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EVALUATION OF DEMONSTRATION TECHNOLOGIES

Quail Creek Water Supply System

EVALUATION OF DEMONSTRATION TECHNOLOGIES QUAIL CREEK WATER SUPPLY SYSTEM

DRINKING WATER TECHNOLOGY BRANCH
OFFICE OF GROUNDWATER AND DRINKING WATER
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
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ACKNOWLEDGEMENT

This project was conducted through the cooperation and efforts of several persons. The participants that had major contributions to the success of this project include: Dr. David Schnare, the USEPA Small System Technology Initative Coordinator; Wendell Ellis, the Owner/Operator of the Quail Creek Water System; Greg Gwaltney, with ECOS, Inc.; Steve Walden and Tony Bennett, with the Texas Water Commission; Robin Cooksey, with the Texas Department of Health; and Greg McKelvey, Glenn Lattimer, Tommy Dorsey, and Don Cornet, with Kinetico, Inc.

1.0 INTRODUCTION

1.1 BACKGROUND

The U.S. Environmental Protection Agency (USEPA) is required to designate best available technology (BAT) for each contaminant regulated under the federal Safe Drinking Water Act, unless it elects to impose a treatment technique to meet safety requirements. To be designated as a BAT, a treatment technology must meet certain criteria. Specifically, a treatment technology must:

- Be demonstrated at field scale;
- Be compatible with other treatment technologies;
- Be applicable in all geographic regions;
- Demonstrate effective contaminant removal; and
- Be affordable to large drinking water utilities.

Best available technologies for small systems may vary from those for large systems. To stimulate the development of affordable treatment systems for small water systems, the USEPA established an initiative in 1989 to look for innovative, low-cost solutions for complying with federal and state drinking water regulations. The Small System Technology and Training Support Initiative was designed to build public/private partnerships to promote the identification, development, marketing, approval, and application of simple, inexpensive drinking water treatment technologies for use by water systems serving less than 3,300 persons. Representatives from the American Water Works Association, Water Quality Association, National Association of Water Companies, National Rural Water Association, Association of State Drinking Water Administrators, and a number of equipment manufacturers participated in the initiative.

Only small water systems serving less than 500 persons are considered as possible demonstration sites. Selection is based on obtaining sites with a variety of specific contaminant problems and located in different geographic regions of the country. Requests for proposals from water treatment equipment supply industries for supplying process equipment and operational assistance are then solicited to identify available treatment technologies. Treatment industry participants then donate equipment to the small water systems and a one year demonstration study is conducted under the supervision of USEPA and state regulatory personnel. At the completion of the study, a report is published presenting the results of the pilot program.

The USEPA is currently demonstrating central and household treatment units at several sites in the United States. The Quail Creek water system near Spicewood, Texas is one of these sites where the technology demonstration program is scheduled to be completed soon as part of the USEPA's Office of Ground Water and Drinking Water demonstration initiative. The Quail Creek system is also of interest to the USEPA's Standards Division because it has operated over one year, the ion exchange treatment appears to be removing radioactivity (radium) from the water supply, and because of waste disposal concerns.

This report provides a summary of this small system demonstration project and presents an evaluation of the information collected during the operation, and by the USEPA in September 1992.

2.0 SYSTEM DESCRIPTION

The Quail Creek Water System is located near Spicewood, Texas, approximately 5.8 miles east of U.S. 281 on the right side of Texas 71. The system is located in a privately owned mobile home development and currently serves 15 connections out of a total of 55 available connections. An ion exchange system was provided by Kinetico, Inc. for the removal of radium from this well supply.

The Quail Creek Water System includes a well, pressure filter, ion exchange units, french drain field, storage tank, transfer pumps, hydropneumatic tank and distribution system (see Figure 2-1). Salt is used for regeneration of the ion exchange units and chlorine is added for disinfection.

2.1 WELL

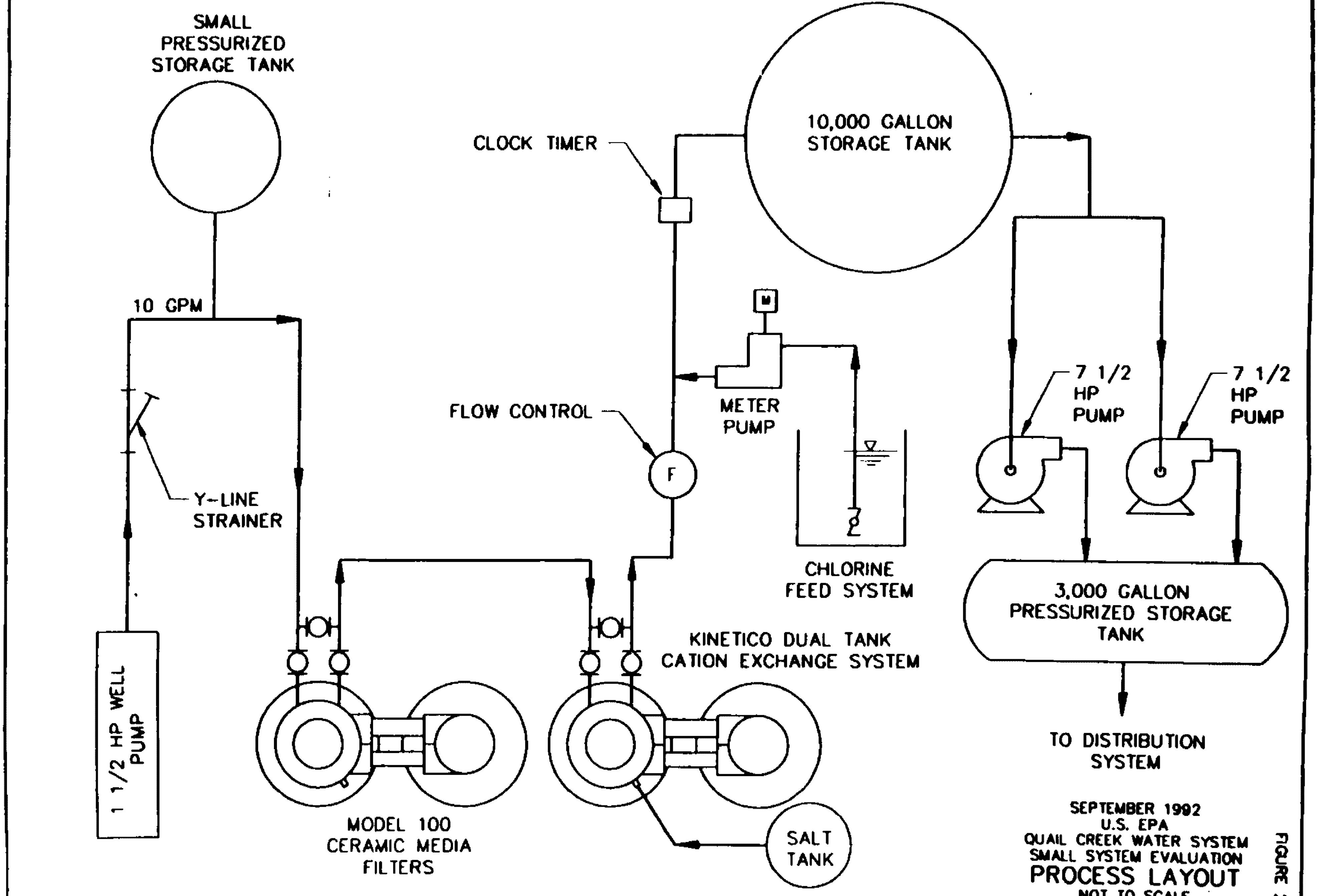
Typical water quality from the well is presented in Table 2-1. As shown, the fluoride level of 2.2 mg/L exceeds the secondary limit of 2.0 mg/L and the sum of the radium 226 and radium 228 levels exceeds the current limit of 5 pCi/L. Hardness levels of 471 mg/L are not considered high for the region and other parameters are within acceptable levels.

The well operation is controlled by a timer that can be controlled in 15-minute increments. Current operation allows the well to operate for 1 hour and 15 minutes, eight times per day at a controlled flow rate of 10 gallons per minute (gpm). This operational sequence was selected due to the artesian nature of the well. If the well is allowed to stand without operation for a period of time, the water level will rise and overflow out of the well vent pipe. In addition, operating the well while the water level is near surface lowers the pumping head on the pump and provides the lowest pumping costs.

