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June 6, 1977

Joseph C. Jackson
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RE: "Field Investigation of the Performance of
Asbestos-Cement Pipe Under Various Water Quality
Conditions", by E.F. McFarren

The above referenced paper has been submitted to us for consideration for publication in JOURNAL AWWA. It is our policy that all papers to be published in the JOURNAL must be reviewed and appraised by at least two authorities in the field. Your name has been suggested as such an authority. May we impose upon you to give us your comments and opinion as to the paper's suitability for publication in the JOURNAL.

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Paul Hersch
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Field Investigation of The Performance
Of Asbestos-Cement Pipe Under
Various Water Quality Conditions

by

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Field Investigation of the Performance of Asbestos-Cement
Pipe Under Various Water Quality Conditions

INTRODUCTION

Asbestos fibers in air are known to be a serious respiratory hazard, although asbestos fibers ingested through drinking water have not been conclusively shown to be similarly hazardous. Because of concern about this problem, in 1974 the A/C Pipe Producer's Association contracted with the American Water Works Association Research Foundation to study the problem of asbestos in water, specifically with relation to the use of asbestos-cement pipe. A committee of six recognized experts in the field, chaired by George W. Wright, M.D., was convened and their report published in September, 1974 as part 2 of that month's Journal of the American Water Works Association. Appendix F of that report contained 11 research needs related to the question "Does the use of asbestos-cement pipe (sic) potable water systems constitute a health hazard?" Research needs 2 through 6 that relate to fiber in distributed water are listed below (not in priority order).

- "2. Determine the quantity of asbestos by categories of size (length and diameter) as it actually exists during variations that might be introduced over time, installation, tapping, etc. in potable water supplies distributed in asbestos-cement, metal and plastic pipe.
3. Determine the increment of asbestos fibers added to the water as it traverses asbestos-cement, metal and plastic pipe systems under varying circumstances of installation and operation.
4. Determine the contribution that the asbestos content of soil, in which pipe of the three kinds is imbedded, makes to the asbestos content of the water traversing the pipe.
5. Determine the effect of water flow in an asbestos-cement pipe loop (not installed in soil) under varying conditions of velocity and aggressiveness, and also with respect to distance and temporal influences.

6. Examine the use of crocidolite content of water as a "marker" of fiber migration from the asbestos-cement pipe wall to water in operating systems. (Pipe loop and in situ)."

As part of this research program, the aim of this project was to determine whether asbestos fibers would be released from the pipe under certain conditions of water quality but not under others. Because pH, hardness, and alkalinity of the water seemed to be the main factors that determine whether water is aggressive to A/C pipe⁽¹⁾ a range of water qualities from the aggressive to the non-aggressive were selected for both laboratory and field evaluation. A field evaluation was made to include 6 public water supply systems that used A/C pipe and covered the desired water quality range. This study is a portion of a three-phase project. The other two phases are; 1) study of fiber release under controlled conditions in a pipe-loop and 2) a field investigation of the usefulness of various control measures in systems where fibers are being released. Reports on these two studies, as well as the health effects of ingested fibers, will be forthcoming.

The AWWA Standard C400-75¹ establishes criteria for determining the quality of water that can be transported through A/C pipe without any adverse effects. These criteria are:

- (a) Use either Type I or Type II pipe where $\text{pH} + \log (\text{AH}) \geq 12.0$
- (b) Use Type II where $\text{pH} + \log (\text{AH}) \geq 10.0$

Where:

pH = index of acidity or alkalinity of the water in standard
pH units

A = the total alkalinity in mg/l as CaCO_3

H = the calcium hardness in mg/l as CaCO_3

Type II A/C pipe is autoclaved and Type I is not.

Table 1 lists the six systems studied, their water quality characteristics, and the calculated aggressive index (A.I.) of each.

Table 1. Water Quality Parameters

Name of System	pH	Alkalinity mg/l CaCO_3	Calcium Hardness mg/l CaCO_3	Aggressiveness Index (A.I.)*
Pensacola, Fla.	5.2	1.0	1.4	5.34
King County Water Dist. No. 58 Seattle, Wash.	7.2	14	14.5	9.51
Grant Hill Assoc., Bloomfield, Conn.	7.5	88	82	11.56
Clark County Utilities, Northridge, OH	7.8	220	250	12.54
Lockhart, Texas	9.4	50	44	12.74
Cleburne, Texas	9.7	36	39	12.85

*As water entered pipe

The samples were collected by local water utility or water supply regulatory personnel. They were collected in 1 qt. (946 ml) cubitainers, preserved with mercuric chloride and shipped to EPA Water Supply Research Laboratory, Cincinnati, Ohio for electron microscopic examination.²

The findings pertaining to each of the six systems will be reviewed individually.

