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USATHAMA

U.S. Army Toxic and Hazardous Materials Agency

Task Order 9 Arsenic Contaminated Groundwater Treatment Pilot Study at the Sharpe Army Depot (SHAD) Lathrop, California

Contract Number DAAA15-88-D-0010
Report Number CETHA-TS-CR-90184

December 1990

Prepared for:
U.S. ARMY TOXIC AND HAZARDOUS
MATERIALS AGENCY
Aberdeen Proving Ground, Maryland 21010-5401

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USATHAMA TASK ORDER 9
ARSENIC CONTAMINATED GROUNDWATER TREATMENT PILOT STUDY

SHARPE ARMY DEPOT
LATHROP, CALIFORNIA

Contract Number DAAA15-88-D-0010

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UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Distribution Unlimited; Approved for Public Release

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
2281-08-09

5. MONITORING ORGANIZATION REPORT NUMBER(S)
CETHA-TS-CR-90184

6a. NAME OF PERFORMING ORGANIZATION
Roy F. Weston, Inc.

6b. OFFICE SYMBOL *(If applicable)*

7a. NAME OF MONITORING ORGANIZATION
U.S. Army Toxic & Hazardous Materials Agency

6c. ADDRESS *(City, State, and ZIP Code)*
1 Weston Way
West Chester, Pennsylvania 19380

7b. ADDRESS *(City, State, and ZIP Code)*
ATTN: CETHA-TS-D
Aberdeen Proving Ground (Edgewood Area)
Maryland 21010-5401

8a. NAME OF FUNDING / SPONSORING ORGANIZATION
USATHAMA

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
DAAA15-88-D-0010 Task No. 9

8c. ADDRESS *(City, State, and ZIP Code)*
ATTN: CETHA-TS-D
Aberdeen Proving Ground (Edgewood Area)
Maryland 21010-5401

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
			T.O. 9

11. TITLE *(Include Security Classification)*
Arsenic Contaminated Groundwater Treatment Pilot Study, Sharpe Army Depot, Lathrop, California

12. PERSONAL AUTHOR(S)
William L. Lowe, Walter J. Wujcik, and Peter J. Marks

13a. TYPE OF REPORT
Final

13b. TIME COVERED
FROM Aug. 1989 TO Dec. 1990

14. DATE OF REPORT *(Year, Month, Day)*
1990 December

15. PAGE COUNT
120 + Appendices

16. SUPPLEMENTARY NOTATION
Wayne Sisk was the USATHAMA Project Officer

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Activated Alumina (AA)
Granular Activated Carbon (GAC)
Ion Exchange (IE)
Trichloroethylene (TCE)
Arsenic
Pilot Plant
Air Stripper
Arsenic Speciation
Isotherms

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Groundwater treatment for the removal of contaminants may be needed at a number of U.S. Army installations, including Army depots. Treatability testing of potentially applicable technologies may be needed to facilitate design and operation of treatment systems. The study described here is a treatability test for the removal of arsenic from groundwater. The goal of the study was to evaluate the effectiveness of ion exchange (IE), granular activated carbon (GAC), and activated alumina (AA) for the removal of arsenic from groundwater.

Laboratory IE, GAC, and AA isotherms were conducted to select the two best performing carbon and resin types and the operating pH for the carbon and alumina media for further testing. Pilot scale continuous flow column tests were conducted at Sharpe Army Depot in Lathrop, California, using the two carbons (Calgon Filtrasorb 400 and Hydrodarco 3000) and the two resins (Amberlite IRA 402 and Ionac A-641) selected during the isotherm studies. Alcoa F-1 AA was also used during the pilot scale continuous flow column tests. The carbon and AA were tested at an adjusted pH of 4.0 and the resin was tested at natural pH. A pilot scale, conventional packed column air stripper was used to remove volatile organics (primarily trichloroethene) from the groundwater prior to treatment by the pilot scale columns. The data from the laboratory and pilot study were analysed and a report was prepared to present the results and conclusions. The study concluded that arsenic can be removed to the EPA MCL for arsenic of 50 ug/l and that AA provided significantly longer runs (as measured by bed volumes of water treated) than either GAC or IE resins.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL
Wayne Sisk

22b. TELEPHONE *(Include Area Code)*
301-671-2054

22c. OFFICE SYMBOL
CETHA-TS-D

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

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GLOSSARY

AA	Activated alumina
ARAR	Applicable or relevant and appropriate requirements
AWQC	Ambient water quality criteria
CONUS	Continental United States
CRWQCB	California Regional Water Quality Control Board
EBCT	Empty bed contact time
EPA	U.S. Environmental Protection Agency
ETL	Environmental Technology Laboratory
GAC	Granular activated carbon
gpm	Gallons per minute
IE	Ion exchange
LOEL	Lowest observed effect level
MCL	Maximum contaminant level
NPDES	National Pollutant Discharge Elimination System
OHM	O.H. Materials Corporation
SDWA	Safe Drinking Water Act
SHAD	Sharpe Army Depot
TCE	Trichloroethylene
TSD	Technical Support Division
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
WESTON	Roy F. Weston, Inc.

EXECUTIVE SUMMARY

Sharpe Army Depot (SHAD), located in Lathrop, California, is an Area Oriented Distribution depot providing supply support to the western continental United States (CONUS), Alaska, and Pacific Army Commands.

SHAD is presently operating a treatment system for the removal of trichloroethylene (TCE) from groundwater. The treated effluent is discharged to the South San Joaquin Irrigation District drainage canal. The groundwater at SHAD also contains arsenic, possibly of natural origin. There may be a need to remove arsenic from the groundwater prior to its discharge to the irrigation canal.

The goal of this study was to evaluate and confirm the ability to remove arsenic from the groundwater at SHAD, using ion exchange, activated carbon, and/or activated alumina treatment processes. This objective was addressed through a combination of laboratory isotherm testing and continuous flow pilot studies. The effluent criterion for the evaluation of these technologies was 50 μg/L total arsenic. This value represents the maximum contaminant level (MCL) for arsenic established under the Safe Drinking Water Act (SDWA).

Arsenic may exist in water in several oxidation states, with the most common being the trivalent arsenite (As^{+3}) and pentavalent arsenate (As^{+5}) forms. Arsenate is more amenable to treatment by most treatment technologies. If the groundwater contains arsenite, oxidation of the arsenite to arsenate (generally by chlorination) would be required as a pretreatment step. To evaluate this possibility, samples of groundwater from potential pilot study supply wells were submitted to the Academy of Natural Sciences for arsenic speciation analysis. Results from these analyses indicated that, for the wells used in this study, the predominant arsenic species present was the oxidized As^{+5} form. Based upon these data, removal of the arsenate alone would permit achievement of the discharge criterion of 50 μg/L. Therefore, an oxidative pretreatment step was not required.

Isotherm testing was performed to evaluate equilibrium adsorption characteristics of various types of adsorbents (activated carbon, ion exchange resins, and activated alumina), to select the best performing types for subsequent pilot testing, and to determine operating pH for the pilot test program. Preliminary selection of media for isotherm testing was based upon existing literature and manufacturer recommendations. Five activated carbons, four ion exchange resins, and one activated alumina were evaluated in isotherm tests. Water for isotherm testing was drawn from wells 403A and 407A at SHAD. Results of these studies indicated that ion exchange resins and activated alumina could achieve equilibrium arsenic concentrations below 50 μg/L. However, activated carbon could achieve this criterion only at very high carbon dosages. These studies also indicated that activated carbon and activated alumina exhibited better performance at reduced pH. Therefore, pilot studies for these media would require a pH reduction step. Two activated carbons, two ion exchange resins, and the activated alumina were selected for continuous flow pilot scale testing at SHAD.

The pilot study was conducted in Building 646 at SHAD, using a skid-mounted pilot plant previously built for the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA). An air stripper was added to the pilot plant to remove any TCE encountered in the test water. Well MW-440A at SHAD was used as the source of water for all pilot study runs.

In accordance with the project Test Plan, the basic pilot test program incorporated five test runs, evaluating the performance of the selected media under various combinations of operating parameters including hydraulic loading rate and empty bed contact time (EBCT). Following completion of the planned test program, two supplemental runs were conducted. The first supplemental run was to reconfirm earlier results obtained with activated carbon. The second supplemental run was to evaluate the arsenic removal by activated alumina in the presence of TCE (i.e., without air stripping). This run was performed in response to a request from USATHAMA. Since the supply well (MW-440A) did not exhibit TCE contamination, the groundwater was spiked with TCE for this test, and the added TCE was removed from the effluent with the air stripper prior to discharge. Effluent from all pilot runs was analyzed for arsenic concentration prior to discharge.

Pilot study runs indicated that both activated alumina and ion exchange resins could provide satisfactory arsenic removal performance, with effluent arsenic concentrations below the 50 μg/L criterion for substantial periods before breakthrough. However, the activated carbons tested in this study were not capable of achieving this criterion. The supplemental runs reconfirmed this performance and showed that the presence of TCE would interfere with arsenic removal by activated alumina.

The following conclusions are drawn from the data obtained in this study:

- Strong base anion exchange resins and activated alumina are capable of treating arsenic-contaminated groundwater from well MW-440A at SHAD to effluent concentrations below the Safe Drinking Water Act MCL of 50 μg/L (as total arsenic). The granular activated carbons tested were not capable of effective arsenic treatment under the conditions evaluated in this study.

- Data from isotherm testing indicate that qualitatively comparable results would be obtained with groundwater from wells MW-403A and 407A.

- Of the successful media, activated alumina provided the longest bed lives (in terms of bed volumes of water treated prior to breakthrough at the MCL level).

- The use of activated alumina requires a pH reduction step. Hydraulic loading rates of 2 to 3 gpm/ft^2 and empty bed contact times (EBCTs) of 9.8 to 14.7 minutes provided the longest bed lives.

- Ion exchange resins exhibited less dependence on hydraulic loading rate or EBCT than did activated alumina. However, bed life at all loading rates was lower than with activated alumina.

- Analytical data from wells MW-403A, MW-407A, MW-431A, and MW-440A indicate that As^{+5} is the predominant arsenic species present in SHAD groundwater and that As^{+3} is present only in small amounts. In fact, removal of As^{+5} alone would be sufficient to achieve the SDWA MCL for total arsenic of 50 μg/L. As a result no oxidative pretreatment step was required or employed in this study and, as long as this situation prevails, oxidative pretreatment should not be required in a full-scale system.

- If activated alumina is used for arsenic treatment, direct treatment at individual well heads without prior removal of TCE would appear to be less favorable than treatment after TCE removal, since the presence of TCE appears to shorten bed life.

SECTION 1

INTRODUCTION

1.1 PROBLEM STATEMENT

Sharpe Army Depot (SHAD), located in Lathrop, California, is an Area Oriented Distribution depot providing supply support to the western continental United States (CONUS), Alaska, and Pacific Army Commands [1]. A site location map is shown in Figure 1-1.

SHAD is presently operating a treatment system for the removal of trichlorethylene from groundwater. The treatment system uses a packed tower air stripper for removal of volatile components. The treated effluent is discharged to the South San Joaquin Irrigation District drainage canal.

The groundwater at SHAD also contains arsenic, possibly of natural origin. There may be a need to remove arsenic from the groundwater prior to its discharge to the irrigation canal.

The investigation of remedial needs and solutions at Army-controlled sites is managed by the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA). USATHAMA's Technical Support Division (TSD) conducts research on promising treatment technologies. USATHAMA has retained Roy F. Weston, Inc. (WESTON) to help develop appropriate remedial technologies. Under this contract, USATHAMA has decided to investigate treatment technologies for arsenic-contaminated groundwater.

1.2 PROJECT OBJECTIVES

The goal of this study was to evaluate and confirm the ability to remove arsenic from the groundwater at SHAD, using ion exchange, activated carbon, and/or activated alumina treatment processes. This objective was addressed through a combination of laboratory isotherm testing (conducted at WESTON's Environmental Technology Laboratory in Lionville, Pennsylvania) and continuous flow pilot studies conducted at SHAD.

The effluent criterion for the evaluation of these technologies was 50 μg/L total arsenic. This value represents the maximum contaminant level (MCL) for arsenic established under the Safe Drinking Water Act (SDWA).

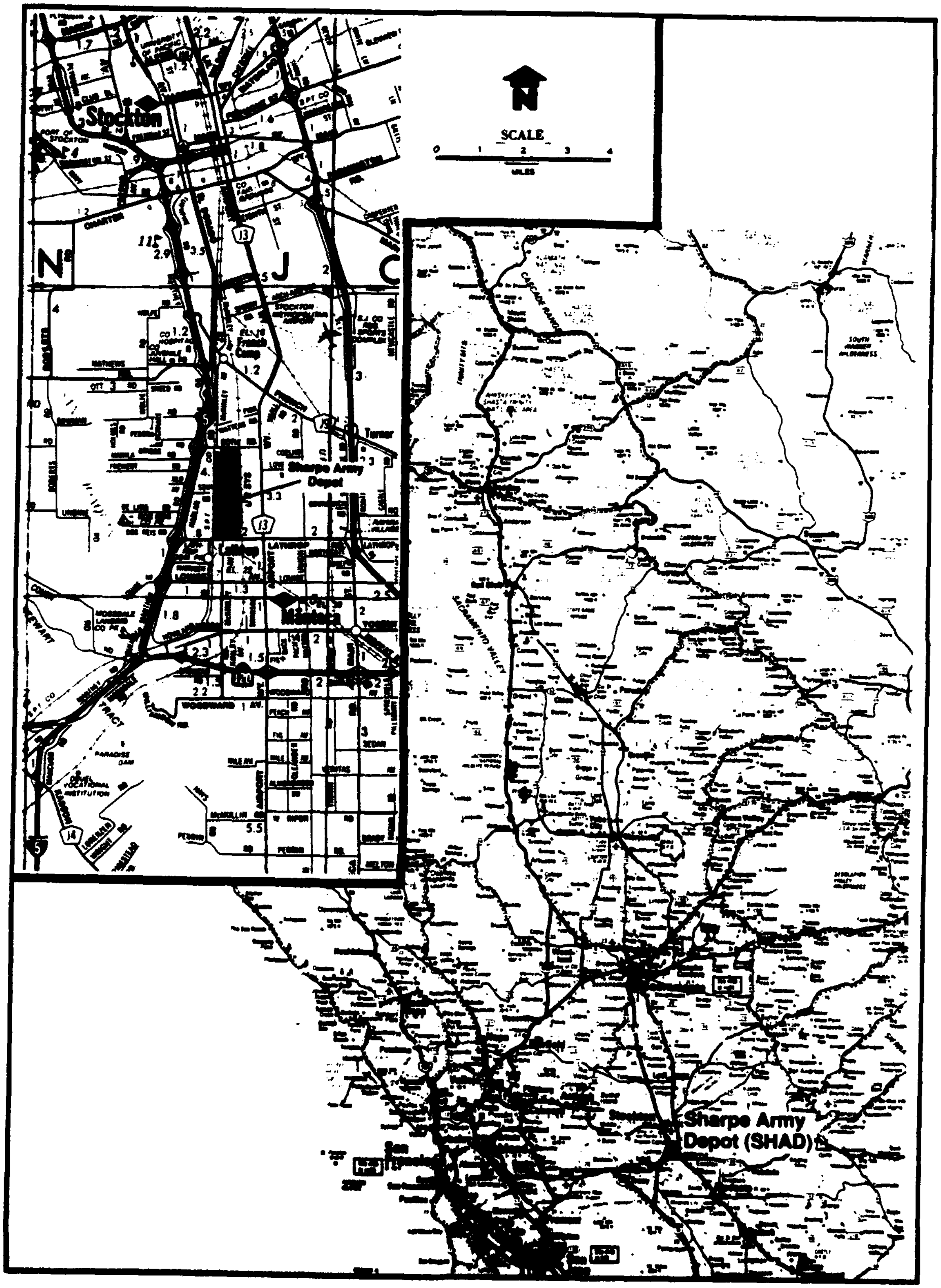

Figure 1-1. Site location map, Sharpe Army Depot, Lathrop, California

SECTION 2

BACKGROUND/LITERATURE REVIEW

2.1 ARSENIC IN GROUNDWATER

Arsenic is a toxic element which may pose a health threat when present in drinking water. The U.S. Environmental Protection Agency (EPA) has established a MCL of 50 μg/L in drinking water under the SDWA.

Arsenic occurs naturally as a constituent of a variety of minerals and in association with a variety of industrially important ores. Arsenic contamination of water can occur during the mixing and processing of these ores. Additional sources of arsenic contamination include arsenical pesticides and herbicides and ceramics manufacturing [2]. However, arsenic may also occur naturally at significant levels in groundwater from zones containing arsenic-based minerals. Consequently, interest in arsenic treatment technologies involves both the treatment of wastewaters prior to discharge and the treatment of drinking water prior to consumption.

Arsenic (As) can occur in four oxidation states in water (+5, +3, 0, and -3). The most commonly found species are the trivalent (+3) and pentavalent (+5) states [3,4]. At low pH, pentavalent arsenate (As^{+5}) exists primarily as H_3AsO_4. Between approximately pH 3.0 and approximately pH 6.5, the predominant arsenate form is $H_2AsO_4^-$, while from pH 6.5 through pH 12.5, $HAsO_4^{-2}$ predominates. Above pH 12.5, AsO_4^{-3} is the predominant species. At all pH values below approximately pH 9, trivalent arsenite (As^{+3}) exists primarily as the undissociated weak acid, H_3AsO_3. The distribution between As^{+3} and As^{+5} species is also determined by the redox condition of the water, with As^{+3} being stable under reducing conditions and As^{+5} under oxidizing conditions [4]. Thus, depending upon both pH and redox potential, various arsenic species may be present. While it might be expected that arsenite species would predominate over arsenate in oxygen deficient groundwater [3,5,6], cases of arsenate predominating have been noted [6].

Arsenite is considered to be more toxic than arsenate [4,7]. SDWA treatment standards do not at present distinguish among arsenic species. However, water quality based effluent standards may. These issues are discussed in Subsection 2.3.

In general, arsenate is more amenable to most treatment processes than arsenite [8,9,10], and oxidation of arsenite to arsenate may be needed as part of the treatment process. Oxidation by aeration alone appears to occur too slowly to be of practical utility, and chemical oxidation (most commonly by chlorine) is generally recommended [8,9,10].

2.2 ARSENIC TREATMENT PROCESS

Historically, the most common treatment methods for arsenic employed various precipitation/coagulation methods. Major examples include lime or lime/soda methods, sulfide precipitation methods, and processes employing iron salts or alum [3,8]. Such processes are well suited for treating relatively high arsenic concentrations such as may be found in process or industrial wastewaters. In recent years, interest in processes such as ion exchange, activated carbon and/or activated alumina has increased, particularly for the removal of relatively low levels of arsenic from potential potable water sources [1,3,5,7,11].

2.2.1 ION EXCHANGE

Ion exchange (IE) processes for water and wastewater treatment employ solid media (often sythentic resins) to which relatively innocuous ionic groups are attached by electrostatic forces [12]. When contaminated water contacts the resin, ionic contaminants may preferentially replace the innocuous ions on the resin. Thus, contaminants in solution are exchanged for innocuous ions from the resin. In the case of anionic constituents (such as arsenite and arsenate species), the exchangeable species on the resin are often chloride or hydroxide ions. When the adsorptive capacity of the resin is reached, or when effluent contaminant levels approach a predetermined breakthrough concentration, the resin is regenerated using a concentrated regenerant solution (such as NaCl or NaOH), to displace the contaminant from the resin. The regenerant solution, containing high concentrations of the contaminant, requires separate treatment and/or disposal.

Previous work has indicated that IE may be a useful treatment technology for removal of low levels or arsenic from water [3,5,8,13-19]. Arsenic levels at or below the MCL of 50 μg/L in the treated water are often achievable. In general, strong base resins in the chloride form have been recommended in this application, although success has also been observed with weak and intermediate base resins [8,14]. Removal of arsenate (As^{+5}) is generally more effective than removal of arsenite (As^{+3}), possibly because the latter exists in water as uncharged species (H_3AsO_3) at typical water treatment pH values [19].

In one laboratory scale study using the IE process, soluble As^{+5} at a concentration of 500 μg/L was completely removed from storm runoff water [15]. An empty bed contact time (EBCT) of 3.6 minutes, hydraulic loading of 4.2 gpm/ft^2, and bed depth of 2 ft were employed in the 1-inch diameter column used in the study. Pilot scale studies on point-of-use (i.e., in-home) arsenic treatment systems have also demonstrated effective removal to below the MCL at raw water arsenic concentrations up to 1.16 mg/L. Strong base anion exchange resins were used. Surface loading rates and EBCT were 2.7 gpm/ft^2 and 7.5 minutes, respectively [18,19].

Other anionic species in groundwater may compete with arsenic anions for adsorption sites on the resin and thereby diminish performance. In addition, precipitation of alkalinity (i.e., calcium carbonate) in the IE vessel is a possible complication with an IE system [20]. This would require the additional expense of removing the cations with a softener (cation exchanger) prior to arsenic removal.

As previously noted, regeneration of IE resin, if used in the chloride form, would be accomplished with sodium chloride (NaCl) solution, which may present cost and handling advantages over the caustic and/or acid regenerants required for activated carbon, activated alumina, or hydroxide-form ion exchange resins.

2.2.2 GRANULAR ACTIVATED CARBON

The removal of contaminants from solution by granular activated carbon (GAC) occurs by adsorption of contaminant molecules to the extensive surface area of the carbon particles. The mechanism is considered to be physical/chemical, as opposed to the electrostatic forces involved in, for example, IE processes. Activated carbon is often effective in removing non-ionic components, and it has been most widely applied for the removal of low levels of organics from wastewaters. It has been evaluated, in some cases, for its ability to remove ionic constituents such as metals from wastewater.

However, limited information is available in the literature on activated carbon treatment of arsenic-contaminated water and wastewater. In one study involving arsenic removal from a potable water supply using an activated carbon bed, 70% removal of As^{+5} was achieved with a raw water arsenic concentration of 200 μg/L, producing an effluent concentration of 60 μg/L [8]. Another study indicated that the optimum pH for adsorption of As^{+5} on activated carbon is 4. However, activated carbon exhibited a relatively low capacity for arsenic adsorption in comparison to other adsorbents tested (activated alumina and activated bauxite) even at its optimum pH [10]. Studies on the removal of As^{+3} from synthetic wastewater and arsenic from goldmine water have also demonstrated that activated carbon was less effective than ion exchange in removing arsenic from solution. Once again, the best results were obtained at pH 4 and the authors postulate that the size of the arsenic species as a function of pH, in comparison to the activated carbon pore size, may determine performance [21].

A recent study in which activated carbon was used for treating a synthetic solution of arsenic (prepared by dissolving As_2O_3 in distilled water) indicated a GAC adsorption capacity of 2.05 lb As^{+3} per 100 lb of carbon [22].
Batch adsorption experiments conducted by O.H. Materials Corporation (OHM) to evaluate GAC for arsenic removal from the groundwater at SHAD indicated an ultimate capacity for arsenic of 0.05 lb As^{+5} per 100 lb of carbon at an influent concentration of 734 μg/L [23]. This is significantly lower than the GAC adsorption capacity reported in the previously mentioned study. The difference could have been due to the different sources of water with different chemical compositions used in the studies.

Recent research has indicated that the performance of activated carbon in removing As^{+5} from solution may be improved by soaking the activated carbon in ferrous iron (Fe^{+2}) salts (such as ferrous ammonium sulfate) prior to use. The improved performance seems to result from the formation of arsenate complexes with ferrous iron adsorbed at the carbon surface. The process is pH-dependent, with the best adsorption occurring at pH 4 to 5. Removal of arsenate from the carbon with strong acid or base also reversed the enhancement effect, and retreatment of the carbon with ferrous salts was needed to restore performance [1,11].

At the present level of technology development, granular activated carbon would appear to be less promising than other potential treatment processes [8].

2.2.3 ACTIVATED ALUMINA

The use of activated alumina (AA) has received increasing attention in recent years for the removal of certain anionic species (most notably, fluoride, selenium, and arsenic) from drinking water [24].

AA is composed of oxides and hydroxides of aluminum, produced by thermal treatment of hydrated alumina [24,25]. It exhibits a highly complex surface structure and removes inorganic species by an IE mechanism.

The potential use of AA for removal of arsenic was first presented approximately 20 years ago [26]. This work indicated that alumina could effectively remove arsenic in continuous flow adsorption columns operating at low hydraulic loading rates of 2.5 to 3.0 gpm/ft^2. Subsequent studies under a variety of conditions have confirmed the need for relatively low hydraulic loading rates, possibly due to the slow kinetics of the adsorption process [6,16,17]. At the same time, short EBCTs of 5 to 7.5 minutes have been found effective [10,16,17].

Additional factors which affect the performance of AA include influent arsenic concentration, temperature, pH, and the presence of other anions which may compete with arsenic ions for exchange sites [3,27]. Several studies have demonstrated that arsenic removal is most effective at pH values below neutral, generally in the range of pH 5 to 6 [10,16,17,27], with good removals achieved over the range of pH 4 to 7 [10]. It has also been shown that the equilibrium capacity of AA for As^{+5} is up to 10 times greater than that of As^{+3}, possibly because at a pH value of less than 9, As^{+3} exists primarily as unionized H_3AsO_3 [3]. Therefore, as with most other treatment processes, oxidation of As^{+3} to As^{+5} is necessary to achieve adequate removal at most pH values of practical interest.

With respect to potential interfering anions, research on selenium removal has suggested the following order of preference for adsorption by AA [25]:

$$OH^-, H_2PO_4^-, F^-, H_2AsO_4^-, HSeO_3^-, (SO_4^{-2}, SeO_4^-, -HCO_3^-, Cl^-), NO_3^-, H_3AsO_3.$$

The relative selectivity of the four anions in parentheses was unknown. Subsequent research indicated that at certain concentrations the concurrent presence of sulfate and chloride in synthetic groundwater could substantially reduce removal of arsenic [27]. As^{+5} removal seems to be more affected by chemical composition than As^{+3} [10].

Isotherm tests for the removal of arsenic using AA, reported in the literature, have shown that contact times on the order of 48 hr may be required to reach equilibrium [10] although shorter periods have been successfully employed [23].

Results from EPA pilot tests on AA systems at Hanford, California indicated that with an EBCT of 7.5 minutes, pH adjustment to 6.0, and oxidation of As^{+3} to As^{+5}, up to approximately 16,000 bed volumes could be processed prior to reaching a MCL of 50 μg/L in the treated water, with a raw water As^{+5} concentration of approximately 100 μg/L [20].

A laboratory study (isotherm tests and fixed bed tests) for arsenic removal from groundwater at SHAD was performed by OHM during June and July of 1986 [23]. The results from batch (isotherm) AA testing, which employed a contact time of 24 hr, indicated an ultimate capacity of 0.15 lb arsenic/100 lb of alumina at an influent groundwater concentration of 734 μg/L of arsenic. Reductions in arsenic concentrations from the initial concentration of 734 μg/L to 12 μg/L were accomplished in the AA batch tests using an alumina dosage of 10 g/L. The results from continuous flow pilot testing with contact times of 8 minutes indicated that AA was capable of removing arsenic from groundwater at SHAD to the EPA MCL of 50 μg/L for arsenic. At saturation of the packed bed, the calculated adsorption capacity was found to be 0.125 lb of arsenic per 100 lb of alumina [23].

When the adsorptive capacity of the AA is reached, it can be regenerated with sodium hydroxide (NaOH) solution. Relatively high caustic concentrations (4 to 5%) are most effective; however, the loss of alumina at these concentrations is high. Effective arsenic desorption with acceptable losses of alumina is achievable with 1% caustic [26]. The general procedure for regeneration, which has been successfully used in pilot tests, includes treatment with NaOH, raw water rinse, and neutralization with sulfuric acid. The regeneration of an AA system would generate a concentrated caustic waste containing elevated levels of arsenic that may require treatment in an approved hazardous waste facility.

In some research preconditioning of AA using essentially the regeneration procedure has been employed [25-27], while in other studies virgin alumina has been used directly [23,28]. In general, the removal capacity of AA does not appear to be greatly diminished following regeneration.

2.3 REGULATORY REVIEW

Limitations on the concentrations of arsenic in water may be derived from the SDWA (PL-92-523) or the Clean Water Act (PL-92-500) (more properly called the Water Quality Act of 1987).

Under the SDWA, EPA has established Primary Drinking Water Regulations for Tap Water from Public Water Systems [29]. These regulations prescribe MCLs for certain harmful contaminants, including arsenic. MCLs apply to the water as delivered to the ultimate user from a free-flowing outlet (except for limits on turbidity). The MCL for arsenic has been established as 50 μg/L [30]. This limit applies to total arsenic concentration in the finished water.

Under Section 304 of the Clean Water Act, EPA has established Ambient Water Quality Criteria (AWQCs) for toxic contaminants (including arsenic) in receiving streams [31]. AWQCs are intended to reflect the concentrations of contaminants in natural water bodies (such as receiving streams) which are protective of the designated use of that stream. AWQCs do not have direct regulatory status, but they can be used to derive regulatory requirements and to establish National Pollutant Discharge Elimination System (NPDES) discharge limitations (using, for example, Waste Load Allocation models). EPA's AWQCs have also been used as applicable or relevant and appropriate requirements (ARARs) in Remedial Investigations under Superfund. Based upon toxicological data, EPA has established freshwater aquatic life acute and chronic criteria for trivalent arsenic of 360 μg/L and 190 μg/L, respectively. Since insufficient data are available to fully establish criteria for pentavalent arsenic, the presently published criteria cite Lowest Observed Effect Levels (LOEL) of 850 μg/L (acute) and 48 μg/L (chronic). Finally, EPA's AWQC documents cite human carcinogenic risk-based criteria of 2.2 nanograms/L (ng/L) (for water and fish ingestion) and 17.5 ng/L (for consumption of fish only), representing the 10^{-6} carcinogenic risk level [31].

Section 307 of the Clean Water Act also requires EPA to establish toxic effluent standards for a range of pollutants including arsenic. These standards, where existing, are enforceable. However, due to the technical difficulty of establishing such standards, they have been developed for only six pollutants to date [29]. Therefore, while arsenic is on the defined list of contaminants to be addressed under this section, discharge standards have not been developed.

2.4 PROJECT APPROVAL

During the planning of this study, a meeting was held between representatives of SHAD, USATHAMA, WESTON, and the California Regional Water Quality Control Board (CRWQCB) at CRWQCB offices in Sacramento, California, on 27 September 1989. The purpose of the meeting was to present and discuss the proposed project and determine CRWQCB's requirements with respect to reporting and permitting. As a result of that meeting and subsequent correspondence, the California Department of Health and Services issued a letter of approval for the study. A copy of the approval letter is reproduced in Appendix A.

SECTION 3

TEST PROGRAM AND CONDITIONS

The basic test program for the SHAD Pilot Study encompassed laboratory isotherm testing for preliminary media selection and pilot studies, using the selected media, at SHAD. In addition to these efforts, initial characterization of groundwater at SHAD was conducted during the planning stages of the project. The overall project approach is presented in the Test Plan [32] and the Health and Safety Plan [33].

3.1 GROUNDWATER CHARACTERIZATION

The purpose of the groundwater characterization effort for this project was twofold: (1) to assist in the selection among existing monitoring wells of a source of arsenic-bearing groundwater for subsequent testing, and (2) to evaluate the potential requirement for an arsenic-oxidation step during subsequent testing, which would be warranted if SHAD groundwater exhibited significant levels of reduced arsenic (As^{+3}).

In order to accomplish the first of these objectives, groundwater samples were collected from candidate monitoring wells and analyzed for arsenic and trichloroethylene (TCE). Candidate wells for sampling were selected on the basis of well diameter, depth to water, and proximity to the pilot plant location at SHAD.

In order to evaluate the need for arsenite oxidation, portions of samples from candidate wells were subjected to arsenic speciation analysis. These specialized analytical services were provided by the Benedict Estuarine Research Laboratory of the Academy of Natural Sciences.

In addition to the above analyses, groundwater samples were analyzed for heavy metals and selected inorganics (ammonia, nitrate/nitrite, sulfate, and phosphate). These data were used in the evaluation of potential interferences for the various adsorption process. They were also provided, at USATHAMA's request, to researchers at Clark Atlanta University in support of a separate USATHAMA project.

3.2 ISOTHERM TESTING

The objective of isotherm testing was to evaluate the equilibrium adsorption characteristics of various types of each medium (IE resins, GAC, and AA). These data, in combination with manufacturer's product literature and recommendations, were to be used in selecting specific media types for subsequent pilot testing.

Isotherms are, by definition, expressions of the relationship between the extent of equilibrium adsorption per unit mass of adsorbent and the concentration of adsorbate in solution at constant temperature [12,34]. Isotherms are evaluated by mixing varying quantities of adsorbent with the test solution and determining the distribution of adsorbate between the adsorbent and solution at equilibrium. While the concept is most strictly applied to physiochemical adsorption (i.e., activated carbon) the same basic protocol is sometimes used to screen IE resins and AA.

The general procedure used for all isotherm testing is discussed in Subsection 3.2.1. Specific modifications to this procedure, as dictated by the characteristics of various adsorbent media, are noted in the presentation of results in Section 5.

3.2.1 GENERAL ISOTHERM TEST PROCEDURE

Isotherm tests were performed for selected IE resins, activated carbon types, and a single AA at WESTON's Environmental Technology Laboratory (ETL) in Lionville, Pennsylvania. Groundwater was collected at SHAD and shipped to ETL for testing.

Since treatment for arsenic removal at SHAD would likely be implemented following removal of TCE in the existing air stripper, the contaminated groundwater from SHAD was pretreated for TCE removal by batch aeration using spargers. For isotherms to be conducted at other than ambient pH [32], the pH of the groundwater was adjusted to the desired value using sulfuric acid. Isotherm tests were then conducted on the pretreated groundwater samples.

Seven 250-mL aliquots were used for each isotherm. Tests were conducted in polyethylene bottles. Preweighed quantities of adsorbent media were added to the groundwater aliquots to provide the dosages outlined in the Test Plan [32]. The bottles were sealed to preclude liquid and vapor losses during agitation. Samples were agitated at room temperature on a rotating laboratory shaker for a period of 24 hr. Each isotherm test included one blank, containing no adsorbent medium.

Following agitation, each sample (including the blank) was filtered through a Whatman 0.45 micron GF/F filter into a clean filter flask to remove the contaminant-laden adsorption medium. Each filtrate sample was then analyzed for total arsenic concentration.

From these data the equilibrium concentration of arsenic in the solution (Ce) and the arsenic loading on the adsorbent medium (qe) were calculated. These data were plotted on log-log paper in accordance with the Freundlich equation for adsorption:

$$q_e = X/M = KC_e^{1/n}$$

where,

q_e = Adsorbent loading.

X = C_o-C_e the amount of arsenic adsorbed for a given volume of solution.

M = Weight of adsorbent added.

C_o = Initial amount of arsenic.

C_e = Amount of arsenic remaining in solution.

K and l/n are empirical constants.

The results of these tests were used to select media to be tested in the pilot plant study phase of the project.

3.3 PILOT PLANT STUDIES

The objective of pilot plant studies was to evaluate potential operating characteristics of selected adsorbent types under actual operating conditions, with respect to such parameters as adsorbent bed depth, hydraulic loading rate and EBCT. While isotherm testing is useful in examining equilibrium adsorption, the data obtained do not transfer directly to continuous flow operation. Pilot column studies are generally necessary to evaluate the potential performance of continuous flow adsorption columns, which are typically employed in full scale treatment systems.

Pilot scale testing of the media selected from the isotherm data was conducted at SHAD using a skid-mounted transportable activated carbon column pilot plant designed and built for USATHAMA. The system can be used to evaluate treatment using GAC, IE, or AA (GAC/IE/AA) technologies. The plant consists of three skids and accessory tankage. One skid consists of the motor control center, feed pumps, and utility pumps. Each of the other two skids contains four plexiglas columns which hold the adsorption media to be tested. This pilot plant was designed to provide a high degree of operating flexibility, using variable bed depths and wastewater flow arrangements. Additional tanks and pumps are provided to allow for groundwater retention, pH adjustment, and flow control as necessary.

The primary groundwater contaminant at SHAD is TCE, and a remedial treatment system for this contaminant is in operation. For purposes of this arsenic treatment study, air stripping was to be used to remove any TCE found in the selected supply well prior to its passing through the adsorption columns [32]. A commercially available packed tower air stripper (previously obtained for use in a similar study at Badger Army Ammunition Plant) was used for this purpose.

The air stripper is 8 inches in diameter by 23 ft high with 15 ft of packing and is designed for a water flow rate of 5 gallons per minute (gpm). A schematic of the air stripper is shown in Figure 3-1. The projected performance of this unit based upon an assumed influent TCE concentration of 50 μg/L is presented in Appendix B.

In addition to the treatment units described above, the following additional tankage was added to the GAC/IE/AA pilot treatment system:

- Two 3,000-gallon influent holding tanks to receive and hold groundwater from the selected well.
- One 2,000-gallon equalization tank between the air stripper and the GAC/IE/AA unit. When required by the Test Plan [32], pH adjustment was carried out in this tank.
- Two 3,000-gallon effluent holding tanks to retain the treated effluent to be discharged after testing.

Figure 3-2 presents the schematic configuration of the combined air stripping/GAC/IE/AA pilot system that was used in this study.

As shown in Figure 3-2, there were three GAC/IE/AA treatment trains. These three trains were operated in parallel to allow for study under three different experimental conditions at the same time.

Each of the three parallel treatment trains (designated A, B, and C) employed two 4.25-inch inside diameter (ID) plexiglas columns arranged in series. Adsorption performance and breakthrough characteristics were examined in the first column in each train. The second column was to provide additional adsorptive capacity as the first column broke through and thus ensure that the final discharge standard of 50 μg/L would be met. Each adsorption column had a total height of 6 ft, and was designed to provide a maximum bed depth of 4 ft and up to 50% bed expansion during backwash. A bed of gravel overlain by high purity (metals-free) glass wool was used to support adsorbent media. Backwashing was conducted when pressure drop across the column exceeded 5 psi. Typical backwash cycle duration was less

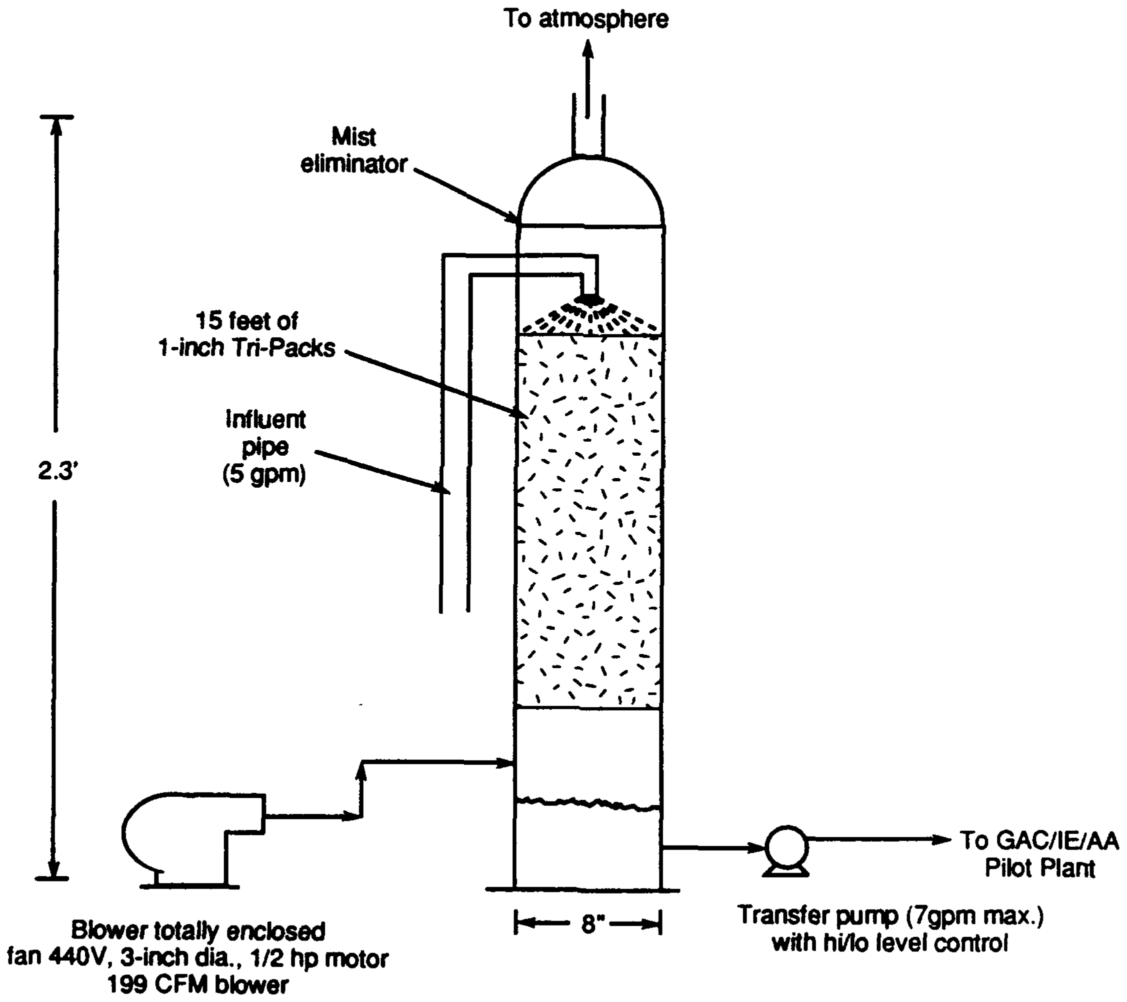

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Figure 3-1. SHAD air stripper schematic.