When the storage tank is full as indicated by a level probe, the timer is by-passed and the well will not operate. This will continue until the level has dropped 2 feet in the storage tank.

2.2 PRESSURE FILTER

Pressure filtration is provided to ensure that particles that may plug the ion exchange resin are removed prior to entering the ion exchange beds. Two Kinetico Model 100 ceramic media backwashing filters were provided by Kinetico Incorporated prior to the ion exchange units to remove suspended solids. The ceramic media is packaged in a fiberglass pressure tank. Two filters allow the system to operate on a continuous basis with one operating while the other filter is in backwash.



ADAPTED FROM KINETICS, INC. PROPOSAL DATED 8/5/91

SEPTEMBER 1992
U.S. EPA
QUAIL CREEK WATER SYSTEM
SMALL SYSTEM EVALUATION
PROCESS LAYOUT
NOT TO SCALE

FIGURE 2-1

TABLE 2-1

TYPICAL WELL WATER QUALITY
QUAIL CREEK WATER SYSTEM

PARAMETER	LEVEL	PARAMETER	LEVEL
Calcium (mg/L)	110	Conductivity (uS)	1,570
Chloride (mg/L)	137	Bicarbonate (mg/L as $CaCO_3$)	405
Fluoride (mg/L)	2.2	Dissolved Solids (mg/L)	784
Magnesium (mg/L)	47	Radium 226 (pCi/L)	7.5
Nitrate (mg/L as N)	0.19	Radium 228 (pCi/L)	2.9
Sodium (mg/L)	93	Gross alpha (pCi/L)	25
Sulfate (mg/L)	171	Gross beta (pCi/L)	32
Total Hardness (mg/L as $CaCO_3$)	471	Total Alkalinity (mg/L as $CaCO_3$)	332
pH	7.6		

During a tour of the facility on September 8, 1992, the system owner/operator indicated that the pressure filters were currently being by-passed and a Y-type screen using a fine stainless steel mesh and a thin stainless steel insert screen were being used. The purpose of this was to reduce the amount of water loss from backwashing the ceramic filters. The Y-type strainer and the flat screen are removed and cleaned as needed. This is typically done once per week. Due to the low suspended solids found in the well water, need for the pressure filters are questionable.

2.3 ION EXCHANGE UNITS

The ion exchange system used two Kinetico Model 100-B cation softening units. The units are constructed of fiberglass and are 10 inches in diameter and 54-inches tall. These contain 1.5 cubic feet (ft^3) of strong-acid cation ion exchange resin. These units were installed to allow continuous operation by alternating between the two ion exchange units and allowing one to be in operation while the other is being regenerated. The full flow is treated with no by-pass or blending provided.

A counter-flow meter on top of the units initiate the regeneration cycle after 1,120 gallons of water are treated (approximately 100 bed-volumes) with a total of approximately 120 gallons used during the regeneration cycle. Brine solution is obtained from a salt tank that has a maximum capacity of 240 gallons. Salt levels of 15 lbs/ft^3 are used to obtain effective radium removal from the ion exchange media.

2.4 FRENCH DRAIN FIELD

A french drain field was installed to dispose of the briney waste stream from the ion exchange system. It is located on the Quail Creek Water System's lot and is 38 feet long, 3 feet wide, and 24 inches deep. The drain was excavated and filled with 12 inches of gravel before installing perforated PVC pipe. This was then covered with approximately 8 inches of soil. While the unit is in the regeneration mode, some water can be seen in some soil sampling holes on top of the drainfield, but quickly subsides after completion of the regeneration cycle.

2.5 STORAGE TANK - DISINFECTION

A 10,000-gallon storage tank receives water from the ion exchange units after chlorination. Chlorine is added using a solution of calcium hypochlorite fed from a day tank using an Wallace & Tiernan electronic metering pump. The metering pump operates only while the well is operating at a pre-determined dose rate.

A level probe in the top of the tank indicates when the tank is full. When this probe is activated, the control system is inactivated and will not allow the well to operate. A second probe, located 2 feet lower, will re-activate the well controls and allow the well to operate when indicated by the timer.

2.6 TRANSFER PUMPS

Two 7½-horsepower pumps are operated in parallel to pump water from the 10,000-gallon storage tank into the hydropneumatic tank. The pumps are manually selected for operation with one pump being operated and one remaining in standby. Operation is controlled by pressure switches located on the hydropneumatic tank. Both pumps are on a concrete slab and are protected by a wood shelter that prevents freezing during cold periods. Heat from the pump's motors is used to keep the wood shelter warm and is monitored using a thermometer located in the enclosure.

2.7 HYDROPNEUMATIC TANK

A 3,000-gallon hydropneumatic tank is used to maintain pressure and feed flow for the distribution system. A sight glass is installed to allow the water/air levels to be monitored and the tank is typically maintained at a little over one-half full of water. Operating pressure is maintained between 40 and 60 psi to prevent the transfer pumps from short-cycling and provide sufficient operational pressure for the distribution system.

2.8 DISTRIBUTION SYSTEM

The distribution system consist of a complete loop constructed of 3-inch PVC pipe with no dead ends. Fifteen connections out of the 55 available connections are currently in operation and all are metered. Approximately 50 persons are served with an average daily demand of 2,800 gpd. The peak hour demand is estimated at 400 gallons per hour. Because of the typical plumbing in mobile homes, pressures in the distribution system are maintained below 60 psi. Over this pressure level, the plastic tubing connections will pull apart creating leaks.

The largest distribution system problem occurs during cold weather periods. During these periods, home owners open their taps to prevent freezing of their plumbing. This additional demand draws down the available storage and lowers system pressures.

3.0 SYSTEM PERFORMANCE

3.1 PRINCIPLES OF ION EXCHANGE

The fundamental principles of cation exchange apply to the removal of radium, as radium is one of the most highly-preferred cations. The following describes the basic principles of the ion exchange process.

Ion exchange resins consist of charged species attached by covalent bonds (strong chemical bond which are not reversible) with a matrix material. The matrix material for an ion exchange resin (also termed "backbone") is normally made of polystyrene, cross-linked with divinylbenzene. The tightness of the matrix material is indicated by the porosity of the resin (e.g., microporous, gel or macroporous). The functional characteristics of the charged species determines the type of resin (such as cation versus anion exchange resin).

The charged species on an ion exchange resin can attract oppositely charged species from a solution. The strength of this electrostatic bonding depends on the characteristics of the charged ions and the associated valency. As the capacity of the charged sites diminishes (breakthrough) the concentration in the solution phase approaches an equilibrium with the solid phase (adsorbed on the resin). Charged ions held by electrostatic forces can be dislodged by passing a brine solution with a higher concentration of another charged species (e.g., sodium (Na^+) for cation exchange resin).

Functional groups associated with a cation exchange resin can be classified into strongly acidic (SAC) and weakly acidic (WAC) cations. Strongly acidic cations such as the sulfonate group (SO_3^-), are ionized throughout the pH range of 1 to 14 and are effective in the exchange of charged ions. On the other hand, weakly acidic cations (such as the carboxyl group COO^-) are effective only in the alkaline pH range because these functional groups are ionized in the alkaline pH range. Similar to the above classification, anion exchange resins are also classified as strong basic (SBA) and weak basic (WBA) anions.

Ion exchange resins have different levels of preference for different ions. The affinity of an ion for a particular type of resin is normally expressed relative to that of the sodium (Na^+) ion. A separation factor, α_{ij} is defined as follows:

$$\alpha_{ij} = \frac{distribution\ of\ ion\ i}{distribution\ of\ ion\ j} = \frac{y_i / x_i}{y_j / x_j}$$

where y represents the solid phase concentration and x represents the liquid phase concentration of the two species. Higher values of α_{ij} are indicative of higher affinities for species i relative to species j. Higher α values also indicate longer breakthrough times. The value of α for radium relative to sodium is reported to be 13.0 for SAC resin (Water Quality and Treatment, 4th ed. 1990) compared to that for calcium of 1.9. This indicates that radium is much more strongly adsorbed by SAC resins relative to calcium.