SYSTEMS STUDIED AND RESULTS

Pensacola, Florida

The Pensacola, Florida Water System has a water use range of 20-25 mgd (75,700 - 94,600 m³/d) in winter and 30-40 mgd (113,500 - 151,400 m³/d) in summer. The population served is estimated at 200,000 with about 60-70,000 of this being in the city of Pensacola. Pensacola furnishes water to a number of outlying communities including Gulf Breeze, Santa Rosa Island and Perdido Keys.

The source of the water is 23 wells spread throughout the service area and two new wells are being completed. The water as pumped from these wells is very corrosive or aggressive and will attack all common plumbing materials except plastic. Some of the chemical qualities of the water that make it so aggressive are pH 5.2, calcium hardness 1.4 mg/l, and alkalinity 1 mg/l which results in an A.I. of 5.34. According to Standard C400-75 this quality of water is unsatisfactory for the use of A/C pipe because the A.I. is less than 10. Lime treatment has been applied at each individual well site for many years, in an effort to control the corrosion but the lime treatment has not been applied consistently nor has it been very effective.

One section of the Pensacola system is of special interest, the Montclair section. This portion of the overall system was originally a privately owned system, initiated in 1957 and added on to through 1968. Much of the distribution piping was of asbestos-cement, 63,386 feet (19,320 m) in place at the time of purchase by the city of Pensacola in October 1968. The remainder of the distribution piping consisted of 40,000 feet (12,190 m) of galvanized steel pipe, most of which was 2-inch (5.1 cm) diameter.

Prior to acquisition of the Montclair system by Pensacola, considerable deterioration of some asbestos-cement pipe occurred. Problems with the A/C pipe surfaced in 1964 through customer complaints of water-borne fibers. The problem continued until a short time after the city had purchased the system and instituted stabilization treatment. Clogged customer meters and problems at a coin-operated laundry were attributed to fiber accumulation. After the city started treatment on a continuous basis, flushed the system, interconnected it with the overall city system and started a program of replacing small galvanized lines, consumer complaints subsided, clogging problems were either overcome or not reported. In June 1974, however, in response to a consumer complaint, a collection of visible fibers was obtained from a kitchen faucet strainer. The fibers were identified as asbestos by EPA.

Some time later, (January 1975) water samples for asbestos analysis were collected from 3 locations in the Montclair system, (1) from the original well supply, (2) a location in the older portion of the system (Chantilly Way), and, (3) a location in the newest portion of the system (E. Shore Drive). The absence of asbestos fibers in the well samples indicated that the asbestos fibers found in the distribution system resulted from the action of corrosive water on the asbestos-cement pipe. As previously indicated, the well water is extremely corrosive having an A.I. of 5.34. However, the lime treated water in the distribution samples also qualifies as a corrosive water at times with a pH range of 6.4 to 9.3. Although sufficient water quality data

are not available to calculate the increase in aggressive index, it was at least 1.2 to 4.1 units higher at the two downstream sampling stations as noted by the increase in pH. The increase in pH as the water flows through the A/C pipe indicates that the pipe is serving as a source of pH adjustment. As the pH rises less fibers are lost from the pipe wall.

The chrysotile fibers ranged from 0.3 to 40 μm in length and from 0.02 to 0.5 μm in diameter although most were single fibrils of no greater than about 0.06 μm in diameter. Approximately 75 percent of the fibers were under 5.0 μm in length. The median length was 2.0 μm . Although most samples contained too few amphibole fibers to be able to count (less than one per 20 or 30 grid holes counted), if all the amphiboles found (15) in all the pipe samples (14) are taken as a group, the crocidolite fiber length ranged from 0.7 to 60 μm in length with a median of 2.5 μm and with diameters of 0.1 to 0.2 μm .