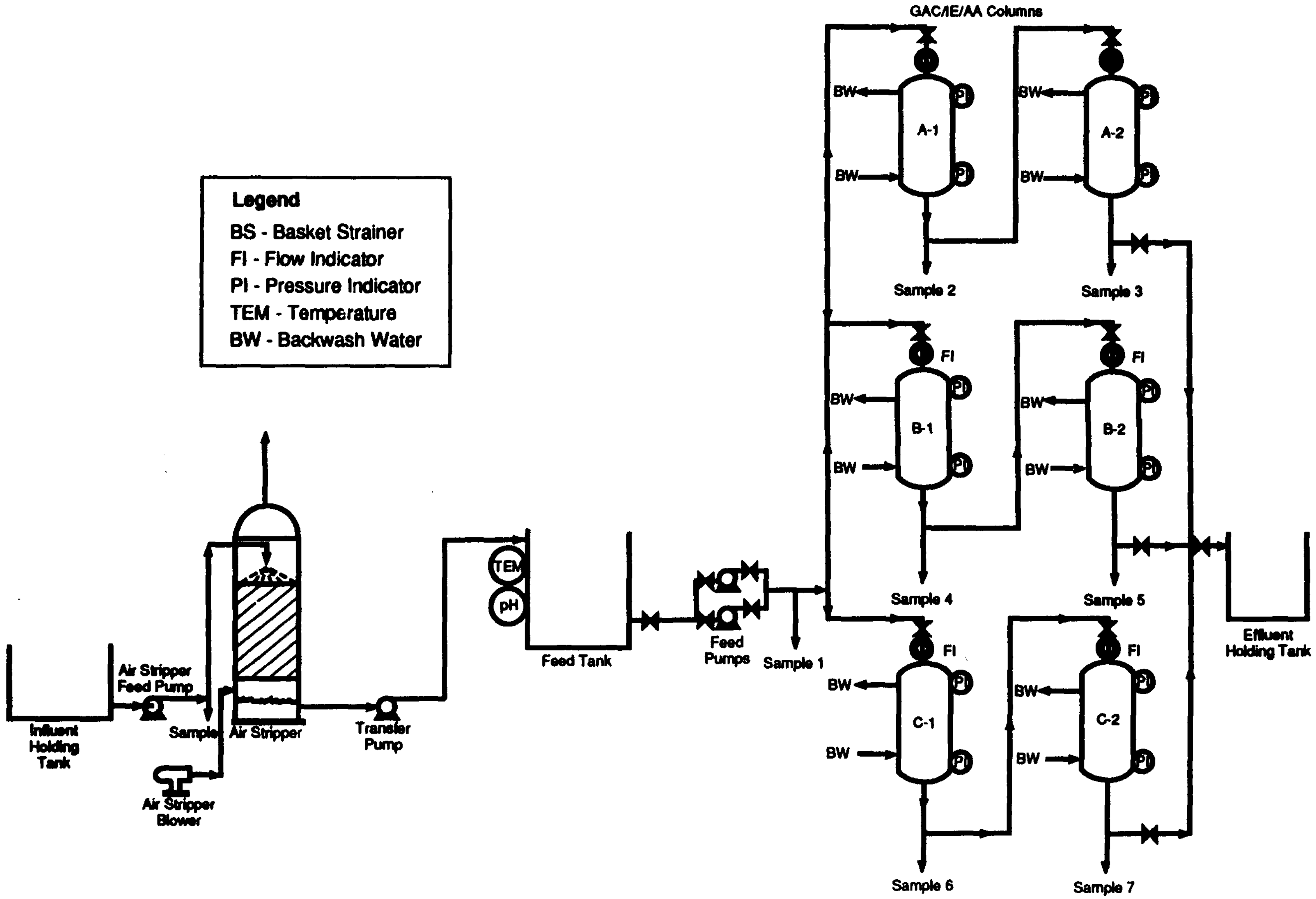

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Figure 3-2. Pilot treatment unit configuration.

than 15 minutes. Column packing, startup, and operating details were as specified in the Test Plan [32] and the pilot plant O&M Manual [35].

The pilot study was conducted in Building 646, located in the South Balloon Area at SHAD. A location map showing Building 646 is presented in Figure 3-3. The influent tanks were placed outside the building and the air stripper was erected on a concrete pad at the southeastern corner of the building. The intermediate feed tank, GAC/IE/AA pilot unit, and the effluent holding tanks were located inside Building 646. Monitor well MW440A was ultimately selected as the supply well for the pilot phase of the study. The basis for this selection is presented in Subsection 4.1.

Groundwater was drawn from the well, using a pump mounted in the well and powered by a portable generator. The groundwater was pumped to a holding tank mounted in the bed of a pickup truck for transport to the pilot plant location, where it was pumped into one influent holding tank. The air stripper was operated intermittently as needed to maintain an adequate supply of pretreated (i.e., stripped) water in the intermediate feed tank, which was also used for pH adjustment when required by the test protocol. After passing through the GAC/IE/AA unit, treated water was stored in one of the effluent holding tanks pending analysis to verify compliance with the discharge standard of 50 μg/L. Analytical samples were taken when the effluent tank was full, with the pilot system effluent stream being shifted to the second holding tank. Upon verification that the discharge criterion had been met, the effluent was discharged, by gravity, to a nearby manhole and plant drain leading to the Southwest Irrigation District drainage canal upstream of SHAD's NPDES discharge point.

3.4 ANALYTICAL PROCEDURES

The primary analytical parameters for this study included total arsenic, trichloroethylene (TCE), and pH. Analysis for other parameters, such as various inorganic constituents, and arsenic speciation analysis was performed for specific purposes as discussed in Sections 4, 5, and 6.

3.4.1 TOTAL ARSENIC

Analysis for total arsenic in samples from the isotherm test program (which was conducted at WESTON's ETL in Lionville, Pennsylvania) were analyzed at WESTON's Analytics Division Lionville laboratory using USATHAMA-certified Method SD01. Analysis for total arsenic in groundwater during the pilot study phase was performed at WESTON's laboratory in Stockton, California using USATHAMA-certified Method SD27. Sampling and analysis procedures are described in the Test Plan [32].

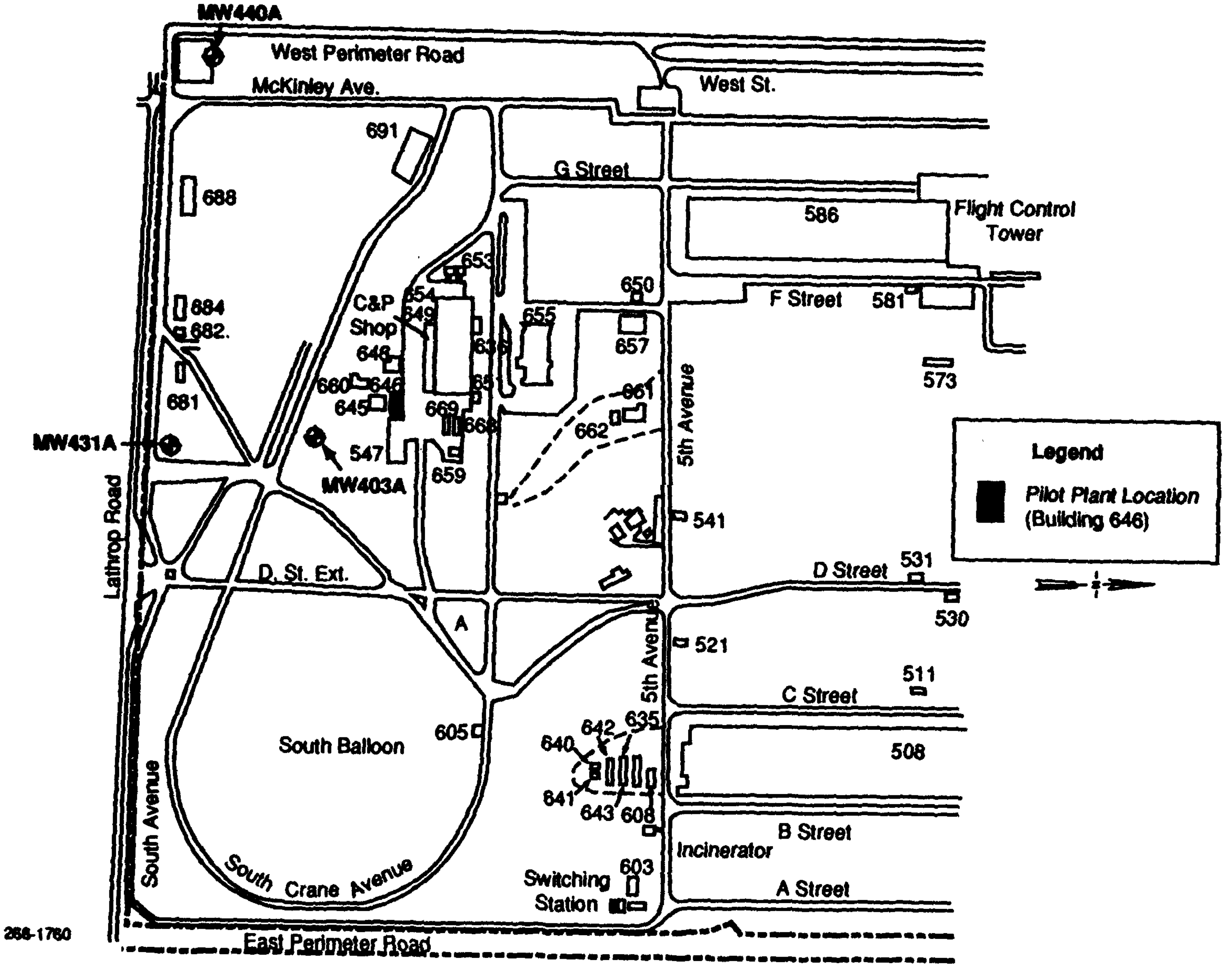


Figure 3-3. Pilot plant location in the South Balloon Area at Sharpe Army Depot.

Source: SHAD Environmental Programs Office

In order to evaluate the agreement between data from these laboratories, a selected split sample was analyzed in both laboratories. At the same time a split sample was spiked at 500 µg/L total arsenic at the Lionville laboratory and shipped single-blind to Stockton for analysis. Data from this effort, presented in Appendix C, indicated good agreement in arsenic results between the laboratories and good spike recovery by each laboratory.

3.4.2 TRICHLOROETHYLENE (TCE)

Analysis for TCE in water was performed at WESTON's Analytics Division Lionville laboratory by USATHAMA Method UM14. One sample was analyzed by the Stockton Laboratory using EPA Method 8010. Sampling and analytical procedures are described in the Test Plan [32].

3.4.3 pH

The pH of the groundwater was analyzed during pilot plant studies with a portable pH meter. The pH meter was calibrated daily using reference standards.

3.4.4 INORGANIC IONS

The following inorganic analyses were performed on one or more groundwater samples during this study: total cadmium, total cobalt, total chromium, total copper, total iron, total lead, total selenium, total zinc, ammonia nitrogen, nitrite/nitrite nitrogen, sulfate, phosphate phosphorous, fluoride, and chloride. Samples for which one of more of these parameters was analyzed are discussed in Sections 4, 5, and 6. Analyses for these parameters was performed by WESTON's Analytics Division laboratory in Lionville, Pennsylvania. Analytical methods for specific parameters are presented in Table 3-1.

3.4.5 ARSENIC SPECIATION

Arsenic speciation analysis (differentiating the trivalent As^{+3} form from the pentavalent As^{+5} form) was performed by Dr. James G. Sanders at the Benedict Estuarine Research Laboratory of The Academy of Natural Sciences. The analytical methodology was based upon cryogenic trapping distillation and detection by quartz furnace atomic adsorption. Some analyses were also performed using a continuous flow hydride generation technique [36,37].

In order to preclude changes in composition during shipment, samples for arsenic speciation analysis were flash frozen in the field immediately after being drawn. Two 250-mL polyethylene bottles were collected for each analysis, and the samples were

Table 3-1

Analytical Methods for Inorganic Parameters in Groundwater

Analyte	Method
Arsenic, total	USATHAMA SD01 or SD27*
Cadmium, total	EPA 200.7
Cobalt, total	EPA 200.7
Chromium, total	EPA 200.7
Copper, total	EPA 200.7
Iron, total	EPA 200.7
Lead, total	EPA 239.2
Selenium, total	EPA 270.2
Zinc, total	EPA 200.7
Ammonia nitrogen	SM 417E
Nitrite/nitrate nitrogen	EPA 353.1
Sulfate	EPA 375.4
Phosphate phosphorous	EPA 365.5
Fluoride	EPA 340.2
Chloride	SM 407D
Phosphate, as phosphorous	EPA 365.5

*SD01 = Lionville Laboratory
SD27 = Stockton Laboratory

Note: Inorganic analyses methods for water derived from EPA Method for Chemical Analysis of Water and Wastes (U.S. EPA 600/4-79-200) or Standard Methods for the Examination of Water and Wastewater, 16th Edition.

immediately placed in a mixture of acetone/dry ice for freezing. These samples were stored on dry ice during shipment to the Benedict Estuarine Research Laboratory.

Results from arsenic speciation analysis are discussed in Subsection 4.2. Raw data reports are presented in Appendix D.

SECTION 4

GROUNDWATER CHARACTERIZATION

4.1 SUPPLY WELL SELECTION

Initial sampling and analysis of monitoring wells at SHAD was conducted during the planning phase of this study. These data were to be used in conjunction with well characteristics (diameter and depth to water) and the proximity of wells to the pilot study location (Building 646), to select the source of groundwater to be used in the pilot study.

Based upon the latter two criteria (well characteristics and proximity to Building 646), wells MW-403A, MW-407A, and MW-431A were initially selected as candidate supply wells. Characteristics of these wells, as well as MW-406A and MW-407C, were measured by WESTON on 31 October 1989. These measurements are provided in Table 4-1. The locations of the potential supply wells are shown in Figure 4-1.

Wells 403A, 407A, and 431A were sampled on 22 December 1989. Well depth was measured. Each well was purged (three well volumes) prior to sampling. Water temperature, conductivity, and pH were measured with field instruments. Characterization data from these samples are presented in Table 4-2. Well logs are provided in Appendix E. Arsenic concentrations in MW-403A and 407A were well above the MCL of 50 μg/L and therefore potentially useful for this pilot study, while the total arsenic level in MW-431A was below the MCL. Other metals were present in all wells at varying levels, with iron exhibiting the highest concentrations, in the low parts per million range. Inorganic anions (oxidized nitrogen and phosphorous) were also present at concentrations exceeding those of arsenic in the samples from MW-403A and MW-407A.

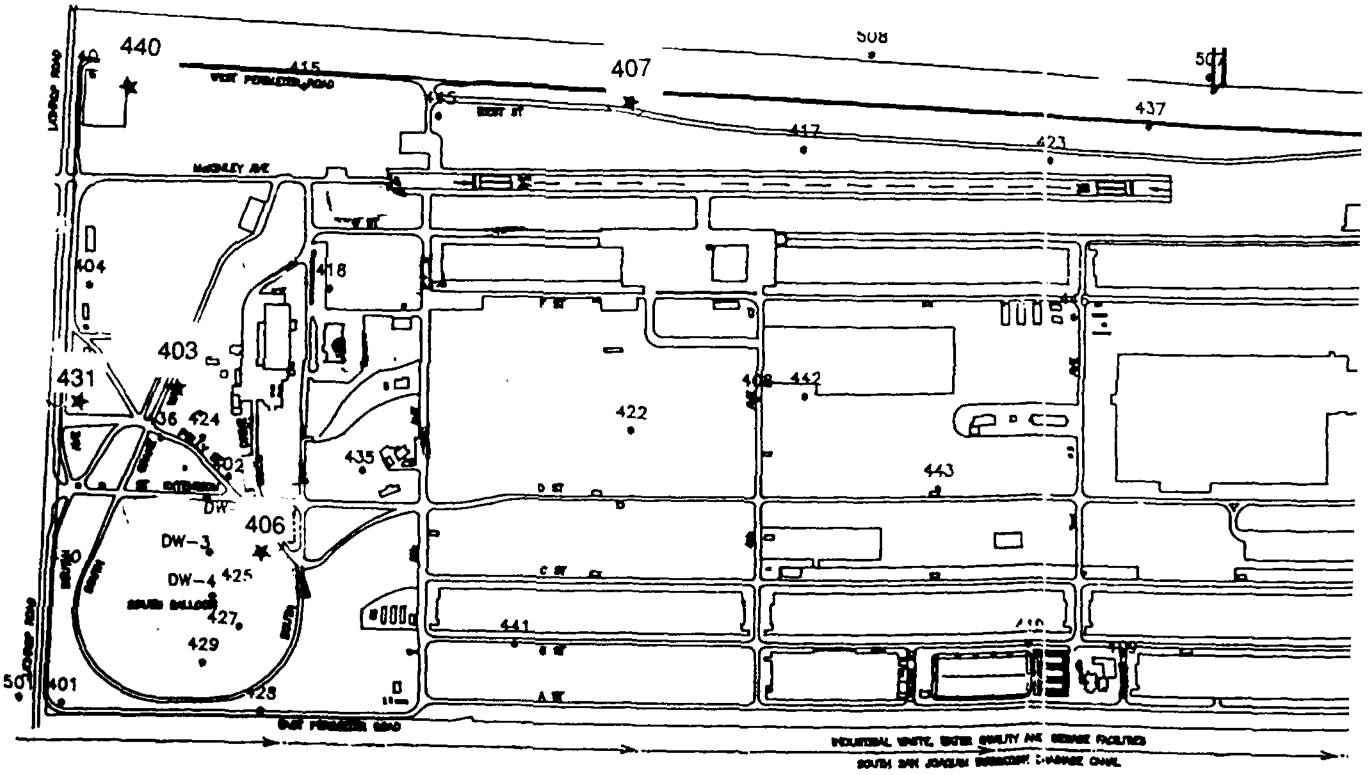
Although wells MW-403A and MW-407A exhibited sufficiently high arsenic levels to be used in this study, the small diameter of these wells was of concern in terms of supplying water consistently for the pilot study. Therefore, consideration was expanded to include other wells and ultimately well MW-440A (shown in Figure 4-1) was selected as the pilot study supply well based upon historical arsenic data. A sample drawn from this well on 8 March 1990, prior to beginning pilot testing, exhibited a total arsenic concentration of 432 ug/L. Historical data for MW-440A also indicated negligible levels of TCE in this well.

Table 4-1

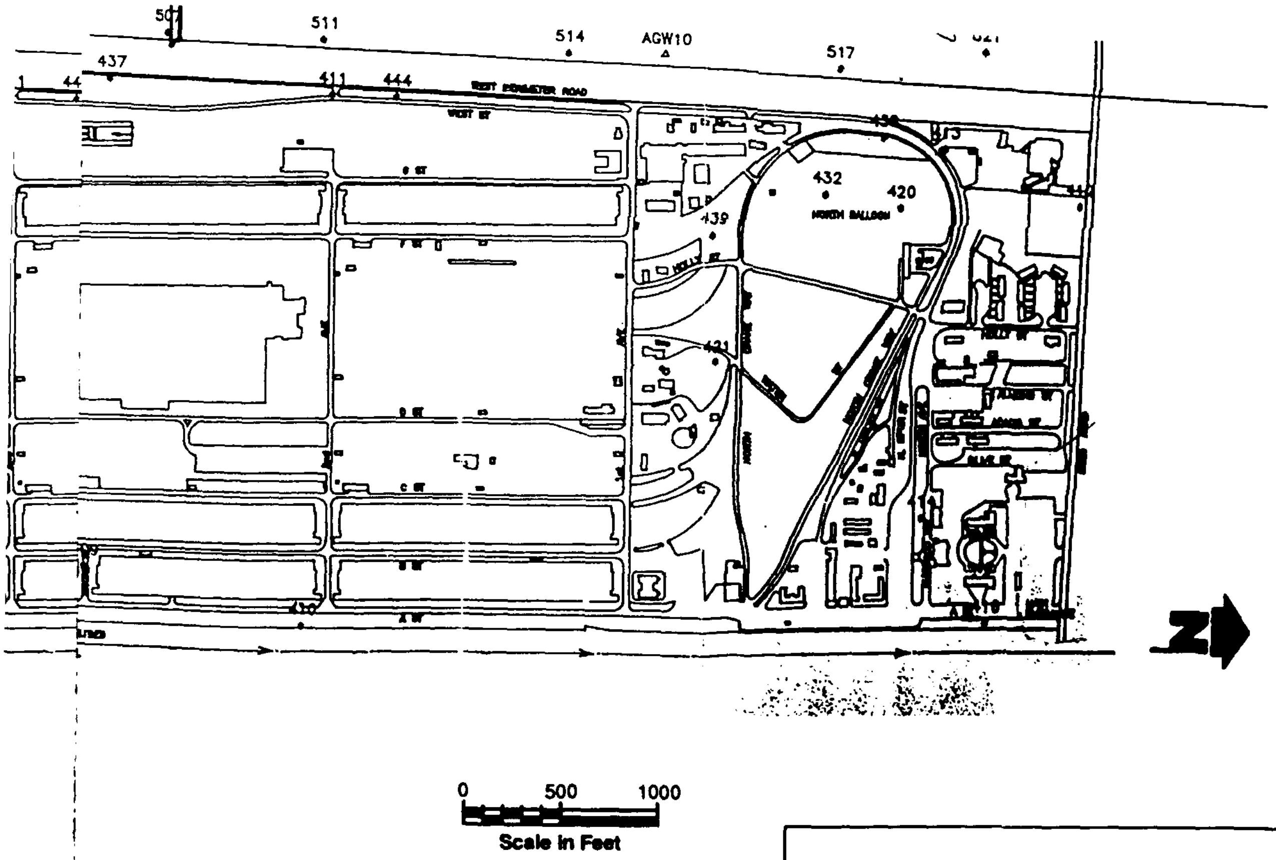
SHAD Monitoring Well Characteristics

Well I.D.	Depth to Water (Ft)	Total Depth (Ft)	Casing Diameter (Inches)	Height of Casing (Ft)	Completion Stick up (Ft)
403A	18.04	19.43	4	2.54	2.83
406A	19.52	22.81	2	2.02	2.46
407A	19.27	22.84	2	1.08	3.17
407C	17.15	*	4	1.28	2.23
431A	20.57	36.87	4	2.41	2.58

*Could not be measured as the depth exceeded the length of the measuring tape.



Source: SHAD Environmental Programs Office were to be used in selecting



tal Programs Office

Legend

401	Monitor Well (typically, Clusters of Three)
SHAD-1	Potable Supply Well

Figure 4-1. Potential Pilot Study Supply Wells.

Table 4-2

SHAD Pilot Study Groundwater Characteristics
(22 December 1989)

Parameter	Well 403A	Well 407A	Well 431A
Volatile Organics			
Trichloroethene, μg/L	5 u	34	5 u
Metals			
Arsenic, total, μg/L	143	214	11.7
Cadmium, total, μg/L	10.0 u	10.0 u	10.0 u
Cobalt, total, μg/L	50.0 u	50.0 u	50.0 u
Chromium, total, μg/L	18.0	10.0 u	10.0
Copper, total, μg/L[a]	8.1	6.8	15.1
Iron, total, μg/L	7,070	4,020	18,000
Lead, total, μg/L[a]	9.6	16.8	15.9
Selenium, total, μg/L	6.3	9.5	5.0 u
Zinc, total, μg/L	172	71.2	196
Inorganics			
Ammonia nitrogen, mg/L	0.10 u	0.10 u	0.10 u
Nitrate/nitrite as nitrogen, mg/L[b]	17.7	23.5	43.1
Sulfate, mg/L	125 u	125 u	125 u
Phosphate as phosphorous, mg/L[c]	1.6	2.3	0.67 u
Other Parameters			
Temperature, °F	53.5	56.0	56
Conductivity, μmhos	1,479	1,250	756
pH	7.47	8.26	7.90

[a] Laboratory control standards for copper and lead were outside the control limits of 80-120%.

[b] Measured as nitrite nitrogen after reduction of nitrate; MCAWW Method 353.1.

[c] Samples analyzed beyond regulated holding time.

Note: u = Compound was analyzed but not detected. The associated numerical value is the sample detection limit.

4.2 ARSENIC SPECIATION

Arsenic speciation in the potential pilot study supply wells was evaluated in order to determine the need for an oxidation step during the pilot study. As discussed in Section 2, most of the candidate treatment technologies are more effective in removing As^{+5} than As^{+3}. If the groundwater at SHAD contained predominantly As^{+3}, a pre-oxidation step using chlorine as the oxidant was planned [32]. Futhermore, a separate experiment was planned to evaluate required chlorine dosages to effectively oxidize the observed As^{+3} concentrations while minimizing the excess chlorine residual in the pilot system discharge [32].

Sampling for the initial characterization of arsenic speciation in MW-403A, 407A, and 431A took place on 28 February 1990. Additional sampling, from MW-440A and at the actual pilot plant influent, took place on 23 May 1990, during the pilot plant phase of the study. Sampling and analytical procedures were as described in Subsection 3.4.5. Arsenic speciation data from these samples are presented in Table 4-3.

These data demonstrate that arsenic in the sampled wells existed almost entirely (≥99.5%) as the oxidized As^{+5} form. This result was somewhat contrary to that anticipated in the presumably anoxic, low redox potential groundwater [3,5,6]. Similar observations were, however, drawn from a previous study in Hanford, California [6]. Whether the observed speciation pattern reflects some regional groundwater conditions or local influences is not known.

Comparison of the data in Table 4-3 with those in Table 4-2 indicates that total arsenic levels in each well (MW-403A, MW-407A, and MW-431A) were comparable in the two rounds of sampling despite the differences in the time of sampling and in the sampling and analytical procedures used.

Although unexpected, the finding that the arsenic to be treated existed in the oxidized form essentially obviated the need for a chlorine oxidation step in the pilot study. Since As^{+3} concentrations were all well below the MCL of 50 μg/L, effective removal of the pre-existing As^{+5} would likely permit attainment of the discharge standard. The incremental increase in bed life (before breakthrough at 50 μg/L total arsenic) which might be achieved by oxidation of the low levels of As^{+3} would likely be slight.

Therefore, based upon the results of the initial arsenic speciation analysis, as confirmed in subsequent resampling during the pilot study phase, chlorine oxidation of the influent groundwater was not employed in this study.

Table 4-3

SHAD Pilot Study
Groundwater Arsenic Speciation Data

Parameter	MW-403A 28 February 1990	MW-407A 28 February 1990	MW-431A 28 February 1990	MW-440A 23 May 1990	Pilot Plant Influent 23 May 1990
Arsenite, (As^{+3}), μg/L	0.64	0.77	0.03	0.91	0.84
Arsenate, (As^{+5}), μg/L	133	240	7.47	224	193
Total Arsenic (Std. Dev.), μg/L	133 (± 4.6)	241 (± 25.1)	7.50 (± 0.34)	225	194

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The planned arsenic oxidation test [32], which was conducted concurrently with isotherm testing and prior to completion of the initial speciation analysis, is discussed in Subsection 4.3.

4.3 ARSENIC OXIDATION TEST

The objective of the arsenic oxidation test was to estimate the chlorine dose which would be required to achieve oxidation of any trivalent arsenic present in the influent groundwater. The procedure of this test, discussed in the Test Plan [32], consisted of adding varying dosages of hypochlorite solution to aliquots of the raw groundwater followed by agitation and analysis for As^{+3}, As^{+5}, and chlorine residual. In order to facilitate planning for the field pilot study, this experiment was conducted concurrently with isotherm testing and prior to completion of the initial arsenic speciation testing. As discussed in Subsection 4.2, those data indicated that As^{+5} was the dominant form present in the raw groundwater, and therefore that no oxidation step would be required. As would be expected, data from the arsenic oxidation test were of limited significance since reduced arsenic was largely absent from the test water. Arsenite concentrations were insignificant in all test samples including the blank. These data are tabulated in Appendix F.

SECTION 5

ISOTHERM TESTING

A single round of isotherm testing was conducted for the purpose of examining equilibrium adsorption characteristics of the various adsorption media and to select media for use in pilot testing. Preliminary selection of media types for isotherm testing was based upon literature and vendor information.

5.1 ION EXCHANGE ISOTHERMS

Four commercially available ion exchange resins were evaluated during isotherm tests:

- Rohm and Haas Amberlite IRA 402
- Rohm and Haas Amberlite IRA 900
- Sybron Ionac A-641
- Sybron Ionac ASB-1

Pertinent characteristics of these resins are summarized in Table 5-1, and product information sheets are presented in Appendix G. The resins recommended by the vendors for this study were all strong base resins. As discussed in Subsection 2.2.1, strong base resins have most commonly been used in previous studies as well.

Isotherm tests were conducted using a composite of samples drawn from MW-403A and MW-407A on 10 February 1990. Previous sampling, presented in Section 4-1, had indicated that arsenic in the other candidate supply well, MW-431A, was too low to be of value in this study.

IE isotherms were conducted at the natural pH of the groundwater. Previous studies have not indicated substantial pH dependence over the range of pH 4 to pH 13 [23]. Pretreatment for the removal of TCE was accomplished by aeration of the raw groundwater sample using air spargers.

Isotherm test data for the four selected IE resins are summarized in Table 5-2 and presented graphically in Figure 5-1.

As indicated in Table 5-2, all four resins achieved equilibrium arsenic concentrations in solution of less than 50 $\mu g/L$ at high resin dosages. Therefore, each resin has the

Table 5-1

Anion Exchange Resin Characteristics

Resin	Type	Ionic Form
IRA 402	Type I, strongly basic, porous gel	Chloride
IRA 900	Type I, strongly basic, macroreticular	Chloride
Ionac A-641	Type I, strongly basic, macroporous	Chloride
Ionac ASB-1	Type I, strongly basic, gel	Chloride

Table 5-2

Ion Exchange Resin Isotherm Data

Resin Dosage (mg/L)	A-641		IRA-402		IRA-900		ASB-1	
	C_e (mg/L)	q_e (mg/mg)	C_e (mg/L)	q_e (mg/mg)	C_e (mg/L)	q_e (mg/mg)	C_e (mg/L)	q^e (mg/mg)
Blank (0)	0.191	--	0.172	--	0.178	--	0.194	--
200	0.169	1.1×10^{-4}	0.170	1.0×10^{-5}	0.188	-5.0×10^{-5}	0.184	5.0×10^{-5}
500	0.146	9.0×10^{-5}	0.166	1.2×10^{-5}	0.170	1.6×10^{-5}	0.182	2.4×10^{-5}
2,500	0.126	2.6×10^{-5}	0.122	2.0×10^{-5}	0.126	2.1×10^{-5}	0.138	2.2×10^{-5}
5,000	0.0985	1.9×10^{-5}	0.825	1.8×10^{-5}	0.091	1.7×10^{-5}	0.0895	2.1×10^{-5}
20,000	<0.05	$>7.1 \times 10^{-6}$	<0.05	$>6.1 \times 10^{-6}$	<0.05	$>6.4 \times 10^{-6}$	<0.05	$>7.2 \times 10^{-6}$
40,000	<0.05	$>3.5 \times 10^{-6}$	<0.05	$>3.1 \times 10^{-6}$	<0.05	$>3.2 \times 10^{-6}$	<0.05	$>3.6 \times 10^{-6}$

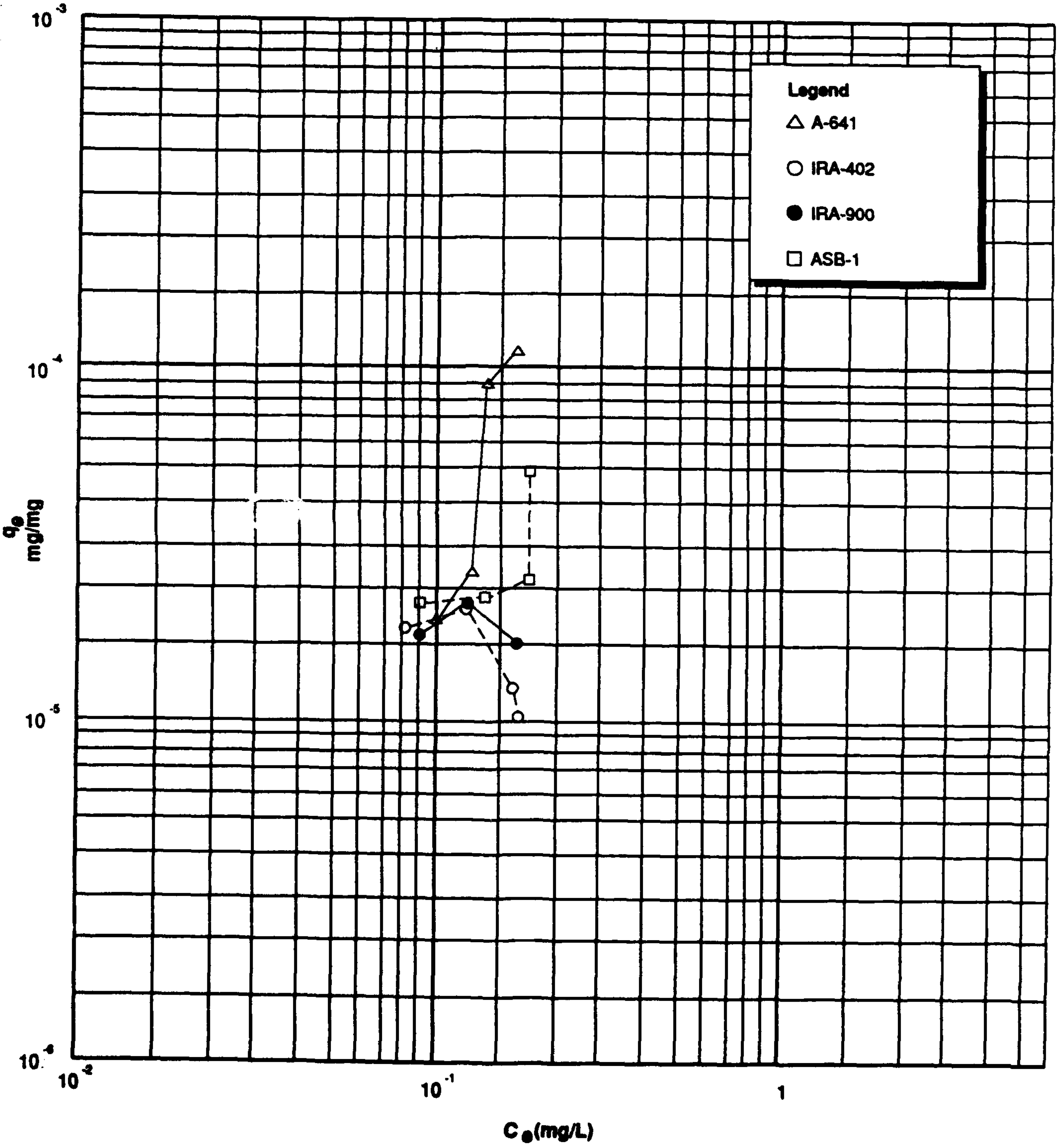

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Figure 5-1. Isotherm test results for ion exchange resins.

potential for achieving the MCL discharge criterion. Figure 5-1 indicates that in general Ionac A-641 had the highest equilibrium adsorption capacity (q_e), followed by ASB-1, IRA-402, and IRA-900. However, the resins did not exhibit clearly recognizable Freundlich isotherm adsorption characteristics.

Based upon these data, Ionac A-641 was selected for pilot scale testing as being superior in performance to the other resins tested. Although ASB-1 exhibited generally higher q_e values than the other resins tested, IRA-402 was selected as the second resin for pilot testing in order to provide a clear contrast between resin types and manufacturers.

5.2 ACTIVATED CARBON ISOTHERMS

Activated carbon isotherm testing was performed according to the basic protocol presented in Subsection 3.2.1. The following carbons were evaluated in isotherm testing:

- Calgon Filtrasorb 200
- Calgon Filtrasorb 300
- Calgon Filtrasorb 400
- Hydrodarco 3000
- Hydrodarco 4000

Characteristics of these carbon types are summarized in Table 5-3.

Based upon previous literature which indicated that adsorption of arsenic on GAC may be pH-dependent [17], isotherms using the above-noted carbons were conducted at pH 4. In addition, one isotherm test was conducted at pH 7, using Filtrasorb 400, to verify the reported pH dependency. Pretreatment for the removal of TCE was accomplished by aeration of the groundwater sample, and pH was adjusted using sulfuric acid [32]. Activated carbons were pulverized prior to isotherm testing.

Results from GAC isotherm testing are tabulated in Table 5-4. Isotherms for all five carbons, conducted at pH 4, are presented in Figure 5-2. In general, these data do not exhibit the expected Freundlich isotherm behavior. Therefore, Freundlich equation constants were not estimated.

Examination of the data in Table 5-4 indicates that in general little, if any, adsorption occurred at carbon dosages lower than 5,000 mg/L. At a carbon dosage of 5,000 mg/L the lowest C_e values were obtained with Calgon Filtrasorb 400 and Hydrodarco 3000.

Table 5-3

Characteristics of Selected Carbons

	Calgon Filtrasorb 200	Calgon Filtrasorb 300	Calgon Filtrasorb 400	Hydrodarco 3000	Hydrodarco 4000
Specific Surface Area, m^2/g	850-900	950-1,050	1,000-1,200	550-650	625
Pore Volume, cm^3/g	N/A*	0.85	0.94	1.0	1.0
Iodine Number	850	900	1,000	550	600
Mean Particle Diameter, mm	0.8-1.0	1.5-1.7	0.9-1.1	1.4-1.6	0.8-1.0

*Not available.