The relative affinity of various ions from a multi-component solution is normally shown by diagram similar to Figure 3-1. In this figure, the ions are arranged according to their preference for adsorption by the resin (Water Quality and Treatment, 4th ed., AWWA-ASCE, 1990).

In a recent study (Subramonian et. al., JAWWA May 1990) comparing various resins and protocols for regeneration, it was concluded that SAC with macroporous resin structure provides the longest operating time before breakthrough of radium. The number of bed volumes treated by this type of resin was in excess of 8,000, whereas, SAC with a gel structure could process only 2,500 bed volumes before breakthrough occurs. WAC resins were also tested for radium removal but were found to be effective for only 700 bed volumes. Regeneration of SAC resins with sodium chloride (table salt) was concluded to be the most cost effective, although on a equivalent basis, calcium chloride is also an efficient regenerant.

3.2 TESTING PROGRAM

The testing program began after installation of the process equipment in July 1991. Several parties were involved in this program including the Quail Creek Water System, Kinetico Inc., the USEPA, the Texas Department of Health (TDH), the Texas Water Commission, and ECOS, Inc.

Process monitoring included the following:

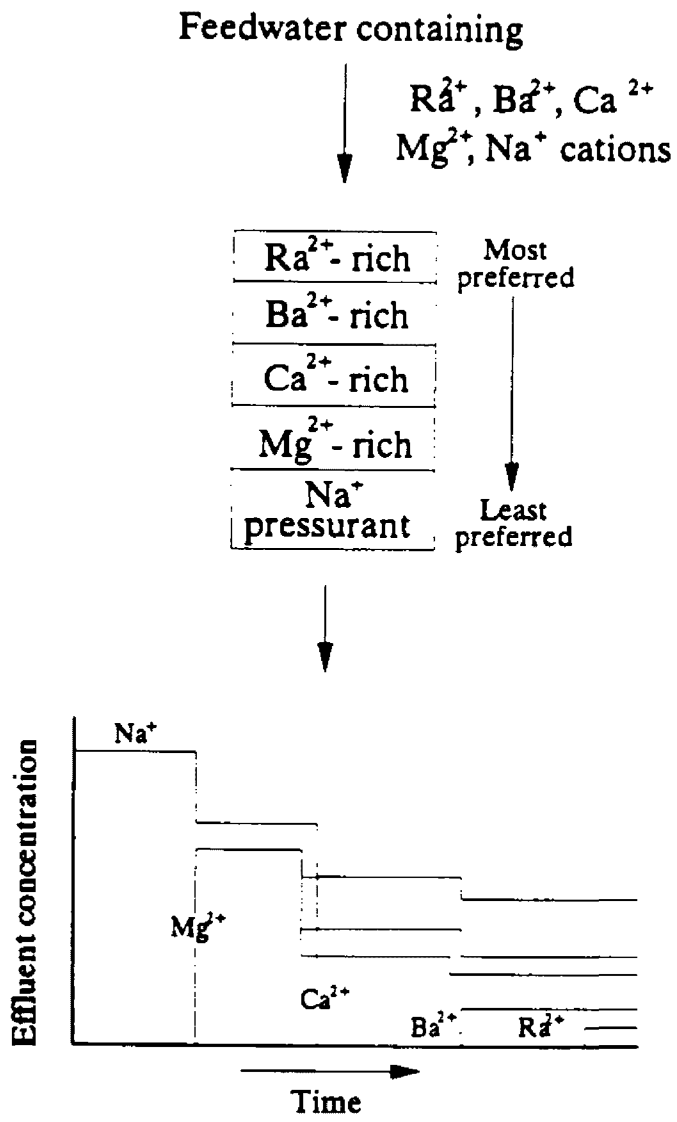
- Daily hardness monitoring (by Quail Creek Water System);
- Monthly radium and gross alpha sampling (by Kinetico, Inc.);
- Monthly radium and gross alpha analysis (by TDH);
- Monthly radiation checks (by Kinetico, Inc.);
- Soil and drain field disposal area water sampling (by TDH);
- Site visits and project management (ECOS, Inc. and U.S. EPA); and
- Site visit and sample collection (Malcolm Pirnie, Inc.).

Hardness monitoring was used as a method to ensure radium removals were being maintained. As mentioned in the previous section, cation exchange resin has a higher affinity for radium than calcium; therefore, increased levels of calcium would occur in the product water prior to any radium breakthrough in the ion exchange system. All of the available hardness measurements of the treated water were less than

FIGURE 3-1

Cation exchange

$$2\overline{RNa} + Ra^{2+} = \overline{R_2Ra} + 2\,Na^{+}$$



Adapted from Water Quality and Treatment
4th Edition, AWWA-ASCE, 1990

SEPTEMBER 1992
U.S. EPA
QUAIL CREEK WATER SYSTEM
CATION EXCHANGE AFFINITY FOR VARIOUS IONS

detection, indicating that the treatment system provided consistent removals during the testing period of the 471 mg/L of hardness in the raw water.

Monthly samples of the treated water were collected by Kinetico personnel and submitted to the TDH during the testing period. As with the hardness levels, the radium levels were low and typically less than the maximum contaminant level (MCL) of 5 pCi/L as presented in Table 3-1. A radium level of 5.8 pCi/L was measured in the treated water in December 1991, exceeding the MCL. However, this was believed to be due to sample contamination and is inconsistent with other results. Table 3-1 also includes gross beta and gross alpha levels that were also reduced to acceptable levels with the exception of the December 1991 sampling event.

Radium levels in the three samples analyzed showed relatively poor performance of the ion exchange system when compared to previous studies. Typical radium removals have been demonstrated to be as much as 97 percent. Possible poor sampling, sample contamination, or analytical problems may have occurred due to the delay between sampling and analysis. Samples analyzed quickly for only gross-α and gross-β showed more typical results.

Monthly radiation checks were made by Kinetico personnel at locations indicated in Figure 3-2. Results of this testing indicated that radiations levels surrounding the ion exchange units were low in comparison to the recommended safe exposure level of 100 millirem per year (mrem/yr) for the general public, equivalent to 100,000 microrem per year. A summary of the monitoring results are presented in Table 3-2.

In February 13, 1992, the TDH's Bureau of Radiation Control collected soil, waste water, and ambient creek water samples to determine the effect of the treatment process residuals on the surrounding environment at several locations, as presented in Figure 3-3. Radiological analysis of the creek adjacent to the brine disposal area and soil samples from the French Drain that receives the brine flow are presented in Table 3-3 (in pCi/L).

The regeneration waste stream radium level of 3.6 pCi/L is much lower than anticipated. This was likely due to when the sample was collected. During a regeneration cycle, the initial levels in the regeneration stream are low and then increase during the cycle. As this sample was collected at the beginning of the regeneration cycle, it is not representative of the amount being removed by the regeneration. As the cycle proceeds, the amount of radium expected in the regeneration stream will increase and then decrease towards the end of the cycle. This provides a "bell curve" distribution of radium levels during the regeneration cycle. Therefore, either grab samples at timed intervals during the regeneration cycle or a composite sample from the entire cycle is needed for this analysis.