Figure 1 is a sketch of the water mains most prominently involved in the transport of the water from the well source to the sample collection points. The most likely path water would travel to reach the 4410 Chantilly Way sample point would be through 1350 ft. (410 m) of 6 in. (15.2 cm) A/C and 655 ft. (200 m) of 2 in. (5.1 cm) galvanized pipe. A likely path for much of the water reaching the 6405 East Shore Drive sample point would be through 200 ft. (61 m) of 10 in. (25.4 cm), 1520 ft. (460 m) of 8 in. (20.3 cm), and 10,100 ft. (3080 m) of 6 in. (15.2 cm) A/C pipe. The pipe lines along these routes are all between 15 and 18 years old, having been installed between January 1958 and September 1960. The pipe along these routes was manufactured by Johns-Manville and Keesby-Madison or Certain-teed.

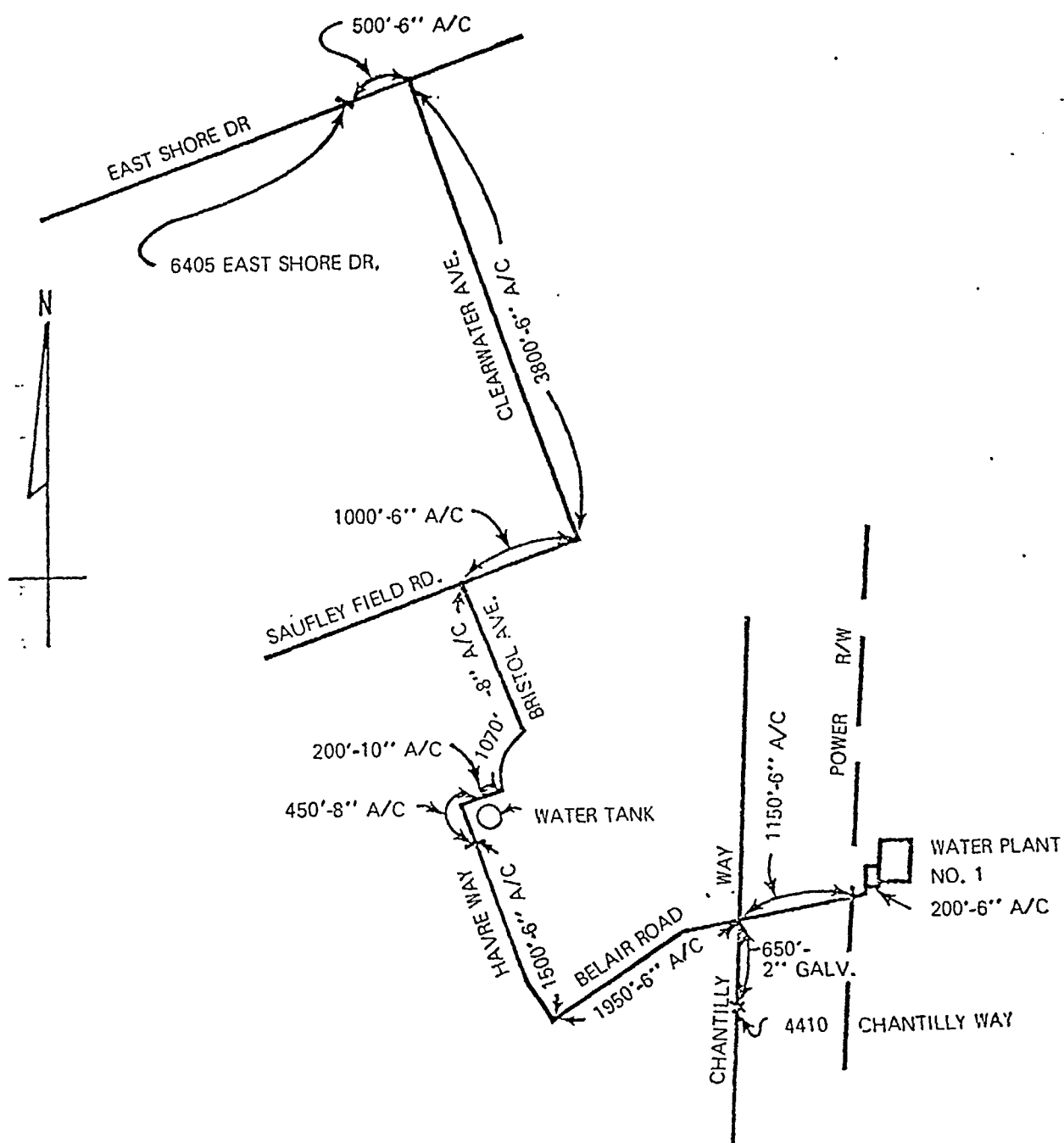


Figure 1. Montclair Subdivision, Pensacola, Florida.