Table 5-4

Granular Activated Carbon Isotherm Data

Carbon Dosage (mg/L)	Filtrasorb 200 pH = 4		Filtrasorb 300 pH = 4		Filtrasorb 400 pH = 4		Filtrasorb 400 pH = 7		Hydrodarco 3000 pH = 4		Hydrodarco 4000 pH = 4	
	C_e (mg/L)	q_e (mg/mg)	C_e (mg/L)	q_e (mg/mg)	C_e (mg/L)	q_e (mg/mg)	C_e (mg/L)	q_e (mg/mg)	C_e (mg/L)	q_e (mg/mg)	C_e (mg/L)	q_e (mg/mg)
Blank (0)	0.178	--	0.172	--	0.174	--	0.196	--	0.174	--	0.192	--
200	0.178	0	0.177	-2.5×10^{-5}	0.180	-3.0×10^{-5}	0.196	0	0.181	-3.5×10^{-5}	0.192	0
500	0.182	-8.0×10^{-6}	0.116	1.1×10^{-4}	0.164	2.0×10^{-5}	0.191	1.0×10^{-5}	0.177	-6.0×10^{-6}	0.187	1.0×10^{-5}
2,500	0.184	-2.4×10^{-6}	0.166	2.4×10^{-6}	0.138	1.4×10^{-5}	0.196	0	0.137	1.5×10^{-5}	0.166	1.0×10^{-5}
5,000	0.184	-1.2×10^{-6}	0.158	2.8×10^{-6}	0.103	1.4×10^{-5}	0.209	-2.6×10^{-6}	0.077	1.9×10^{-5}	0.116	1.5×10^{-5}
20,000	0.112	3.3×10^{-6}	<0.05	$>6.1 \times 10^{-6}$	<0.05	$>6.2 \times 10^{-6}$	0.280	-4.2×10^{-6}	<0.05	$>6.2 \times 10^{-6}$	0.074	5.9×10^{-6}
40,000	0.065	2.8×10^{-6}	<0.05	$>3.1 \times 10^{-6}$	<0.05	$>3.1 \times 10^{-6}$	0.333	-3.4×10^{-6}	<0.05	$>3.1 \times 10^{-6}$	<0.05	$>3.6 \times 10^{-6}$

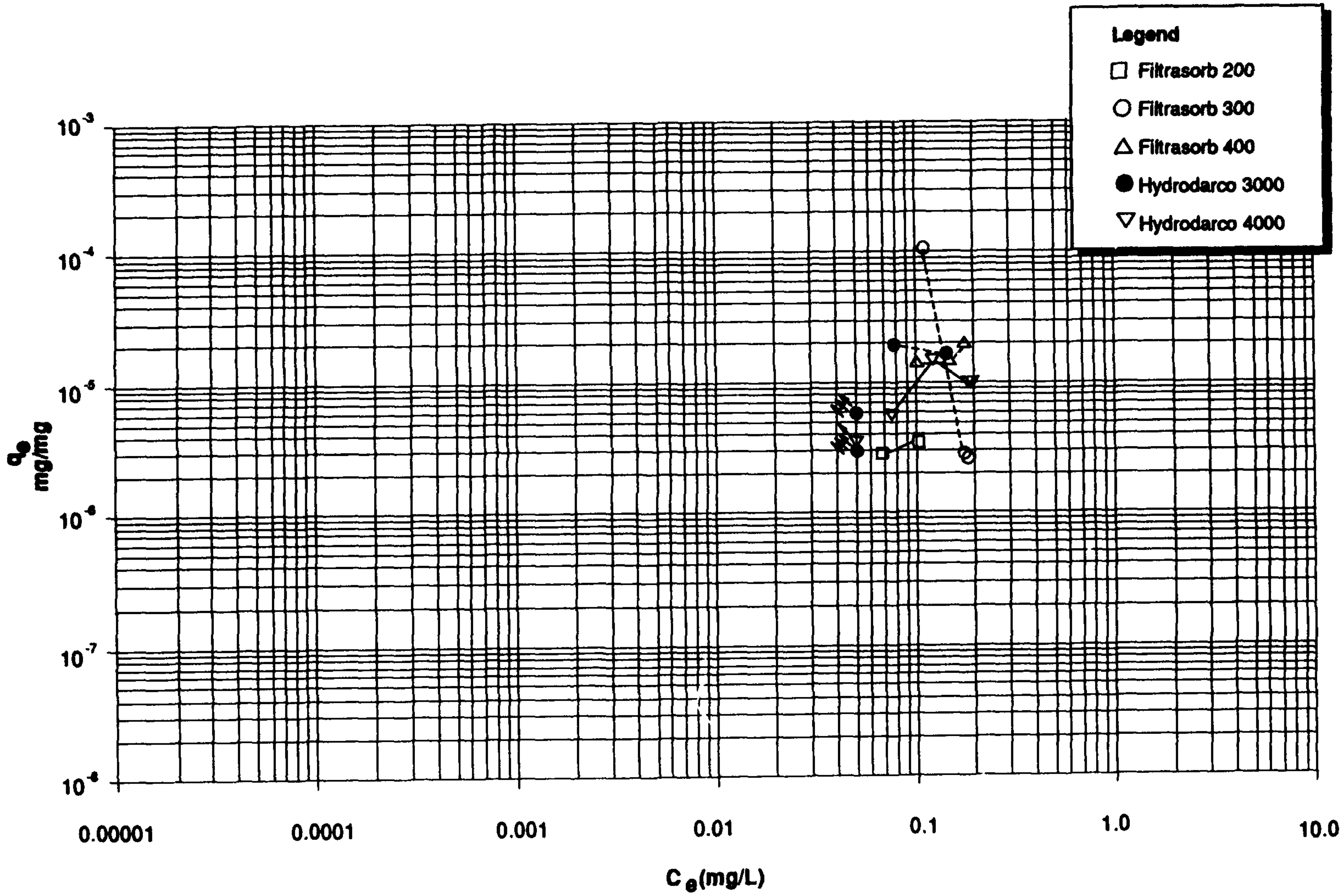

Figure 5-2. Activated carbon isotherms.

268-1746

C_e values at or below 50 µg/L were achieved by Filtrasorb 300, Filtrasorb 400 (at pH 4) and Hydrodarco 3000 only at carbon dosages of 20,000 µg/L and above. Hydrodarco 4000 achieved this criterion only at a carbon dosage of 40,000 mg/L, and Filtrasorb 200 did not achieve this level at any value within the range of carbon dosages examined.

Filtrasorb 400 exhibited anomalous behavior at pH 7, with progressively higher Ce values (even exceeding the blank concentration) at carbon dosages of 5,000 µg/L and higher (see Table 5-4). These results are therefore not presented graphically. These data would appear to suggest desorption of pre-existing metals from the carbon. This would be more likely, however, at reduced pH. Nevertheless, at carbon dosages below 5,000 µg/L the net removal achieved by Filtrasorb 400 at pH 7 was lower than at pH 4. These results are in qualitative agreement with previously discussed literature. Therefore, the decision was made to conduct activated carbon pilot studies at pH 4.

Based upon the results of the carbon isotherm study Filtrasorb 400 and Hydrodarco 3000 were selected for evaluation in the pilot study phase.

5.3 ACTIVATED ALUMINA ISOTHERMS

While several grades of AA are produced for particular applications, the form generally used for water treatment applications (such as fluoride or arsenic removal) is Type F-1 granular activated alumina, produced by Alcoa. Therefore, Alcoa F-1 was used in this study exclusively.

Properties of F-1 AA are summarized in Table 5-5, and product data are in Appendix F. Type F-1 is almost entirely alpha alumina and is more inert than other aluminas [25]. While a variety of mesh sizes is produced, Alcoa recommends the 24 x 48 mesh size for arsenic removal to provide the best arsenic removals and minimal operating problems (such as plugging of the alumina bed).

Since the removal of arsenic from water by AA is pH-dependent [10,16,17,27] (although with good removal in the range of pH 4 to pH 7), isotherms were performed at pH 4 and at pH 6 to evaluate whether lowering the pH in the pilot study would improve performance. Sulfuric acid was used to lower the pH; and as with all isotherm tests, TCE was stripped from solution using batch aeration prior to conducting the isotherm tests.

Data from AA isotherm tests are tabulated in Table 5-6 and presented graphically in Figure 5-3. Based upon previous studies [23], the maximum AA dosages used in this study were lower than the maximum IE resin or GAC dosagesemployed. As shown

Table 5-5

Properties of Alcoa F-1 Activated Alumina

Chemical Constituents		wt%
	Al_2O_3	92.1
	SiO_2	0.72
	Fe_2O_3	0.11
	Na_2O	0.57
	*LOI, (250-1,200°C)	5.8
Physical Properties		
	Graded mesh sizes	1/4 x 8, 8 x 14, 14 x 28, 28 x 48, 48 x 100, -100, -325

*LOI = Loss on ignition.

Source: Vendor Literature; see Appendix F.

Table 5-6

Activated Alumina Isotherm Data
Alcoa Type F-I

Activated Alumina Dosage (mg/L)	pH 4		pH 6	
	C_e (mg/L)	q_e (mg/mg)	C_e (mg/L)	q_e (mg/mg)
Blank (0)	0.190	–	0.188	–
200	0.116	3.7×10^{-4}	0.140	2.4×10^{-4}
500	<0.05	$>2.8 \times 10^{-4}$	0.0885	2.0×10^{-4}
1,000	<0.01	$>1.8 \times 10^{-4}$	<0.05	$>1.4 \times 10^{-4}$
2,500	<0.01	$>7.2 \times 10^{-5}$	<0.01	$>7.1 \times 10^{-5}$
5,000	<0.01	$>3.6 \times 10^{-5}$	<0.01	$>3.6 \times 10^{-5}$
10,000	<0.01	$>1.8 \times 10^{-5}$	<0.01	$>1.8 \times 10^{-5}$

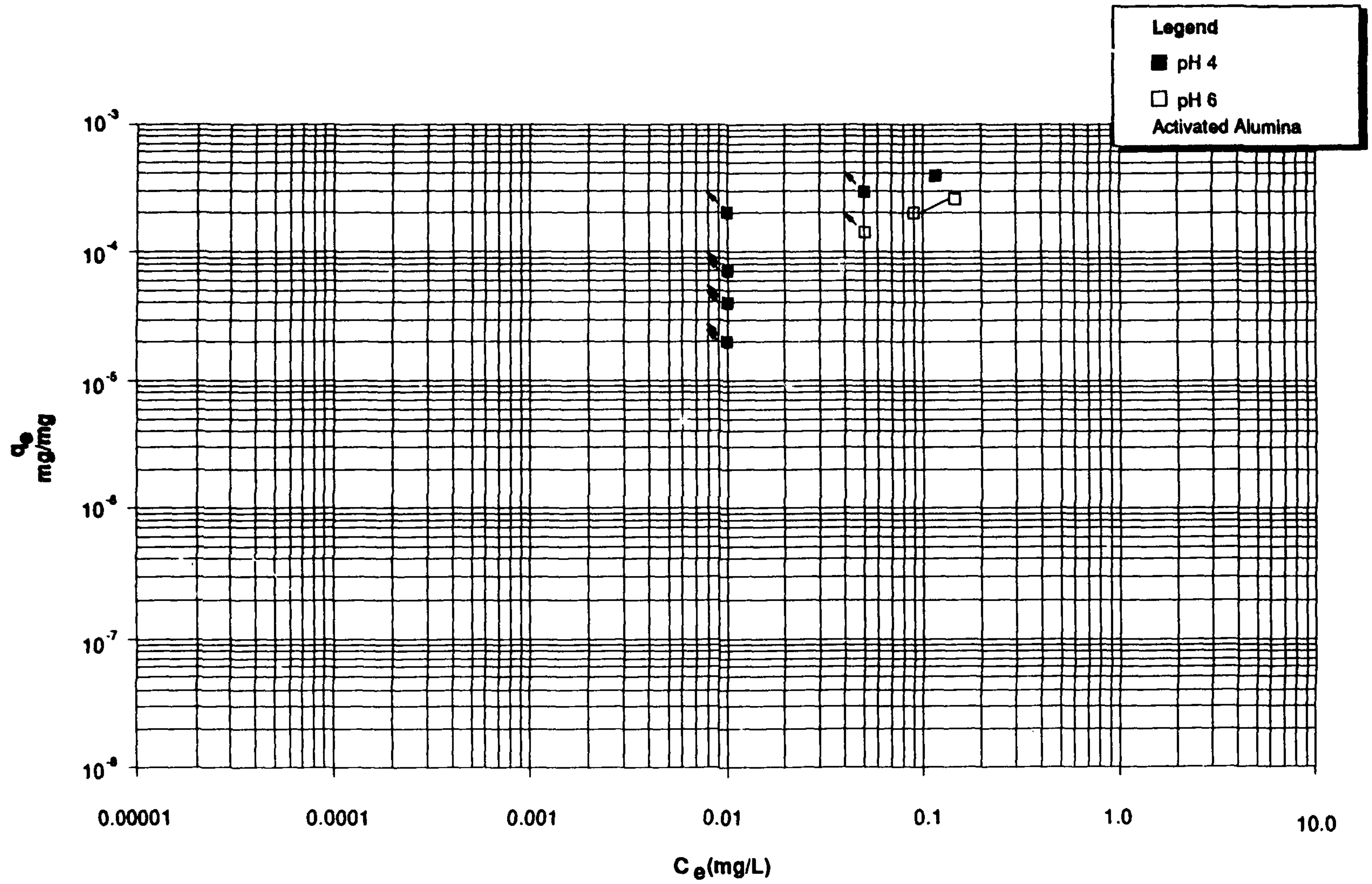

Figure 5-3. Activated alumina isotherms.

268-1749

in Table 5-6, the performance of F-1 AA, in terms of the equilibrium solution concentration of arsenic (C_e), was good, with C_e values lower than 50 µg/L being achieved at an alumina dosage of 500 mg/L at pH 4, and at a dosage of 1,000 mg/L at pH 6. Comparison of these data with IE results in Table 5-2 and with GAC results in Table 5-4 indicates that activated alumina at either pH achieved this level of performance at lower dosages (in terms of net weight of adsorbent per volume of contaminated water) than the other adsorbent media tested. Likewise, the maximum contaminant loading (q_e) values achieved by AA at pH 4 and pH 6 were higher than the maxima achieved by other adsorbent media. These data suggest that AA may provide better performance than IE resins or GAC in continuous flow adsorption columns.

Because arsenic was removed to below the quantifiable level (generally 10 µg/L) over a wide range of alumina dosages, isotherm plots in Figure 5-3 show only a few quantifiable values. Formal interpretation of the isotherm relationship and estimation of Fruendlich constants was therefore not attempted.

The data presented in Table 5-6 indicate that somewhat better arsenic removal was achieved at pH 4 than at pH 6 although, as discussed above, performance at the latter value still exceeded that achieved with other adsorbent media. These results suggest that better performance and/or lower cost might be achieved in a continuous flow treatment system by lowering the pH of the contaminated influent groundwater. It should be recognized that the lowest pH value which would be permissible for direct discharge of the treated effluent would be pH 6. Therefore, operation of a treatment system at pH 4 may require two, rather than one, additional unit operations (pretreatment to lower pH and post treatment to neutralize the effluent for discharge). Since good performance was achieved at pH 6 as well as pH 4, the ultimate selection of operating pH for a full-scale treatment system may depend upon the economic tradeoff between the increased arsenic removal and adsorbent bed life achieved at pH 4 and the capital and operating costs associated with the additional unit operations. For purposes of the pilot phase of this study, the determination was made to evaluate the potential performance of AA at reduced pH.

5.4 SUMMARY OF ISOTHERM TESTING

The single round of isotherm tests performed during this study indicated that each of the major media types (IE resin, GAC, and AA) may be capable of treating arsenic-bearing groundwater at SHAD to less than 50 µg/L. The lowest required dosages (weight of adsorbent per volume of contaminated water) and highest q_e values for equilibrium adsorption were observed with F-1 AA. In general, the selected ion exchange resins appeared to perform better than activated carbon when compared on the basis of adsorbent dosages, with GAC achieving equilibrium arsenic concentrations less than 50 μg/L only at high carbon dosages. Table 5-7 summarizes the results of isotherm testing in terms of the media selected for pilot scale evaluation.

Table 5-7

Summary of Media Selection

Adsorbent	Adsorbents Screened in Isotherms	Adsorbents Selected for Pilot Testing
Ion Exchange Resin	Rohm and Haas Amberlite IRA-402 Rohm and Haas Amberlite IRA-900 Sybron Ionac A-641 Sybron Ionac ASB-1	Rohm and Haas Amberlite IRA-402 Sybron Ionac A-641
Activated Carbon	Calgon Filtrasorb 200 Calgon Filtrasorb 300 Calgon Filtrasorb 400 Hydrodarco 3000 Hydrodarco 4000	Calgon Filtrasorb 400 Hydrodarco 3000
Activated Alumina	Alcoa Type F-1, 28 x 48 Mesh	Alcoa Type F-1, 28 x 48 Mesh

SECTION 6

PILOT TESTING RESULTS

6.1 OBJECTIVES

The overall objective of the pilot scale test program was to evaluate the potential performance of the selected media in removing arsenic under continuous flow conditions simulating those likely to be employed in a full scale treatment system. Specific objectives pertinent to this effort included:

- To determine the effectiveness of the media in removing arsenic to the MCL (50 µg/L) under continuous flow conditions.
- To determine the adsorption capacities of the media.
- To select the best performing media.
- To evaluate potential operating conditions for a treatment system, including hydraulic loading rate and EBCT.

6.2 TEST PROGRAM

These objectives were addressed in a test program conducted at SHAD using USATHAMA's skid-mounted transportable pilot system described in Subsection 3.3. The overall duration of the pilot test program (not including mobilization and demobilization) was approximately 17 weeks. Construction of the pilot system at SHAD began on 5 February 1990. The pilot system was located in and around Building 646 in the South Balloon Area. Pilot test runs began on 19 March 1990 and ended on 13 July 1990. Dismantling of the pilot system and demobilization commenced on 18 July 1990 and was completed on 24 August 1990. The pilot system was placed into storage at SHAD pending further disposition by USATHAMA. Wastes generated during the study, including spent adsorption media and chemical reagents, were turned over to SHAD for disposal.

The test program encompassed a total of seven experimental runs. The first five of these runs (Runs 1, 2, 3, 4, and 5) were conducted in accordance with the Test Plan [32] to evaluate the performance of each of the five selected media (Rohm and Haas IRA 402, Sybron Ionac A-641, Hydrodarco 3000, Calgon Filtrasorb 400, and Alcoa

Type F-1) at three different hydraulic loading rates and EBCT values. Following completion of the planned test program, two additional runs were conducted:

- Run 6, to reevaluate or confirm the results of Run 3 with respect to activated carbon performance.
- Run 7, to evaluate the removal of arsenic by AA without prior TCE removal or pH adjustment and to evaluate the removal of arsenic by AA without pH adjustment.

The logic behind these additional runs will be discussed in the individual results subsections. Table 6-1 presents a summary of the entire pilot test program.

6.3 COLUMN OPERATION

Test columns used in all pilot runs were operated in accordance with the detailed procedures presented in the Test Plan [32] and the O&M Manual [35]. The following subsections briefly resummarize these procedures.

6.3.1 COLUMN STARTUP AND OPERATION

Each adsorbent bed rested upon a 1-ft-thick base consisting of a layer of stone (3/8 inch x 1/2 inch or 3/8 inch x 5/8 inch) sandwiched between two layers of borosilicate glass wool, specified as being free from heavy metals, fluorine, and alumina. Adsorption media were prepared as water slurries, allowed to soak overnight, and then added to the columns to provide a settled bed depth of 4 ft. The column was sealed, leak tested and backwashed prior to commencing each test run. Once begun, each test ran continuously until breakthrough with the exception of brief shutdowns for necessary repairs. Breakthrough was defined as the MCL of 50 μg/L.

6.3.2 COLUMN SAMPLING

Samples for total arsenic analysis were drawn from the effluent of the primary adsorption column at 4-hour intervals. Sample locations are indicated in Figure 3-2. As indicated in the Test Plan, primary column effluent samples from longer intervals (typically 16 hours during the early stages of the run) were routinely analyzed to evaluate system performance. Intermediate samples were stored for subsequent analysis in the event that substantial changes in arsenic concentration were observed between routine analyses, indicating that contaminant breakthrough was occurring.

Table 6-1

Summary of Pilot Study Test Runs

Test	Adsorbent (primary column)	Train[b]	Flow rate (gpm)	hydraulic loading (gpm/ft²)	Bed Depth (ft)	EBCT[a] (min)	Influent pH	Dates (all 1990)	Notes
1a	IRA 402	A	0.2	2	4	14.7	natural[c]	19 - 26 March	
1b	IRA 402	B	0.3	3	4	9.8	natural[c]	19 - 24 March	
1c	IRA 402	C	0.7	7	4	4.2	natural[c]	19 - 23 March	
2a	A-641	A	0.2	2	4	14.7	natural[c]	29 March - 3 April	
2b	A-641	B	0.3	3	4	9.8	natural[c]	29 March - 2 April	
2c	A-641	C	0.7	7	4	4.2	natural[c]	29 March - 1 April	
3a	Hydrodarco 3000	A	0.7	7	4	4.2	±4	28 - 29 April	
3b	Hydrodarco 3000	B	0.2	2	4	14.7	±4	28 - 29 April	
3c	Hydrodarco 3000	C	0.3	3	4	9.8	±4	28 - 29 April	
4a	Filtrasorb 400	A	0.3	3	4	9.8	±4	1 May	
4b	Filtrasorb 400	B	0.7	7	4	4.2	±4	1 May	
4c	Filtrasorb 400	C	0.2	2	4	14.7	±4	1 May	

Table 6-1

Summary of Pilot Study Test Runns (continued)

Test Notes	Adsorbent (primary column)	Train[b]	Flow rate (gpm)	hydraulic loading (gpm/ft^2)	Bed Depth (ft)	EBCT[a] (min)	Influent pH	Dates (all 1990)	Notes
5a	Alcoa F-1	A	0.2	2	4	14.7	4-6	5 May - 17 June	
5b	Alcoa F-1	B	0.3	3	4	9.8	4-6	5 May - 30 May	
5c	Alcoa F-1	C	0.7	7	4	4.2	4-6	5 May - 13 May	
6	Filtrasorb 400	C	0.1	1	4	29.4	natural[c]	9 June - 11 June	distilled H_2O slurry
7a	Alcoa F1	A	0.2	2	4	14.7	natural[c]	21 - 28 June	with TCE spike
7b	Alcoa F1	C	0.3	3	4	9.8	natural[c]	21 - 27 June	with TCE spike
7c	Alcoa F1	A	0.3	3	4	9.8	natural[c]	3 - 13 July	with no TCE spike

[a] Empty bed contact time.
[b] refer to Figure 3-2.
[c] Influent pH generally ranged between 8 and 9.

Samples of the influent to the primary columns were collected. Samples were taken from the effluent of the second adsorption column in each train when the monitoring data indicated that arsenic had broken through the primary column or at periodic intervals. These data are presented in Appendix H. Each tank of collected effluent was sampled and analyzed prior to its discharge to verify compliance with the 50 μg/L effluent criterion.

Additional sampling for arsenic or other parameters as warranted by test conditions is discussed with the results from each test run.

6.3.3 BACKWASHING

Each column was backwashed as needed during the run to remove accumulated solids at the head of the column which interfered with flow and contributed to excessive headloss across the column. In general, columns were backwashed when the headloss across the column exceeded 5 psi, as indicated by the pressure gauges mounted on the inlet and outlet of each column. During backwashing the adsorbent bed was also generally broken up, minimizing plugging or channelling of flow through the bed. Potable water from the SHAD system was used for backwashing. The basic backwash procedure was conducted as described in the Test Plan. In general, the duration of the backwashing operation was approximately 15 minutes. Three samples of the backwash water were taken during the pilot runs and analyzed for total arsenic. Data from these samples are presented in Appendix I. The backwash water was routed to the feed tank to preclude discharge of any desorbed arsenic.

6.3.4 INFLUENT TANK DISINFECTION

During the latter stages of the pilot study runs, problems were encountered with algal growth in the influent holding tanks and feed tank (refer to Figure 3-2). These problems began during a protracted shutdown following the IE runs and prior to beginning activated carbon runs.

In order to avoid potential fouling and clogging of the treatment columns, the influent holding tanks and the feed tank were cleaned and disinfected using hypochlorite bleach prior to restarting the system. Accumulated influent, which had been stored in the tanks during the shutdown, was treated using spare ion exchange media and discharged.

Throughout the remainder of the activated carbon experiments, hypochlorite bleach was used, as necessary to control additional algal growth. However, discussions with Alcoa representatives indicated that hypochlorite would not be preferable for use during the activated alumina runs. Therefore, hydrogen peroxide was added to the feed tank during activated alumina runs to control algal growth.

6.3.5 AIR STRIPPER OPERATION

Although historical data indicated that groundwater from MW-440A did not contain TCE, the influent groundwater was passed through the existing air stripper (see Figure 3-2) as a precautionary measure. The air stripper, which had a design flow rate of 5 gpm, was operated in a batch mode, i.e., batches of groundwater from the influent holding tanks were stripped as needed and stored in the feed tank to be fed to the treatment columns at combined flow rates (for three parallel trains) up to 1.2 gpm.

The air stripper was also used during Run 7 (to be discussed in Section 6.7.2) to remove TCE added to the influent for that run. TCE data for all runs are presented in Appendix J.

6.3.6 EFFLUENT DISCHARGE SAMPLING

Effluent from the treatment columns was collected in one of the holding tanks for analysis prior to discharge. The tank was sampled either when it was full or at another convenient stopping point (such as the end of a run). Any additional effluent produced after sampling the effluent tank was sent to the alternate collection tank. If the results of the analysis indicated that the arsenic concentration in the accumulated effluent exceeded 50 µg/L, the water in that tank was retreated (using spare ion exchange resin) and reanalyzed prior to discharge.

Data from samples taken from the effluent tanks are provided in Appendix K. In one instance (sample D-24, 19 June 1990) the discharged effluent exhibited an arsenic concentration slightly exceeding the discharge standard. This resulted from misinterpretation of the preliminary data report received verbally from the laboratory. The subsequent written confirmatory report indicated a concentration of 54 µg/L.

6.4 ION EXCHANGE RESULTS

6.4.1 RUN 1 - IRA 402

The first ion exchange run, employing Rohm and Haas IRA 402 resin, began on 19 March 1990. Test conditions in the primary columns A1, B1, and C1 were as indicated in Table 6-1. Operating data for columns A1, B1 an C1 are presented in Tables 6-2, 6-3, and 6-4, respectively. Arsenic data are plotted in Figures 6-1, 6-2, and 6-3.

Good initial removal of total arsenic was achieved under all operating conditions tested, with sustained effluent concentrations below the quantifiable reporting limit

Table 6-2
Arsenic Data, IRA 402, 2 gpm/ft²

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)		MCL (ug/l)	Water Temperature (F)
1515	19-Mar-90	0	0	0.0	0.0		50	71.8
1700	19-Mar-90	21	7	161.0	2.5	u	50	70.5
1700	20-Mar-90	309	105	225.0	2.5	u	50	75.3
1700	21-Mar-90	597	202	267.0	2.5	u	50	75.8
1700	22-Mar-90	885	300	220.0	2.5	u	50	
0900	23-Mar-90	1077	365		7.4		50	65.0
1300	23-Mar-90	1125	381		21.6		50	
1700	23-Mar-90	1173	398	237.5	28.7		50	74.5
2100	23-Mar-90	1221	414		36.6		50	64.4
0100	24-Mar-90	1269	430		45.2		50	60.5
0500	24-Mar-90	1317	446		49.0		50	57.3
0900	24-Mar-90	1365	463		63.6		50	69.4
1300	24-Mar-90	1413	479		80.8		50	77.3
1700	24-Mar-90	1461	495	203.0	96.8		50	75.7
2100	24-Mar-90	1509	512		175.0		50	60.4
0100	25-Mar-90	1557	528		138.0		50	58.5
0500	25-Mar-90	1605	544		211.0		50	56.5
1700	25-Mar-90	1749	593	247.0	314.0		50	68.1
0500	26-Mar-90	1893	642		460.0		50	53.9

Table 6-3
Arsenic Data, IRA 402, 3 gpm/ft^2

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	MCL (ug/l)	Water Temperature (F)
1515	19-Mar-90	0	0	0.0	0.0	50	71.8
1700	19-Mar-90	32	11	161.0	2.5 u	50	70.5
1700	20-Mar-90	464	157	225.0	2.5 u	50	75.3
1700	21-Mar-90	896	304	267.0	3.9	50	75.8
1900	21-Mar-90	932	316		4.7	50	71.2
2100	21-Mar-90	968	328		10.4	50	66.8
2300	21-Mar-90	1004	340		17.6	50	65.0
0100	22-Mar-90	1040	352		28.3	50	61.5
0300	22-Mar-90	1076	365		36.2	50	59.8
0500	22-Mar-90	1112	377		50.1	50	59.6
0900	22-Mar-90	1184	401		71.6	50	68.2
1300	22-Mar-90	1256	426		84.3	50	75.4
1700	22-Mar-90	1328	450	220.0	110.0	50	
2100	22-Mar-90	1400	474		153.0	50	
0100	23-Mar-90	1472	499		193.0	50	59.7
0500	23-Mar-90	1544	523		318.0	50	58.2
1700	23-Mar-90	1760	596	237.5	435.0	50	74.5
0500	24-Mar-90	1976	670		485.0	50	57.3

Table 6-4
Arsenic Data, IRA 402, 7 gpm/ft^2

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	MCL (ug/l)	Water Temperature (F)
1515	19-Mar-90	0	0	0.0	0.0	50	71.8
1700	19-Mar-90	74	25	161.0	2.5 u	50	70.5
0500	20-Mar-90	578	196		2.5 u	50	57.8
1700	20-Mar-90	1082	367	225.0	2.5 u	50	75.3
1900	20-Mar-90	1166	395		5.0	50	70.8
2100	20-Mar-90	1250	424		11.7	50	66.5
2300	20-Mar-90	1334	452		21.5	50	62.6
0100	21-Mar-90	1418	481		32.1	50	60.5
0300	21-Mar-90	1502	509		47.8	50	59.9
0500	21-Mar-90	1586	537		63.6	50	58.2
0900	21-Mar-90	1754	594		130.5	50	66.6
1300	21-Mar-90	1922	651		224.0	50	78.2
1700	21-Mar-90	2090	708	267.0	405.0	50	75.8
0500	22-Mar-90	2594	879		585.0	50	59.6
1700	22-Mar-90	3098	1050	220.0	228.0	50	
0500	23-Mar-90	3602	1221		272.5	50	58.2

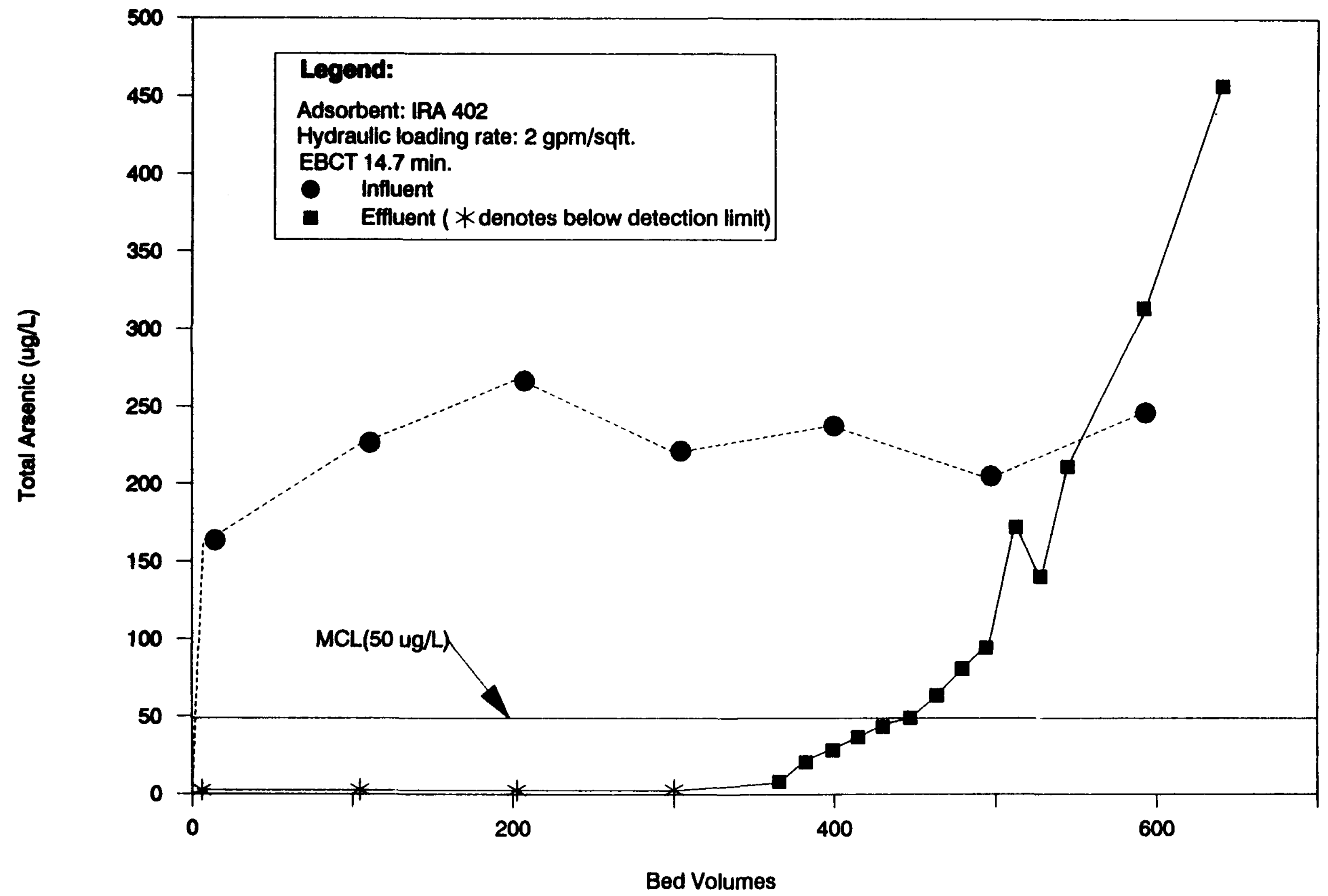

Figure 6-1. Arsenic removal results, Run 1a.

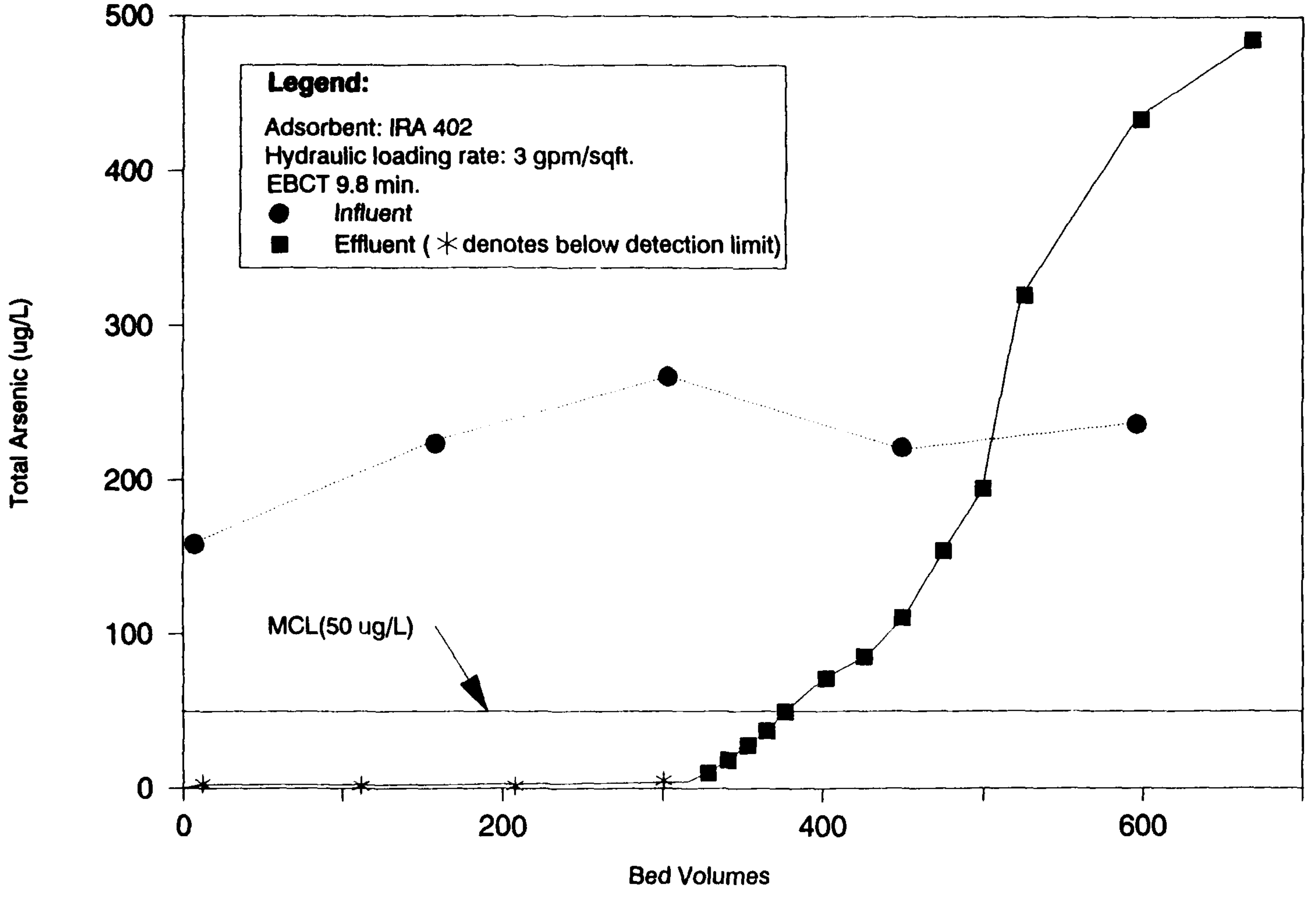

Figure 6-2. Arsenic removal results, Run 1b.

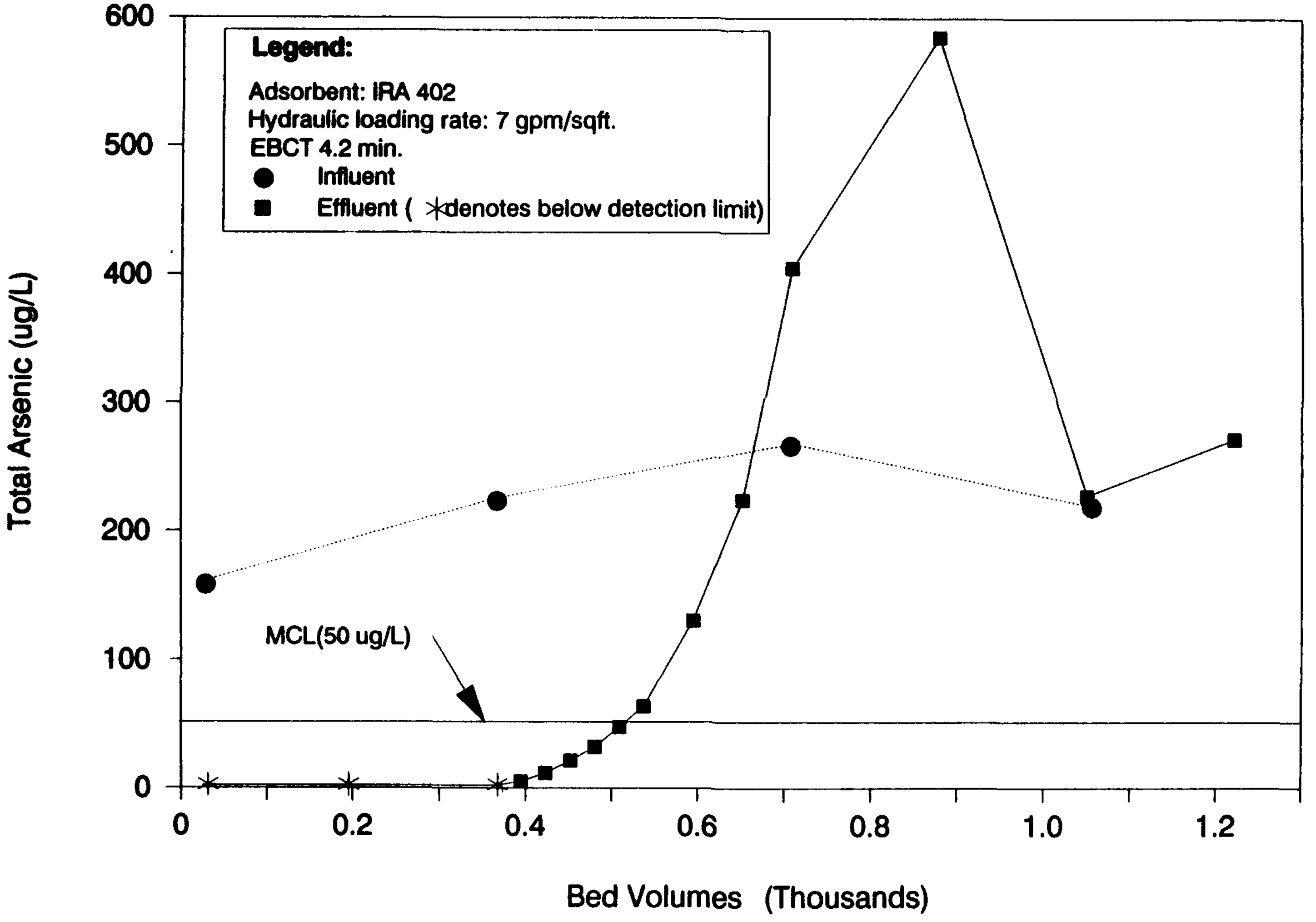

Figure 6-3. Arsenic removal results, Run 1c.

of 2.5 $\mu g/L$, and well below the breakthrough criterion of 50 $\mu g/L$. Once arsenic appeared in the effluent, breakthrough occurred quickly. Effluent arsenic concentrations rose rapidly and ultimately exceeded the influent concentration at all three operating conditions. In the case of column C1 (for which, because of its short EBCT, a number of bed volumes were processed before shutdown), the effluent concentration decreased again to approximate the influent levels. These results suggest a brief period of desorption of arsenic from the resin, possibly as a result of preferential replacement by interfering anions (such as chloride or sulfate). It is possible that columns A1 and B1 would have exhibited similar behavior had the runs been extended. While this desorption phenomenon may be of some concern in a full scale treatment system, it should be noted that the operating life of the adsorption column would be based upon an effluent concentration conservatively below the discharge criterion. Therefore, as long as the breakthrough characteristics are understood, the brief period of desorption should be avoidable.