TABLE 3-1

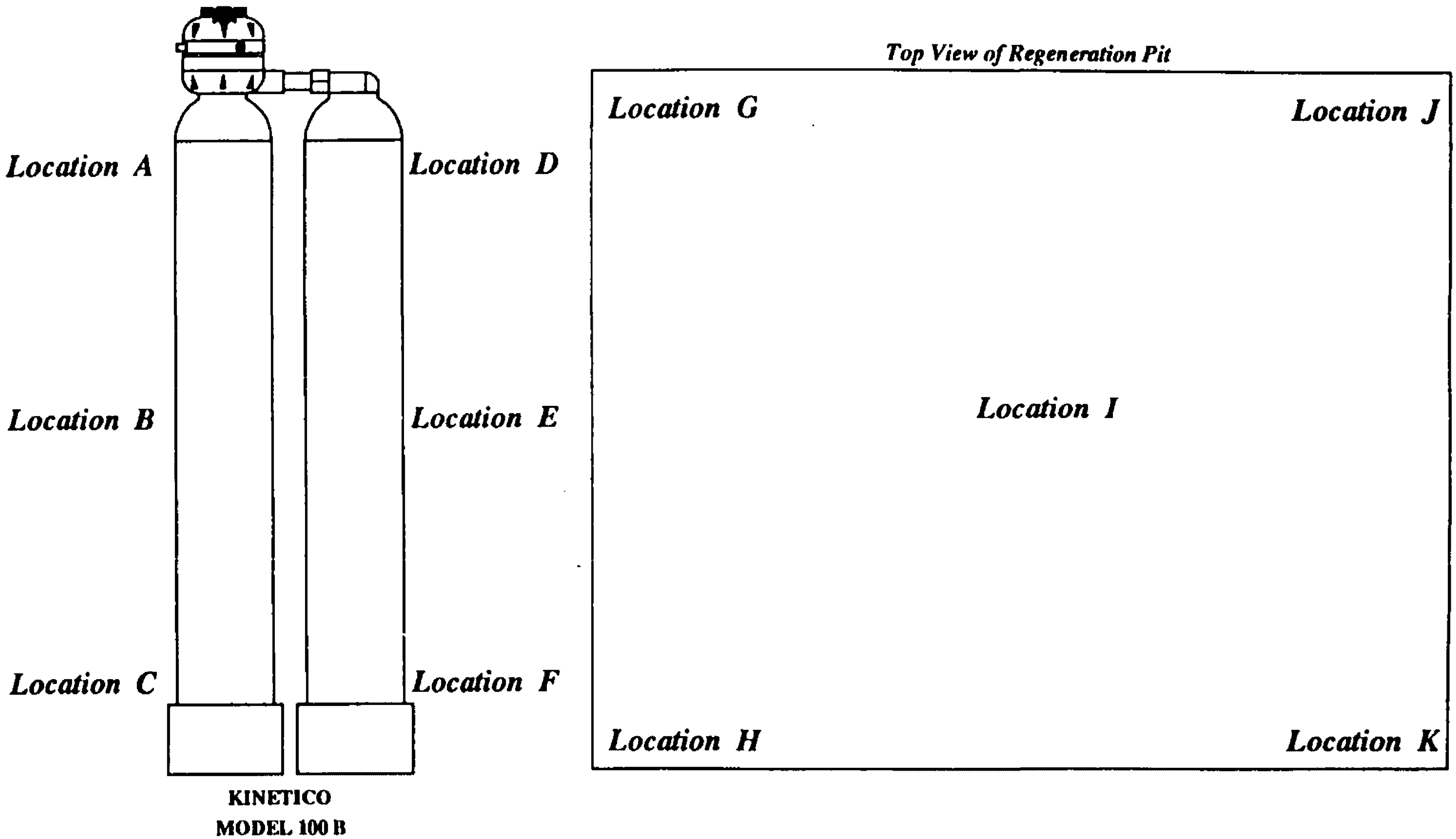
RADIOLOGICAL ANALYTICAL RESULTS
TREATED WATER

DATE	GROSS ALPHA	TOTAL RADIUM	RADIUM 226	RADIUM 228	GROSS BETA	TOTAL HARD.
Jun. 1991	4.0 ± 2.5	1.8 ± 0.3	1.8 ± 0.2	< 1.0	< 4.0	< 1
Nov. 1991	< 2.0					< 1
Dec. 1991	9.3 ± 3.5	5.8 ± 0.5	6.4 ± 0.4	< 1.0	27.0 ± 6.0	< 1
Jan. 1992	< 2.0				< 4.0	< 1
Apr. 1992	4.6 ± 1.9	3.2 ± 0.4	3.5 ± 0.5	< 1.0	8.9 ± 2.1	< 1
Sep. 1992	0.8 ± 0.1		0.09 ± 0.09			

Notes:

1. All results presented in pCi/L units except for total hardness which in grains per gallon

2. Analysis provided by the Texas Department of Health except for September 1992 samples that were conducted by Lucas Laboratory.



Adapted from Kinetico, Inc. Report (Dated 9/92)

SEPTEMBER 1992
U.S. EPA
QUAIL CREEK WATER SYSTEM
DOSIMETRY READING LOCATIONS

FIGURE 3–2

TABLE 3-2

MONTHLY RADIATION MONITORING RESULTS

DATE	LOCATIONS												
	A	B	C	D	E	F	G	H	I	J	K	BK[3]	Temp[4]
9/91	30	40	30	30	30	20	60	70	60	40	50		90
10/91	30	40	40	30	40	50	50	40	35	60	50	30	90
11/91	30	40	30	30	40	30	60	50	50	50	60	30	68
12/91	40	40	50	40	45	50	50	55	50	60	60		62
1/92	40	50	50	40	40	50	40	40	40	50	50		58
2/92	30	30	40	30	30	50	70	80	60	50	40		72
3/92	40	40	40	50	40	40	60	60	50	50	50	60	70
4/92	40	40	40	40	50	30	60	50	40	70	50	40	80
5/92	50	50	50	50	40	40	70	70	50	70	70		72
7/92	30	30	40	40	40	40	50	50	40	60	60	40	92

Notes:

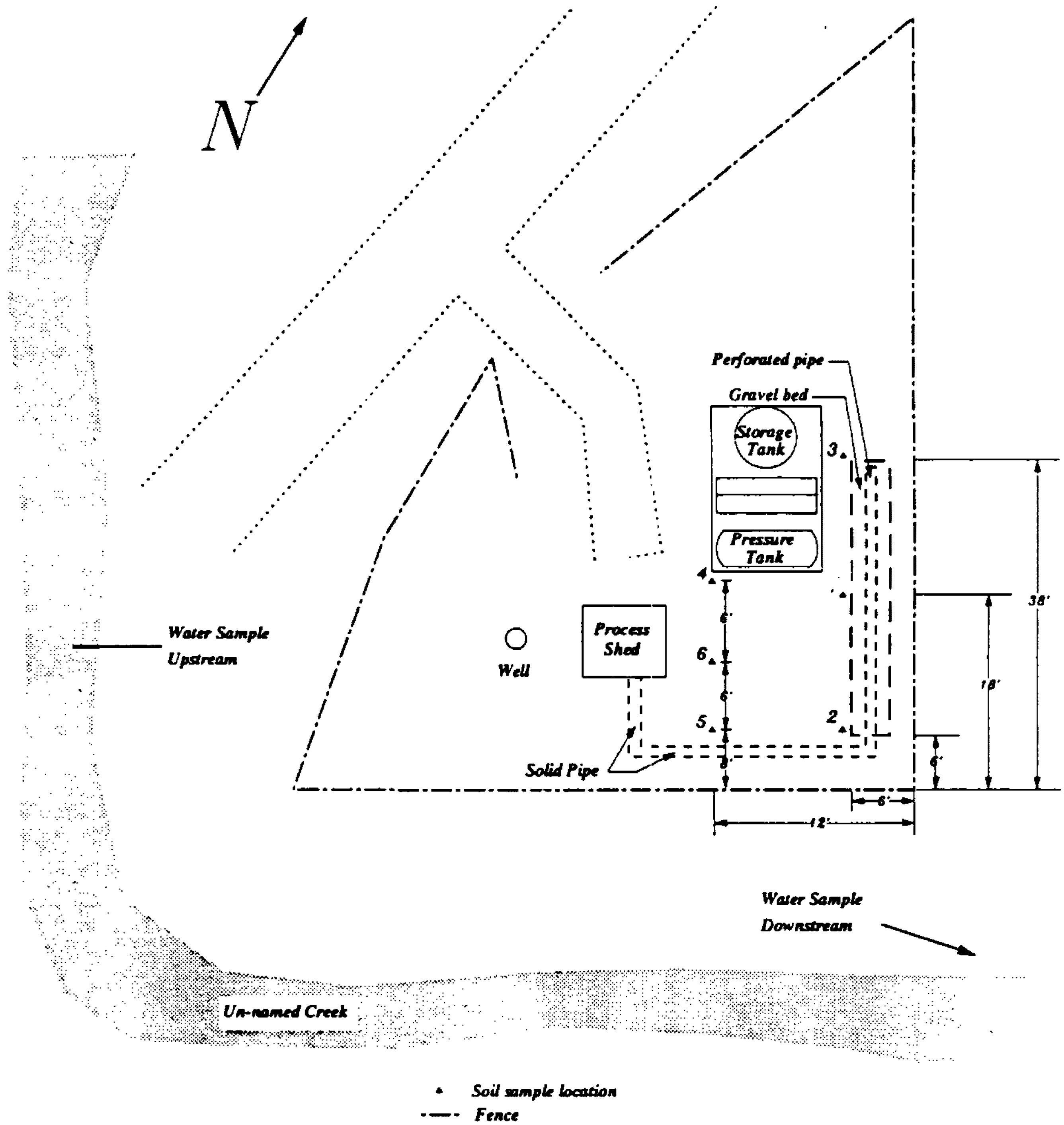
1. Measurements in micro rems (0.1 scale) as collected by Kinetico, Inc.

