOLUMN

Data reduction for column packed 03/19/92 Total C = 50.3 mg, 200 × 325 C, 2.4 cm bed ht MILILANI INFLUENT AUTOCLAVED FOR 50 MIN AT 110°C					
DATE	VOLUME (mL)	TCP (ng/L)		DBCP (ng/L)	
		Infl.	Effl.	Infl.	Effl.
03/20/92	0	288.1	--	7.34	--
03/21/92	1490	<i>286.13</i>	--	<i>7.21</i>	--
03/22/92	1200	<i>284.54</i>	--	<i>7.11</i>	--
03/23/92	1210	<i>282.94</i>	0	7	0
03/24/92	--	--	--	7	--
03/25/92	2370	279.8	0	6.8	0
03/26/92	1260	279.8	--	6.8	--
03/26/92	0	116.1	--	3	--
03/27/92	1240	<i>104.77</i>	--	2.5	--
03/29/92	1645	<i>89.75</i>	--	2	--
03/30/92	--	--	--	--	--
03/31/92	--	--	--	--	--
04/01/92	720	<i>83.17</i>	NQ	1	0
04/02/92	960	74.4	70.3	NQ	0

Total volume of water to breakthrough = 12 095 mL

TCP to breakthrough = 2 565 ng

DBCP to breakthrough = 61 ng

Total C usage = 0.0347 lb/1000 gal

NOTE: Calculated values in *italics*; "not measured" indicated by dashes (--); NQ = not quantifiable.

APPENDIX TABLE C.5. DEIONIZED WATER SPIKED WITH TCP AND DBCP ANALYSIS BY MINICOLUMN

Data reduction for column packed 04/07/92

Total C = 50.3 mg, 200 × 325 C, 2.7 cm bed ht

DEIONIZED WATER (18 MEG-OHM) SPIKED WITH TCP AND DBCP

DATE	VOLUME (mL)	TCP (ng/L)		DBCP (ng/L)		
		Infl.	Effl.	Infl.	Effl.	
04/08/92	0	875.3	0	30.1	0	Total volume of water to breakthrough = 19 493 mL TCP to breakthrough = 29 429 ng DBCP to breakthrough = 995 ng Total C usage = 0.0215 lb/1000 gal
04/09/92	1570	772.2	0	27.5	0	
04/09/92	0	2448.4	0	109.8	0	
04/10/92	1500	1582.4	0	127.7	0	
04/10/92	0	1281.9	0	41.6	0	
04/11/92	1500	1246	0	39.8	0	
04/12/92	1500	1210.2	0	38	0	
04/13/92	1600	1171.9	0	36.1	0	
04/13/92	0	1099.4	0	34.2	0	
04/14/92	1350	1533.1	0	63.6	0	
04/14/92	0	1825.2	0	72.1	0	
04/15/92	1560	1666.2	0	60.3	0	
04/16/92	1540	1509.2	0	48.6	0	
04/17/92	1580	1509.2	0	48.6	0	
04/17/92	0	1824.8	0	49.1	0	
04/18/92	1930	1688.1	0	46.4	0	
04/19/92	1520	1580.5	0	44.2	0	
04/20/92	1500	1474.3	38.8	42.1	0	
04/20/92	0	1512.6	--	45.1	--	
04/21/92	1520	1389.4	149.1	43.1	0	
04/22/92	1390	1246.8	484.6	41.2	0	
04/23/92	1600	1147.2	536.6	39.1	0	
04/24/92	1570	1147.2	978.6	39.1	0	
04/24/92	0	1592.3	--	47.2	--	
04/25/92	1870	1575.8	1243.1	47.2	0	
04/26/92	1595	1561.8	1807.7	47.2	0	
04/27/92	970	1553.2	2180.9	47.2	0	
04/28/92	1395	1540.9	1747.2	49.6	0	

NOTE: Calculated values in *italics*; "not measured" indicated by dashes (--).