These data also suggest relatively little effect of operating conditions on bed life, at least over the range of such conditions evaluated. Breakthrough above the effluent criterion occurred between 300 and 500 bed volumes under all three operating conditions, without clear correlation to those conditions. In fact, the longest bed life (and largest volume of water treated before breakthrough) was achieved in this study at the highest loading rate and shortest EBCT. The apparent lack of correlation between loading and performance over this range may reflect rapid kinetics of the exchange process itself. In any event, these data do not demonstrate a requirement for low loading rates or long contact times.

Table 6-5 presents the estimated arsenic loading on the ion exchange resin at the breakthrough point. These calculations are based upon the (weighted) average influent concentration and approximate volume of water treated at the breakthrough point. In calculating the total quantity of arsenic removed, the quantity discharged in the column effluent between the point at which arsenic was first detected and final breakthrough at 50 $\mu g/L$ was considered insignificant. The estimated resin loadings at breakthrough shown in Table 6-5 were somewhat higher than equilibrium isotherm loadings at $C_e = \pm 50$ $\mu g/L$, shown in Table 5-2.

6.4.2 RUN 2 - IONAC A-641

Run 2, using Sybron Ionac A-641 ion exchange resin, began on 29 March 1990. Operating conditions in the three primary columns (A1, B1, and C1) are presented in Table 6-1. Operating data for columns A1, B1, and C1 are presented in Tables 6-6, 6-7, and 6-8, respectively. Arsenic results are presented graphically in Figures 6-4, 6-5, and 6-6.

Table 6-5

Arsenic Loading at Breakthrough
Rohm and Haas IRA 402

Run	1a	1b	1c
Hydraulic Loading Rate (gpm/ft^2)	2	3	7
EBCT (minutes)	14.7	9.8	4.2
Influent Arsenic, weighted average (μg/L)	227.8	227.1	200.5
Volume Treated at Breakthrough (gal, approximate)	1320	1110	1510
Resin Weight, primary column (lb*)	17	17	17
Total Arsenic Removed at Breakthrough (lb)	2.5×10^{-3}	2.1×10^{-3}	2.5×10^{-3}
Arsenic Loading on Resin at Breakthrough (lb/lb)	1.5×10^{-4}	1.2×10^{-4}	1.5×10^{-4}

*Based upon vendor literature for packed density.

Table 6-6
Arsenic Data, Ionac A-641, 2 gpm/ft^2

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration		MCL (ug/l)	Water Temperature (F)
				Influent (ug/l)	Effluent (ug/l)		
1630	29-Mar-90	0	0	0.0	0.0	50	
1700	29-Mar-90	6	2	225.0	2.5 u	50	70.7
0500	30-Mar-90	150	51		2.5 u	50	63.4
1700	30-Mar-90	294	100	265.0	2.5 u	50	72.0
0500	31-Mar-90	438	148		2.5 u	50	54.6
1700	31-Mar-90	582	197	225.0	2.5 u	50	71.8
2100	31-Mar-90	610	207		6.0	50	61.6
0100	01-Apr-90	658	223		15.6	50	55.5
0500	01-Apr-90	706	239		23.4	50	54.9
1300	01-Apr-90	802	272		35.5	50	70.6
1500	01-Apr-90	826	280		45.5	50	75.7
1700	01-Apr-90	850	288	237.0	62.0	50	77.3
2100	01-Apr-90	898	304		92.2	50	65.5
0100	02-Apr-90	946	321		132.0	50	57.4
0500	02-Apr-90	994	337		196.0	50	54.6
0900	02-Apr-90	1042	353		249.0	50	59.5
1300	02-Apr-90	1090	369		274.0	50	73.8
1700	02-Apr-90	1138	386	250.0	309.0	50	78.5
0500	03-Apr-90	1282	435		426.0	50	61.2

Table 6-7
Arsenic Data, Ionac A-641, 3 gpm/ft^2

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	MCL (ug/l)	Water Temperature (F)
1630	29-Mar-90	0	0	0.0	0.0	50	
1700	29-Mar-90	9	3	225.0	2.5 u	50	70.7
1700	30-Mar-90	441	149	265.0	2.5 u	50	72.0
1900	30-Mar-90	477	162		2.5 u	50	67.3
2100	30-Mar-90	513	174		2.5 u	50	63.4
2300	30-Mar-90	549	186		2.5 u	50	58.7
0100	31-Mar-90	585	198		4.2	50	58.0
0300	31-Mar-90	621	211		10.1	50	56.8
0500	31-Mar-90	657	223		21.5	50	54.6
0700	31-Mar-90	693	235		30.8	50	57.5
0900	31-Mar-90	729	247		41.5	50	62.9
1100	31-Mar-90	765	259		86.8	50	71.2
1300	31-Mar-90	801	272		107.0	50	73.8
1500	31-Mar-90	837	284		140.0	50	72.2
1700	31-Mar-90	873	296	225.0	167.0	50	71.8
2100	31-Mar-90	945	320		243.0	50	61.6
0100	01-Apr-90	1017	345		310.0	50	55.5
0500	01-Apr-90	1089	369		320.0	50	54.9
1700	01-Apr-90	1305	442	237.0	380.0	50	77.3
0500	02-Apr-90	1521	516		420.0	50	54.6

Table 6-8
Arsenic Data, Ionac A-641, 7 gpm/ft²

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	MCL (ug/l)	Water Temperature (F)
1630	29-Mar-90	0	0	0.0	0.0	50	
1700	29-Mar-90	21	7	225.0	2.5 u	50	70.7
1900	29-Mar-90	105	36		2.5 u	50	66.2
2100	29-Mar-90	189	64		2.5 u	50	61.7
2300	29-Mar-90	273	93		275.0	50	57.7
0100	30-Mar-90	357	121		2.5 u	50	57.2
0300	30-Mar-90	441	149		2.5 u	50	57.6
0500	30-Mar-90	525	178		11.8	50	63.4
0700	30-Mar-90	609	206		46.9	50	58.8
0900	30-Mar-90	693	235		108.0	50	64.7
1100	30-Mar-90	777	263		176.0	50	68.2
1300	30-Mar-90	861	292		2.5	50	74.1
1500	30-Mar-90	945	320		311.0	50	76.0
1700	30-Mar-90	1029	349	265.0	345.0	50	72.0
0500	31-Mar-90	1533	520		425.0	50	54.6
1700	31-Mar-90	2037	691	225.0	207.0	50	71.8
0500	01-Apr-90	2541	861		241.0	50	54.9

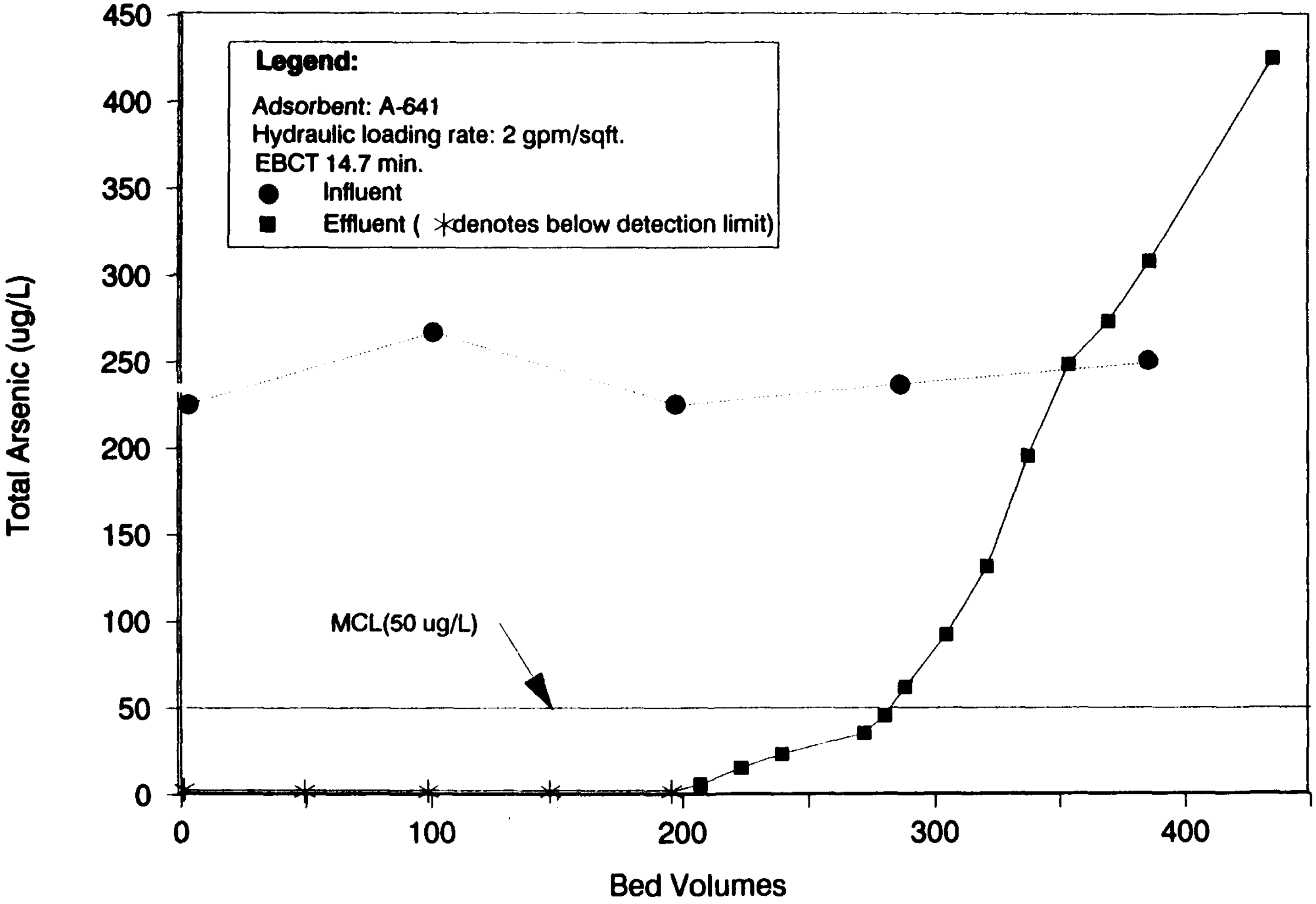

Figure 6-4. Arsenic removal results, Run 2a.

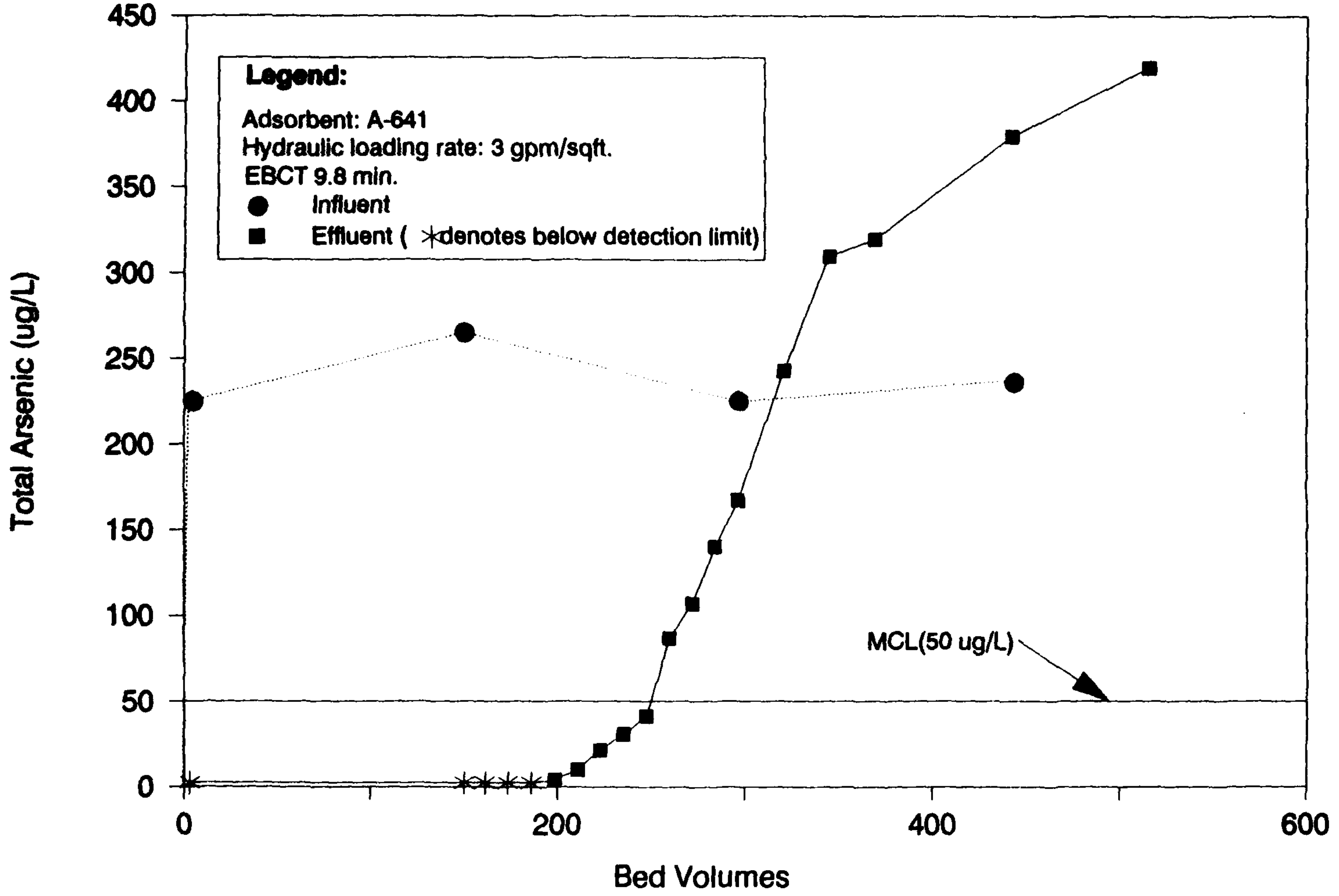

Figure 6-5. Arsenic removal results, Run 2b.

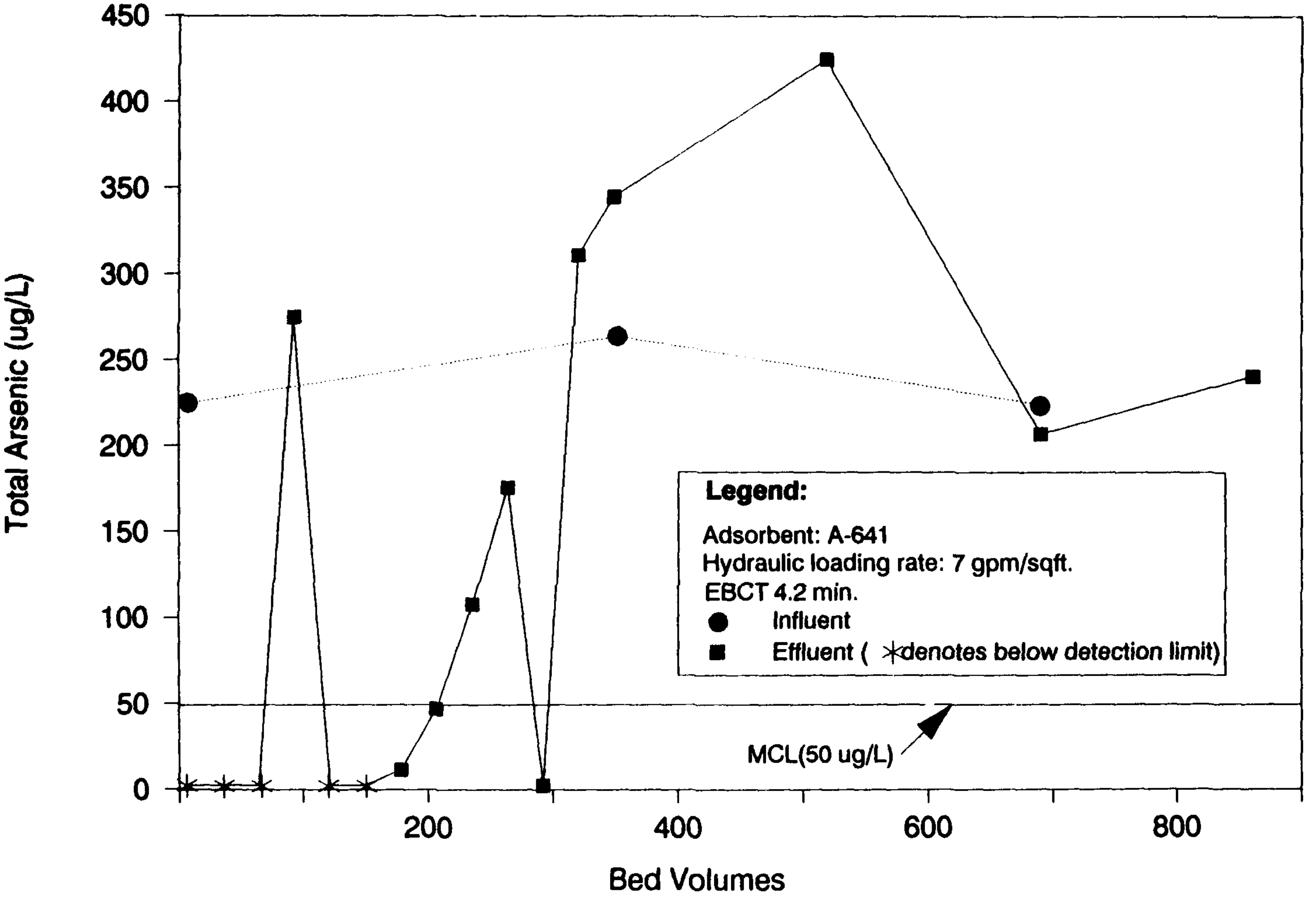

Figure [illegible]. Arsenic removal results, Run 2c.

The results obtained with Ionac A-641 were qualitatively similar to those observed with IRA 402. Influent arsenic concentrations in Run 2 were generally moderately higher than in Run 1. Initial removal of arsenic to below the quantifiable limit was achieved with Ionac A-641 at all operating conditions. As with IRA 402, once breakthrough occurred, effluent values exceeding influent concentrations were achieved, and data from column C1 (Figure 6-6) again indicated that this was a relatively short lived phenomenon.

However, breakthrough at the MCL criterion (50 μg/L) occurred sooner (in terms of bed volumes of water treated) than with IRA 402. Breakthrough occurred between 200 and 300 bed volumes of water treated at all operating conditions (as compared to 300 to 500 bed volumes for IRA 402). These results may reflect in part the generally higher influent concentrations observed in Run 2. In contrast to results from IRA 402, there appears to be a relationship between bed life and operating conditions for Ionac A-641, with increasing EBCT and decreasing hydraulic loading corresponding to increasing bed life, at least over the range of conditions tested.

Table 6-9 presents the estimated arsenic loading on the IE resin at the breakthrough point. These calculations are based upon the (weighted) average influent concentration and appropriate volume of water treated at the breakthrough point. In calculating the total quality of arsenic removed, the quantity discharged in the column effluent between the point at which arsenic was first detected and final breakthrough at 50 μg/L, was considered insignificant.

The estimated resin loadings of breakthrough shown in Table 6-9 were somewhat higher than equilibrium isotherm loadings at C_e = ±50 μg/L, shown in Table 5-2.

6.5 GRANULAR ACTIVATED CARBON RESULTS

6.5.1 RUN 3 - HYDRODARCO 3000

Run 3, the first activated carbon test run, began on 28 April 1990 using Hydrodarco 3000 granular activated carbon. Operating conditions in the primary columns (A1, B1, and C1) were as indicated in Table 6-1. Run 3 was to be conducted at reduced pH, with a target pH of approximately 4.

Operating data for the primary columns (A1, B1, and C1) are presented in Tables 6-10, 6-11 and 6-12, respectively. Graphical representations of arsenic results are provided in Figures 6-7, 6-8, and 6-9.

The data in these tables and figures indicate essentially immediate breakthrough of arsenic in the effluent from the primary treatment columns, regardless of operating conditions. In each case, arsenic was detected above the MCL in the first effluent sample taken after startup.

Table 6-9

Arsenic Loading at Breakthrough
Ionac A-641

Run	2a	2b	2c
Hydraulic Loading Rate (gpm/ft^2)	2	3	7
EBCT (minutes)	14.7	9.8	4.2
Influent Arsenic, weighted average (μg/L)	238.7	252.8	225
Volume treated at breakthrough (gal)	840	740	620
Resin Weight, primary column (lb)*	17	17	17
Total Arsenic Removed at Breakthrough (lb)	1.7×10^{-3}	1.6×10^{-3}	1.2×10^{-3}
Arsenic Loading on Resin at Breakthrough (lb/lb)	1×10^{-4}	9.4×10^{-5}	7.1×10^{-5}

*Based upon vendor literature for packed density.

Table 6-10
Arsenic Removal, Hydrodarco 3000, 7 gpm/ft^2

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	pH	MCL	Water Temperatur (F)
1410	28-Apr-90	0	0	0.0	0.0	5.0	50	78.9
1500	28-Apr-90	35	12	189.0	147.0	4.5	50	79.4
1700	28-Apr-90	119	40	182.0	125.0	4.5	50	75.4
0500	29-Apr-90	623	211		155.0	5.5	50	71.6

Table 6-11
Arsenic Removal, Hydrodarco 3000, 2 gpm/ft^2

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	pH	MCL (ug/l)	Water Temperatur (F)
1410	28-Apr-90	0	0	0.0	0.0	5	50	78.9
1500	28-Apr-90	10	3	189.0	99.3	4.5	50	79.4
1700	28-Apr-90	34	12	182.0	129.0	4.5	50	75.4
0500	29-Apr-90	178	60		170.0	5.5	50	71.6

Table 6-12
Arsenic Removal, Hydrodarco 3000, 3 gpm/ft^2

Time	Date	Water Volume (gal)	Bed Volume	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	pH	MCL (ug/l)	Water Temperature (F)
1410	28-Apr-90	0	0	0.0	0.0	5.0	50	78.9
1500	28-Apr-90	15	5	189.0	137.0	4.5	50	79.4
1700	28-Apr-90	51	17	182.0	106.0	4.5	50	75.4
0500	29-Apr-90	267	91		168.0	5.5	50	71.6

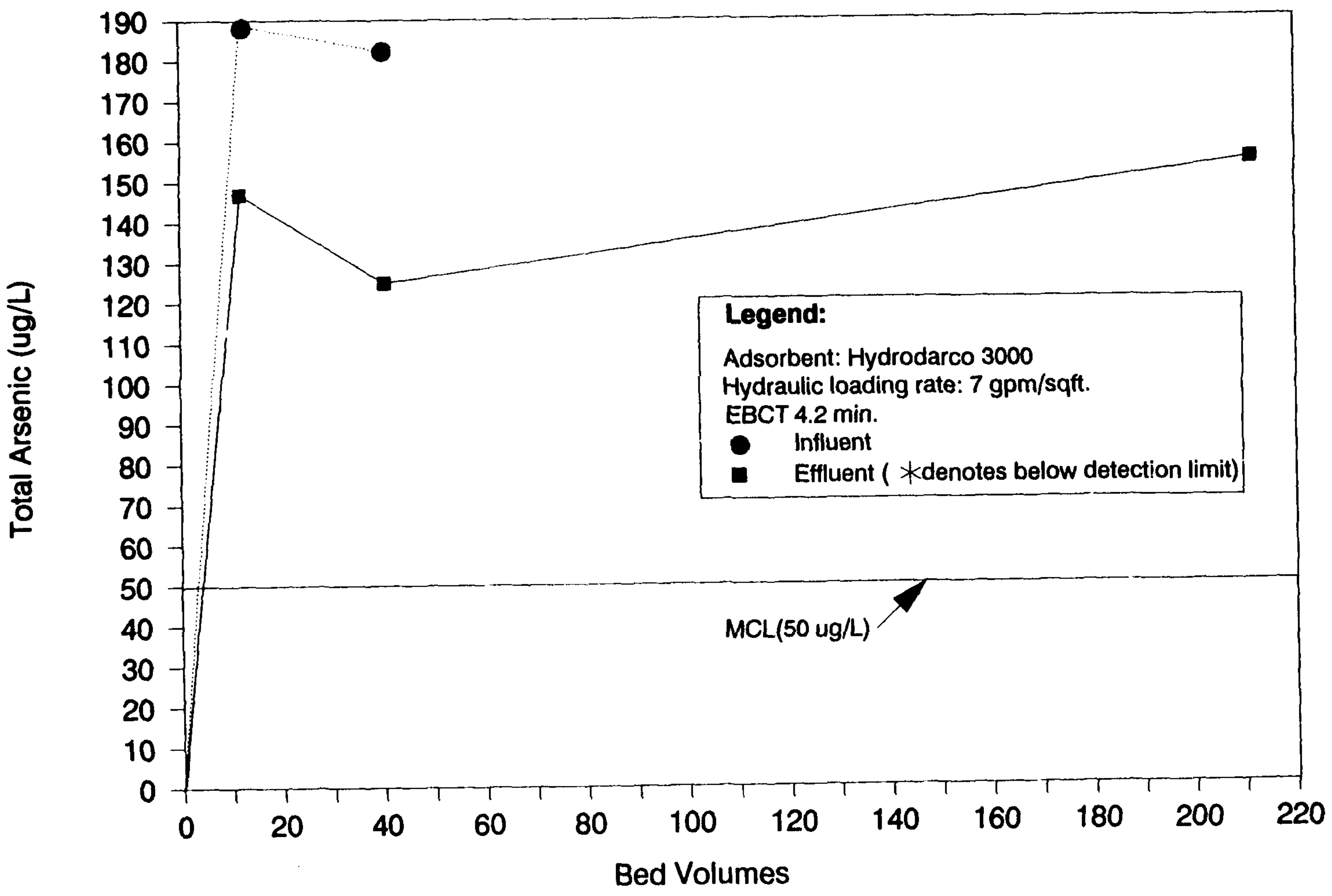

Figure 6-7. Arsenic removal results, Run 3a.

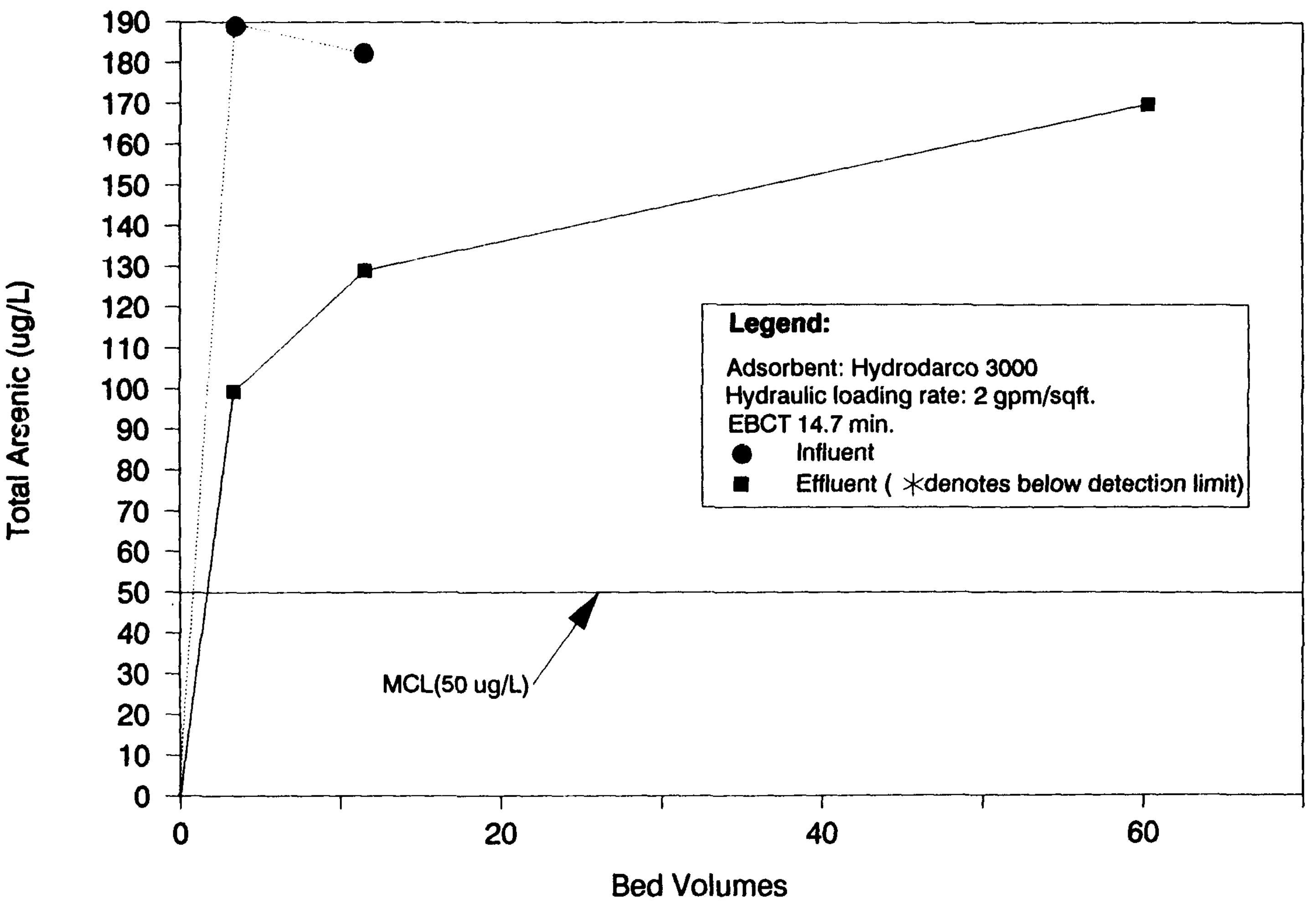

Figure 6-8. Arsenic removal results, Run 3b.

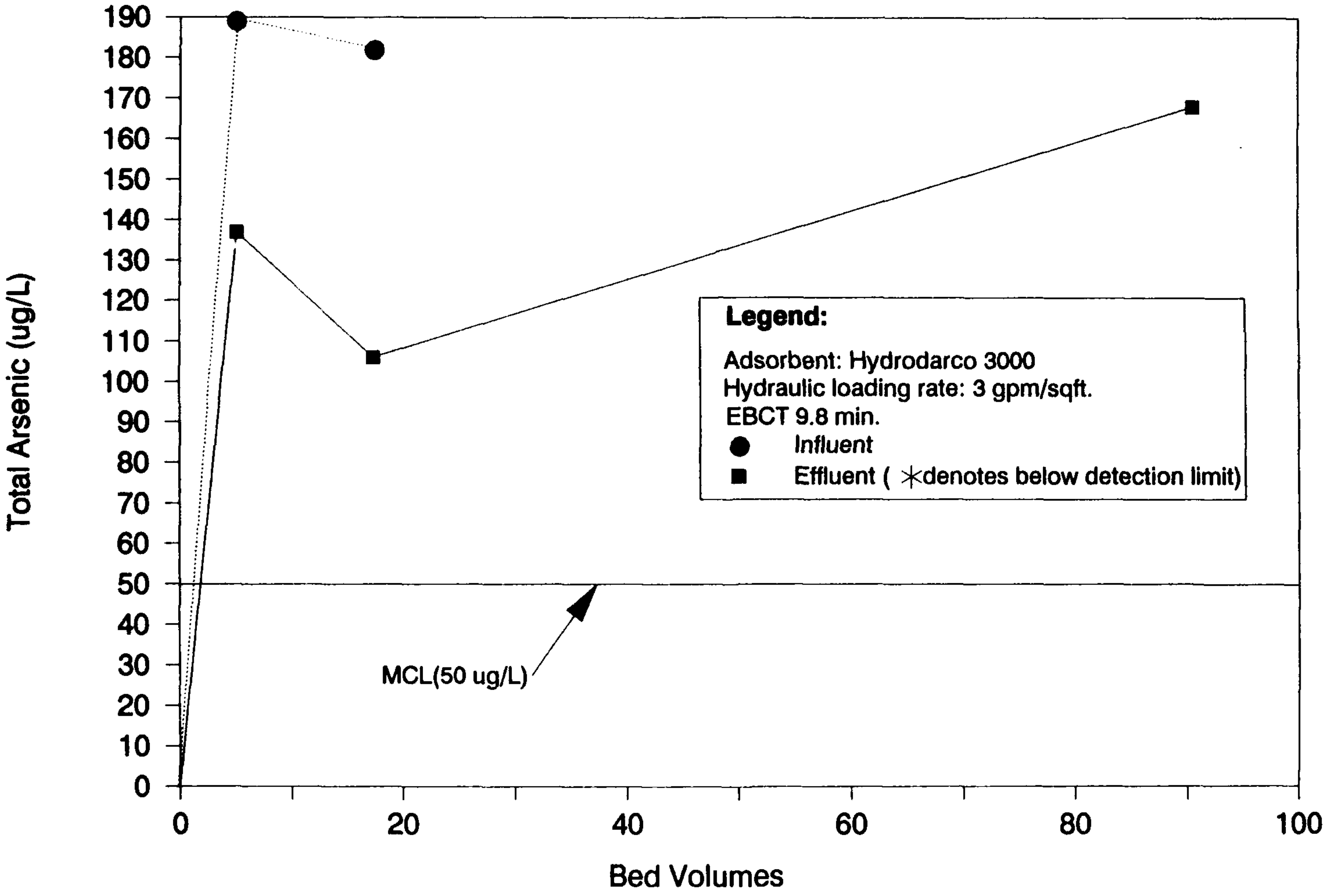

Figure 6-9. Arsenic removal results, Run 3c.

The lowest loading rate and highest EBCT (Column B1, Figure 6-8) provided the lowest initial effluent arsenic concentration, 99.3 $\mu g/L$. Although the initial effluent concentration data for the three columns suggest a relationship between effluent concentration and loading rate or EBCT time, subsequent decreases in effluent concentrations in columns A1 and C1, of undetermined cause, prevent a clear comparison.

As discussed in Subsection 5.2, isotherm data demonstrated that the use of granular activated carbon would achieve equilibrium (24-hour contact) arsenic concentrations below 50 $\mu g/L$ only at very high carbon dosages. The results of the pilot tests may indicate poor absorbability as well as kinetic limitations.

Since effective adsorption was not observed, arsenic loading on the activated carbon were not calculated.

6.5.2 RUN 4 - CALGON FILTRASORB 400

The fourth test run using Calgon Filtrasorb 400 GAC, was initiated on 1 May 1990. Operating conditions in the primary columns (A1, B1 and C1) were as indicated in Table 6-1. Run 4 was to be conducted at reduced pH, with a target pH of approximately 4.

Operating data with respect to arsenic and influent pH for the primary columns (A1, B1, and C1) are represented in Tables 6-13, 6-14 and 6-15, respectively. Arsenic removal data are presented graphically in Figures 6-10, 6-11, and 6-12.

As with Hydrodarco 3000, essentially immediate breakthrough of arsenic was observed with Calgon Filtrasorb 400. Paradoxically, arsenic concentrations in the first effluent sample were higher than influent concentrations at all three operating conditions. The cause of this phenomenon is not known. As discussed in Subsection 5.2, final (C_e) arsenic levels exceeding initial levels were observed in isotherm testing were observed for Filtrasorb 200 and Filtrasorb 400 (particularly at pH 7). Because of these anomalous results, the determination was made to perform an additional test (Run 6, discussed in Subsection 6.7.1) to conform these findings.

6.6 ACTIVATED ALUMINA RESULTS

6.6.1 RUN 5 - ALCOA TYPE F-1

Pilot testing of AA for arsenic removal began on 5 May 1990. Operating conditions for the three primary columns (A1, B1, and C1) are shown in Table 6-1. Operating data for the AA tests are tabulated in Tables 6-16, 6-17, and 6-18 for columns A1, B1, and C1, respectively. Arsenic removal data are presented graphically in Figures 6-13, 6-14, and 6-15.

Table 6-13
Operating Data, Filtrasorb 400, 3 gpm/ft^2

				Total Arsenic Concentration			
Time	Date	Water Volume (gal)	Bed Volumes	Influent (ug/l)	Effluent (ug/l)	MCL (ug/l)	Water Temperature (F)
0545	01-May-90	0	0	213.0	285.0	50	65.8
0615	01-May-90	9	3		200.0	50	65.7
0715	01-May-90	27	9		232.0	50	61.0
1600	01-May-90	185	63		140.0	50	73.2

Table 6-14
Operating Data, Filtrasorb 400, 7 gpm/ft²

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	MCL (ug/l)	Water Temperature (F)
0545	01-May-90	0	0	213.0	262.0	50	65.8
0615	01-May-90	21	7		222.0	50	65.7
0715	01-May-90	63	21		216.0	50	61.0
1600	01-May-90	431	146		180.0	50	73.2

Table 6-15
Operating Data, Filtrasorb 400, 2 gpm/ft²

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	MCL (ug/l)	Water Temperature (F)
0545	01-May-90	0	0	213.0	392.0	50	65.8
0615	01-May-90	6	2		210.0	50	65.7
0715	01-May-90	18	6		270.0	50	61.0
1600	01-May-90	123	42		108.8	50	73.2

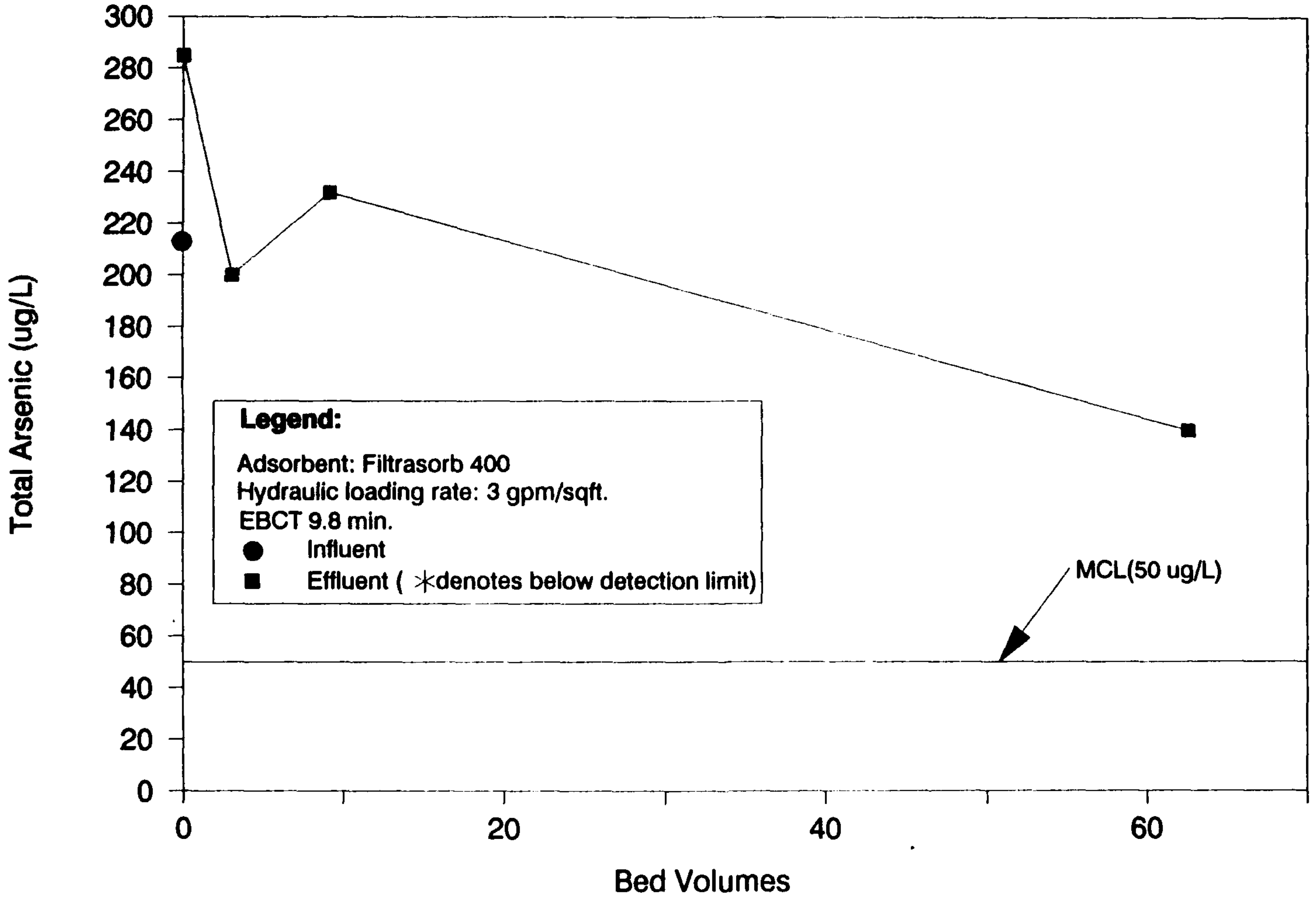

Figure 6-10. Arsenic removal results, Run 4a.