As indicated in Table 2, asbestos fibers were found regularly in the samples taken from the Montclair System. As is usual in analyzing water samples for asbestos the fiber count in Table 2 is reported in fibers per liter of water. However, in these studies pipes of various diameters and lengths were involved and hence, the water in the pipe was of varying volume and not always exposed to the same area of pipe surface. In an effort to make comparisons easier, and to relate fiber count more directly to the surface area to which the water within the pipe was exposed, the fiber count per square foot or square meter of pipe surface has also been calculated in Table 2 by using the following relationships:

$$\text{fibers/ft}^{2*} = \text{fibers/liter} \times 28.316 \text{ liters/ft}^3 \times \frac{\text{volume in ft}^3}{\text{surface area in ft}^2}$$

This formula can be reduced algebraically to a more simplified form; namely,

$$\text{fibers/ft}^2 = \text{fibers/liter} \times 28.316 \text{ liters/ft}^3 \times d/4$$

where d = diameter of the pipe in feet

and can be converted to fibers/m² by multiplying by 10.74.

King County, Washington

The King County, Washington, Water District No. 58 had an average water use of 1.6 mgd (5,960 m³/d) in 1975. The population served is estimated at 20,000. The source of the water is the Seattle Water Department through their Transmission Line from Young's Lake (Cedar River). The water supplied to the distribution system is of a corrosive nature. Table 1 shows a pH of 7.2, alkalinity of 14 mg/l, and calcium hardness of 14.5 mg/l that results in an aggressiveness index of 9.51. The only treatment of the water is chlorination for disinfection and fluoridation for prevention of dental caries.

*Assumed to be constant throughout the length of the pipe.

Table 2. Asbestos Fiber Counts for Pensacola, Fla.

Montclair Subdivision

Date of Sample	Sample Stations							
	Montclair Well pH 5.2 A.I. ≥ 5.34		4410 Chantilly Way pH 7.0 A.I. ≥ 7.04		6405 E. Shore Dr. pH 9.0 A.I. ≥ 9.04			
	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile		
	f/l $\times 10^6$	f/l $\times 10^6$	f/l $\times 10^6$	f/l $\times 10^6$	f/l $\times 10^6$	f/l $\times 10^6$	f/l $\times 10^6$	fibers/unit of exposed pipe surface* $\times 10^6$
1-17-75	BDL	0.22	0.07	1.70	0.18	1.16	4.4	47.4
2-21-75	BDL	NSS	NSS	32.7	BDL	0.44	1.7	18.3
3-26-75	BDL	NSS	NSS	1.74	BDL	0.29	1.1	11.8
5-9-75	BDL	NSS	BDL	1.23	BDL	0.68	2.6	28.0
7-7-75	BDL	NSS	NSS	0.69	BDL	0.14	0.5	5.4
9-5-75	BDL	NSS	NSS	0.17	BDL	BDL	-	-
12-4-75	BDL	BDL	BDL	0.42	BDL	BDL	-	-

* The total number of fibers in the volume of water in the pipe divided by the total surface area of the pipe.

BDL (Below Detection Limits)

NSS (Not statistically significant)

Figure 2 is a sketch of the water mains most probably involved in transport of the water to the sampling points. The probable principle path of flow to both distribution system sample points, based on head loss through the pipes, is direct from Source No. 1. Of course, numerous flow path variations occur. The path of flow to the 14810 Petrovitsky Road sample point traverses 3,435 ft. (1050 m) of 10 in. (25.4 cm) A/C and 2,655 ft. (810 m) of 8 in. (20.3 cm) A/C pipe for a total A/C pipe length of 6,090 ft. (1860 m). The flow path to the Meridian Jr. High School sample point traverses 8,520 ft. (2600 m) of 12 in. (30.5 cm) A/C, 5,930 ft. (1810 m) of 10 in. (25.4 cm) A/C, 10,100 ft. (3080 m) of 8 in. (20.3 cm) A/C, and 6,570 ft. (2000 m) of 6 in. (15.2 cm) A/C pipe for an overall distance of 32,110 ft. (9790 m) of A/C pipe. Most of the pipe is Johns-Manville Class 150 Type II but there is 600 ft. (180 m) of Belgium manufactured pipe. This pipe was all installed from 1965 to 1967.