2. See Figure 3-2 for location of sample sites (measurements taken on ground or tank surface).

3. BK are background readings from outside air.

4. Degrees fahrenheit.

FIGURE 3-3



Adapted From Texas Department of Health Report (2/25/92)

SEPTEMBER 1992
U.S. EPA
QUAIL CREEK WATER SYSTEM
SOIL SAMPLING AROUND RADIUM
REMOVAL SYSTEM OUTLET
SAMPLE DATE: FEBRUARY 13, 1992
NOT TO SCALE

TABLE 3-3

SOIL AND WATER ANALYSIS
AROUND FRENCH DRAIN FIELD

LOCATION	GROSS ALPHA	RADIUM TOTAL	RADIUM 226	RADIUM 228	GROSS BETA
Backwash Water (pCi/L)	11	3.6	2.6	1.0	15
Downstream (pCi/L)	< 2.0	0.3	0.4	< 0.3	< 4.0
Upstream (pCi/L)	< 2.0	0.8	0.3	0.5	< 4.0
1-15 cm (pCi/g) Sites 1, 2, and 3		6.5	2.0	4.5	
> 15 cm (pCi/g) Sites 1, 2, and 3		5.2	1.9	3.3	
1-15 cm (pCi/g) Sites 4, 5, and 6		8.4	1.5	6.9	
> 15 cm (pCi/g) Sites 4, 5, and 6		4.0	1.8	2.2	

Note: Samples collected and analyzed by Texas Department of Health

Soil samples were collected from six different locations within the 100 square-meter area around the french drain field. The top 6 inches of Sites 1, 2, and 3 were combined into one sample, and Sites 4, 5, and 6 were combined into another single sample. This procedure was repeated for soil samples collected from a depth greater than 6 inches for Sites 1, 2, and 3, and Sites 4, 5, and 6. Radiation levels found in the soil samples were low, but some may be above background levels. Typical background levels in soil are 1 to 2 pCi/g.

Site visits were conducted periodically during the project by ECOS and USEPA personnel to obtain operational and customer views on system performance. Most comments were positive and the customers generally were pleased with the softer water. However, some residents voiced concern with the "slippery feel" of the bath tubs while taking showers. Bypassing some of the well water around the ion exchange process to allow some hardness to enter the distribution system may assist with this concern. If this practice were considered, it would be necessary to ensure that undesirable levels of radium were not present in the blended water.

On September 21, 1992, samples were collected from the ion exchange installation at the Quail Creek Water System to evaluate the removal efficiency of radium-226 and gross-α radiation. The solid phase concentration (ion exchange media) and regeneration behavior were also evaluated. The ion exchange columns operate on a cycle based on flow and switch to a regeneration cycle after treating 1,200 gallons of water. At the time of sampling, one of the two parallel ion exchange columns went through a regeneration cycle. Raw and treated water samples were collected just before the beginning of the regeneration cycle.

Analysis of the samples collected on September 21, 1992 for the USEPA showed the following concentrations:

Sample Location	Radium-226	Gross-α
Raw Water	7.3 ± 0.5 pCi/L	16.1 ± 1.3 pCi/L
Treated Water	0.09 ± 0.09 pCi/L	0.8 ± 0.1 pCi/L

Based on these concentrations, the ion exchange system at Quail Creek was effectively removing 97 percent of the radium-226 and 91 percent of gross-α. These numbers are somewhat different than those previously reported. Results presented in Table 3-1 presented higher levels of radium-226 in the treated water. However, it appears that the results of this sampling are consistent with previous radium removal studies as described in Section 3.1. As such, it is likely that the Kinetico ion exchange system is effectively reducing radium levels to acceptable levels. This is reinforced by the consistent low hardness levels obtained from the treatment system. It would be anticipated that hardness levels would increase prior to radium levels breakthrough in the treated water.

Samples were not analyzed for radium-228 as the concentration of this contaminant was historically at or below the detection limit in the raw water.

To evaluate the efficiency of the regeneration cycle, regenerant brine was collected in a large drum during the cycle. The total volume of brine and backwash water collected during this phase was approximately 200 liters. A composite sample of the total volume of brine and backwash water was collected for analysis. In addition, the brine stream was also sampled at specified time intervals. This was done to define the bell-shaped curve for the concentration of radium-226 and gross-α.

Figure 3-4 presents the concentration of the radium-226 and gross-α in the regenerant brine solution. The brine flow rate was approximately 3 L/min. Based upon the sampling time and the concentration at specific times during the cycle, the total amount of contaminant recovered can be calculated by determining the area (shaded in the figure) under the curve. The total amount of radium-226 recovered was calculated to be 18,800 pCi and that of gross-α was 132,500 pCi. It was assumed during these calculation that the brine solution was free of any contaminant at the end of the regeneration cycle.

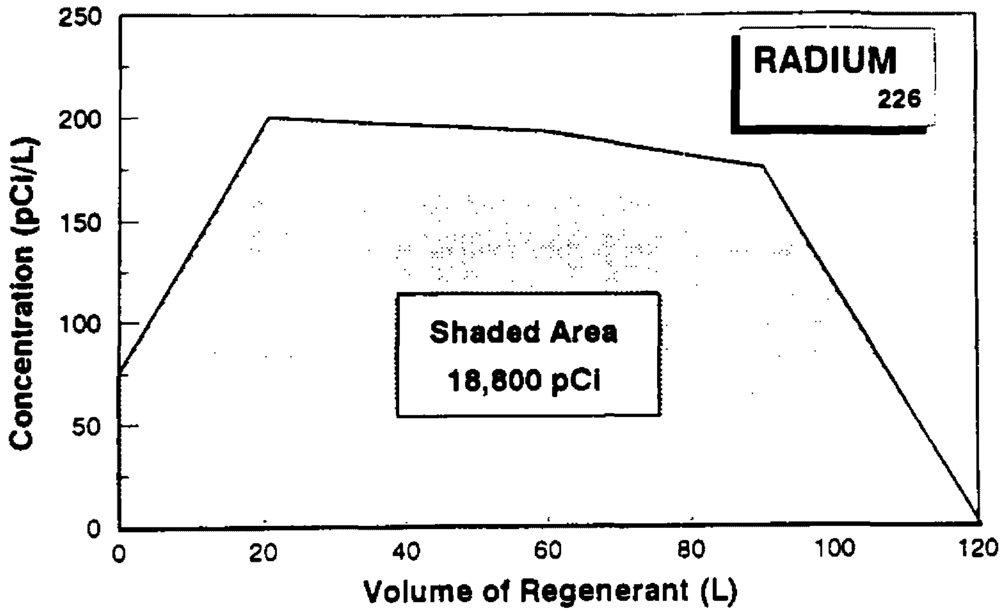
The total amount of water collected during the regeneration and the backwash cycle was approximately 200 liters. An analyses of this sample showed the following concentration:

Sample Location	Radium-226	Gross-α
Regeneration Waste	93 ± 4 pCi/L	484 ± 35 pCi/L