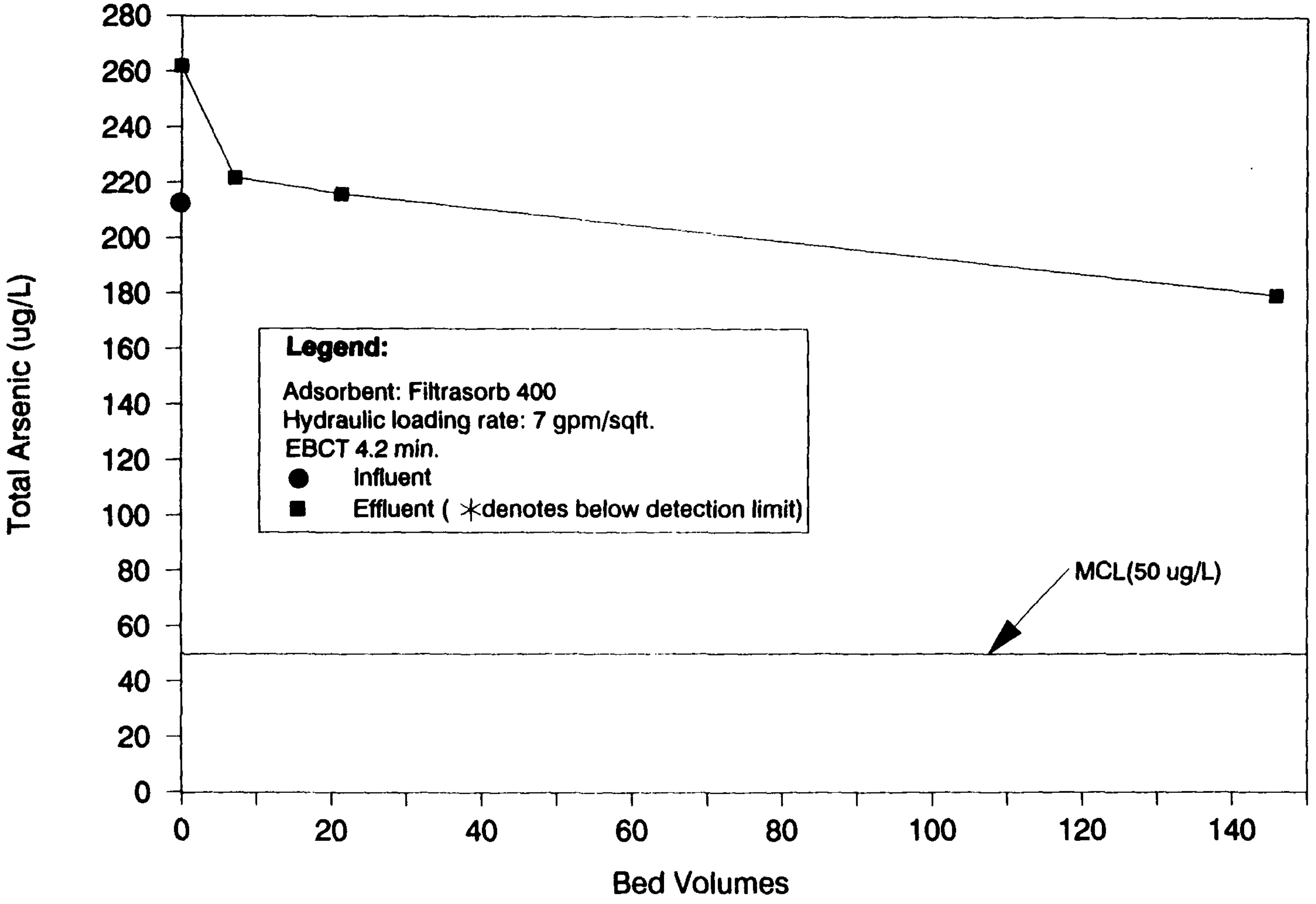

Figure 6-11. Arsenic removal results, Run 4b.

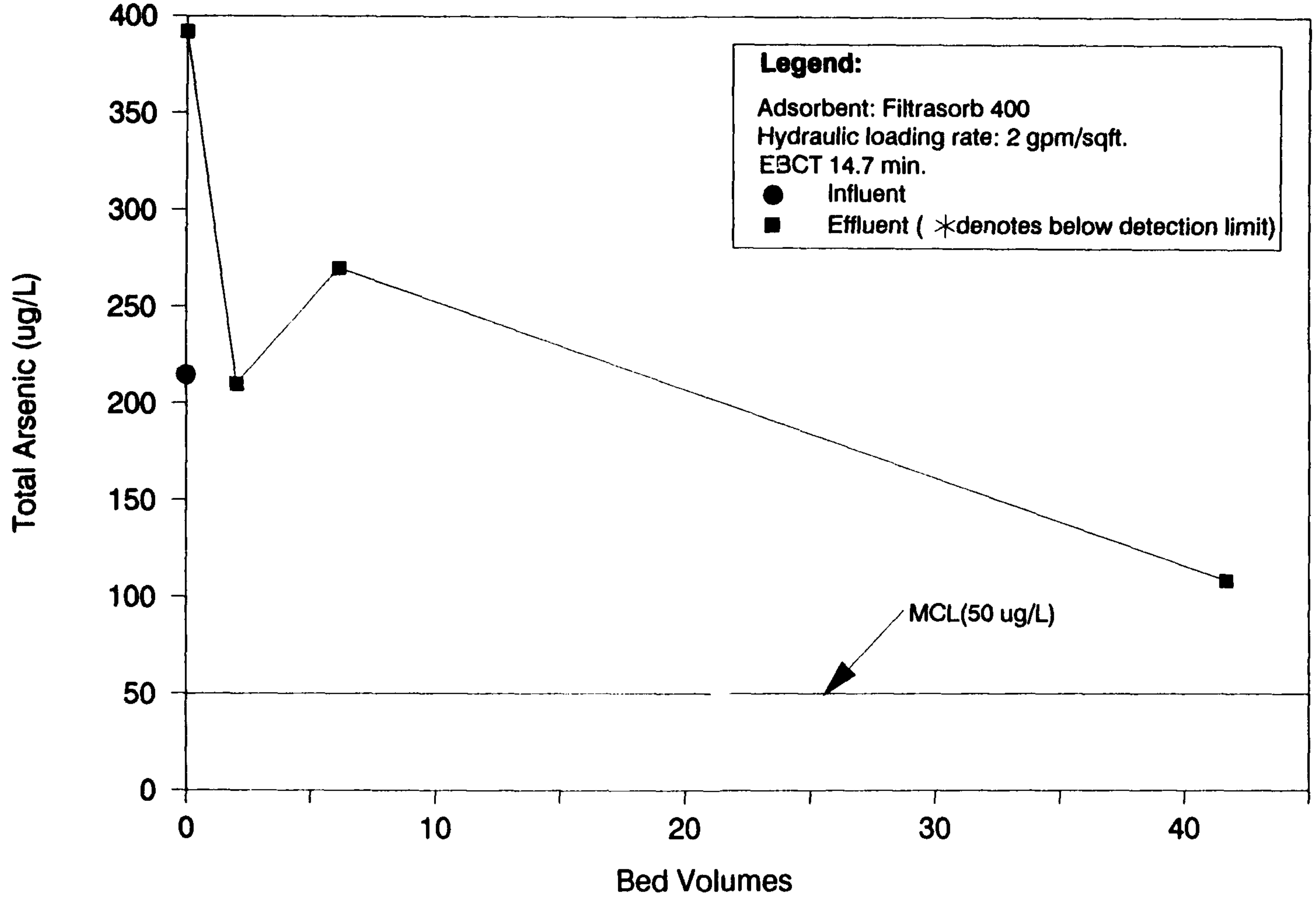

Figure 6-12. Arsenic removal results, Run 4c.

Table 6-16
Operating Data, Alcoa F-1, 2 gpm/ft²

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration		pH	MCL (ug/l)	Water Temp. (F)
				Influent (ug/l)	Effluent (ug/l)			
1800	05-May-90	0	0	0	0	0	50	
1900	05-May-90	12	4	232	2.5 u	5.5	50	75.6
0200	06-May-90	96	33		2.5 u	5.2	50	74.4
1800	06-May-90	288	98		2.5 u	5.3	50	76.7
1000	07-May-90	480	163	233	2.5 u	5.0	50	72.9
0200	08-May-90	672	228		2.5 u	5.5	50	76.1
1800	08-May-90	864	293		2.5 u	4.2	50	82.3
1000	09-May-90	1056	358	246	2.5 u	6.5	50	73.4
0200	10-May-90	1248	423		2.5 u	5.0	50	74.2
1800	10-May-90	1440	488		2.5 u	6.0	50	70.5
1000	11-May-90	1632	553	320	2.5 u	6.2	50	69.3
0200	12-May-90	1824	618		2.5 u	5.5	50	66.8
1800	12-May-90	2016	683		2.5 u	6.2	50	72.0
1000	13-May-90	2208	748	193.5	2.5 u	6.0	50	64.6
0200	14-May-90	2400	814		2.5 u	5.9	50	68.4
1800	14-May-90	2592	879		2.5 u	4.5	50	70.0
1000	15-May-90	2787	945		2.5 u	5.0	50	68.1
1800	15-May-90	2880	976		2.5 u	5.4	50	69.1
1000	16-May-90	3168	1074	200	2.5 u	6.0	50	69.2
1800	16-May-90	3264	1106		2.5 u	4.0	50	84.0
1000	17-May-90	3456	1172	186	2.5 u	5.2	50	70.3
1800	17-May-90	3552	1204		3.1	5.0	50	69.3
1000	18-May-90	3744	1269	177	2.8	6.0	50	66.3
1800	18-May-90	3840	1302		2.5 u	4.4	50	68.5
1000	19-May-90	4032	1367	209	2.5 u	4.0	50	67.4
1000	20-May-90	4320	1464	182.5	2.5 u	6.4	50	69.1
1000	21-May-90	4608	1562	218.5	2.5 u	6.0	50	74.2
1000	22-May-90	4896	1660	150.5	2.5 u	3.8	50	74.6
1000	23-May-90	5184	1757	330	2.5 u	5.0	50	65.2
1000	24-May-90	5472	1855	171	2.1 u	4.0	50	68.9
1000	25-May-90	5760	1953	234	3.1	2.8	50	71.7
1000	26-May-90	6048	2050	157.5	2.5 u	3.5	50	75.6
1000	27-May-90	6336	2148	163	2.6	3.5	50	74.2
1000	28-May-90	6624	2245	145.5	7.7	3.0	50	70.5
1000	29-May-90	6912	2343	153	13.7	3.8	50	69.0
1000	30-May-90	7200	2441	182.5	41.7	2.8	50	65.7
1000	31-May-90	7488	2538	172.5	25.0	3.0	50	67.1
1000	01-Jun-90	7776	2636	163	21.5	6.0	50	68.0
1000	02-Jun-90	8064	2734	173	27.5	3.8	50	69.0
1000	03-Jun-90	8352	2831	165	20.1	4.0	50	72.2
1000	04-Jun-90	8640	2929	181	26.3	6.1	50	73.9
1000	05-Jun-90	8928	3026	166.5	26.8	5.5	50	70.6

Table 6-16
Operating Data, Alcoa F-1, 2 gpm/ft²
(continued)

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	pH	MCL (ug/l)	Water Temp. (F)
1000	06-Jun-90	9216	3124	141.5	23.6	3.5	50	73.9
1100	07-Jun-90	9515	3225	163.5	32.9	3.5	50	75.3
1000	08-Jun-90	9791	3319	175	25.7	3.5	50	77.1
1000	09-Jun-90	10079	3417	181	26.8	3.4	50	78.8
1000	10-Jun-90	10367	3514	153	22.7	3.0	50	74.5
1600	10-Jun-90	10439	3539		20.7	3.4	50	76.2
2400	10-Jun-90	10535	3571		34.5	3.3	50	76.3
0800	11-Jun-90	10631	3604		31.5	3.2	50	74.0
1000	11-Jun-90	10655	3612	168	35.6	3.2	50	74.0
1600	11-Jun-90	10727	3636		40.9	3.5	50	75.8
2400	11-Jun-90	10823	3669		27.8	3.7	50	75.9
0400	12-Jun-90	10871	3685		41.5	3.8	50	74.2
0800	12-Jun-90	10919	3701		48	3.2	50	72.8
1000	12-Jun-90	10943	3709	161.5	54.8	3.4	50	69.4
1600	12-Jun-90	11015	3734		65.4	3.4	50	71.4
1000	13-Jun-90	11231	3807	139.5	37.5	3.4	50	72.0
1200	13-Jun-90	11255	3815		60.8	3.4	50	72.2
1000	14-Jun-90	11519	3905	156.5	68.0	3.5	50	70.8
1000	15-Jun-90	11807	4002	186.5	64.8	3	50	72.0
1200	15-Jun-90	11831	4011		65.6	3	50	72.5
1600	15-Jun-90	11879	4027		73.6	3	50	74.1
2000	15-Jun-90	11927	4043		83.6	3.0	50	75.3
2400	15-Jun-90	11975	4059		86	2.9	50	75.0
0400	16-Jun-90	12023	4076		101	2.8	50	74.4
1000	16-Jun-90	12215	4141	194	232.0	3.0	50	71.5
1000	17-Jun-90	12503	4238	189	162.0	3.0	50	73.2
1200	17-Jun-90	12527	4246		174	3.0	50	73.9

Table 6-17
Operating Data, Alcoa F-1, 3 gpm/ft^2

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration		pH	MCL (ug/l)	Water Temp. (F)
				Influent (ug/l)	Effluent (ug/l)			
1800	05-May-90	0	0	0.0	0.0		50	
1900	05-May-90	18	6	232.0	2.5 u	5.5	50	75.6
0200	06-May-90	144	49		2.5 u	5.2	50	74.4
1800	06-May-90	432	146		2.5 u	5.3	50	76.7
1000	07-May-90	720	244	233.0	2.5 u	5.0	50	72.9
0200	08-May-90	1008	342		2.5 u	5.5	50	76.1
1800	08-May-90	1296	439		2.5 u	4.2	50	82.3
1000	09-May-90	1584	537	246.0	2.5 u	6.5	50	73.4
0200	10-May-90	1872	635		2.5 u	5.0	50	74.2
1800	10-May-90	2160	732		2.5 u	6.0	50	70.5
1000	11-May-90	2448	830	320.0	2.5 u	6.2	50	69.3
0200	12-May-90	2736	927		2.5 u	5.5	50	66.8
1800	12-May-90	3024	1025		2.5 u	6.2	50	72.0
1000	13-May-90	3312	1123	193.5	2.5 u	6.0	50	64.6
0200	14-May-90	3600	1220		2.5 u	5.9	50	68.4
1800	15-May-90	3888	1318		2.5 u	4.5	50	69.1
1000	16-May-90	4176	1416	200.0	2.5 u	6.0	50	69.2
1800	16-May-90	4320	1464		2.5 u	4.0	50	84.0
1000	17-May-90	4608	1562	186.0	2.5 u	5.2	50	70.3
1800	17-May-90	4752	1611		2.2 u	5.0	50	69.3
1000	18-May-90	5040	1708	177.9	1.6 u	6.0	50	66.3
1800	18-May-90	5184	1757		2.5 u	4.4	50	68.5
1000	19-May-90	5472	1855	209.0	2.5 u	4.0	50	67.4
1000	20-May-90	6336	2148	182.5	2.7	6.4	50	69.1
1000	21-May-90	6768	2294	218.5	3.6	6.0	50	74.2
1000	22-May-90	7200	2441	150.5	2.5 u	3.8	50	74.6
1000	23-May-90	7632	2587	330.0	4.0	5.0	50	65.2
1000	24-May-90	8064	2734	171.0	1.5 u	4.0	50	68.9
1000	25-May-90	8496	2880	234.0	3.6	2.8	50	71.7
1000	26-May-90	8928	3026	157.5	2.5 u	3.5	50	75.6
1000	27-May-90	9360	3173	163.0	2.4 u	3.5	50	74.2
1000	28-May-90	9792	3319	145.5	14.4	3.0	50	70.5
1000	29-May-90	10224	3466	153.0	48.9	3.8	50	69.0
1000	30-May-90	10656	3612	182.5	123.0	2.8	50	65.7

Table 6-18
Operating Data, Alcoa F-1, 7 gpm/ft^2

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	MCL (ug/l)	pH	Water Temp. (F)
1800	05-May-90	0	0		0.0	50	0.0	0.0
1900	05-May-90	42	14	232.0	2.5 u	50	5.5	75.6
0200	06-May-90	336	114		2.5 u	50	5.2	74.4
1800	06-May-90	1008	342		2.5 u	50	5.3	76.7
1000	07-May-90	1680	569	233.0	2.5 u	50	5.0	72.9
0200	08-May-90	2352	797		2.5 u	50	5.5	76.1
1800	08-May-90	3024	1025		2.5 u	50	4.2	82.3
1000	09-May-90	3696	1253	246.0	2.5 u	50	6.5	73.4
0200	10-May-90	4368	1481		2.5 u	50	5.0	74.2
1800	10-May-90	5040	1708		6.5	50	6.0	70.5
0200	11-May-90	5376	1822		12.7	50	5.6	70.2
1000	11-May-90	5712	1936	320.0	24.8	50	6.2	69.3
0800	11-May-90	6048	2050		25.4	50	5.8	72.0
0200	12-May-90	6384	2164		52.4	50	5.5	66.8
1000	12-May-90	6720	2278	225.0	50.6	50	6.0	69.2
1800	12-May-90	7056	2392		99.6	50	6.2	72.0
0200	13-May-90	7392	2506		131.0	50	6.2	66.7
1000	13-May-90	7728	2620	193.5	136.0	50	6.0	64.6
1300	13-May-90	7854	2662		151.0	50	6.0	65.4

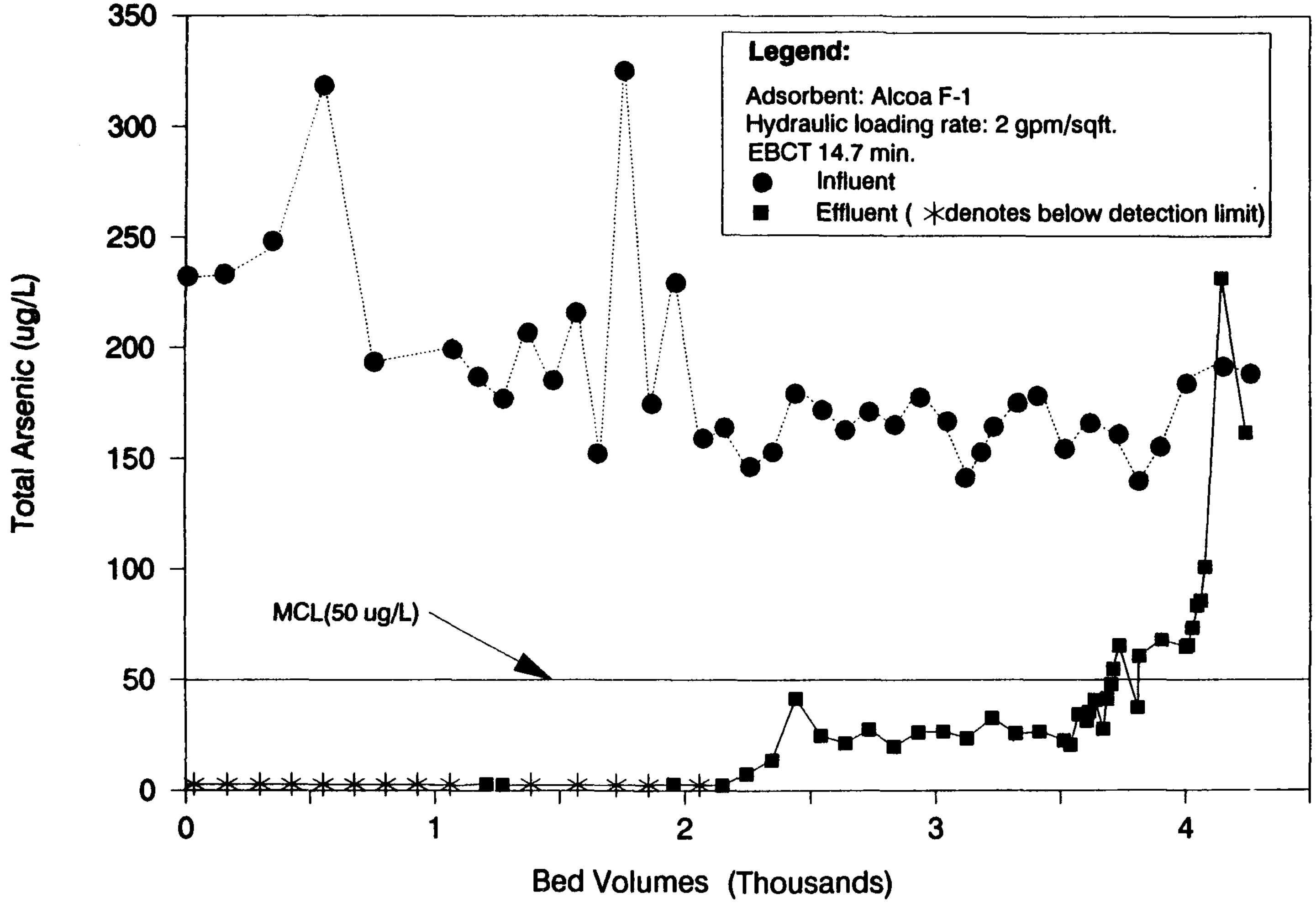

Figure 6-13. Arsenic removal results, Run 5a.

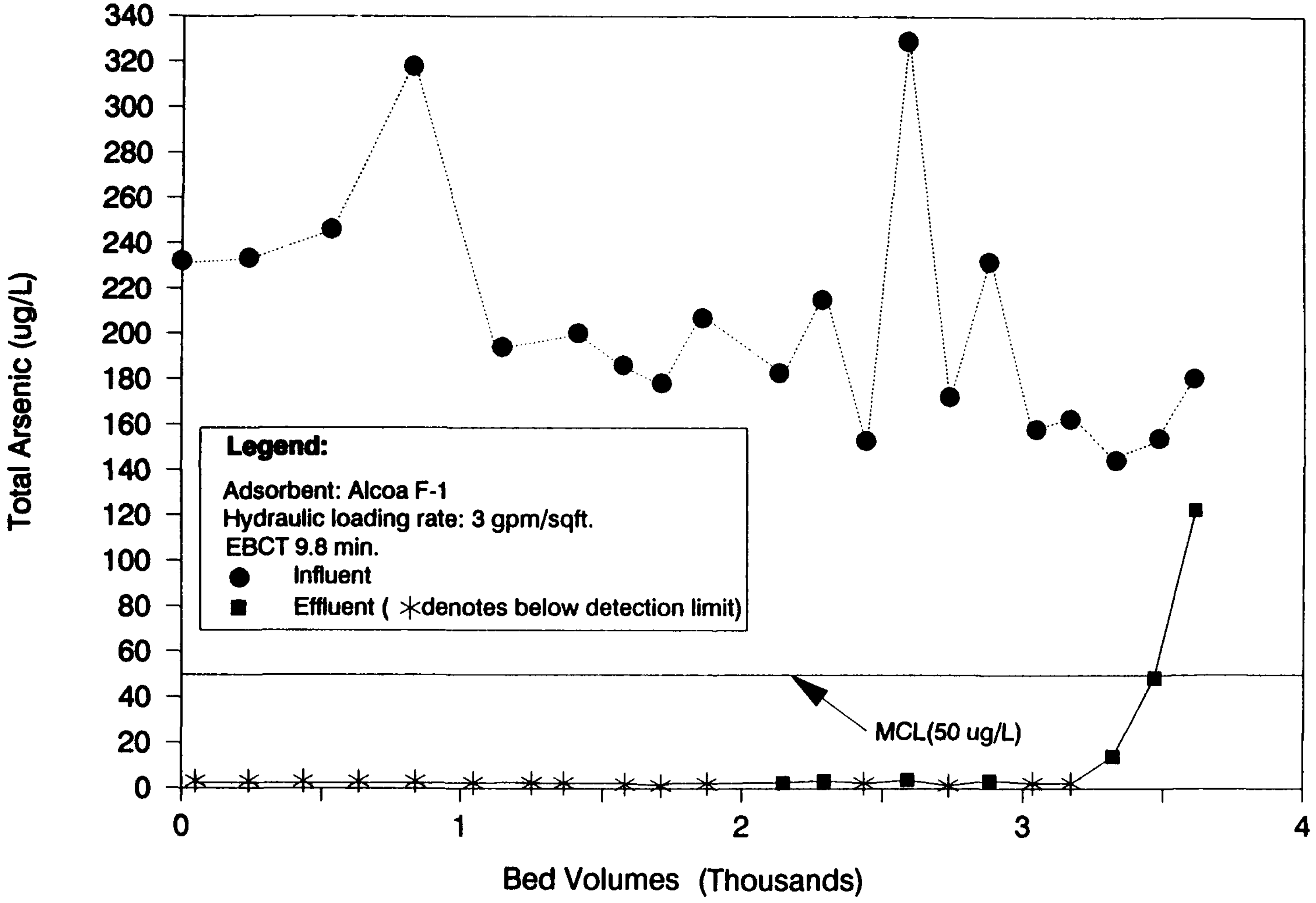

Figure 6-14. Arsenic removal results, Run 5b.

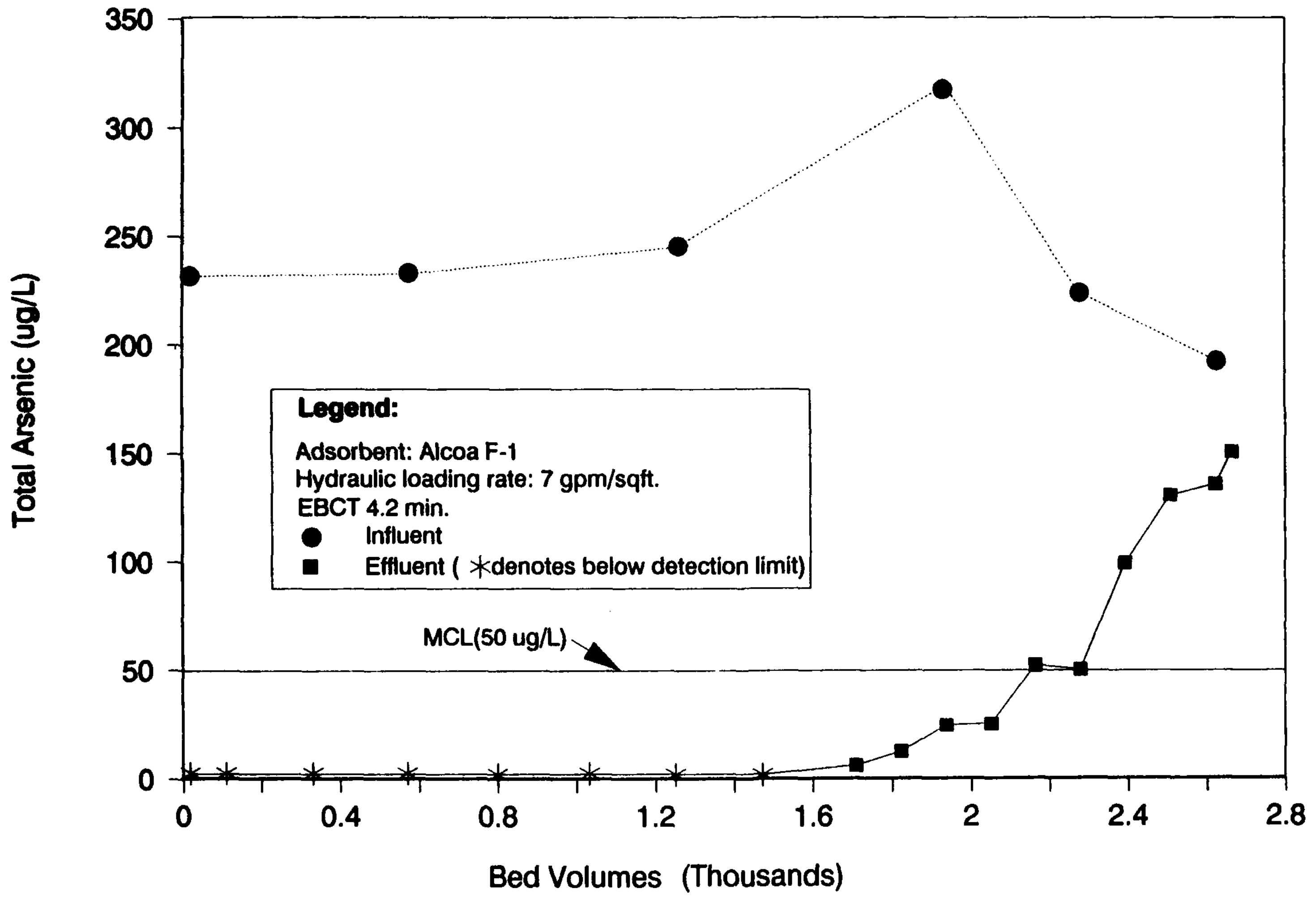

Figure 6-15. Arsenic removal results, Run 5c.

Good initial removals of total arsenic were achieved in all cases, with primary column effluent concentrations being maintained at less than the quantifiable limit (2.5 μg/L) for a minimum of 2,000 bed volumes at each operating condition. At the two higher loading rates (columns B1 and C1, shown in Figure 6-14 and 6-15, respectively) breakthrough occurred rapidly once effluent concentrations began to rise. In contrast, column A1, at the lowest loading rate, exhibited a protracted period of low but detectable effluent concentrations (20 to 30 μg/L) before final breakthrough was achieved. The effluent concentration from column A1 briefly exceeded the influent concentration in one sample near the end of the run.

At breakthrough, Column A1 had treated approximately 3,700 bed volumes of contaminated groundwater, Column B1 had treated approximately 3,465 bed volumes, and Column C1 had treated approximately 2,100 bed volumes. These results indicate that lower hydraulic loading rates provide better performance. This observation is in agreement with previous studies and is possibly related to the relatively slow kinetics of the AA adsorption/exchange process [6, 16, 17]. However, it should also be recognized that the influent arsenic concentration in the water drawn from MW440A gradually diminished over time during this run. This factor may have had an effect on bed life particularly, for Run 7a which spanned the greatest time period. While these results were promising, previous studies had suggested that even longer runs (higher numbers of bed volumes treated) might be achievable [20]. These previous studies were, however, conducted at somewhat lower influent arsenic concentrations.

One factor that may affect the bed life as well as the effluent concentration is the presence of other anionic species which compete with arsenic for adsorption sites. Table 6-19 presents data on competing species in the influent, obtained during the activated alumina test. Comparing these data to the tentative selectivity series discussed in Subsection 2.2.3, it can be seen that both fluoride and phosphate, which rank above arsenate in the selectivity series, were present at higher concentrations than arsenic in these runs. Chloride and sulfate were present at very high concentrations as compared to arsenic. Previous studies have shown that chloride and sulfate (particularly the latter) at high concentration will diminish activated alumina performance [27]. These anions may affect the bed lives obtainable during treatment of SHAD groundwater. It might be noted that some of these ions may also have effected effluent results obtained with IE resins. As discussed in Subsection 5.1, these resins were used in the chloride from and high chloride levels may have displaced arsenate from the resins. The removal of competing anions by either adsorption medium was not evaluated. Lastly, it might be noted that the use of acid to lower pH, while increasing removal to some extent, may also introduce substantial levels of potentially competing sulfate anions. Previous studies have employed

Table 6-19

Potential Interferring Anions
MW-440A

Constituent	Date of Sample	Concentration
Selenium	5/21/90	0.007 µg/L
Chloride	5/22/90	90.5 mg/L
Fluoride	5/22/90	0.59 mg/L
Phosphate, as P (ortho)	5/22/90	0.50 mg/L
Sulfate	5/22/90	53.6 mg/L

sulfuric acid [16, 17] or hydrochloric acid [10] for pH adjustment. Other studies have suggested that below pH 6, increasing competition from acid anions reduces the extent of adsorption of arsenic by AA [27].

Table 6-20 presents the estimated arsenic loading on the AA at the breakthrough point. These calculations are based upon the (weighted) average influent concentration and approximate volume of water treated at the breakthrough point. In calculating the total quantity of arsenic removal, the quantity discharged in the column effluent between the point at which arsenic was first detected and final breakthrough at 50 μg/L, was considered insignificant. The estimated alumina loadings at breakthrough shown in Table 6-20 were slightly higher than equilibrium isotherm loadings at $C_e = \pm 50$ μg/L shown in Table 5-6.

6.7 SUPPLEMENTAL TEST RUNS

With the completion of AA testing discussed in Subsection 6.6, the investigative program outlined in the test plan had been fulfilled. Two supplemental tests runs were conducted to either reexamine questions raised by the initial runs or to address additional data requested by USATHAMA. These supplemental test runs are addressed in the following subsections.

6.7.1 RUN 6 - CALGON FILTRASORB 400

The original test with Filtrasorb 400 (discussed in Subsection 6.5.2), indicated essentially immediate breakthrough of arsenic at concentrations even exceeding those in the influent. Run 6 was intended to reconfirm these results and examine potential causes.

As with other adsorption media, the activated carbon for the original carbon run was slurried and soaked overnight in potable water from the SHAD system, prior to being placed in the pilot columns. It was postulated that the carbon may have adsorbed trace levels of arsenic from the potable water source during the soaking step. Therefore, for Run 6, Filtrasorb 400 was slurried and soaked in distilled, deionized water from WESTON's Analytics Division Laboratory in Stockton, California, prior to use.

Test Run 6 also evaluated a lower hydraulic loading rate (1 gpm/ft^2) and longer contact time (29.4 minutes) than employed in the previous Filtrasorb test (Run 4). Finally, Run 6 was conducted at the natural pH of the groundwater rather than at reduced pH.

Table 6-20

Arsenic Loading at Breakthrough
Alcoa F-1, 24-48 Mesh

Run	5a	5b	5c
Hydraulic Loading Rate, (gpm/ft^2	2	3	7
EBCT (minutes)	14.7	9.8	4.2
Influent Arsenic Concentration, weighted average, (μg/L)	196.2	212.7	257.8
Volume treated at Breakthrough (gal)	10,920	10,250	6,180
Alumina weight, primary column (lb)	24	24	24
Total Arsenic Removed at Breakthrough (lb)	1.8×10^{-2}	1.8×10^{-2}	1.3×10^{-2}
Arsenic Loading on Alumina at Breakthrough (lb/lb)	7.5×10^{-4}	7.5×10^{-4}	5.4×10^{-4}

Test Run 6 commenced on 9 June 1990 and ran concurrently with the latter stages of Run 5a, which employed AA (see Subsection 6.5). Operating conditions for the primary column in Run 6 are shown in Table 6-1. The backup column for this test run was packed with ion exchange resin to minimize the need to retreat the effluent should the primary column fail to remove the arsenic.

Despite the modifications in procedures and conditions, arsenic broke through in the primary column essentially immediately. As with the previous GAC tests, the initial effluent sample indicated a higher effluent concentration than influent. The second sample showed a lower but still elevated effluent concentration. The test was shut down based upon these results. The column was restarted on 10 June 1990 to obtain confirmatory samples. Effluent concentrations remained high, and the test was terminated on 11 June 1990. Since removal of arsenic was not achieved, arsenic loadings on the activated carbon were not calculated.

6.7.2 RUN 7 - ACTIVATED ALUMINA

On 12 June 1990, a meeting was held at SHAD to review the preliminary results of this pilot study. Participants included USATHAMA TSD, WESTON, SHAD Environmental Programs personnel, and USATHAMA's IR division and its contractor, Environmental Science and Engineering (ESE). During that meeting the possibility of arsenic treatment at individual wellheads was raised. In this scenario, the contaminated groundwater would not pass through the existing groundwater treatment system prior to the arsenic treatment step, as had been previously assumed. Therefore, either small TCE removal units would be required in conjunction with the individual arsenic adsorption systems at the well head or arsenic treatment would have to take place in the presence of whatever TCE contamination existed at the wellhead. USATHAMA's IR division requested that the latter possibility be evaluated [38].

Run 7 was intended to evaluate the ability of AA to remove arsenic from the groundwater with no prior pretreatment (no TCE removal or pH adjustment) or partial pretreatment (TCE removal) as might be the case in a wellhead treatment scenario. Three additional tests were conducted to provide a preliminary evaluation of these options:

- Run 7a: AA, with TCE added, at 2 gpm/ft^2, natural pH
- Run 7b: AA, with TCE added, at 3 gpm/ft^2, natural pH
- Run 7c: AA, with no TCE added, at 3 gpm/ft^2, natural pH

Tests 7a and 7b were run concurrently. Test 7c was run following these two tests. AA was selected as the adsorbent based upon its performance in the initial series of pilot tests.

As discussed in Subsection 6.3.5, groundwater from the well used for this pilot study, MW-440A, did not contain TCE. A data search revealed no other suitable wells in reasonable proximity to the pilot plant which exhibited an appropriate combination of arsenic and TCE contamination for this test. Consequently, MW-440A was used as the water source for this test, and TCE was added at the influent tank to simulate groundwater exhibiting both contaminants. Reagent grade TCE (Mallinkrodt Catalog #8000-500) was added to the feed tank. A sample taken at the influent to the pilot plant indicated a TCE concentration of 25 μg/L.

The spiked groundwater was passed through the activated alumina treatment trains (each employing a primary and a backup column). Operating conditions for the primary columns are presented in Table 6-1. Based upon the results of the initial AA tests, only the lower two hydraulic loading rates (and longer contact times) were evaluated.

After passing through the test trains, the column effluents were collected in one effluent tank for arsenic analysis. Upon determination that the arsenic level was below the MCL, the combined effluent was transferred to a spare influent tank and passed through the packed column air stripper to remove the added TCE. The final effluent was discharged to the plant drain. A sample drawn from the air stripper discharge verified that the TCE in the discharge was below quantifiable limits (see Appendix J). Operating data from these runs are tabulated in Tables 6-21, 6-22, and 6-23 for the primary columns in each test. Arsenic removal performance is plotted in Figures 6-16, 6-17, and 6-18. As shown in these figures, good initial removal of arsenic occurred at each operating condition. Approximately 500 bed volumes were treated before breakthrough in Run 7a, 520 in Run 7b, and 850 in Run 7c.

Comparison of these results with the previous AA performance data, however, reveals that both the lack of pH adjustment in these runs and the presence of TCE appears to negatively affect bed life. Comparing Figure 6-18 with Figure 6-14 indicates that omitting the pH adjustment step reduced to bed life from approximately 3,500 bed volumes to approximately 850 bed volumes at a loading rate of 3 gpm/ft^2 (EBCT = 9.8 min). Influent arsenic concentrations in the two runs were roughly comparable.