APPENDIX TABLE C.6. AERATED MILILANI WELL WATER ANALYSIS BY MINICOLUMN

Data reduction for column packed 04/28/92

Total C = 50.3 mg, 200 × 325 C, 2.6 cm bed ht

AERATED MILILANI INFLUENT

DATE	VOLUME (mL)	TCP (ng/L)		DBCP (ng/L)		
		Infl.	Effl.	Infl.	Effl.	
04/29/92	0	614.5	--	20.45	--	Total volume of water to breakthrough = 19 554 mL TCP to breakthrough = 13 103 ng DBCP to breakthrough = 513 ng Total C usage = 0.0214 lb/1000 gal
04/30/92	1500	<i>521.39</i>	0	<i>19.79</i>	0	
05/01/92	1350	437.6	0	19.2	0	
05/01/92	0	713.1	0	28.3	--	
05/02/92	1655	<i>666.48</i>	0	<i>26.16</i>	0	
05/03/92	1500	<i>624.22</i>	0	<i>24.22</i>	0	
05/04/92	1550	<i>580.56</i>	0	<i>22.22</i>	0	
05/05/92	1410	<i>540.84</i>	0	<i>20.4</i>	0	
05/06/92	1549	497.2	0	18.4	0	
05/07/92	1300	497.2	0	<i>18.4</i>	0	
05/07/92	0	834.8	--	31.7	--	
05/08/92	1450	<i>809.77</i>	0	<i>31.2</i>	0	
05/09/92	1831	<i>778.17</i>	0	<i>30.6</i>	0	
05/10/92	0	<i>778.17</i>	--	<i>30.6</i>	--	
05/11/92	2750	730.7	NQ	29.7	0	
05/11/92	0	902.5	--	39.3	--	
05/12/92	1380	<i>776.24</i>	85.6	<i>32.92</i>	0	
05/13/92	1450	<i>643.58</i>	149.1	<i>26.21</i>	0	
05/14/92	1365	<i>518.7</i>	461.9	<i>19.9</i>	0	
05/15/92	1390	531.2	477.2	22.3	0	

NOTE: Calculated values in *italics*; "not measured" indicated by dashes (--); NQ = not quantifiable.

APPENDIX TABLE D.1. SUMMARY OF CARBON ANALYSIS DATA FROM MINICOLUMN EXPERIMENTS (INFLUENT AND EFFLUENT)

Sample	Date Collected/Analyzed	TC (mg/L)	NPOC (mg/L)
A. Column Influent: Mililani I GAC Influent			
Influent	03-25-92	10.563	0.5553
Effluent	03-25-92	11.063	0.7132
Influent	04-02-92	11.172	0.5556
Effluent (kept in refrigerator)	03-29-92/04-02-92	overscale	overscale
Effluent (freshly collected)	04-02-92	13.574	3.0979
Influent	04-03-92	11.546	1.6957
Effluent	04-03-92	13.210	2.9097
B. Column Influent: Deionized Water Spiked with TCP and DBCP in Methanol			
Influent	04-15-92	73.831	68.798
Effluent (freshly collected)	04-15-92	74.818	66.686
Effluent (overnight collection)	04-15-92	70.427	67.315
Effluent (kept in refrigerator)	04-14-92/04-15-92	62.680	58.442
DI Water	04-10-92/04-15-92	0.342	0.251
DI Water + 1 drop Methanol	04-15-92	41.017	38.962
Influent	04-20-92/04-21-92	64.291	64.291
Effluent	04-21-92	63.929	63.929
C. Column Influent: Aerated Mililani I GAC Influent			
Influent	04-28-92/04-30-92	10.624	0.4525
Effluent (overnight collection)	04-30-92	10.512	0.5328
Effluent (freshly collected)	04-30-92	10.750	0.4271
Mililani I GAC Influent	04-30-92	11.460	1.0088
Influent	04-28-92/05-01-92	10.411	0.6377
Effluent (freshly collected)	05-01-92	10.513	0.4176
Influent (new 05-01-92)	05-01-92/05-04-92	10.697	0.6537
Influent (freshly collected)	05-04-92	10.691	0.3821
Influent	05-01-92/05-06-92	10.556	0.3658
Influent (repeated)	05-01-92/05-06-92	10.862	
Effluent	05-06-92	10.680	0.3791
Influent	05-07-92	10.586	0.4196
Effluent (overnight collection)	05-07-92	11.283	1.0863
Effluent (freshly collected)	05-07-92	10.431	0.3090
Influent	05-06-92/05-11-92	10.518	
Influent	05-06-92/05-11-92	10.518	0.6161
Effluent (2 nights collection)	05-11-92	10.406	0.3090
Effluent (freshly collected)	05-11-92	10.437	0.4271
Influent (new 05-11-92)	05-08-92/05-11-92	10.737	0.5995
Influent	05-08-92/05-13-92	10.434	0.6668
Effluent (overnight collection)	05-13-92	11.953	1.8883
Effluent (freshly collected)	05-13-92	10.354	0.3085
Influent	05-14-92	10.429	0.3298
Effluent (overnight collection)	05-14-92	10.885	0.5384
Effluent (freshly collected)	05-14-92	10.327	0.7174