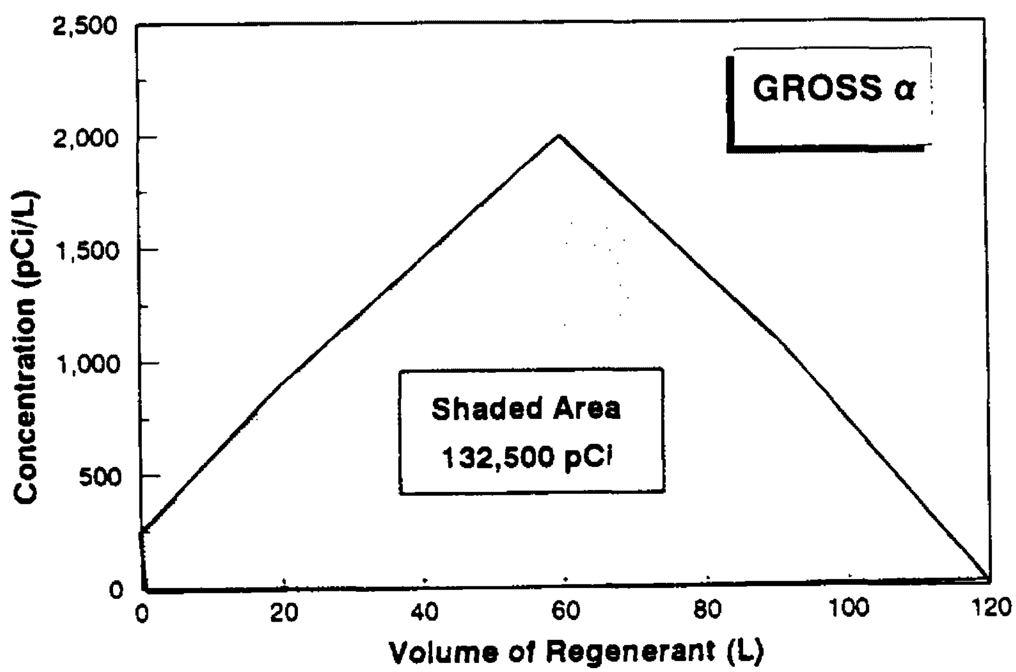
The anticipated concentration based upon the calculation shown on Figure 3-4 was 94 and 660 pCi/L for radium-226 and gross-α, respectively. Concentration of radium-226 compared favorably with the measured concentration. However, the concentration of gross-α was higher than expected.

Mass balance calculations using the measured radium levels in the regeneration waste were used to determine theoretical radium levels in the feed water. The calculated feed water radium and gross-α levels using the mass balance calculations were 4.2 pCi/L and 22 pCi/L, respectively. The calculated radium level compares well with the measured 7.3 pCi/L in the feed water considering the combined accuracy levels of the measured volumes and radium levels used for the calculation. The gross-α level was substantially less than the 16.1 pCi/L measured in the feed water. This is consistent with the lower than anticipated gross-α levels measured in the regeneration waste.

FIGURE 3-4



RADIUM
226
Shaded Area
18,800 pCi
Concentration (pCi/L)
250
200
150
100
50
0
0
20
40
60
80
100
120
Volume of Regenerant (L)



GROSS α
Shaded Area
132,500 pCi
Concentration (pCi/L)
2,500
2,000
1,500
1,000
500
0
0
20
40
60
80
100
120
Volume of Regenerant (L)

The laboratory analyzing the samples, Lucas Laboratory, indicated that high brine concentrations interfere with gross-α measurement. This may be the reason for apparent disagreement between the measured and calculated numbers for gross-α.

Resin samples were collected before and after the regeneration cycle to analyze for radium-226 and radium-228. Two resin samples were collected at both times; one sample was collected approximately 6 inches below the surface of the resin, and the other sample collected from approximately the center of the bed.

An analyses of the resin samples indicated that the solid phase concentration of radium was low, both before and after regeneration. The concentration of radium-228 for all the samples were same at a level of 1.5 ± 0.2 pCi/L . The concentration of radium-226 in the sample collected from the center of the bed showed the same concentration of 2.1 ± 0.3 pCi/L both before and after regeneration. The concentration in the resin sample collected from 6 inches below the surface was slightly higher after regeneration and increased from 2.5 ± 0.3 pCi/L to 3.5 ± 0.3 pCi/L. The difference between these samples are small and probably not significant. One explanation may be that the increase was due to the combination of using a up-flow regeneration stream and flocculent particles found in the resin samples. It was observed that some of the flocculent particles were attached to the resin and included in the radium readings. By flushing upward, the flocculent particles may have been pushed to the top of the resin, thereby providing the slightly increased radium levels.

Based on these analyses, it can be concluded that the current mode of operation of the ion exchange system is not completely utilizing the resin capacity. It is anticipated that the number of bed volumes between regeneration cycles could be increased without adversely affecting treated water quality.

4.0 SYSTEM COSTS

4.1 EQUIPMENT COSTS

The equipment supplied by Kinetico, Inc. included the following:

- Kinetico Model 100 cation softening unit (two each);
- Kinetico Model 100 paraflow ceramic backwash filter (two each);
- Well-X-Trol pressure tank (one each); and
- 36 x 6 x 2 regeneration drain bed (one each).

Fair market value for this equipment as cited by Kinetico, Inc. is $6,200 and includes the equipment, freight, and installation of the equipment. This does not include the cost for installation of the waste stream drainfield. Both the cation softening unit and the Paraflow ceramic backwash filter units consist of two tanks. This allows one tank to remain in service while the other is in regeneration or backwash cycles.

4.2 OPERATION AND MAINTENANCE COSTS

Operation and maintenance costs can be divided into fixed and variable costs. Fixed costs are those that are constant for a given period of time and are not affected by the amount of water treated. Examples of fixed costs include labor, capital expense payments, regulatory monitoring, and routine maintenance. These costs are typically given in annual cost units ($/yr). Variable costs are directly related to the amount of water treated and include chemicals and power costs and are typically given in cost per 1,000 gallons supplied to the distribution system.

4.2.1 Fixed Costs

Labor costs directly related to the operation of the treatment facility include labor by Kinetico, Inc. and the owner/operator of the Quail Creek Water System. The labor rate for the Kinetico, Inc. personnel conducting the monthly servicing of the treatment unit was $45 per hour. It may be possible for the system operator to assume these responsibilities and reduce these labor costs. A labor rate was not available for Wendell Ellis, the owner/operator of the Quail Creek Water System. As such, the standard operator rate established by USEPA for small system operators of $14.70 per hour is used in this report.

The total number of service hours provided by Kinetico, Inc. personnel during the study period between July 1991 and July 1992 was 13.5 hours, fielding an average service time of 1.25 hours per month. During most months, the service time was only 1 hour. The slight increase was due to additional time spent conducting special sampling requested by the TDH. As such, 1 hour of service time per month is used for calculating labor costs in this report giving an annual cost of $540.

Mr. Ellis estimated that mixing chemicals, reading meters, maintaining the grounds, and inspecting the treatment process required an average of 1½ hours per day. No measurable increase in labor for monitoring the ion exchange system is anticipated. This is expected to be consistent with other small water systems and our past experience. Therefore, the hours required by the owner/operator is estimated to be 548 hours per year or an average of 46 hours per month, for an annual cost of $8,060.

Amortization of the capital equipment, valued at $6,200, by Kinetico, Inc. was calculated at 10 percent over 10 years. Financing is based over 10 years because of anticipated replacement or refurbishment of the ion exchange units and the limited customer base available to pay the user fees. Because of the limited financing alternatives available for small, privately owned water systems, it is assumed that a 10 percent interest rate could be obtained. This is higher than what larger municipal systems can obtain but is a more realistic rate for small systems. This provided an annual cost of $1,010, or a monthly cost of approximately $84/month.

Regulatory monitoring is performed by the water system with water analyses performed by the TDH. The state charges for these services, estimated to be approximately $380 per year by Wendell Ellis, the owner/operator of the Quail Creek Water System. Other regulatory costs include licensing the operator and includes a biannual course costing $75 and a $20 annual licensing fee. In addition, a $50 fee is imposed on all public water systems to be able to operate in the State of Texas. Additional monitoring for the ion exchange system consists of daily analysis of hardness. This is estimated to cost $55 per year based on a chemical cost of $0.15 per test. The total annual cost for monitoring and other regulatory miscellaneous cost are $545.