Comparing Figure 6-18 with Figure 6-17 indicates that, at natural pH values, the presence of 25 μg/L TCE further reduced bed life from 850 bed volumes to approximately 520 bed volumes at a loading rate of 3 gpm/ft^2 (EBCT = 9.8 min), in

Table 6-21
Operating Data, Alcoa F-1, TCE Added, 2 gpm/ft^2

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	pH	MCL (ug/l)	Water Temp. (F)
1900	21-Jun-90	0	0	0.0	0.0	0.0	50	0.0
0800	22-Jun-90	156	53	195.0	2.5 u	7.0	50	79.6
0800	23-Jun-90	444	151	160.0	2.5 u	8.0	50	77.2
0800	24-Jun-90	732	248	183.0	2.5 u	6.0	50	78.3
0800	25-Jun-90	1020	346	182.0	2.6	8.4	50	76.6
0800	26-Jun-90	1308	443	187.0	23.2	8.6	50	76.8
0800	27-Jun-90	1596	541	172.0	73.5	8.8	50	77.7
0800	28-Jun-90	1884	639		156.0	8.8	50	76.7
1900	28-Jun-90	1896	643		136.0	8.6	50	81.0

Table 6-22
Operating Data, Alcoa F-1, TCE Added, 3 gpm/ft^2

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration Influent (ug/l)	Total Arsenic Concentration Effluent (ug/l)	pH	MCL (ug/l)	Water Temp. (F)
1900	21-Jun-90	0	0	0.0	0.0	0.0	50	0
0800	22-Jun-90	234	79	195.0	2.5 u	7.0	50	79.6
0800	23-Jun-90	666	226	160.0	2.5 u	8.0	50	77.2
0800	24-Jun-90	1098	372	183.0	2.5 u	6.0	50	78.6
0800	25-Jun-90	1530	519	182.0	43.8	8.4	50	76.6
0800	26-Jun-90	1962	665	187.0	146.0	8.6	50	76.8
0800	27-Jun-90	2394	812	172.0	202.0	8.8	50	77.7

Table 6-23
Operating Data, Alcoa F-1, Natural pH, 3 gpm/ft^2

Time	Date	Water Volume (gal)	Bed Volumes	Total Arsenic Concentration		pH	MCL (ug/L)	Water Temp. (F)
				Influent (ug/l)	Effluent (ug/l)			
0700	03-Jul-90	0	0	0.0	0.0	0.0	50	0.0
0800	03-Jul-90	18	6	227.0	5.0 u	9.0	50	73.4
0800	04-Jul-90	450	153	220.0	5.0 u	9.0	50	75.4
0800	05-Jul-90	882	299	204.0	5.0 u	8.6	50	75.6
0900	06-Jul-90	1314	445	215.0	10.2	8.6	50	76.1
0900	08-Jul-90	1764	598	176.0	19.4	8.4	50	82.8
0800	09-Jul-90	1956	663	179.0	10.7	8.2	50	77.2
0800	10-Jul-90	2244	761	203.0	21.4	8.4	50	78.9
1600	10-Jul-90	2340	793		20.3	8.7	50	82.2
2000	10-Jul-90	2364	801		14.7	8.8	50	84.4
0800	11-Jul-90	2412	818	177.0	17.2	8.6	50	81.9
1600	11-Jul-90	2537	860		55.2		50	84.2
2000	11-Jul-90	2633	893		64.0	8.8	50	86.4
0800	12-Jul-90	2784	944	218.0	68.2	8.5	50	85.0
1600	12-Jul-90	2928	993		57.5		50	86.5
2000	12-Jul-90	3000	1017		58.5	8.8	50	88.5
0800	13-Jul-90	3187	1080	216.0	232.0	8.6	50	84.8
1630	13-Jul-90	3340	1132	189.0	162.0	8.7	50	86.4

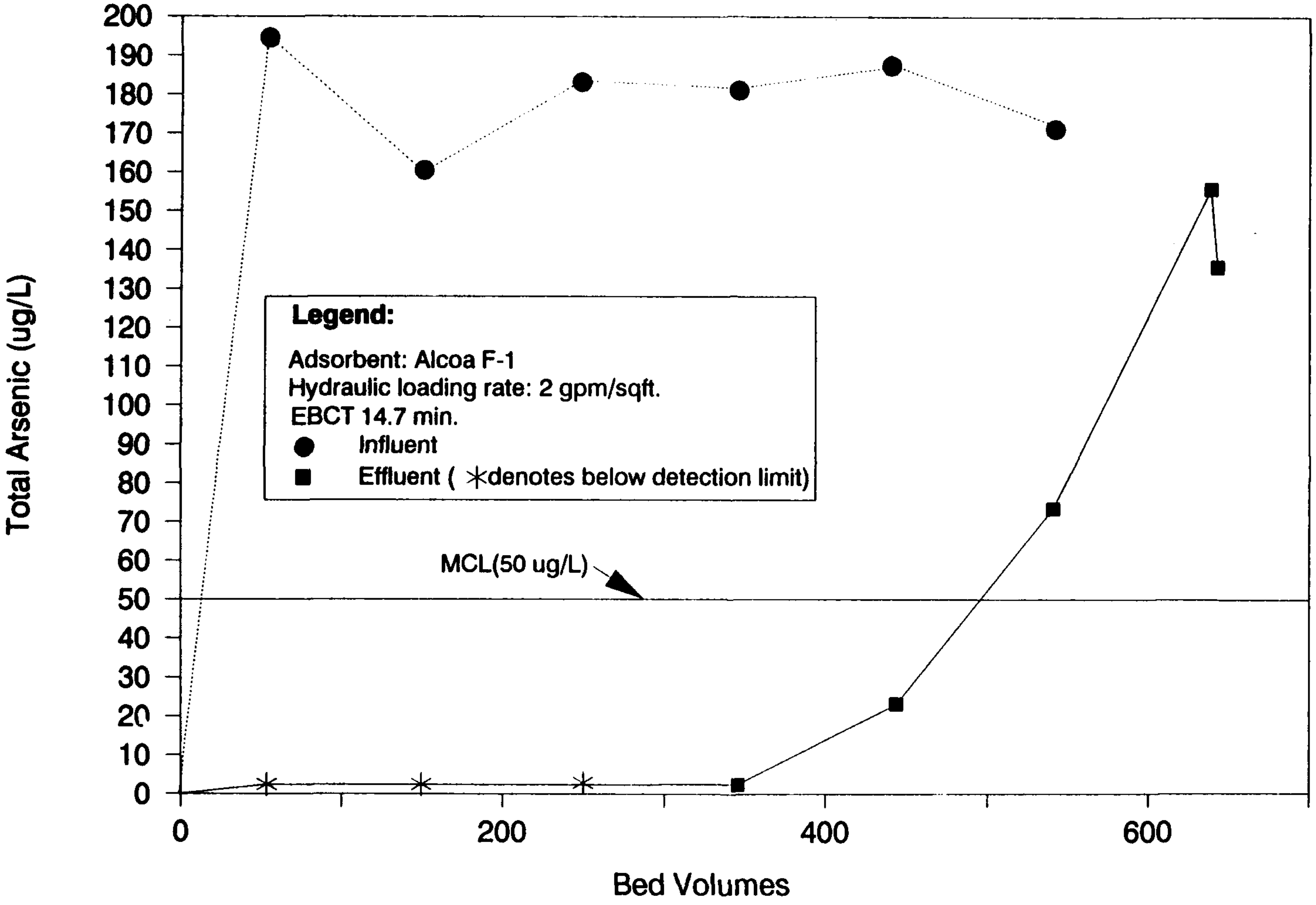

Figure 6-16. Arsenic removal results, Run 7a, TCE added.

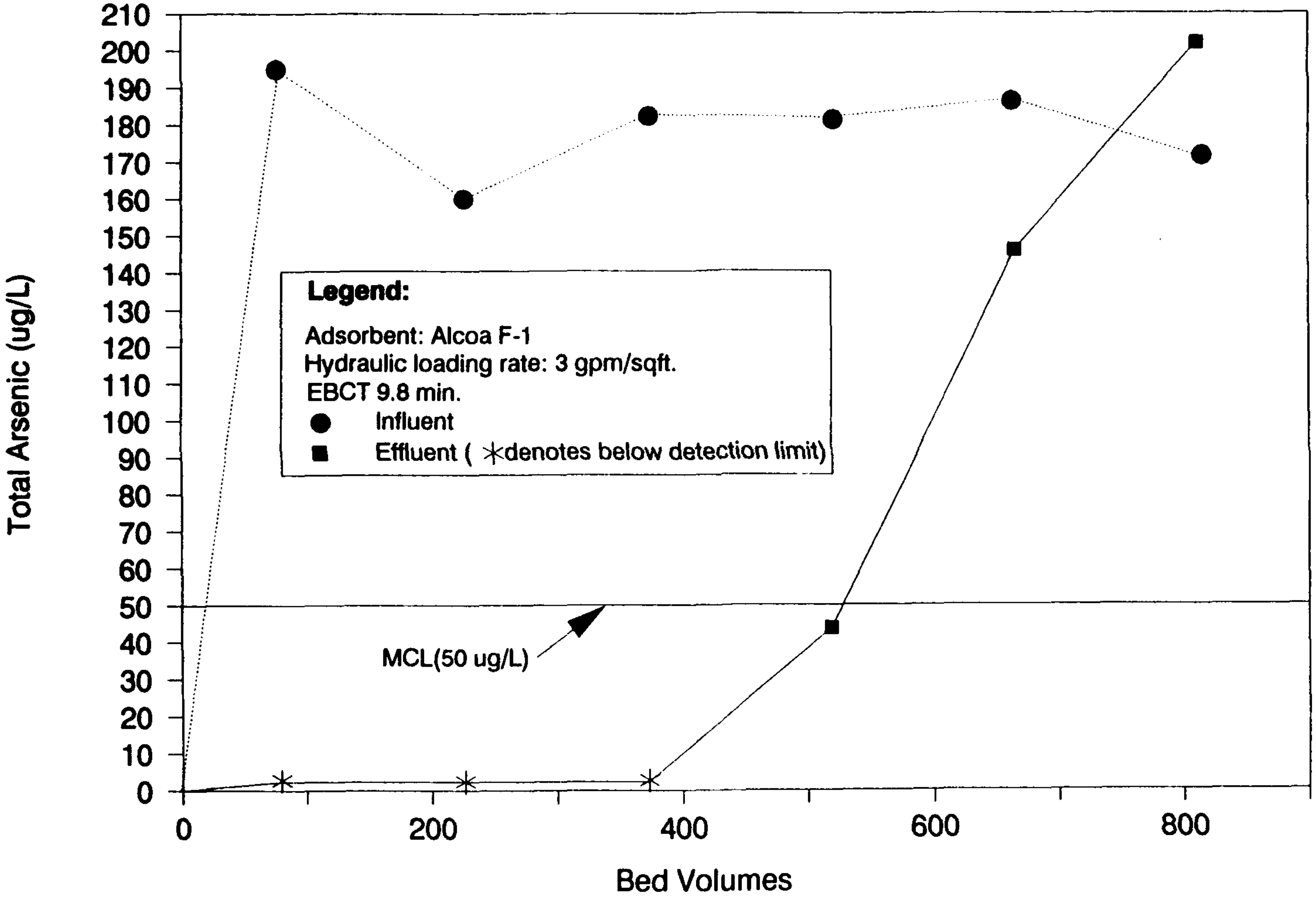

Figure 6-17. Arsenic removal results, Run 7b, TCE added.

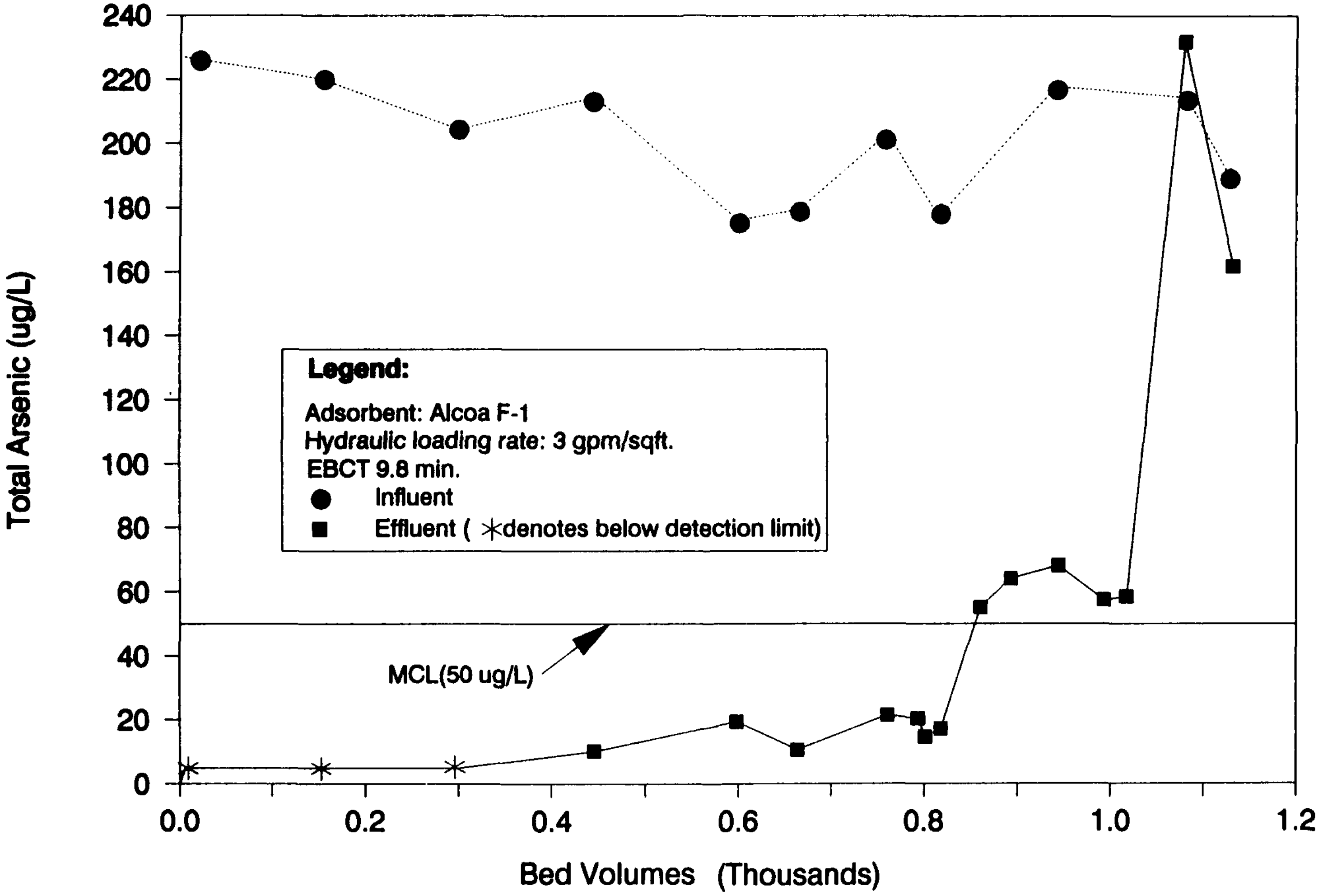

Figure 6-18. Arsenic removal results, Run 7c, no TCE added.

spite of the fact that average influent arsenic concentration was slightly lower during the run with TCE present.

Surprisingly, performance at 2 gpm/ft^2 in the presence of TCE (Figure 6-16) was slightly lower than at 3 gpm/ft^2 (Figure 6-17), in contrast to previous observations regarding hydraulic loading rates and contact times. Comparison of results at 2 gpm/ft^2 with TCE (Figure 6-16) and no pH adjustment with those without TCE but with pH adjustment (Figure 6-13) reveals a decrease in bed life from approximately 3,700 bed volumes to 500 bed volumes. Influent arsenic concentration in the presence of TCE (Run 7a) was comparable to that in the absence of TCE (Run 6a). Therefore, the decrease in bed life was not attributable to increased arsenic loading.

While these results are not definitive, since parallel runs differing only in one operating condition were not possible, the data clearly indicate that the presence of TCE will negatively affect the life of an activated alumina bed used for arsenic removal and that a reduction in influent pH to approximately pH 4 to 6 provides longer bed life in such a system.

Table 6-24 presents the estimated arsenic loading on the AA at the breakthrough point. For Run 7 these calculations are based upon the (weighted) average influent concentration and approximate volume of water treated at the breakthrough point. In calculating the total quantity of arsenic removed, the quantity discharged in the column effluent between the point at which arsenic was first detected and final breakthrough at 50 μg/L, was considered insignificant.

As would be expected the estimated resin loadings at breakthrough shown in Table 6-24 were lower than those observed in the AA test with pH adjustment and TCE removal (see Table 6-20).

Table 6-24

Arsenic Loading at Breakthrough
Alcoa F-1, 28 x 48 Mesh

Run	7a natural pH with TCE	7b natural pH with TCE	7c natural pH without TCE
Hydraulic Loading Rate (gpm/ft^2	2	3	3
EBCT (minutes)	14.7	9.8	9.8
Influent Arsenic Concentration, weighted average (μg/L)	181.6	179.9	202.9
Volume treated at Breakthrough (gal)	1,470	1,550	2480
Alumina weight, primary column (lb)	24	24	24
Total Arsenic Removal at Breakthrough (lb)	2.2×10^{-3}	2.3×10^{-3}	4.2×10^{-3}
Arsenic Loading on Alumina at Breakthrough (lb/lb)	9.2×10^{-5}	9.6×10^{-5}	1.8×10^{-4}

SECTION 7

DISCUSSION

This study has evaluated the potential treatment of arsenic-contaminated groundwater by three different technologies: ion exchange (IE), granular activated carbon (GAC) adsorption, and activated alumina (AA). While the specific mechanism of arsenic removal may vary, the implementation of each of these technologies is similar, each likely employing a series of fixed bed down flow treatment columns (although other configurations are possible) with varying degrees of pretreatment and/or post treatment. Therefore, the performance of the different media can be compared in part on the basis of the quantity of contaminated water, normally expressed in terms of bed volumes, which can be treated prior to breakthrough.

Table 7-1 summarizes the results of pilot tests conducted in this study in terms of the quantity (bed volumes) of contaminated groundwater treated under various operating conditions prior to breakthrough in the primary column effluent, with breakthrough being defined as effluent arsenic concentrations equal to or exceeding the SDWA MCL of 50 μg/L.

These data indicate that both IE resins and AA can provide treatment of SHAD groundwater to levels below the MCL. The longest bed lives were achieved with AA at reduced pH, relatively low hydraulic loading rates and contact times on the order of 9.8 to 14.7 min. Bed lives on the order of 3,000 or more bed volumes of water treated appear to be achievable in a single AA column operating under these conditions. By contrast, IE bed lives on the order of 200 to 500 bed volumes of water might be obtained. GAC does not appear capable of meeting the arsenic treatment requirements under the conditions used in this study.

Definite selection between the two treatment technologies exhibiting satisfactory performance in this study would depend upon analysis of the relative treatment costs, and the operating advantages/disadvantages associated with each technology. This comparative analysis would consider the capital equipment requirements as dictated by such factors as hydraulic loading and contact time, pre- and post-treatment requirements, regeneration requirements and the attrition rate and replacement costs of the media themselves. For example, although AA exhibited the longest bed lives in this study, the data indicate that a pH adjustment step is required and that relatively low hydraulic loading rates and long contact times (corresponding to relatively large adsorption units) are required. By contrast, IE data suggest relatively little dependence on loading rate and contact time over the ranges evaluated, such that relatively smaller adsorbers operating at higher loadings may prove suitable.

Table 7-1

Summary of Pilot Test Results

Test	Medium	Hydraulic Loading Rate (gpm/ft²)	EBCT (min)	Influent[a] Arsenic (μg/L)	Influent pH	TCE	Bed Volumes of Water[b] Treated (Approximate)
1a	IRA 402	2	14.7	227.8	Natural[c]	Absent	450
1b	IRA 402	3	9.8	227.1	Natural[c]	Absent	375
1c	IRA 402	7	4.2	200.5	Natural[c]	Absent	510
2a	A-641	2	14.7	238.7	Natural[c]	Absent	285
2b	A-641	3	9.8	252.8	Natural[c]	Absent	250
2c	A-641	7	4.2	225	Natural[c]	Absent	210
3a	Hydrodarco 3000	7	4.2	182.9	4-6	Absent	d
3b	Hydrodarco 3000	2	14.7	182.9	4-6	Absent	d
3c	Hydrodarco 3000	3	9.8	182.9	4-6	Absent	d
4a	Filtrasorb 400	3	9.8	213	4-6	Absent	d
4b	Filtrasorb 400	7	4.2	213	4-6	Absent	d
4c	Filtrasorb 400	2	14.7	213	4-6	Absent	d
5a	Alcoa F-1	2	14.7	196.1	4-6	Absent	3,700
5b	Alcoa F-1	3	9.8	212.7	4-6	Absent	3,475
5c	Alcoa F-1	7	4.2	257.8	4-6	Absent	2,100
6a	Filtrasorb 400	2	14.7	--	Natural[c]	Absent	d
6b	Filtrasorb 400	1	29.4	--	Natural[c]	Absent	d
7a	Alcoa F-1	2	14.7	181.6	Natural[c]	Spiked	500
7b	Alcoa F-1	3	9.8	179.9	Natural[c]	Spiked	520
7c	Alcoa F-1	3	9.8	202.9	Natural[c]	Absent	850

[a] Weighted average concentration.
[b] Volumes treated prior to breakthrough effluent arsenic concentration ≥ 50 μg/L.
[c] Natural pH generally varied between pH8 and pH9.
[d] Immediate breakthrough observed.

Regeneration of media was not addressed in this study. Since the adsorption capacities of regenerated media may differ in some respects from these of virgin media, this aspect should be addressed prior to design of a treatment system. Based upon previous research and manufacturer's recommendations (summarized in Table 7-2) regeneration of either IE resins or AA is a relatively straightforward operation, requiring conventional reagents, and attrition of the media during regeneration can be controlled.

With respect to media replacement, it should be noted that the ion exchange resins recommended by vendors for use in this study were relatively expensive as compared to, for example, conventional softening resins. The recommended resins cost approximately \$230/ft^3. By contrast, the cost for AA is relatively low, at approximately \$71/ft^3 (\$1.65/lb).

Finally it would appear that treatment of SHAD groundwater by AA without prior removal of TCE (e.g., at individual well heads) may significantly reduce the operating life of the adsorption columns and therefore increase treatment costs.

Table 7-2

Regeneration Requirements

Ion Exchange

Example: IRA-402:

1. NaC1, 5-10% solution, ± 4 lb. salt/ft^3 resin, at 0.25 - 1.0 gpm/ft^3
2. Rinse with water.

Source: Amberlite IRA-402 Technical Literature (Appendix F)

Activated Alumina

1. Regeneration, NaOH, 1% solution, 4 bed volumes.
2. Rinse with water, 8 bed volumes minimum.
3. Acid rinse, 0.05 N H_2SO_4, 1 bed volume minimum.
4. Final rinse, water, 1 bed volume.

Source: References 15, 24, 25.

SECTION 8

CONCLUSIONS

The following conclusions are drawn from the data obtained in this study.

- Strong base anion exchange resins (specifically Rohm and Haas IRA 402 and Sybron Ionac A-641) and AA (specifically Alcoa Type F-1, 28 x 48 mesh) are capable of treating arsenic-contaminated groundwater from well MW-440A at SHAD to effluent concentrations below the SDWA MCL of 50 μg/L (as total arsenic). The GAC tested were not capable of effective arsenic treatment under the conditions evaluated in this study.

- Data from isotherm testing indicate that qualitatively comparable results would be obtained with groundwater from wells MW-403A and 407A.

- Of the successful media, AA provided the longest bed lives (in terms of bed volumes of water treated prior to breakthrough at the MCL level).

- The use of AA requires a pH reduction step. Hydraulic loading rates of 2 to 3 gpm/ft^2 and EBCTs of 9.8 to 14.7 min provided the longest bed lives.

- IE resins exhibited less dependence on hydraulic loading rate or EBCT than did AA. However, bed life at all loading rates was lower than with AA.

- Analytical data from wells MW-403A, MW-407A, MW-431A, and MW-440A indicate that pentavalent arsenic (As^{+5}) is the predominant arsenic species present in SHAD groundwater and that trivalent arsenic (As^{+3}) is present only in small amounts. In fact, removal of As^{+5} alone would be sufficient to achieve the SDWA MCL for total arsenic of 50 μg/L. As a result no oxidative pretreatment step was required or employed in this study and, as long as this situation prevails, oxidative pretreatment should not be required in a full-scale system. It should, however, be recognized the predominance of As^{+5} in groundwater is somewhat unexpected based upon available literature.

- If AA is used for arsenic treatment, direct treatment at individual well heads, without prior removal of TCE would appear to be less favorable than treatment after TCE removal, since the presence of TCE appears to shorten bed life.

SECTION 9

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APPENDIX A

PROJECT APPROVAL LETTER
CALIFORNIA DEPARTMENT OF HEALTH SERVICES

STATE OF CALIFORNIA—HEALTH AND WELFARE AGENCY GEORGE DEUKMEJIAN, Governor

DEPARTMENT OF HEALTH SERVICES
TOXIC SUBSTANCES CONTROL PROGRAM
REGION 1
10151 CROYDON WAY
SACRAMENTO, CA 95827
(916) 855-7700

November 13, 1989

Mr. Abel W. Haines, P.E., Chief
Environmental Program Manager
Sharpe Army Depot
ATTN: SDSSH-AFE-E
Lathrop, CA 95331-5000

Dear Mr. Haines:

APPROVAL OF ARSENIC PILOT PLAN PROPOSAL, SHARPE ARMY DEPOT

The Department of Health Services (Department) has reviewed the proposed pilot project for treatment of arsenic in ground water that was contained in your 18 October 1989, letter. According to that letter, the pilot project consists of a Granular Activated Carbon/Ion Exchange/Activated Alumina (GAC/IE/AA) treatment plant. The pilot project is being undertaken at the direction of the Regional Water Quality Control Board (RWQCB) and the Environmental Protection Agency (EPA).

The Department has no objections to the Army implementing this pilot plan. However, we encourage you to keep us informed as to the progress of this project.

If you should have any questions or comments on this matter, please contact Tracie Billington at (916) 855-7873.

Sincerely,

Anthony J. Landis

Anthony J. Landis, P.E.
Chief, Site Mitigation Unit

cc: See next page.

APPENDIX B

ANALYSIS OF STRIPPING TOWER

```
******* A N A L Y S I S   OF   S T R I P P I N G   T O W E R  ******

PROJECT  : SHAD PILOT STUDY                          DATE :  10/19/1989

ENGINEER : K.N. PANNEERSELVAM                        PAGE :  1/2


                              PHYSICAL CONSTANTS

Design temperature                 :     55.0 degrees F.
Density of water                   :     62.4 lb/ft^3
Density of air                     :   0.0771 lb/ft^3
Viscosity of water                 : 8.13E-04 lb/ft.s
Viscosity of air                   : 1.17E-05 lb/ft.s
Surface tension of water           :       74 dyne/cm
Atmospheric pressure               :     1.00 atm


                            CONTAMINANT PROPERTIES

Name                               :   Trichloroethylene
Molecular weight                   :    131.3 g/mol
Boiling point                      :      189 degrees F.
Molal volume at boiling point      :   0.1071 L/mol
Henry's Constant                   :  0.33000
Enthalpy upon dissolution in water :     3793 cal/mol
Molecular diffusivity in air       : 8.68E-05 ft^2/s
Molecular diffusivity in water     : 7.27E-09 ft^2/s


                              PACKING PROPERTIES

Name                               :  Jaeger Tripacks
Packing Material                   :  Plastic
Nominal Size                       :    1.00 inch
Specific Area                      :    84.7 ft^2/ft^3
Critical surface tension           :      33 dyne/cm
Packing depth                      :    15.0 ft
Air friction factor                :      28


     AIRSTRIP Ver. 1.0  (C) 1988             3209 Garner  Ames, Iowa 50C

                     *****    Roy F. Weston, Inc.    *****
```

[illegible]

```
******* A N A L Y S I S   O F   S T R I P P I N G   T O W E R *****

PROJECT  : SHAD PILOT STUDY                           DATE :  10/19/1989

ENGINEER : K.N. PANNEERSELVAM                         PAGE :  2/2


                              LOADING RATES

Water mass loading rate               :     2.0 lb/ft^2.s
Air mass loading rate                 :   0.369 lb/ft^2.s
Water volumetric loading rate         :   14.29 gpm/ft^2
Air volumetric loading rate           :    2144 gpm/ft^2
Air pressure gradient                 :   0.292 " H2O/ft
Volumetric air/water ratio            :   150.0
Stripping factor                      :    33.9


                        MASS TRANSFER PARAMETERS

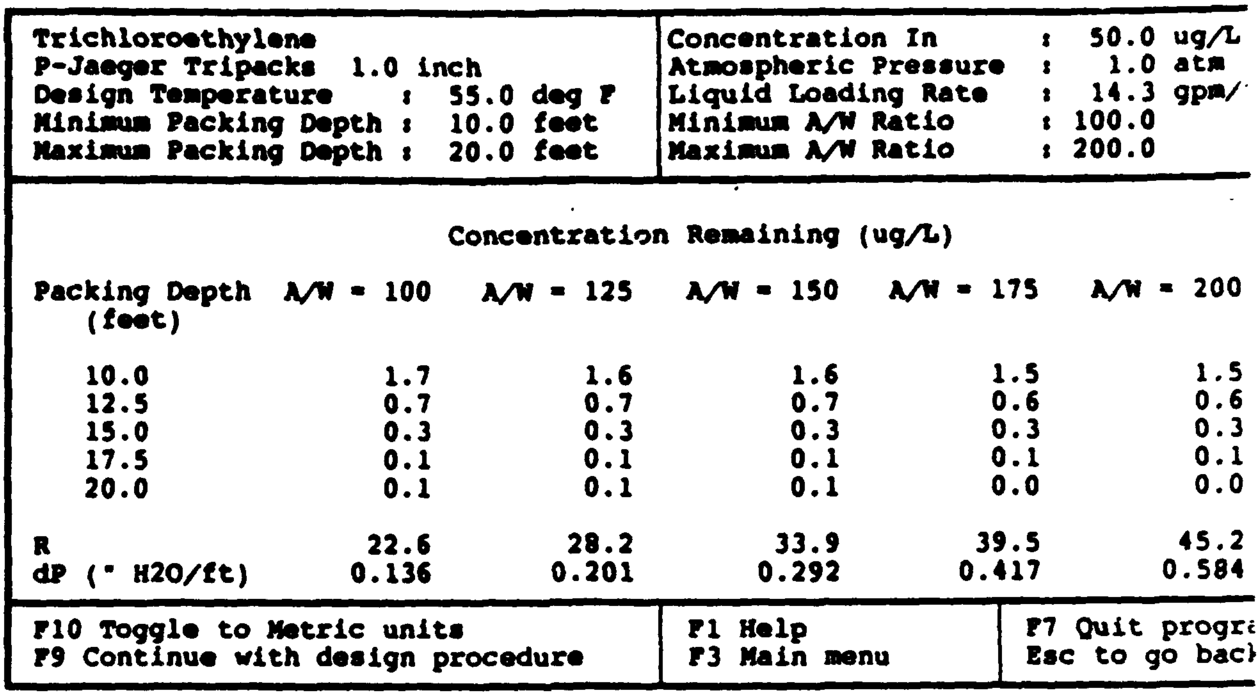
Percentage of packing area wetted     :       39.8 %
Wetted packing area                   :       33.8 ft^2/ft^3
Transfer rate constant in water       :   0.000342 ft/s
Transfer rate constant in air         :   0.071660 ft/s
Overall transfer rate constant        :   0.000335 ft/s
Overall mass transfer coefficient     :     0.0113 1/s
NTU                                   :     5.3041
HTU                                   :     2.8280 ft


                          CONTAMINANT REMOVAL

Influent concentration                :      50.0 ug/L
Effluent concentration                :       0.3 ug/L
Fraction removed                      :      99.4 %
Mass of contaminant removed           :   0.00853 lb/ft^2.day
Concentration in airstream            :   0.00087 mg/ft^2.ft^3

*   Expressed per unit of stripping tower cross-sectional area
#   Expressed per unit of tower length


    AIRSTRIP Ver. 1.0  (C) 1988              3209 Garner  Ames, Iowa 500
```



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Trichloroethylene                        Concentration In       :  50.0 ug/L
P-Jaeger Tripacks  1.0 inch              Atmospheric Pressure   :   1.0 atm
Design Temperature    :  55.0 deg F      Liquid Loading Rate    :  14.3 gpm/
Minimum Packing Depth :  10.0 feet       Minimum A/W Ratio      : 100.0
Maximum Packing Depth :  20.0 feet       Maximum A/W Ratio      : 200.0

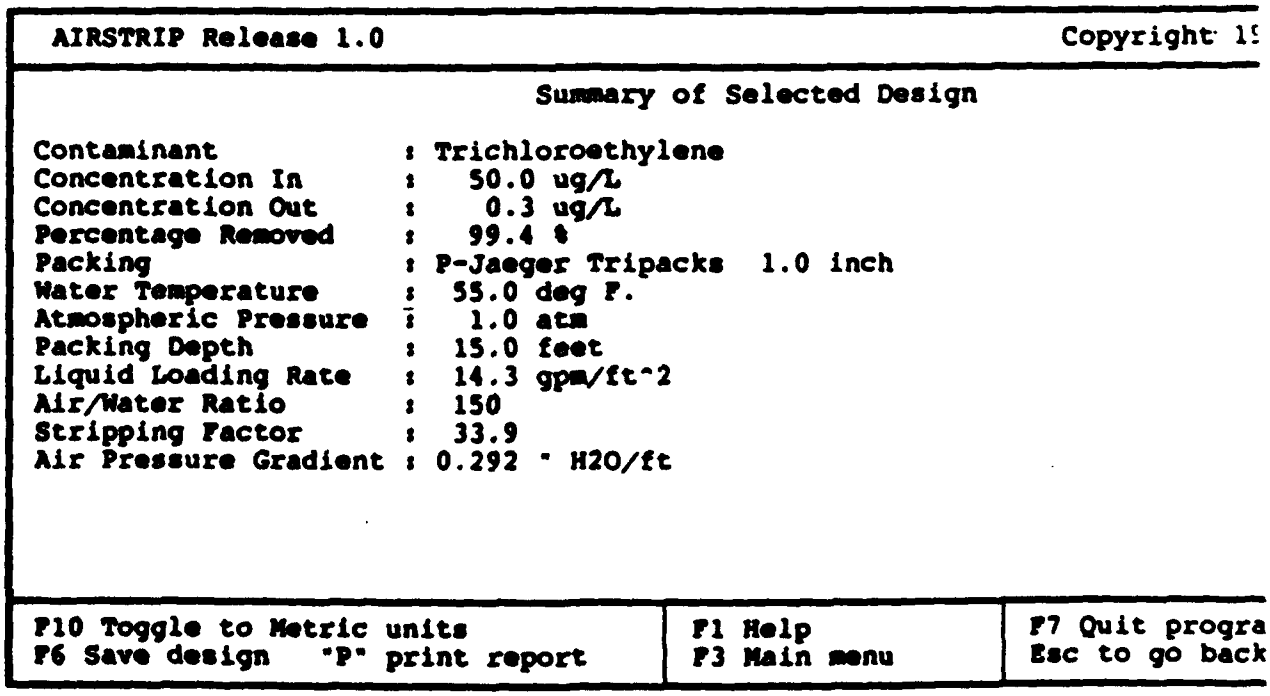
                     Concentration Remaining (ug/L)

Packing Depth  A/W = 100   A/W = 125   A/W = 150   A/W = 175   A/W = 200
   (feet)

   10.0              1.7         1.6         1.6         1.5         1.5
   12.5              0.7         0.7         0.7         0.6         0.6
   15.0              0.3         0.3         0.3         0.3         0.3
   17.5              0.1         0.1         0.1         0.1         0.1
   20.0              0.1         0.1         0.1         0.0         0.0

R                   22.6        28.2        33.9        39.5        45.2
dP (" H2O/ft)      0.136       0.201       0.292       0.417       0.584

F10 Toggle to Metric units               F1 Help             F7 Quit progr
F9 Continue with design procedure        F3 Main menu        Esc to go bac
```



```
 AIRSTRIP Release 1.0                                          Copyright 1

                        Summary of Selected Design

Contaminant             : Trichloroethylene
Concentration In        :   50.0 ug/L
Concentration Out       :    0.3 ug/L
Percentage Removed      :   99.4 %
Packing                 : P-Jaeger Tripacks  1.0 inch
Water Temperature       :  55.0 deg F.
Atmospheric Pressure    :   1.0 atm
Packing Depth           :  15.0 feet
Liquid Loading Rate     :  14.3 gpm/ft^2
Air/Water Ratio         :  150
Stripping Factor        :  33.9
Air Pressure Gradient   : 0.292 " H2O/ft