Table 3 shows the asbestos fiber counts from samples taken in the King County Water District No. 58. No chrysotile fibers were found in the source water samples, although a few actinolite-tremolite fibers (1 or 2 fibers per 20 or 30 grid holes counted), presumably from native rock sources, were found. Three samples from the Petrovitsky Road sample point contained chrysotile fibers. All but one of the Meridian Jr. High samples contained chrysotile fibers. The water has a fairly short retention time from Source No. 1 to the Petrovitsky Road sample point. This is partially because of the relatively short distance of 6,090 ft. (1860 m) of A/C pipe in which the water travels but mainly because of the high flow as this line serves as a feeder line to

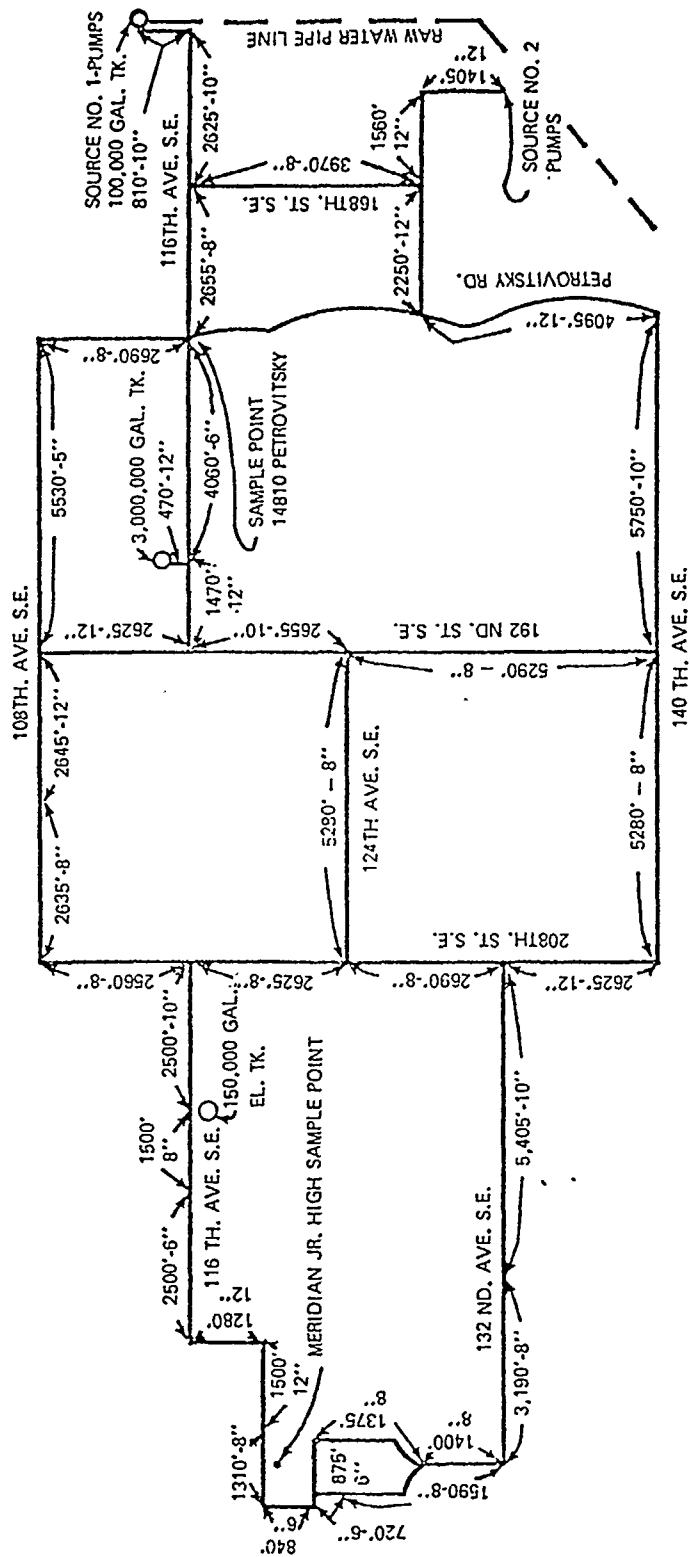


Figure 2. King County Washington Water District No. 58.