Routine maintenance supply costs and major equipment replacement costs are estimated based on assumed equipment life times and supply usage. Routine maintenance supplies include paint, pump seals and bearings, lubricants, cleaners, fuel, tools, and all other consumables and regularly replaced items. This cost is estimated to be $200 per year. Major equipment replacement accounts for material and labor costs for replacement and infrequent instrument, valve and structural replacement and repairs on an annual cost basis. The transfer and well pumps are anticipated to have a 10-year life and a 2-year life for the chemical metering pump. The annual costs for replacement of this equipment is $800 per year. The total annual cost for routine maintenance and major equipment replacement is $1,300. This includes an estimated $300 annual cost for the ion exchange equipment and replacement of the resin.

The estimated annual fixed costs for the Quail Creek Water System is $11,455 with the installed ion exchange demonstration treatment system. This is an increase of $1,905 per year by addition of the ion exchange equipment. A summary of these costs is presented in Table 4-1.

4.2.2 Variable Costs

As discussed earlier, variable costs are those costs that are directly related to the amount of water treated. These costs include chemicals and process power requirements.

Two chemicals are used by the Quail Creek Water System; chlorine and salt. Chlorine is purchased as calcium hypochlorite in a dry form. The crystals are mixed with water when undissolved solids are removed and disposed. The remaining solution is pumped into the water line to the 10,000-gallon storage tank by an electronic metering pump. The system adds sufficient chlorine solution to maintain between a 0.5 and 1.5 mg/L chlorine residual in the distribution system. Based on this, an average feed dosage of 1.5 mg/L is assumed. This requires 0.013 pounds of chlorine per 1,000 gallons treated.

The Quail Creek Water System currently pays $100 for an 80-lb drum of calcium hypochlorite; a cost of $1.25 per pound of stock chlorine crystals. The stock crystals provide approximately 65 percent available chlorine. Therefore, to provide the required 0.013 pounds per 1,000 gallons, approximately 0.02 pounds of stock chlorine crystals will be required for a cost of $0.025 per 1,000 gallons treated.

Salt is used to regenerate the cation exchange resin. An 80-pound bag costs $8.50 delivered to the treatment facility based on actual costs provided by Kinetico, Inc. This is a cost of $0.106 per pound of salt. The regeneration process uses approximately 22.5 pounds of salt each regeneration cycle. A cycle occurs when 1,120 gallons is treated and uses 120 gallons during the regeneration cycle. Therefore, 22.5 pounds of salt is used to treat a net production of 1,000 gallons. This is a cost of $2.385 per 1,000 gallons for salt.

Electricity is used to power the well pump, chemical metering pump, and the transfer pumps during the operation of the treatment facility. Based on information collected by Kinetico, Inc., during the demonstration program, the average monthly electric bill was $55.26. Of this, only an increase of $13.50 per month can be attributed to the ion exchange system. With an average monthly production of 93,290 gallons, the total electrical cost per 1,000 gallons produced is $0.59 per 1,000 gallons produced which includes an increase of approximately $0.10 per 1,000 gallons for the ion exchange system.

The estimated total variable costs for the Quail Creek Water System is $3.00 per 1,000 gallons produced with operation of the ion exchange demonstration treatment system. A summary of these costs is presented in Table 4-2.

TABLE 4-1

SUMMARY OF ESTIMATED FIXED COSTS

ITEM	COST/YR	
	TOTAL SYSTEM	ION EXCHANGE
Labor*	$8,600	$ 540
Capital Amortization	1,010	1,010
Monitoring and Miscellaneous	545	55
Maintenance*	1,300	300
TOTAL	**$11,455**	**$1,905**
* Estimated, Not Actual		

TABLE 4-2

SUMMARY OF VARIABLE COSTS

ITEM	COST/Kg[1]	
	TOTAL SYSTEM	ION EXCHANGE
Chlorine	$0.03	$0.0
Salt	2.39	2.39
Power	0.59	0.10
TOTAL	**$3.00**	**$2.49**
Note: [1] Kg = 1,000 gallons		

4.2.3 Total Estimated Costs

Using the July 1991 through June 1992 actual annual production of 1,120,000 gallons, total operating and maintenance costs were developed for the water treatment facilities and the ion exchange (IX) system. These estimated costs are as follows:

COST ITEM	ANNUAL $		$ PER 1,000 GALLON	
	TOTAL SYSTEM	ION EXCHANGE	TOTAL SYSTEM	ION EXCHANGE
FIXED				
Labor*	$ 8,600	$ 540	$ 7.68	$0.48
Capital Amortization**	1,010	1,010	0.90	0.90
Monitoring/Misc.	545	55	0.49	0.05
Maintenance*	1,300	300	1.16	0.27
VARIABLE				
Chlorine	30	0	0.03	0.00
Salt	2,670	2,670	2.38	2.38
Power	664	112	0.59	0.10
TOTAL	**$14,819**	**$4,687**	**$13.23**	**$4.18**

* Estimated - Not Actual

** Financing $6,200 over 10 years at 10 percent interest for Kinetico equipment

At this annual cost, the average monthly bill for each of the 15 connections to the water system would be $82.31 to cover the costs of operating and maintaining the water system. Of the total cost, only approximately 30 percent is due to the ion exchange system.

5.0 ISSUES

Although the Quail Creek Water System appears to be removing radium from their drinking water supply, other concerns have been raised relative to the implementation of the ion exchange process for radionuclide removal both here and at other locations that may wish to consider this option. These concerns are divided into regulatory, and cost, design and operating issues in the following sections.

5.1 REGULATORY ISSUES

During a meeting with TDH personnel on September 9, 1992 to discuss the project, the disposal of the brine produced by the regeneration cycle was highlighted as the pivotal issue. The Quail Creek Water System has been successful at using a French drain field, designed similar to a septic tank drain field, to dispose of the brine. This is possible because of the low water table in the area (over 100 feet below the surface) and the permeability of the soil in the region. Brine water discharged in to the drain field is able to percolate through the ground and is anticipated to be diluted by heavy rain events that typically occur in the region.

Without the site-specific conditions experienced by the Quail Creek Water System, this method of disposal for the brine may not be possible. One observation shared by TDH personnel was that clay soils collect radium over time. The presence of clay soils would then exclude the drain field option from consideration. As such, the site-specific options to safely dispose of the regeneration brine and the ability to obtain a discharge permit may limit the use of ion exchange for removing radionuclides at a specific site.

Regulations concerning the disposal of waste streams from water treatment processes and radioactive solutions are also becoming stricter and more complex. Permitting the waste stream from the treatment process is most likely the most difficult concern to be addressed when considering this or any other treatment technology.

5.1.1 USEPA Guidelines

Guidelines for the disposal of radioactive liquid wastes from water treatment processes were developed by the USEPA and published in July 1990. The USEPA is planning to update that guidance in 1993. These are only guidelines as each state has primary and specific requirements for waste stream disposal.

Disposal of water treatment plant residuals into a storm sewer to surface waters is subject to the National Pollutant Discharge Elimination System (NPDES) regulatory framework as a discharge directly to surface waters. Prevailing conditions of flow and geometry within the storm sewer and the receiving water body should prevent the buildup of radionuclides in the water column and/or sediment and provide adequate downstream mixing. For these site conditions, a limiting concentration, such as drinking water MCL, or a percentage of background concentration of radionuclides (i.e., 10 percent), may be set to limit the increase of radionuclides in the water body due to the discharge. Other solutions need to be examined if the conditions of flow and geometry are not adequate to prevent a buildup of radionuclides in the storm drain, the surface water or sediments, to within the limit set by regulators. These may include additional waste treatment, waste storage and controlled discharge measures.

The General Pretreatment Regulations (40 CFR Part 403) governing discharges to sanitary sewers apply to water treatment wastes. In addition, USEPA recommends that all discharges to sanitary sewers meet regulations established by the Nuclear Regulatory Commission (NRC) for licensees. NRC limits the discharge of wastes containing radioactive materials into sewers and these limits are listed in 10 CFR Part 20, that are to be revised as of January 1993. Along with the limits on the daily quantities of soluble radium 226 and 228, and soluble uranium, there is a limit on the annual quantity of radioactive material disposed into sanitary sewers of less than 1 curie per year. If there is an accumulation of radioactive material in the sanitary sewers, then other type of treatment technologies such as evaporation of liquid wastes, sand drying, lagoons or chemical precipitation should be selected.