F10 Toggle to Metric units               F1 Help             F7 Quit progra
F6 Save design   "P" print report        F3 Main menu        Esc to go back
```

APPENDIX C

ARSENIC SPLIT SAMPLING

Inter-Office Memorandum

WESTON
MANAGERS DESIGNERS/CONSULTANTS

TO: [redacted]
cc: Gail Celaschi
Stacy Brunner

FROM: Leo O'Shea
DATE: March 26, 1990
PROJECT: Sharpe Army Depot
W.O. NO.: 2281-08-09
SUBJECT: Arsenic Comparability Study
ACTION:

As requested, a split sample was analyzed for total arsenic in the Stockton and Lionville laboratories. A split sample was also spiked at 500 ug/L by the Lionville laboratory and shipped single-blind for analysis in Stockton.

The data are presented in the attached table. As you can see, the data are comparable from each of the laboratories. A 12% difference between the analyses at the dilution required is reasonable. The spiked analysis also shows reasonable comparability.

If you have any questions concerning these data I may be reached at (215) 524-7360.

Arsenic Analysis
Comparability Study
Stockton/Lionville

Client: Sharpe Army Depot
WO#: 2281-08-09

Sample Id	Lionville Result ug/L	Stockton Result ug/L	RPD
Sample 1	384	433	11.9%
Sample Spike(500 ug/L)	892	905	1.4%
% Recovery	101.6%	94.5%	--

Analysis at Lionville performed with a 20 fold dilution
Analysis at Stockton performed with a 25 fold dilution

Leo E. O'Shea
Project Manager

3/26/90
Date

APPENDIX D

ARSENIC SPECIATION DATA REPORTS

THE ACADEMY OF NATURAL SCIENCES

FOUNDED IN 1812
RESEARCH · MUSEUM · EDUCATIO

NEDICT ESTUARINE RESEARCH LABORATORY

MEMORANDUM

To: Dr. William Lowe, Western Analytic

From: Jim Sanders

Date: 4 June 1990

Subj: Arsenic speciation in groundwater samples

Enclosed are the concentrations of arsenate and arsenite (in μg/L) in the two groundwater samples collected 23 May. To date, we have run 13 samples for you (9 plus 1 rerun caused by organic contamination during freezing in the original batch and 2 plus 1 rerun caused by organic contamination in this batch). This effectively completes our current contract with you and I will be submitting a bill to you next week. If you feet that you will have additional samples in the future, please call me to initiate a new contract.

Sample No.	Arsenite	Arsenate	Total
Influent	0.84	193	194
MW440A	0.91	224	225

BENEDICT, MARYLAND 20612 · (301) 274-3134
Telemail (OMNET) Address: BENEDICT. LAB

THE ACADEMY OF NATURAL SCIENCES

FOUNDED IN 1812
RESEARCH · MUSEUM · EDUCATION

BENEDICT ESTUARINE RESEARCH LABORATORY

MEMORANDUM

To: Bill Lowe, Weston Analytics

From: Jim Sanders

Subject: Arsenic speciation in groundwater samples

Enclosed are the concentrations of arsenate and arsenite (in µg/L) in both the original groundwater samples and the latest experimental samples. Please call me if you have any questions.

Sample No.	Arsenite	Arsenate	Total (Std Dev)
407A	0.77	240	241 ± 25.1
403A	0.64	133	133 ± 4.6
431A	0.03	7.47	7.50 ± 0.34
407A-1-BLK	<1	230	230
407A-2	<1	218	218
407A-3	<1	234	234
407A-4	<1	232	232
407A-5	<1	207	207
407A-6	<1	189	189

BENEDICT, MARYLAND 20612 · (301) 274-3134
Telemail (OMNET) Address: BENEDICT. LAB

APPENDIX E

WELL LOGS

WESTON

GROUNDWATER WELL LOG SHEET

Site SHAD **Samplers** JFH, TLR

Field # 403 A

Sample I.D. 403 A **Date** 12/22/89 **Time** 1120

TOTAL WELL DEPTH 24.80 **FT.** 2" well

S.W.L. 18.62 **FT.**

WATER COLUMN ______ **FT.**

WATER VOLUME 1.01 **G.**

X3= 3.03 **G.**

FLOW RATE ______ **G.P.M.**

PUMPING TIME REQUIRED ______ **MINS.**

ACTUAL PUMPING TIME ______ **MINS.**

rged ~~**BAILED**~~ 3 gal

SAMPLES TAKEN: @1120

Metals
NO_3
NH_3
P
SO_4
624

Some minor drawdown noted during purge.

53.5 **°~~C~~ F (Immediate)**

1479 **Conductivity (umhos)**

7.47 **pH**

~~[illegible]~~ **°C (at pH Cond. Readings)**

Duplicate Taken: **Yes** [✓ **No**]

I.D. Assigned ______

Field # ______

______ **°C (Immediate)**

______ **Conductivity (umhos)**

______ **pH**

______ **°C (at pH Cond. Readings)**

SAMPLES TAKEN:

WESTON

GROUNDWATER WELL LOG SHEET

Site SHAD **Samplers** JFH TLR

Field # 407A

Sample I.D. 407A **Date** 12/22/89 **Time** [illegible]

TOTAL WELL DEPTH 22.88 ~~28~~ [illegible] **FT.** 2" well

S.W.L. 18.84 **FT.**

WATER COLUMN ______ **FT.**

WATER VOLUME 0.66 **G.**

X3= 1.78 **G.**

FLOW RATE ______ **G.P.M.**

PUMPING TIME REQUIRED ______ **MINS.**

ACTUAL PUMPING TIME ______ **MINS.**

purged/**BAILED** 2 gal.

SAMPLES TAKEN: @ 1[illegible]

Metals
NO_3
NH_3
P
SO_4
624

Little drawdown during purge.

56.0 **°~~C~~F (Immediate)**

1250 **Conductivity (umhos)**

8.26 **pH**

______ **°C (at pH Cond. Readings)**

Duplicate Taken: Yes [✓ No]

I.D. Assigned ______

Field # ______

______ **°C (Immediate)**

______ **Conductivity (umhos)**

______ **pH**

______ **°C (at pH Cond. Readings)**

SAMPLES TAKEN:

WESTON

GROUNDWATER WELL LOG SHEET

Site SHAD **Samplers** JEH TLR

Field # 431 A

Sample I.D. 431 A **Date** 12/22/89 **Time** 1240

TOTAL WELL DEPTH 36.70 **FT.** 4" well

S.W.L. 21.17 **FT.**

WATER COLUMN ______ **FT.**

WATER VOLUME 10.14 **G.**

X3= 30.41 **G.**

FLOW RATE ______ **G.P.M.**

PUMPING TIME REQUIRED ______ **MINS.**

ACTUAL PUMPING TIME ______ **MINS.**

purged/ **BAILED** 32 gal.

SAMPLES TAKEN: @ 1240

metals
NO_3 P
NH_4
SO_4
624

little/no drawdown noted during purge.

56 **°~~C~~F (Immediate)**

756 **Conductivity (umhos)**

7.90 **pH**

______ **°C (at pH Cond. Readings)**

Duplicate Taken: Yes [✓ No]

I.D. Assigned ______

Field # ______

______ **°C (Immediate)**

______ **Conductivity (umhos)**

______ **pH**

______ **°C (at pH Cond. Readings)**

SAMPLES TAKEN: gal. bailed { || 卌 卌 卌 卌 卌 卌

APPENDIX F

ARSENIC OXIDATION TEST

Table F-1

Results of Arsenic Oxidation Test[a]

Flask	NaOCl[b] Dosage (mL/L)	Sample ID	Arsenite[c] (ug/L)	Arsenate[c] (ug/L)	Total Arsenic (ug/L)	Chlorine Residual (mg/L)
1	-	407A-1-BLK	<1	230	230	0
2	0.20	407A-2	<1	218	218	0
3	1.01	407A-3	<1	234	234	0.02
4	2.02	407A-4	<1	232	232	0.03
5	10.1	407A-5	<1	207	207	0.16
6	20.2	407A-6	<1	189	189	0.26

[a] Refer to experimental protocol in Test Plan [31].
[b] 5.25% sodium hypochlorite solution.
[c] Refer to original data reports, Appendix D.

APPENDIX G

ADSORBENT MEDIA PRODUCT INFORMATION

ROHM AND HAAS COMPANY
PHILADELPHIA, PENNSYLVANIA 19105
LUID PROCESS CHEMICALS

AMBERLITE ION EXCHANGE RESINS

Amberlite IRA-402 is a gel-type synthetic, high capacity, porous anion exchange resin supplied as small, insoluble beads in the chloride form. Amberlite IRA-402 is recommended where treatment of organic bearing waters has caused operating difficulties with standard porosity anion exchange resins and where the high capacity of a gel-type resin is required.

IMPORTANT FEATURES OF AMBERLITE IRA-402

HIGH POROSITY AND HIGH CAPACITY—The porous structure of Amberlite IRA-402 permits greater removal of organic contaminants from influent water streams resulting in higher effluent quality. During the regeneration cycle, these organics are more completely removed than in similar regeneration of standard porosity resins. As a result, organic fouling—the principal cause of poor anion exchange resin performance—is reduced through the use of Amberlite IRA-402. Since this resin exhibits the high capacity characteristics of standard porosity anion exchange resins, such as Amberlite IRA-400, it is no longer necessary to sacrifice capacity to obtain good performance on waters of moderate organic content.

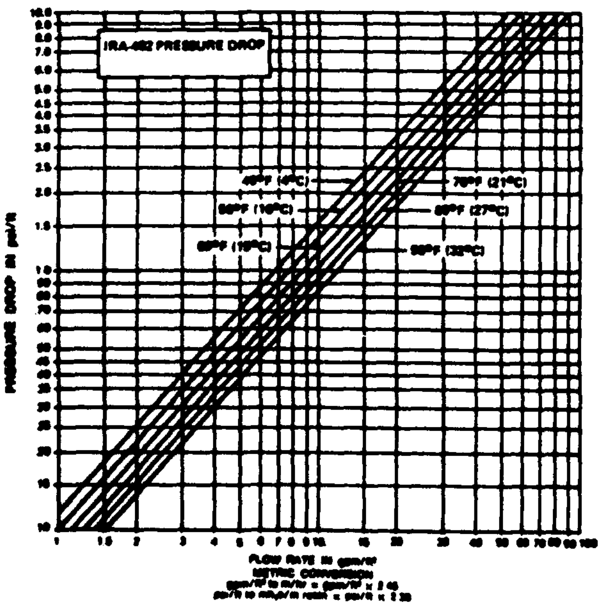
DIVINYLBENZENE CROSSLINKAGE—Amberlite IRA-402 is one of many strongly basic anion exchange resins produced by Rohm and Haas Company using divinylbenzene as the crosslinking agent. Since this is the most stable material known for this purpose, long term physical stability is obtained by using Amberlite IRA-402 or any of the other Amberlite anion exchange resins.

STABLE OVER ENTIRE pH RANGE.

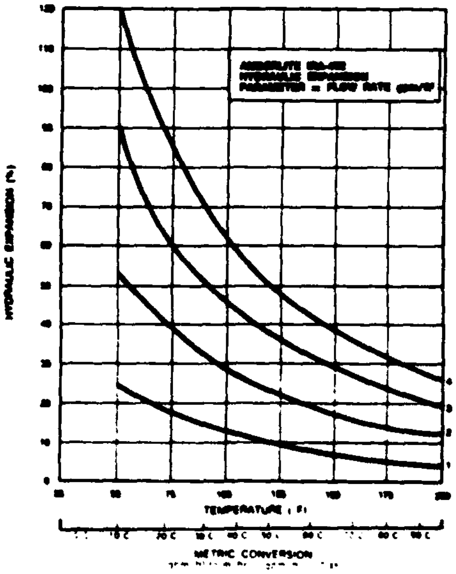
INSOLUBLE IN ALL COMMON SOLVENTS.

HYDRAULIC CHARACTERISTICS

PRESSURE DROP—The curves show the expected pressure drop per foot of bed depth in normal downflow operation at various temperatures as a function of flow rate.



BACKWASH CHARACTERISTICS — After each operational cycle Amberlite IRA-402 should be backwashed for approximately ten minutes to overcome any compaction of the bed that may have occurred during the previous service run and to purge the bed of any insoluble material which may have collected on top of the resin. The resin bed should be expanded a minimum of 50% during backwash.



PHYSICAL CHARACTERISTICS

YSICAL FORM — Uniform, attrition-resistant, spherical par-cles, shipped moist in the chloride salt form

SHIPPING WEIGHT — 43 lbs/ft³ (688g/l)

MOISTURE CONTENT — 54%*

CREEN GRADING (WET) — 16 to 50 mesh (U.S. Standard Screens)

NES CONTENT — <1%* through a 50 mesh U.S. Standard reen

SWELLING — 22%* upon complete conversion from chloride to droxide form

EFFECTIVE SIZE — 0.50 mm*

NIFORMITY COEFFICIENT — 1.5*

pproximate

OPERATING CHARACTERISTICS

Suggested operating conditions for Amberlite IRA-402 e listed below:

H Limitation	None
laximum Temperature	
(hydroxide form)	140°F (60°C)
(chloride form)	170°F (77°C)
Minimum Bed Depth	24 in (0.61m)
ackwash Flow Rate	2-3 gpm/ft² (4.9-7.35 m/hr) at 70°F (21°C)
Regenerant Concentration*	4% NaOH
egenerant Flow Rate	0.25 to 1.0 gpm/ft³ (2.0 to 8.0 l/hr/l)
Regeneration Level	See text
inse Flow Rate	Same as regeneration flow rate initially, then 1.5 gpm/ft³ (12.0 l/hr/l)
Rinse Water Requirements	40 to 90 gal/ft³ (5.4 to 12.1 l/l)
Service Flow Rate	2-5 gpm/ft³ (16.0-40.1 l/hr/l)
xchange Capacity	See text

ee Safe Handling Information Section

REGENERATION LEVEL AND CAPACITY

The regeneration level employed will depend upon the capacity desired in the exhaustion cycle, the leak-e of anions that can be tolerated during service and onomic considerations. The relationship between the capacity of Amberlite IRA-402 and various acids as a nction of the regeneration level is illustrated in the ble of acid removing capacity that follows.

Lbs. of NaOH/ft³ Resin	gms of NaOH/L Resin	CAPACITY (a) kgr as $CaCO_3/ft^3$ (b) $gCaCO_3/L$													
		HCl (a)	HCl (b)	H_2SO_4 (a)	H_2SO_4 (b)	H_2SiO_3 (a)	H_2SiO_3 (b)	H_2CO_3 (a)	H_2CO_3 (b)	HNO_3 (a)	HNO_3 (b)	H_3PO_4 (a)	H_3PO_4 (b)	CH_3COOH (a)	CH_3COOH (b)
2	32	9.0	20.6	11.3	25.9	—	—	16.0	36.6	4.7	10.8	14.0	32.1	13.9	31.8
4	64	12.0	27.5	14.6	33.4	12.6	28.9	19.0	43.5	7.9	18.1	16.1	36.9	19.8	45.3
8	128	14.9	34.1	17.5	40.1	16.7	38.2	21.3	48.8	11.3	25.9	18.4	42.1	23.4	53.6
10	160	17.0	38.9	19.6	44.9	18.9	43.3	21.7	49.7	13.0	29.8	19.8	45.3	25.2	57.7
12	192	20.1	46.0	22.9	52.4	22.0	50.4	22.0	50.4	15.6	35.7	21.8	49.9	27.0	61.8

APPLICATIONS

DEIONIZATION—Amberlite IRA-402 is particularly recommended for use in multiple bed or mixed bed units wherever complete deionization of water supplies containing organic compounds is required. More complete removal of these organics will be of special significance in treatment of water used in the production of electronic components and other manufacturing where extremely high purity water is required. In treatment of water for boiler makeup, the relative freedom of Amberlite IRA-402 from organic fouling insures good performance for a longer time.

DESILICIZERS—In treatment of water supplies high in silica and relatively low in other dissolved solids, the use of a cation exchange resin such as Amberlite IR-120, operating in the sodium cycle and a strongly basic anion exchange resin operating in the hydroxide form has been effective in providing low silica makeup for medium pressure boilers. This represents a considerable saving over the use of deionization equipment. Laboratory studies have established that on many waters Amberlite IRA-402 exhibits higher total capacity and higher silica capacity than standard porosity type I anion exchange resins in this application.

OTHER APPLICATIONS—The porous structure and high capacity of Amberlite IRA-402 offer advantages in removing various acids from process streams. Consideration should be given to employing Amberlite IRA-402 in either the chloride or hydroxide form for non-water treatment applications involving the exchange of anions.

SAFE HANDLING INFORMATION—A Material Safety Data Sheet is available for Amberlite IRA-402. To obtain a copy contact your Rohm and Haas representative.

CAUTION—Acidic and basic regenerant solutions are corrosive and should be handled in a manner that will prevent eye and skin contact. Nitric acid and other strong oxidizing agents can cause explosive type reactions when mixed with ion exchange resins. Proper design of process equipment to prevent rapid buildup of pressure is necessary if use of an oxidizing agent such as nitric acid is contemplated. Before using strong oxidizing agents in contact with ion exchange resins, consult sources knowledgeable in the handling of these materials.

IE-68-62/80 February 1983 Printed in U.S.A.

ROHM AND HAAS COMPANY
PHILADELPHIA, PENNSYLVANIA 19105
FLUID PROCESS CHEMICALS

AMBERLITE ION EXCHANGE RESINS

AMBERLITE® IRA-900

Amberlite IRA-900 is a strongly basic, Type I, macroreticular anion exchange resin which derives its exchange activity from quaternary ammonium groups. The fixed porosity of the resin bead structure is important. It is a true, discretely porous network which differs completely from conventional strongly basic gel type resins, and provides more complete removal of large organic molecules, and therefore a very high quality effluent. The resin beads are extremely resistant to physical breakdown.

IMPORTANT FEATURES OF AMBERLITE IRA-900

- **HIGHEST BASICITY**: Amberlite IRA-900 is highly recommended for deionization systems where effective removal of silica and organics from waters is desired. It exhibits the high degree of basicity and porosity necessary to produce a very high quality water.

- **MAXIMUM RESIN LIFE**: Being a Type I, macroreticular anion exchange resin. Amberlite IRA-900 offers maximum temperature stability and the greatest resistance to loss of strong base capacity due to oxidation. From a physical standpoint, the tough, durable structure of the resin offers unusual resistance to attrition due to osmotic or physical stresses.

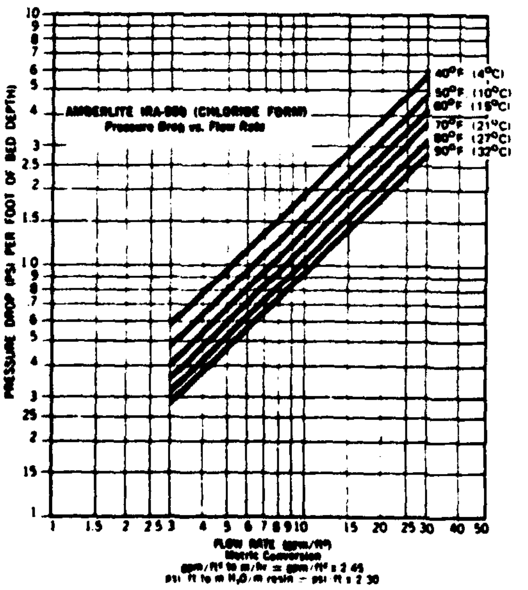
- **HIGH POROSITY**: An important feature of Amberlite IRA-900 is the fixed porosity of the resin's bead structure. The macropores in this resin are completely different from the gel porosity of a conventional resin. The high rate of reaction and adsorptive capacity for high molecular weight organic anions make Amberlite IRA-900 ideally suitable for the production of ultra high quality water and the decolorization of process systems and the isolation and recovery of organic acid.

- **STABLE OVER THE ENTIRE pH RANGE.**

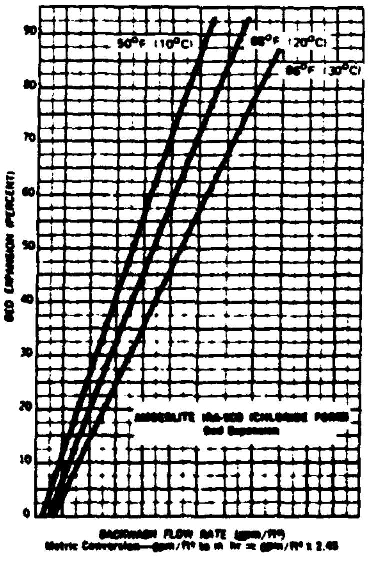
- **INSOLUBLE IN ALL COMMON SOLVENTS.**

HYDRAULIC CHARACTERISTICS

• **PRESSURE DROP**—The curves show the expected pressure drop per foot of bed depth in normal downflow operation at various temperatures as a function of flow rate.



• **BACKWASH CHARACTERISTICS**—After each operational cycle Amberlite IRA-900 should be backwashed for approximately 10 minutes with water to reclassify the resin particles and purge the bed of any suspended insoluble material which may have collected on top of the resin. The resin bed should be expanded a minimum of 50% during backwash.



PHYSICAL CHARACTERISTICS

- **PHYSICAL FORM**—Uniform, attrition resistant, spherical particles, shipped in the chloride salt form in a moist, completely swollen condition.
- **SHIPPING WEIGHT**—42 lbs/ft³ (672 g/l).
- **MOISTURE CONTENT**—60%.*
- **SCREEN GRADING (WET)**—16 to 50 mesh (U.S. Standard Screen).
- **EFFECTIVE SIZE**—0.53 millimeters.*
- **UNIFORMITY COEFFICIENT**—1.8 maximum.
- **SWELLING**—20%* upon complete conversion of the resin from the chloride to the hydroxide form.
- **FINES CONTENT**—1% maximum through a 50 mesh U.S. Standard Screen.

*Approximate.

SUGGESTED OPERATING CONDITIONS

pH Limitation	None
Maximum Temperature	
(hydroxide form)	140°F (60°C)
(chloride form)	170°F (77°C)
Minimum Bed Depth	24 inches (0.61 m)
Backwash Flow Rate	See detailed information
Regenerant Concentration*	4% NaOH
Regenerant Flow Rate	0.25 to 0.5 gpm/ft³ (2.0 to 4.0 l/hr/l)
Regeneration Level	See table below
Rinse Flow Rate	0.25-0.5 gpm/ft³ (2.0 l/hr/l) initially, to displace regenerant then 1.5 gpm/ft³ (12.0 l/hr/l)
Rinse Water Requirements	Approx. 75 gal/ft³ (10.0 l/l)
Service Flow Rate	1 to 3 gpm/ft³ (8.0 to 24.1 l/hr/l)
Exchange Capacity	See detailed information

*See Safe Handling Information section.

REGENERATION LEVEL AND CAPACITY

The regeneration level employed will depend upon the capacity desired in the exhaustion cycle, the leakage of anions that can be tolerated during service and economic considerations. The acid removing capacity of Amberlite IRA-900 at different regeneration levels is shown in the following table.

Regeneration NaOH @ 70°F		Capacity (as $CaCO_3$)							
		HCl		H_2SO_4		H_2SiO_3		H_2CO_3	
lbs/ft³	g/l	Kgr/ft³	g/l	Kgr/ft³	g/l	Kgr/ft³	g/l	Kgr/ft³	g/l
4	64	8.8	20.2	10.3	23.6	8.6	19.7	14.4	33.0
6	96	10.4	23.8	11.8	27.0	10.3	23.6	15.6	35.7
8	128	11.5	26.3	13.0	29.8	11.5	26.3	15.9	36.4
10	160	12.2	27.9	13.9	31.8	12.4	28.3	16.2	37.1

APPLICATIONS

- **DEIONIZATION**—Amberlite IRA-900 is particularly recommended for use in multiple bed or mixed bed units wherever complete deionization of water supplies containing organic compounds is required. The resin exhibits the high degree of basicity and porosity necessary to produce a very high quality water. The macroreticular structure of the resin will resist fouling and physical breakdown.

- **SILICA REMOVAL**—Strongly basic anion exchange resins are frequently used to reduce the silica content of boiler feedwater. The water must be pre-softened and treated with acid to reduce pH after contact with the anion exchange resin. Although this system is often the optimum one for a given installation, organics in the raw water may seriously shorten the life expectancy of conventional strongly basic anion exchangers. Amberlite IRA-900 is excellent for this application. Its macroreticular structure better copes with the organics and its silica removal characteristics are unexcelled.

- **SPECIAL APPLICATIONS**—Amberlite IRA-900 in the chloride form has been found to have a remarkably high capacity for organic color bodies. Because of its porosity, Amberlite IRA-900 removes color bodies and other organics which are then efficiently eluted from the resin by the use of brine. Amberlite IRA-900 performs well in decolorizing and removing organic acids from sugar, pharmaceuticals and chemicals. Due to its high physical stability, Amberlite IRA-900 is particularly effective in applications where the resin may be subjected to serve osmotic or mechanical shock.

- **SAFE HANDLING INFORMATION**—A Material Safety Data Sheet is available for Amberlite IRA-900. To obtain a copy contact your Rohm and Haas representative.

Caution: Acidic and basic regenerant solutions are corrosive and should be handled in a manner that will prevent eye and skin contact.

Nitric acid and other strong oxidizing agents can cause explosive type reactions when mixed with ion exchange resins. Proper design of process equipment to prevent rapid buildup of pressure is necessary if use of an oxidizing agent such as nitric acid is contemplated. Before using strong oxidizing agents in contact with ion exchange resins, consult sources knowledgeable in the handling of these materials.

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IE-100-66/81 December 1982 Printed in U.S.A.

SYBRON | CHEMICAL DIVISION Ionac

SYBRON CORPORATION/CHEMICAL DIVISION
BIRMINGHAM, N.J. 08011 • 609/894-8211 • TELEX 843407

IONAC® ASB-I
Anion Exchange Resin
Strong Base, Type I

IONAC ASB-1 is a rugged, strongly basic Type I quaternary ammonium anion exchange resin based on a styrene-divinylbenzene copolymer matrix. It may be used in all types of deionization systems but is especially recommended for systems which will produce high quality, practically silica-free, water. IONAC ASB-1 provides excellent service in both mixed bed and in multiple bed demineralizer systems. Since IONAC ASB-1 has a very high basicity it is effective in removing weak acids such as silica and carbon dioxide. In addition to its high capacity for silica removal, IONAC ASB-1 demonstrates the stability to high temperature regeneration required for minimum silica leakage.

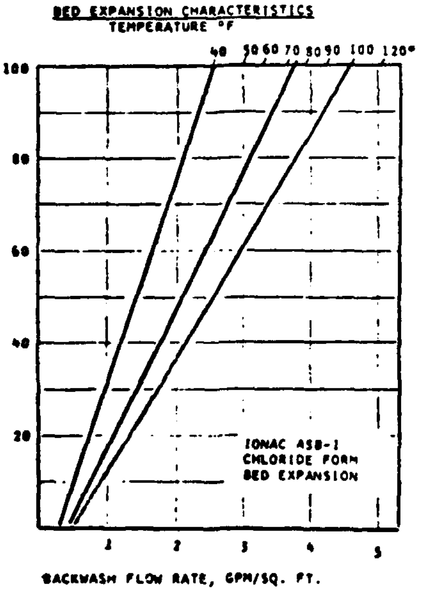
IONAC ASB-1 is classed as a strong base (TYPE I) anion exchange resin with a gel structure of polystyrene crosslinked with divinylbenzene, supplied in small, uniform, moist beads (20 to 50 U.S. mesh screen size).

Strong base anion exchangers are capable of removing weak acids such as silica and carbonic, as well as strong mineral acids. TYPE I anion resins such as ASB-1 have a higher basicity and greater resistance to oxidation than TYPE II resins.

In deionization, TYPE I anion resins are employed when highest effluent quality and lowest silica residuals are the prime considerations.

Regeneration for Deionization

Regenerant	Sodium Hydroxide (NaOH)
Level	Dependent on Capacity Desired
Concentration	2 - 4%
Rinse Requirement.....	60 gals./cu.ft.



TYPICAL CHARACTERISTICS

Polymer Structure		Styrene divinyl-benzene
Functional Structure		$AR-N^{+}(CH_3)_3X^{-}$
Physical Form		Spherical beads
Ionic Form (as shipped)........		Chloride
Screen Size,U.S.std.Mesh (wet).		20-50
Particle Size Range............		0.3-0.84 mm.
Uniformity Coefficient		<1.7
Total Capacity	Volumetric	1.4 meq/ml
	Weight ...	3.7 meq/gm
Swelling...........	Cl → OH	<10%
Moisture Content as shipped....		43-49%
pH range (stability)...........		0-14
Shipping Weight		44 lbs/cu.ft. 705 grams/liter
Solubility..........	Insoluble in all common solvents	
Standard Packaging..	5 cu.ft. poly-lined fiber drums	

SUGGESTED OPERATING CONDITIONS WHEN USED IN TWO-BED DEMINERALIZATIONS

	U.S.Units	Metric Units
Max.Operating Temp.		
OH form	140°F.	60°C.
Salt form ..	212°F.	100°C.
Min. bed depth	24"	60 cm
Backwash Flowrate........	1.5-2.5 gpm/sq.ft.	3.6-6.0 meters per hr.
Backwash Expansion*	50-75%	50-75%
Service flowrate	3 gpm/cu.ft.	24 l/hr/l
Regenerant...............	NaOH	NaOH
Regeneration flowrate ...	0.2-0.5 gpm/cu.ft.	1.6/4.0 l/hr/l
Regenerant Contact Time..	30/60 min.	30/60 min.
Slow rinse rate..........	30/60 min.	30/60 min.
Fast rinse rate	2 gpm/cu.ft.	16 l/hr/l

* See Figure I

Influent Limitations

Maximum Free Chlorine.........	0.1 ppm
Maximum Turbidity............	5 A.P.H.A.Units
Maximum Iron & Heavy Metals..	0.1 ppm

CAPACITY AND LEAKAGE (RESIDUALS)

IONAC ASB-1 Exchange Capacity for Hydrochloric Acid (influent concentration: 500 mg/l. as $CaCO_3$)

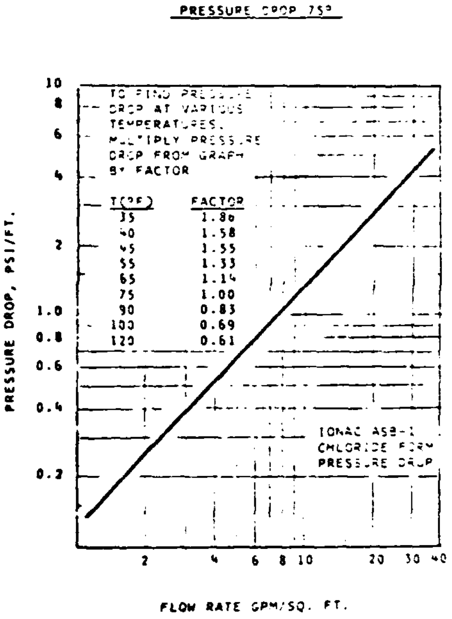
Lbs.NaOH/cu.ft.	Capacity (Kgr./cu.ft.)
1	6.0
2	7.4
3	9.5
4	11.0
6	13.4
8	15.1
10	16.2
12	17.0

Salt Splitting Capacity and Leakage using Sodium Chloride (influent concentration: 500 mg/l. as $CaCO_3$)

Lbs.NaOH/ cu.ft.	Capacity (Kgr./cu.ft.)	Leakage (% of Infl.Cl^-)
1	5.0	12
2	6.1	8
3	8.3	5.5
4	9.7	3.7
6	11.8	1.5
8	13.3	0.7
10	14.3	0.2
12	14.9	0.1

Function of silica/total anion ratio vs. total and silica exchange capacity (regenerant level: 6 lbs.NaOH/cu.ft. @ 35°C.)

		SiO_2 Capacity	
SiO_2/TA	Total Capacity (Kgr/cu.ft.)	Kgr/cu.ft.	Lbs.SiO_2/cu.ft.
0.05	12.1	0.61	0.105
0.10	11.6	1.16	0.199
0.20	10.7	2.14	0.368
0.30	10.0	3.00	0.516



Cation leakage vs. pH and silica leakage in 2-step operation

		Leakage of Silica	
Leakage of Cations ppm.as $CaCO_3$	Final pH of Deionized Effluent	ppm.as SiO_2	ppm.as $CaCO_3$
1	7.7	0.01	0.008
2	8.2	0.02	0.016
3	8.6	0.02	0.016
4	9.0	0.03	0.025
5	9.4	0.04	0.033
6	9.6	0.06	0.050
7	9.8	0.10	0.083
8	10.0	0.15	0.125
10	10.3	0.20	0.167
12	10.5	0.30	0.250
16	10.7	0.40	0.330
18	11.0	1.00	0.833

FOR METRIC CONVERSIONS:

Multiply gpm sq. ft. x 2.44 = Meters/hr.
Multiply gpm cu. ft. x 8 = l/hr./l
Multiply PSI/ft. bed x .22 = Atmosphere/m/bed depth
Multiply Bed depth, ft. x 30.48 = cm
Multiply lb./cu. ft. x 16 = Grams/l
Multiply Kgr./cu. ft. x 2.29 = Grams $CaCO_3$ / l

SYBRON | CHEMICAL DIVISION Ionac

SYBRON CORPORATION/CHEMICAL DIVISION/BIRMINGHAM, N.J. 08011 • 609/894-8211 • TELEX 843407

SYBRON

IONAC A-641

Type I Strong Base Macroporous ANION EXCHANGE RESIN

IONAC CHEMICAL COMPANY · division SYBRON CORPORATION · BOX 66 · BIRMINGHAM, N. J 08011 (609) 894-8211 TELEX 843407

IONAC A-641 is a highly efficient and durable strong base macroporous anion exchange resin. IONAC A-641's controlled fixed pore structure provides exceptionally high operating capacity for removal of inorganic and also organic anions. Excellent regeneration and outstanding resistance to organic fouling are readily attainable with IONAC A-641. Toughness of IONAC A-641 resin beads insures stability to osmotic, thermal and impact shock when used in all types of demineralizing systems, particularly condensate polishing and moving bed units.

IONAC A-641 consists of a crosslinked styrene-divinylbenzene polymer backbone structure with a high concentration of functional quaternary groups

IONAC A-641 is supplied as moist, spherical beads in the chloride form with a particle size distribution designed to provide good kinetics and a minimum pressure drop.

IONAC A-641 offers many outstanding features:

- —high capacity of gel resins combined with the stability of macroporous structures.
- —*effective removal* of all anions, including weakly disassociated silica and carbon dioxide, resulting in high water quality with very low silica leakage.
- —better kinetics than other macroporous and conventional gel anion exchangers because of higher diffusion rate of anions in and out of IONAC A-641 beads.
- —ability to adsorb and desorb organic anions during regeneration without the severe fouling limitations of gel resins.
- —high bead strength to withstand thermal and osmotic shock encountered in high flow rate condensate polishing and moving bed systems thereby resulting in lower fines generation than with other anion exchange resins.

IONAC A-641's superior properties and performance lead to its selection for many anion exchange applications including:

- —conventional multiple, mixed or layered demineralizing beds.
- —high flow rate condensate polishing.
- —moving bed systems with minimum physical attrition.
- —systems where resistance to organic fouling is needed.
- —decolorization and organic removal from sugar, pharmaceutical and chemical solutions.

TYPICAL CHARACTERISTICS

Polymer structure	styrene-divinylbenzene
Functional structure	$-N-(CH_3)_3^+$
Physical form	Moist spherical beads
Ionic form as shipped	chloride
Screen size U.S. mesh, wet	16-50
Particle size range	0.3-1.2 mm
Uniformity coefficient	1.7 max.
Total capacity, weight	3.9 meq/g
Volume	1.15 meq/ml
Swelling (Cl– OH)	9-10%
Water retention as shipped	54-58%
pH range stability	0-14
Shipping weight	43 lb./cu. ft. 686 gms./liter
Solubility	insoluble in all common solvents
Standard Packaging	7 cu. ft. polyethylene lined fiber drums

RECOMMENDED OPERATING CONDITIONS

	U.S. Units	Metric
Max. operating temperature		
OH Form	140°F	60°C
Salt Form	212°F	100°C
Minimum Bed Depth	24"	160 mm
Freeboard	100%	100%
Backwash expansion, min.*	50%	50%
Service flow rate, max.	5 gpm/cu. ft.	40 l/h/l
Regeneration flow rate	0.25 gpm/cu. ft.	2 l/h/l
Regeneration injection time, min.**	45 minutes	45 minutes
Slow rinse rate	same as regeneration rate	
Fast rinse rate	same as service rate	
Total rinse volume	75 gal/cu. ft.	10/l/l

INFLUENT LIMITATIONS

Maximum Turbidity	5 A.P.H.A. Units
Maximum Iron and Heavy Metals	

* Figure 2 shows bed expansion at various flow rates and temperatures Backwash should be 15 minutes or until bed is clean

**The recommended injection time provides optimum water quality when followed by slow rinse at the same flow rates. Faster injection or higher flow rates cause slightly poorer effluent quality.

The data included herein are based [illegible] test information obtained [illegible] Chemical Company. These data are be[illegible] imply any warranty or performance guarantee. We recommend that [illegible] user determine per[illegible] by testing [illegible] ment. We assume no liability or res[illegible] for patent infringe[illegible] from the use [illegible] product.

CHEMICAL AND PHYSICAL PROPERTIES

IONAC A-641's unusually good chemical and physical properties makes it suitable for a wide range of operating conditions.

Chemical Stability

IONAC A-641 is insoluble in acid, alkali and all common solvents. It can be used over the entire pH range for aqueous or non-aqueous applications.

Physical Stability

IONAC A-641's excellent bead integrity and high bead strength offers maximum resistance to attrition from osmotic, thermal and physical stresses. Lab and field data indicate the superiority of IONAC A-641 over gel and other macroporous resins where physical abuse of the resins are anticipated. To maintain the overall stability of IONAC A-641 and any other ion exchange resin, drying and rewetting or alternate freezing and thawing of the resin should be avoided.

Bead Size

IONAC A-641's particle size distribution is closely controlled and monitored during production. The screen analysis typically falls within 16-50 U.S. mesh screen range (0.3 - 1.2 mm). Special coarse mesh grades with a minimum percentage through 40 mesh are available to avoid pressure drop problems for high flow rate condensate polishing. To obtain optimum kinetics and physical stability, IONAC A-641 does not contain any significant quantity of beads larger than 16 mesh.

Pressure Drop

Pressure drop or head loss from water flowing through the resin bed is normal. IONAC A-641's particle size distribution, sphericity and attrition resistance insure a minimum pressure drop across the bed. Excessive pressure drop should be avoided to prevent channeling of the feed solution and non-uniform contact with the resin. This condition reduces the operating capacity and increases anion leakage.

Figure 1 shows the pressure loss of typical particle size distribution IONAC A-641 as a function of influent water flow rate and temperature. The total pressure drop across the bed can be readily calculated by multiplying the pressure drop per foot of bed from Figure 1 by the total bed depth. This pressure loss data is based on new resin and clean water. Any particulate matter in the influent water would be filtered out by the resin bed and would result in additional pressure drop.

Backwashing

After the service step and prior to regeneration, the resin bed is backwashed upflow with water to remove suspended matter deposited or occluded in the bed during the service cycle. Backwashing eliminates gas pockets and channels and also classifies the resin bed. Any resin fines that develop from normal attrition are washed out. The backwash rate will expand the resin bed by 50% to 75% for about 15 minutes or until the backwash effluent is clean. Backwash water should be softened to prevent the formation of precipitates. The flow rate should be achieved gradually to prevent resin loss through a surge carryover.

Figure 2 provides the relationship between the percentage of bed expansion and the water rate and temperature. Normally, the design is based on a backwash rate for the lowest water temperature anticipated to avoid resin loss from carryover. When higher temperature water is used, the backwash rate should be increased to obtain the proper bed expansion.

OPERATING CHARACTERISTICS

IONAC A-641 is supplied in the chloride form and must be regenerated before use with a good grade of sodium hydroxide solution. In a typical demineralizing plant, regeneration takes place after the exhausted resin has been backwashed. Sodium hydroxide regenerant removes the anions adsorbed during the service step and converts the resin to the hydroxide form for the next water treatment cycle. Regeneration consists of contacting the resin initially with sodium hydroxide solution, followed by a slow water rinse and finally a fast rinse to completely displace any regenerant.

IONAC A-641 will produce quality water with a high operating capacity and efficiency. Influent composition, service and regenerant conditions affect IONAC A-641 performance. Data in Figure 3 through Figure 13 provide an assessment of these factors using typical production quality IONAC A-641.

Service Conditions

All data are based on using a flow rate of 2 gpm per cu. ft., an influent water temperature of 75°F. and a leakage of 0 ppm sodium from the hydrogen cation exchange unit. Influent anion composition was varied to obtain acid removal capacities for H_2CO_3, H_2SO_4, HC1 and H_2SiO_3. IONAC A-641 may be operated at flow rates of 2 to 5 gpm per cu. ft. without appreciably affecting its performance.

Regenerant Conditions

IONAC A-641 data were based on initially preheating a 30 inch resin bed with hot deionized water. Regeneration was based on using a 4% sodium hydroxide solution downflow at 0.25 gpm per cu.ft. and regenerant temperatures of 75°F., 90°F. and 120°F. Regeneration levels range from 2 lbs. to 10 lbs. NaOH (100% basis) per cu.ft. of resin.

A regenerant contact time of approximately 45 minutes is usually adequate. Silica leakage increases below 45 minutes and is significant at 30 minutes or less. A regenerant contact time of 60 minutes or greater is needed for very low regenerant levels or where warm caustic cannot be used. At 6 lb. regenerant level, a 4 hour contact at 75°F. is equivalent in silica leakage to 1 hour at 95°F. Therefore, the regenerant contact time will be a function of the silica leakage desired and the regenerant level and temperature.

Since precipitated iron will foul all anion exchangers by blocking out the active groups, the regenerant to be used should be free of iron and heavy metals. For best results, a high quality regenerant, such as mercury cell or rayon grade caustic, should always be used.

Rinse Requirements

The importance of rinsing the resin bed after regeneration cannot be minimized. Caustic regenerant remaining in the resin bed will adversely affect the service water effluent quality by increasing silica and anion leakage. Effective rinsing insures complete removal of excess regenerant. Rinsing consists of an initial slow rinse to displace free regenerant in the resin bed voids followed by a fast rinse to reduce any unreacted regenerant on the surface or within the beads. The slow rinse volume of about 10 gallons per cu. ft. of resin is passed downflow at the regenerant flow rate of 0.25 to 0.5 gpm/cu.ft. and at the regenerant temperature. The rate is then increased to the service flow rate of 2.0—5.0 gpm/cu.ft. and maintained at this rate until rinsing is completed. The combined slow and fast rinse volume for IONAC A-641 is approximately 75 gallons per cu.ft. of resin.

Silica Removal

The controlled macropore structure, better kinetics and higher regeneration efficiency of IONAC A-641 are key factors in attaining very low silica leakages.

Silica chemistry and exchange are complex. Silica is one of the least strongly held anions and usually appears first in the effluent. Being weakly ionized, silica does not contribute to conductivity. Silica may be present on the resin as $HSiO_3^-$, as a soluble low molecular weight polymer or as an insoluble higher molecular weight colloidal silica polymer. Acid or low pH favors silica polymerization, while an alkaline or high pH medium promotes depolymerization and resolubilization. It is extremely important that the amount of silica remaining on the resin after regeneration be minimal. Otherwise, it will be displaced by more strongly adsorbed anions during the service step. Silica leakage is further increased by cation leakage (principally sodium) from the hydrogen cation exchange resin bed. Sodium in the influent is converted to caustic as it passes through the anion resin bed and acts as a mild regenerant, displacing any residual silica present in the bed. Therefore, a high regeneration efficiency is crucial for low silica leakage. Increasing the regenerant concentration level, temperature and contact time all contribute to a more complete removal of silica from the resin during regeneration and insures a lower silica leakage during the subsequent service step. Other factors affecting silica leakage are the composition, temperature and flow rate of the service water influent.

Figure 3 through Figure 9 show silica leakage of IONAC A-641 as a function of the silica content of the influent, the regenerant temperature and the regenerant level. The data show that the silica leakage is reduced when the silica content of the influent is decreased and when the regenerant level and temperature are increased. This data are based on treating water at 75°F. and with 0 ppm sodium content.

Silica leakage correction factors are shown in Figure 10 for different sodium concentrations and temperatures of the influent water. As expected, silica leakage decreases as the sodium leakage from the cation exchange unit and the influent water temperature are decreased.

Anion Removal

IONAC A-641 is very effective for removing highly ionized anions such as sulfates, chlorides and carbonates, particularly when there is sufficient hydrogen cation exchange capacity to convert them to the free acid prior to contact with the anion resin bed. The equilibrium leakage of these anions generally fall within the ppb range. The relative acid removal capacity of IONAC A-641 to a 1% leakage endpoint by conductivity measure is shown in Table I for different regeneration levels.

TABLE I — IONAC A-641 ACID REMOVAL CAPACITY

Regeneration Level lb. NaOH (100% basis) per cu. ft. a 75°F.	IONAC A-641 Capacity (Kgr/cu. ft. as $CaCO_3$)			
	H_2CO_3	H_2SO_4	HCl	H_2SiO_3
2	14.7	—	7.6	—
4	18.4	14.0	10.5	10.6
6	19.4	16.1	12.0	12.2
8	19.9	17.2	13.3	13.5
10	20.3	17.8	14.4	14.3

The anion removal capacities of IONAC A-641 for regeneration levels ranging from 2-10 lbs. sodium hydroxide per cu. ft. and for regenerant temperatures of 75°F., 95°F and 120°F. are shown in Figure 11 through Figure 13. For this temperature range, there is very little difference in the individual operating capacities for sulfates, chlorides and carbon dioxide removal. However, the silica capacity increases significantly as the regeneration temperature increases due to more favorable silica solubilization and removal.

Organic Removal

Organic materials are present in different concentrations in all surface waters. Organic materials are usually high molecular weight aromatic carboxylic acids of the humic or fulvic type. As a class, organic materials exhibit an unusually high affinity for anion exchange resins but with extremely slow kinetics. Conventional gel anion exchange resins are limited in their ability to effectively deionize water containing organic materials with molecular weights in excess of 250. These large molecules will not be exchanged onto gel resins but will pass through the resin bed, resulting in increased conductivity, lower pH and generally poor water quality. Even if the organic materials are small enough to be removed by gel resins, organic fouling still results because of the slow diffusion rate into and out of the gel resin beads. During the long service run, organics adsorbed by the gel resin continuously penetrate the beads. The relatively short regeneration cycle time is not sufficient to totally desorb these organic materials. Blocking or fouling of the exchange sites occurs because of incomplete regeneration. Consequently, the organic-fouled gel resin exhibits slower kinetics or anion removal, increased silica leakage and lower operating capacity.

IONAC A-641 has a high porosity and larger pore size than gel resins. The macroporous structure offers a high surface area for the adsorption and removal of the slow reacting organic materials. Even when the percentage of organic material in the influent water is relatively high, IONAC A-641 is able to reversibly adsorb and desorb the organic substances with little or no fouling, especially when warm regeneration is used. Thus, IONAC A-641 is an ideal resin for demineralizing systems designed to treat organic-containing waters. For those cases where extremely high levels of high molecular weight organic foulants are encountered, periodic alkaline-brine treatment of IONAC A-641 followed by a double caustic regeneration will maintain its long term satisfactory performance.

Applications

IONAC A-641 can be used to advantage in demineralizing systems where severe osmotic thermal or mechanical shock exist, because of its innate physical stability and bead toughness.

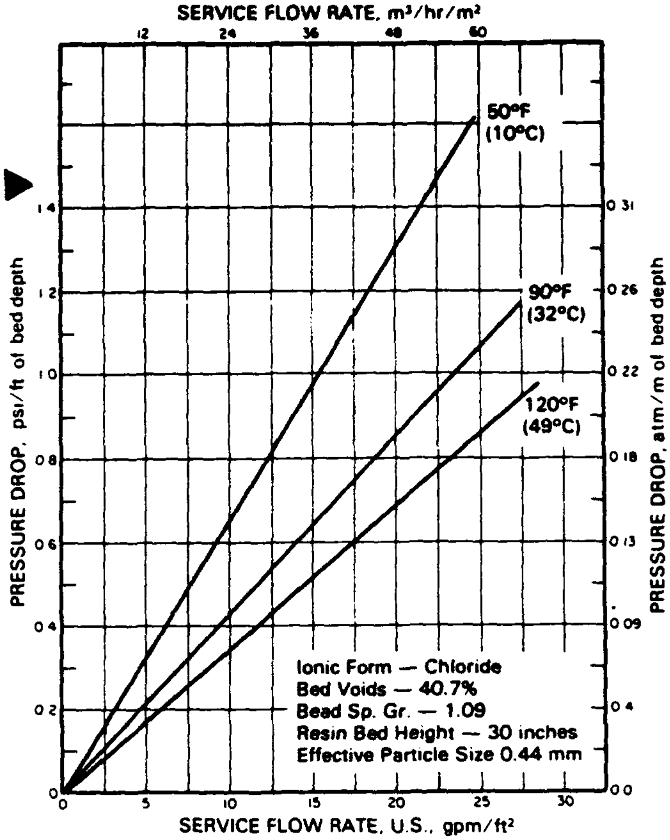
IONAC A-641 in the chloride form has a remarkably high decolorizing capacity for the removal of organic substances from sugar, pharmaceuticals and chemical streams. Regeneration with warm brine will effectively strip off these color bodies from the resin.

When IONAC A-641 is to be used for treating waters for food processing, it should be initially treated with at least 3 cycles of caustic regeneration-salt exhaustion. IONAC A641 will meet the requirements of Paragraph 121.1148 of the Food Additives Regulations of FDA.

Figure 1. **IONAC A-641**

PRESSURE LOSS

The pressure drop or head loss through a bed of IONAC A-641 is directly related to the feed solution flow rate and temperature. Figure 1. provides pressure loss data for clean water and new resin. Any particulate matter in the water being treated may be filtered out by resin bed causing increased pressure losses and/or channeling of the influent through the resin bed.



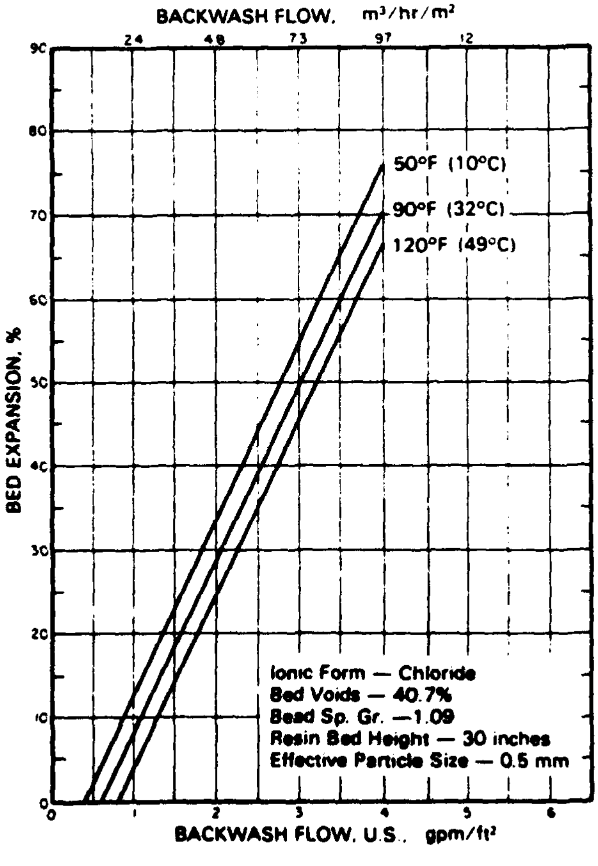


Figure 2. **IONAC A-641**

BACKWASH AND BED EXPANSION

The upflow backwash step will remove any particulate matter filtered out by the IONAC A-641 resin bed during the service cycle. Backwashing also regrades the resin bed and eliminates any channels formed. A backwash rate is recommended that will expand the bed 50 to 75 percent for 15 minutes or until the bed is clean. The backwash rate should always be achieved gradually to prevent resin loss by a surge carryover. Figure 2. shows the relationship between the precent of bed expansion and the backwash rate and temperature.

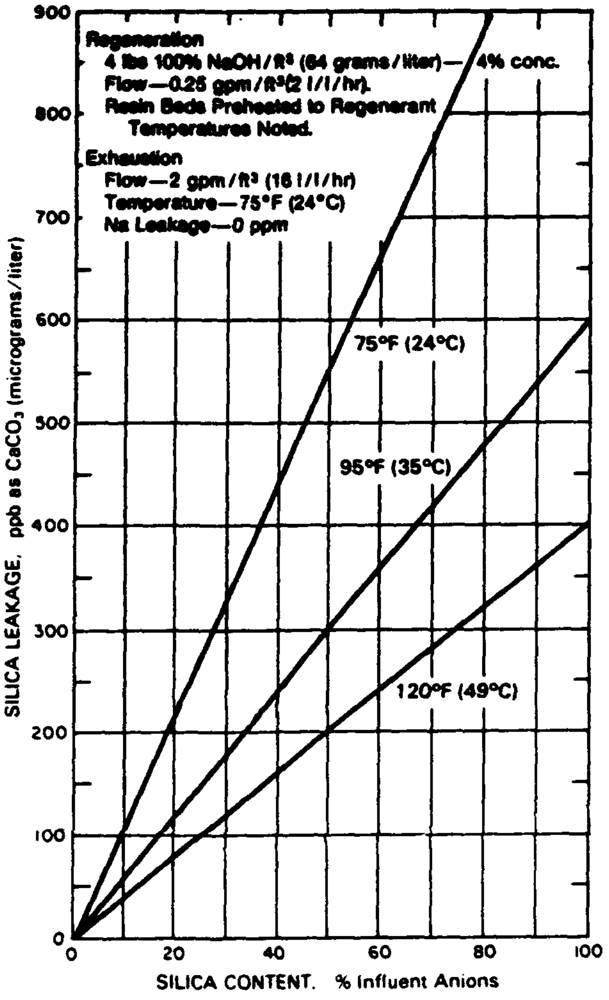


Figure. 3. **IONAC A-641**

SILICA LEAKAGES AT 4 LBS 100% NaOH REGENERATION LEVEL AND VARIOUS REGENERANT TEMPERATURES

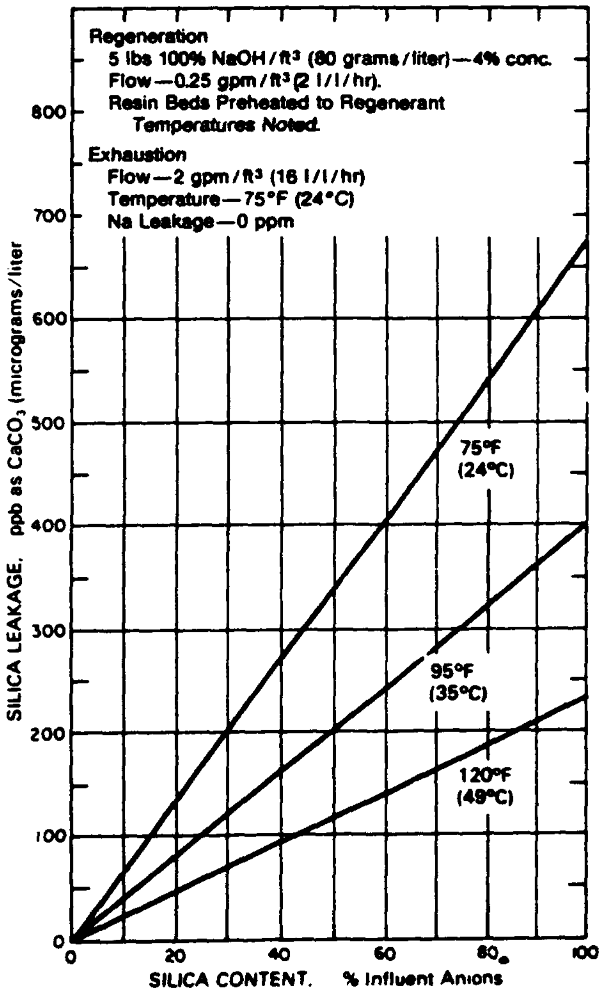
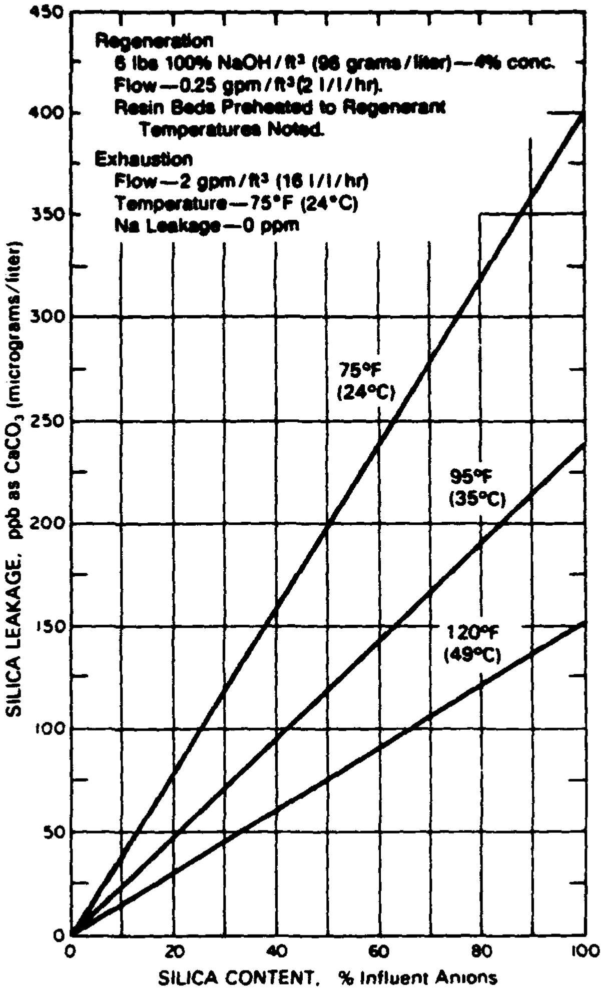


Figure 4. **IONAC A-641**

SILICA LEAKAGES AT 5 LBS 100% NaOH REGENERATION LEVEL AND VARIOUS REGENERANT TEMPERATURES

Figure 5. **IONAC A-641**

SILICA LEAKAGES AT 6 LBS 100% NaOH REGENERATION LEVEL AND VARIOUS REGENERANT TEMPERATURES



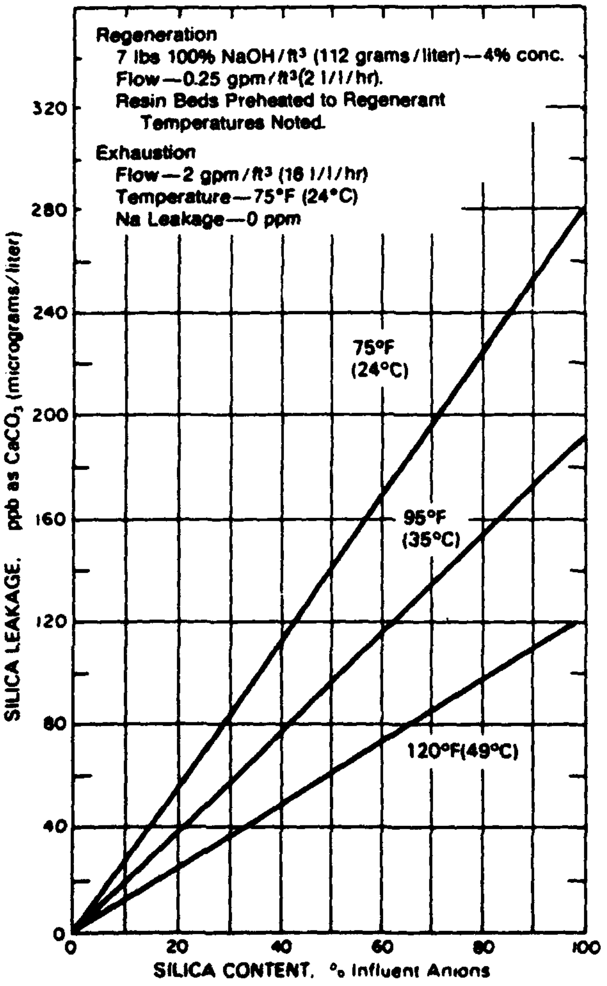


Figure 6. **IONAC A-641**

SILICA LEAKAGES AT 7 LBS 100% NaOH REGENERATION LEVEL AND VARIOUS REGENERANT TEMPERATURES

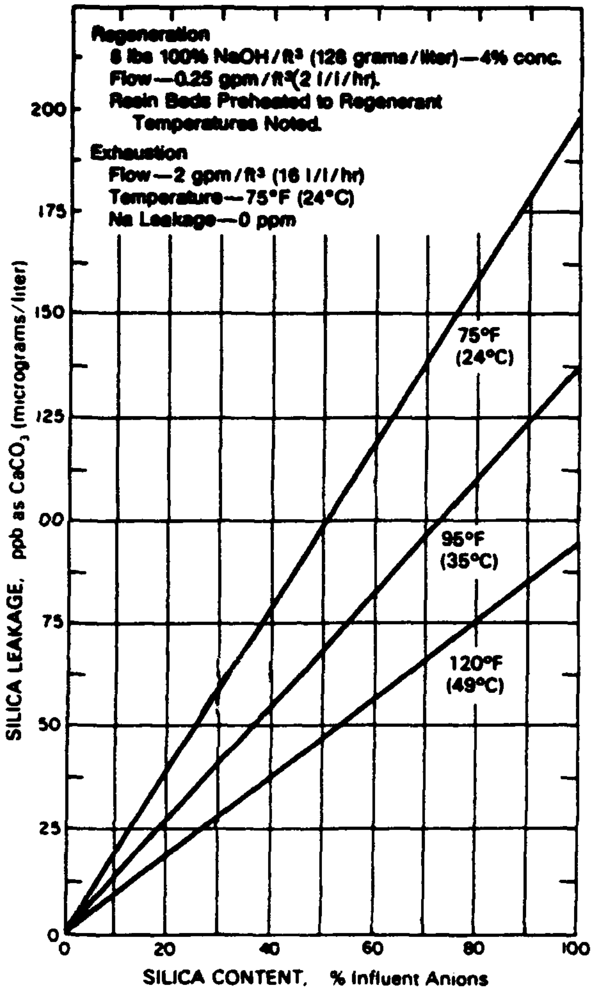


Figure 7. IONAC A-641

SILICA LEAKAGES AT 8 LBS 100% NaOH REGENERATION LEVEL AND VARIOUS REGENERANT TEMPERATURES

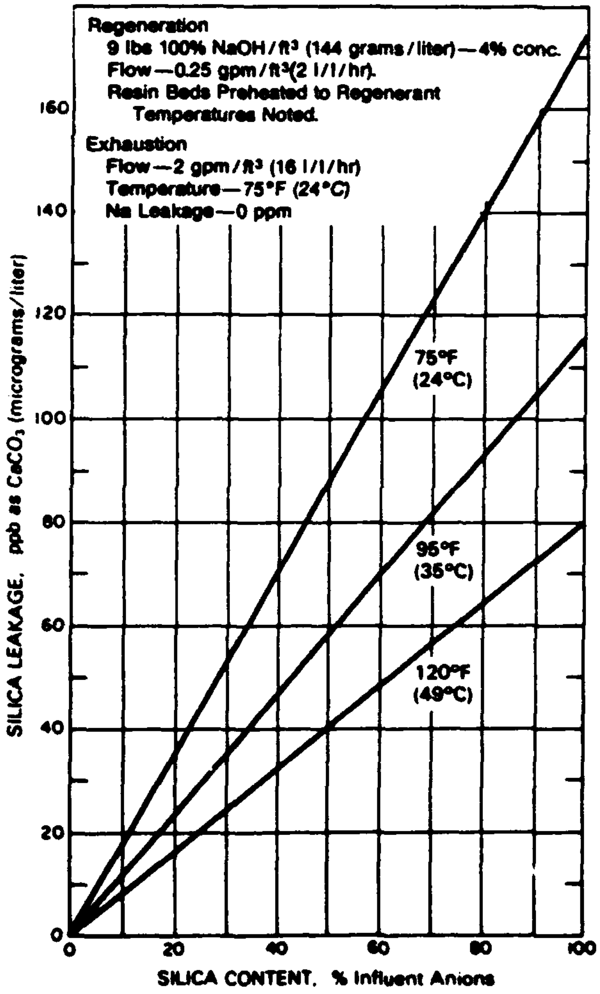
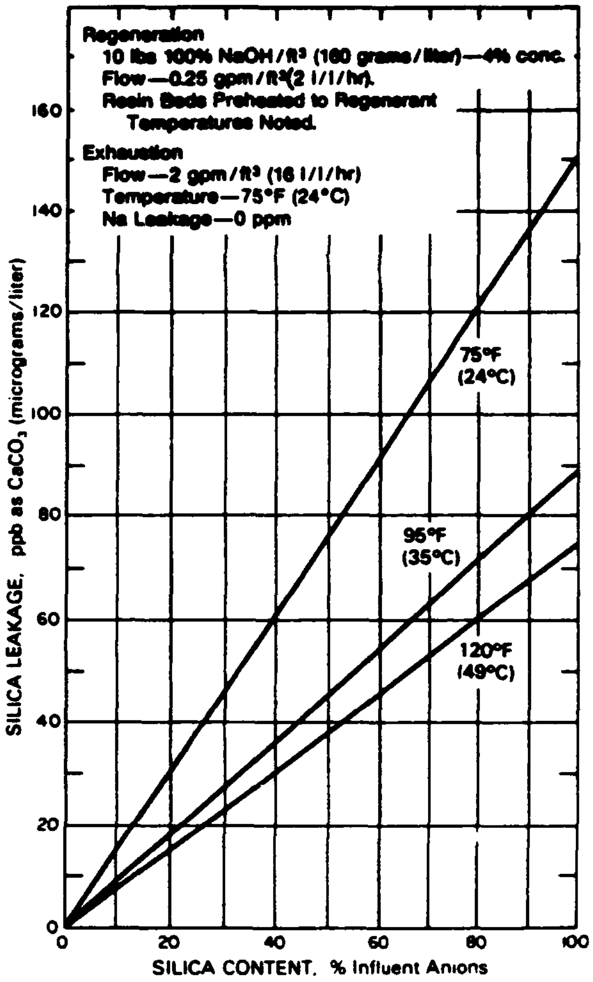


Figure 8. IONAC A-641

SILICA LEAKAGES AT 9 LBS 100% NaOH REGENERATION LEVEL AND VARIOUS REGENERANT TEMPERATURES

Figure 9. IONAC A-641

SILICA LEAKAGES AT 10 LBS 100% NaOH REGENERATION LEVEL AND VARIOUS REGENERANT TEMPERATURES



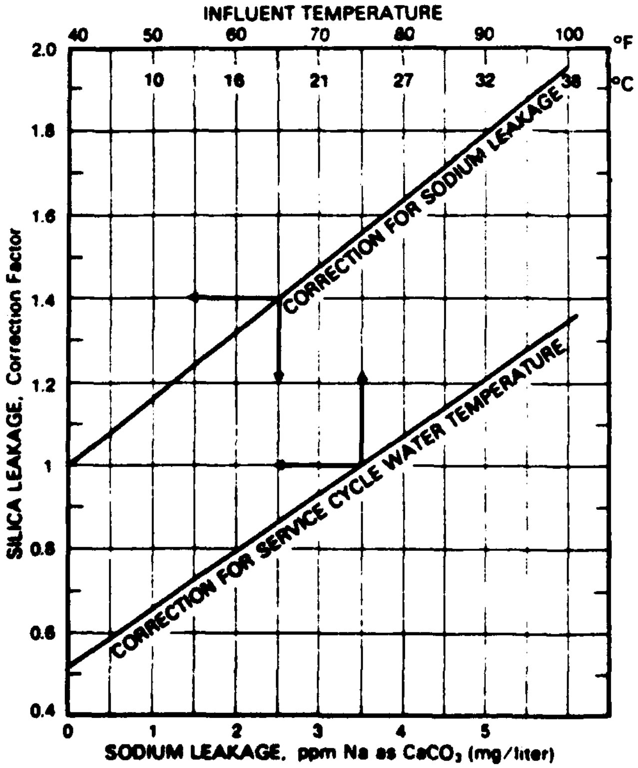


Figure 10. IONAC A-641

SILICA LEAKAGE CORRECTIONS VS. CATION (SODIUM) LEAKAGE AND INFLUENT TEMPERATURES

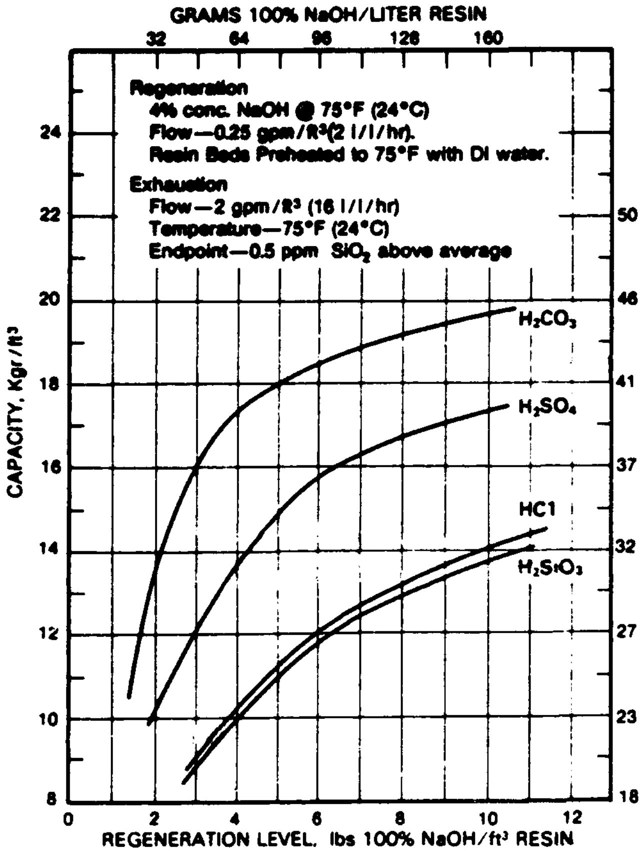


Figure 11. **IONAC A-641**

IONAC A-641 CAPACITY AT 75°F REGENERATION TEMPERATURE VS. REGENERATION LEVEL

Figure 12. **IONAC A-641**

IONAC A-641 CAPACITY AT 95°F REGENERATION TEMPERATURE VS. REGENERATION LEVEL

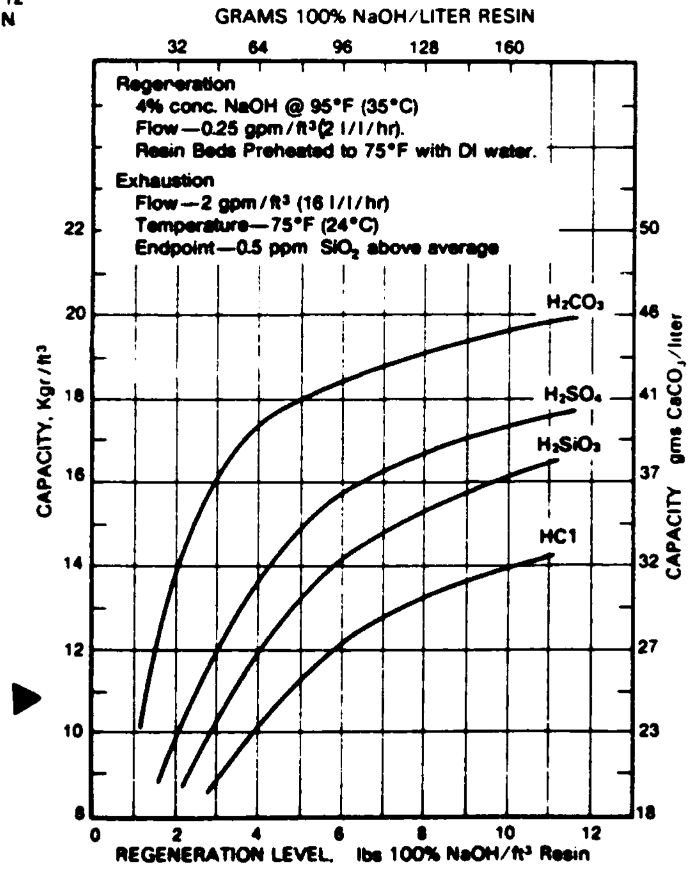
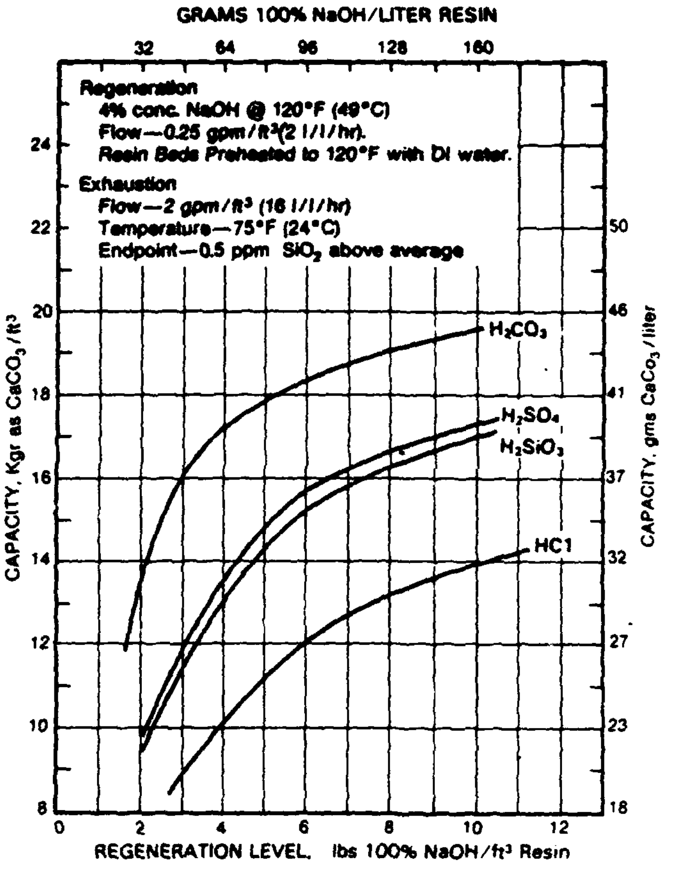


Figure 13. IONAC A-641

IONAC A-641 CAPACITY AT 120°F REGENERATION TEMPERATURE VS. REGENERATION LEVEL



NOTES:

IONAC A-641 CAPACITY DETERMINATION

The following problem illustrates the use of the curves given in the IONAC A-641 bulletin to calculate silica leakage and operating exchange capacity of IONAC A-641 when it is used in a conventional demineralizing system.

Water Analysis (influent to IONAC A-641 anion exchange bed):

	ppm as $CaCO_3$	%Total Anions	Ratio to Total Anions
SO_4	50	26%	0.26
Cl	75	40%	0.40
CO_2	50	26%	0.26
SiO_3	15	8%	0.08
TOTAL ANIONS	190	100%	1.00

Cation Leakage (Sodium): 2 ppm (as $CaCO_3$). **Water Temperature:** 40° to 75°F

Required Effluent: 25 ppb (parts per billion) Max. ionizable silica (as $CaCO_3$).

The "design" and the "actual" or required silica leakage may differ due to influent temperature and sodium. It is important to determine the design silica leakage so that the design curves can accurately predict actual results.

Calculation: Regenerant @ 75°F.

1. *Determine the silica "design" leakage* from Figure 10. Obtain the silica correction for the influent temperature and sodium leakage. Divide the required silica leakage by these corrections.

   Water temperature correction @ 75°F. max. = 1.0
   (75°F. used because it is worse condition)
   Sodium leakage correction @ 2 ppm max. = 1.31

   $$\text{Design silica leakage} = \frac{\text{required silica leakage}}{\text{corrections}}$$

   $$= \frac{25\text{ ppb}}{1.0 \times 1.31} = 19\text{ ppb}$$

2. *Determine minimum regeneration level* from Figure 3 through Figure 9 that will yield a silica design leakage value of 19 ppb or less at a regeneration temperature of 75°F. and for a silica influent content of 8%.

   The minimum regeneration level satisfying these conditions is 8 lb. NaOH per cu.ft. (Figure 7).

3. *Determine for each anion component*, its capacity at 8 lb. regeneration and a regenerant temperature of 75°F. from Figure 11. The capacity values for the individual components are then multiplied by the ratio of each anion to the total anions. The operating capacity is the sum of the individual component capacities.

Anion		Ratio		Anion Component Rating at 8 lbs. per Cu.Ft. and 75°F. Regeneration		
SO_4	=	0.26	×	16.7	=	4.3
Cl	=	0.40	×	13.4	=	5.4
CO_2	=	0.26	×	19.2	=	5.0
SiO_3	=	0.08	×	13.0	=	1.0
Operating Capacity (Kgr. $CaCo_3$ per Cu. Ft. IONAC A-641)					=	15.7

Calculation: Regenerant @ 120°F.

1. *Determine silica design leakage* from corrections in Figure 10. Since corrections for service water temperature (75°F.) and sodium leakage (2ppm) remain the same as previously calculated, the silica design basis is 19 ppb as $CaCO_3$.

2. *Determine minimum regeneration level* for 19 ppb silica leakage; regenerant temperature of 120°F. and for 8% silica content in influent. Figure 4 shows that a 5 lb. regenerant level at 120°F. will meet the silica design value of 19 ppb or less.

3. *Determine capacity rating* from Figure 13 (regenerant temperature of 120°F.) for 5 lb. regeneration level:

Anion		Ratio		Anion Component Rating at 5 lbs. per Cu.Ft. and 120°F. Regeneration		
SO_4	=	0.26	×	14.8	=	3.9
Cl	=	0.40	×	11.3	=	4.5
CO_2	=	0.26	×	17.9	=	4.7
SiO_3	=	0.08	×	14.3	=	1.1
Operating Capacity (Kgr. $CaCo_3$ per Cu. Ft. IONAC A-641)					=	14.2

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NDI 1/84 A-641 - 1.5M

PRODUCT DATA

F-1

SEP 921

Granular Activated Alumina

Alcoa Separations Technology Division

January 1989

Product Information

Alcoa® F-1 is a granular activated alumina suitable for a wide range of adsorption applications for drying and impurity removal. F-1 is available as 1/4x8 mesh, 8x14 mesh, 14x28 mesh, 28x48 mesh, 48x100 mesh, −100 mesh, and −325 mesh sizes. Packaging includes sling bags, paper bags, and drums.

Applications

F-1 is used in a wide variety of applications where granular adsorbents are preferred for liquid treatment, for example, fluoride and arsenic removal from drinking water, lubricant filtration, TBC removal from monomers, and in petrochemical applications such as purification of process streams in hydrogen peroxide production and in liquid-phase polymer production. F-1 is also used as a desiccant for both gas and liquid streams. The 1/4x8 mesh size is commonly used in air driers. The −100 and −325 mesh sizes are used in chromatographic applications and in specialty product formulations.

TYPICAL PHYSICAL PROPERTIES OF F-1

	8-14 Mesh
Surface area, m^2/gm	240
Equilibrium water capacity @ 60% RH, wt%	16
Total pore volume, cc/gm	0.4
Nitrogen pore volume, (<35 Å), cc/gm	0.2
Packed bulk density, lbs/ft^3	63
Packed bulk density for various sizes ranges from lbs/ft^3 (kg/m^3)	60-63 (961-1,009)

TYPICAL CHEMICAL PROPERTIES OF F-1 · WT %

Al_2O_3	92.1
SiO_2	0.72
Fe_2O_3	0.11
Na_2O	0.57
LOI (250 · 1, 200°C)	5.8

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APPENDIX H

BACKUP COLUMN SAMPLE DATA

Appendix H

Backup Column Total Arsenic Data

Run	Date	Time	Primary Column Adsorbent	Secondary Column Data		Total Arsenic in Effluent µg/L
				Column	Adsorbent	
1c	22Mar90	1100	IRA 402	C2	IRA 402	19.6
1c	22Mar90	2300	IRA 402	C2	IRA 402	95
1b	23Mar90	0900	IRA 402	B2	IRA 402	2.5u
1b	24Mar90	0900	IRA 402	B2	IRA 402	18.9
1a	26Mar90	0900	IRA 402	A2	IRA 402	3.6
2b	2Apr90	0500	A-641	B2	A-641	19.6
2a	3Apr90	0500	A-641	A2	A-641	2.5u
3a	29Apr90	1100	HD3000	A2	HD3000	208
3b	29Apr90	1100	HD3000	B2	HD3000	38.5
3c	29Apr90	1100	HD3000	C2	HD3000	173
4a	1May90	1645	Filtrasorb 400	A2	Filtrasorb 400	33.5
4b	1May90	1645	Filtrasorb 400	B2	Filtrasorb 400	160
4c	1May90	1645	Filtrasorb 400	C2	Filtrasorb 400	109
5c	13May90	1300	F-1	C2	F-1	2.5u
5b	30May90	2020	F-1	B2	F-1	6.1
5a	5Jun90	1000	F-1	A2	F-1	22.1
5a	8Jun90	1000	F-1	A2	F-1	2.5
5a	9Jun90	1000	F-1	A2	F-1	2.5
5a	10Jun90	1000	F-1	A2	F-1	3.1
5a	11Jun90	1000	F-1	A2	F-1	2.5u
5a	12Jun90	1000	F-1	A2	F-1	2.5u
5a	13Jun90	1000	F-1	A2	F-1	2.9u
5a	14Jun90	1000	F-1	A2	F-1	2.5u
5a	15Jun90	1000	F-1	A2	F-1	2.5u

Appendix H

Backup Column Total Arsenic Data
(continued)

Run	Date	Time	Primary Column Adsorbent	Secondary Column Data		Total Arsenic in Effluent µg/L
				Column	Adsorbent	
5a	16Jun90	1000	F-1	A2	F-1	2.5u
5a	17Jun90	1000	F-1	A2	F-1	2.5u
6a	9Jun90	1545	Filtrasorb 400	A2	IE Resin	2.5u
7a	27Jun 90	0800	F-1	A2	F-1	2.5u
7c	27Jun90	0800	F-1	C2	F-1	2.5u
7c	28Jun90	1900	F-1	C2	F-1	5.0u

APPENDIX I

BACKWASH WATER SAMPLING DATA

Table I-1

Total Arsenic Concentrations in Column Backwash Water

Date	Run	Condition	Total Arsenic, ug/L
2 May 90	4	Calgon Filtrasorb 300	23.7
28 June 90	7	Alcoa F1 with TCE added	73.8
8 July 90	7	Alcoa F1 with no TCE added	148

APPENDIX J

TCE DATA

TCE Data

Sample ID	Date	Description/Sample Location	TCE (μg/L)
TCE-2	3 Apr 90	Feed Tank	5u
TC-3	1 May 90	Feed Tank	1u
TCE-4	9 May 90	Feed Tank	5u
TCE-5	21 May 90	Feed Tank	5u
I1080062290	21 May 90	Feed Tank, spiked with TCE (Run 7)	25
S26103062690	26 Jun 90	Air stripper discharge line (Run 7)	0.5u
TB-1	26 Jun 90	Trip Blank	0.5u
TCE-7	7 Jul 90	Feed Tank	5u

u = Compound analyzed for but not detected. Numerical value indicates sample quantitation limit.

APPENDIX K

EFFLUENT DISCHARGE DATA

Effluent Discharge Data

Sample	Date	Composition	Total As ($\mu g/L$)	Disposition
D1	21 Mar 90	accumulated effluent, ion exchange Run	2.5u	discharged
D2	22 Mar 90	accumulated effluent, ion exchange Run	5.6	discharged
D3	26 Mar 90	accumulated effluent, ion exchange Run	28.6	discharged
D4	31 Mar 90	accumulated effluent, ion exchange Run	2.7	discharged
D5	2 Apr 90	accumulated effluent, ion exchange Run	111	resampled
D5R	3 Apr 90	accumulated effluent, ion exchange Run resample	114	held for retreatment
D7	16 Apr 90	accumulated effluent, ion exchange Run	2.8	discharged
D8	18 Apr 90	contaminated GAC Feed water	70.5	held for retreatment
D9	22 Apr 90	retreated effluent GAC Feed water, (IE)	2.5u	discharged
D10	25 Apr 90	contaminated influent tank water, treated by IE	6.6	discharged
D11	29 Apr 90	accumulated influent, first column run	93.9	held for retreatment
D12	1 May 90	retreated effluent, first carbon run		discharged
D13	3 May 90	retreated effluent, second carbon run (directly related based upon backup column analysis)	10.0	discharged
D14	8 May 90	accumulated effluent	2.5u	discharged
D15	10 May 90	accumulated effluent	2.5u	discharged
D16	12 May 90	accumulated effluent	2.5u	discharged
D17	13 May 90	accumulated effluent	2.5u	discharged
D18	18 May 90	accumulated effluent	2.5u	discharged
D19	22 May 90	accumulated effluent	2.5u	discharged
D20	27 May 90	accumulated effluent	2.5u	discharged
D21	3 Jun 90	accumulated effluent	11.5	discharged
D22	13 Jun 90	accumulated effluent	2.5u	discharged
D23	18 Jun 90	accumulated effluent	2.5u	discharged
D24	19 Jun 90	accumulated effluent	54	discharged
D25	25 Jun 90	accumulated effluent	2.5u	discharged
D26	29 Jun 90	accumulated effluent	5.0u	discharged
D28	14 Jul 90	accumulated effluent	5.0u	discharged
D29	17 Jul 90	accumulated effluent	5.0u	discharged

---

*Preliminary data report indicated 22.2 $\mu g/L$. Final report indicated 308 $\mu g/L$.