Guidelines for the disposal of radioactive wastes into subsurface disposal systems (i.e., injection wells) should meet the minimum requirements of the Underground Injection Control (UIC) program promulgated at 40 CFR Parts 124, 144,145 and 146. Regulations of water treatment plant residuals containing radionuclides depends on their concentration. Furthermore, requirements are specified for shallow and deep well injection. If the waste is classified as radioactive under 40 CFR 144.3 then shallow injection (i.e., injection above or into an underground source of drinking water (USDW)) is banned under the UIC program. Injection below USDW is considered as Class V well and is under study by USEPA for regulatory action. If the waste is not classified as radioactive, injection beneath the lowermost USDW, classified as Class I well, is allowed provided that the waste contains no other hazardous constituents. Class I wells have permitting requirements that are extensive and adequately protect USDWs and human health. It must be noted that septic systems are not a recommended method for disposal of liquid, briny wastes (USEPA Guidelines, 1990).

5.2 COST, DESIGN, AND OPERATING

Approximately 90 percent of drinking water violations occur in small water systems and offer a unique problem to the drinking water industry. Finding low-cost treatment solutions for these systems is the purpose of this and other projects being conducted under the Small Systems Initiative. Recent reviews of other small water systems under the Small Systems Initiative and experience at the Quail Creek Water System highlight some other issues that affect the implementation of low-cost technology at these sites. These include the impact of costs, design, and operation.

Even small increases in the cost of treatment or capital purchases can have a significant impact on small water systems. As shown in Section 4.0, water rates will need to be increased by approximately 45 percent from $9.00 to $13.20 per 1,000 gallons for the Quail Creek Water System to purchase and operate the Kinetico, Inc. ion exchange system based on estimated operating costs. Cost effects on other small water systems will vary depending on raw water quality and other site-specific conditions. Table 5-1 presents a comparison of he major Quail Creek Water System costs and those estimated by the USEPA.

Many, if not all, States regulate service charges and user fees that private water systems can charge their customers. Publicly owner water systems operators must convince public officials to increase the cost for services to their constituents and hold public hearings. Neither of these methods are easily achieved and require considerable effort and time, especially when substantial rate increases are required. Therefore, each small water system must de designed and constructed with the minimization of capital and operational costs as a top priority.

Package treatment systems are designed to allow installation in water systems that make up a broad range of conditions. Only by being able to serve a wide range of conditions can a package system be economically developed and allow the savings to be passed on to the consumers. However, site-specific needs must be addressed and elimination of process equipment not required for a specific site should be deleted from the design. For example, ceramic filters were installed to remove suspended particles from the feed water to protect the ion exchange system in the Quail Creek Water System. Although this is a good design feature, stainless steel microscreens in an in-line Y-line strainer and an orifice screen are capable of filtering out the low levels of suspended solids from the Quail Creek Water System's well. This minor design change can eliminate the use of backwash water and provide substantial savings based on the cost of treatment to produce the treated water used for backwash.

An important design consideration for this system is the number of bed volumes that can be treated between regeneration cycles. The current operation regenerates the bed every 100 bed volumes. Increasing the number of bed volumes would provide savings to the water system by reducing the amount of brine water to be disposed and the amount of salt that is used. As discussed earlier in Section 3, studies have shown that the number of bed volumes prior to radium breakthrough for various resins were 700, 2,500, and in excess of 8,000 bed volumes (Subramonian, et al., JAWWA May 1990). Even with the hardness levels present in the Quail Creek well, regeneration after 300 to 500 bed volumes should not adversely effect the treated water quality.

TABLE 5-1

COST ESTIMATE COMPARISON

PARAMETER	USEPA COST ESTIMATE	QUAIL CREEK WATER SYSTEM
Capacity (gpd)	24,000 (1)	14,400
CAPITAL COSTS (Lump Sum)		
Building	$ 7,350	$ 0
Site Work/Excavation	3,000	0
Equipment (installed)	7,900	6,200
Contingencies	3,025	0
Standby Power & Subsurface work	6,382	0
Legal, Fiscal, Administration	1,573	0
Interest During Construction	389	0
General Contractor Overhead & Profit	3,319	0
Engineering	4,646	0
Total Capital Cost	**$ 37,584**	**$ 6,200**
OPERATION AND MAINTENANCE COSTS (Annual Cost)		
Power	$ 410	$ 110
Labor	3,100	8,060 (2)
Maintenance Materials	188	300
Chemicals	125	2,670 (3)
Total Operation and Maintenance Cost	**$ 3,823**	**$ 11,140**
TOTAL ANNUAL COST (4)	**$ 8,238**	**$ 11,868**

(1) Smallest system size included in Technologies and Cost Document for Radionuclide Removal.
(2) USEPA estimated at 209 and Quail Creek estimated at 548 hours per year.
(3) Higher salt costs due to frequent regenerations (every 100 bed volumes) and use of enough salt per regeneration to regenerate entire resin bed capacity.
(4) Capital costs financed over 20 years at 10-percent interest

One possible method for maximizing the number of bed volumes between regenerations would be to monitor the calcium hardness levels in the treated water. As calcium will break through the ion exchange bed before radium, the system could be safely operated at the lowest operating cost.

Operational design considerations have an effect on costs and performance. As presented in Section 5.2, the different regeneration cycles used in the Spicewood water system and the USEPA estimate costs have a significant impact on operational costs. Maximizing this design parameter should be done to make the ion exchange process a cost effective technology for reducing radium levels in contaminated sources.

6.0 CONCLUSIONS

The Kinetico, Inc. ion exchange treatment process performed satisfactory and was able to reduce radium levels in the Quail Creek Water System to acceptable levels. The treatment system was readily accepted by the Quail Creek community and the owner/operator.

When reviewing the costs, however, it should be noted that Wendell Ellis does not charge for his time to the water system. Therefore, his time should not be included in the total Quail Creek Water System's costs for a savings of $8,060 per year. In addition, because of the cost impact from implementing a comprehensive preventative maintenance program, most small systems do not perform the level of maintenance that might be anticipated. By using reduced routine maintenance costs to cover only items such as emergency repairs that may be required on a well-maintained system such as the Quail Creek Water System, the maintenance costs are lower than they may be for other systems.

Costs for the Kinetico ion exchange treatment system have been maintained lower than those estimated by the USEPA. This has been possible by not following conventional design and construction procedures. However, operating costs are higher due to the frequent salt regeneration. Even though the overall Quail Creek Water System treatment costs are low, they still have a significant impact on the total cost for the small water system. The current water rate of $17.50 for the first 4,000 gallons plus $2.50 for each additional 1,000 gallons provides an annual income for the water system of $4,500. This is based on the 1,120,000-gallon annual usage in 1992 with the first 4,000 per resident each month being charged at $17.50 and each additional 1,000 gallons at $2.50 for an annual income of $4,150 per year. It can be seen that current income is approximately equal to the ion exchange system's annual cost of $4,687.

Therefore, either water rates would have to be doubled or the capital and operational cost for the ion exchange system must be reduced. Authorization for any increase in water rates must be petitioned from the Public Utilities Commission, which established utility rates in the state of Texas. Nominal water rate increases should be possible.

Capital costs may be reduced by eliminating the ceramic filters. However, the major potential cost savings appears to be operational. By optimizin~ the resin usage, additional bed volumes can be treated between regeneration improving system recoveries and reducing salt usage. Installing a controlled by-pass around the ion exchange system to blend in treated with treated well water can also be done to reduce salt and regeneration water usage.

Waste disposal does not appear to be a concern in the Quail Creek Water System based on current information. However, long-term impacts could not be determined and the drainfield should continue to be monitored.

With these changes, using ion exchange to remove radium from the Quail Creek Water System appears to be a cost effective, viable alternative for meeting drinking water requirements.

REFERENCES

American Water Works Association, ***Water Quality and Treatment***, Fourth Edition, Denver, Colorado, 1990.

Kinetico, Inc., ***Quail Creek Subdivision Demonstration Report***, September 1992.

Subramonian, et. al., "Evaluating Ion Exchange for Removing Radium from Groundwater," Journal of American Water Works Association, Denver, Colorado, May 1990.

U.S. Environmental Protection Agency, ***Suggested Guidelines for the Disposal of Drinking Water Waste Containing Naturally Occurring Radionuclides***, July 1990.