Table 3. Asbestos Fiber Counts for
King County, Washington, Water District No. 58

Date of Sample	Sample Stations					
	Control Works pH 7.2, Ca 5.8 mg/l Alkalinity 14 mg/l A.I. = 9.51		14810 Petrovitsky Rd. pH 7.6, Ca 8.0 mg/l Alkalinity 18.8 mg/l A.I. = 10.17		Meridian Jr. High pH 9.0, Ca 11.0 mg/l Alkalinity 24.6 mg/l A.I. = 11.78	
	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile
	f/l X 10 ⁶	f/l X 10 ⁶	f/l X 10 ⁶	f/l X 10 ⁶ fibers/unit of exposed pipe 6 surface* X 10 ⁶ ft ² m ²	f/l X 10 ⁶	f/l X 10 ⁶ fibers/unit of exposed pipe 6 surface* X 10 ⁶ ft ² m ²
2-26-75	NSS	NSS	NSS	0.18 1.0 10.8	NSS	0.44 2.5 26.9
4-29-75	BDL	NSS	NSS	NSS - -	NSS	0.72 4.1 44.1
5-27-75	NSS	NSS	NSS	NSS - -	NSS	1.59 9.0 96.9
7-29-75	NSS	NSS	NSS	0.50 2.7 29.1	NSS	0.72 4.1 44.1
8-26-75	NSS	NSS	BDL	BDL - -	BDL	0.86 4.9 52.7
9-30-75	BDL	NSS	BDL	NSS - -	BDL	NSS - -
11-18-75	NSS	NSS	NSS	0.23 1.2 12.9	0.14	0.26 1.5 16.1

* The total number of fibers in the volume of the pipe divided by the total surface area of the pipe.

the distribution system and a 3 mg (11,360 m³) storage tank. The water to the Meridian Jr. High sample point has a much longer retention time because it flows through 32,100 ft. (9,780 m) of A/C pipe and also because it serves only the needs of customers in this section of the system. The effect of these detention times is evident in both asbestos fiber counts and pH values. The fiber counts are higher after the longer detention time. The pH change from Source No. 1 to Petrovitsky Road is about 0.5 units and that to Meridian Jr. High is about 2 units. Although the AI is higher at the Meridian Jr. High sample point, the fiber release per unit area of exposed pipe surface is higher because of the longer retention time. This increase in pH indicates that the A/C pipe is serving as the source for pH adjustment and stabilization of the water in the system. As the pipe is sacrificed to provide this pH adjustment and stabilization, asbestos fibers probably are freed from their cement bond through dissolution of calcium.

The chrysotile fiber lengths ranged from 0.2 to 10 μ m in length and from 0.02 to 0.06 μ m in diameter. Approximately 95 percent were under 5.0 μ m. The median length was 1.0 μ m. Although most samples contained too few amphibole fibers to count (less than one per 20 or 30 grid holes counted), if all of the amphiboles found (13) in all of the pipe samples (14) are taken as a group, the crocidolite fiber length ranged from 0.7 to 15.0 μ m with a median length of 2.0 μ m and with a diameter of 0.1 to 0.2 μ m.

Grant Hill, Connecticut

The Grant Hill Water System in Bloomfield, Connecticut is a private system which is owned and operated by the users. The daily water use is about 12,000 gallons per day ($45.4 \text{ m}^3/\text{d}$) serving 41 customers (about 160 people). The water, from a well source, is given no treatment. The well water quality is pH 7.5, calcium hardness of 82 mg/l and alkalinity of 88 mg/l that results in an aggressive index of 11.56.

Figure 3 is a sketch of the water system. The 34 Grant Hill Road sampling station has 550 ft. (170 m) of 4 in. (10.2 cm) A/C pipe and 500 ft. (150 m) of 2 1/2 in. (6.4 cm) galvanized pipe connecting it to the well. Fourteen services are tapped off of this line. The A/C pipe is Johns-Manville class 150, type II installed in 1949.

The 56 Burr Road sampling station can be supplied by two routes that form a loop. One consists of 950 ft. (290 m) of 4 in. (10.2 cm) A/C pipe and 400 ft. (120 m) of 2 1/2 inch (6.4 cm) galvanized pipe. The other consists of 700 ft. (220 m) of 4 in. (10.2 cm) A/C pipe and 1,000 ft. (305 m) of 2 1/2 in. (6.4 cm) galvanized pipe. The A/C pipe manufacturer is the same as described for the other sampling station. Twenty-seven services are tapped off of this loop. The general absence of asbestos fibers (Table 4) in the samples taken from this system is because of the non-aggressive water as indicated by the Index.

North Ridge, Ohio

The North Ridge Waterworks is a part of the Clark County, Ohio Utilities District. The daily water use averages about 0.5 mgd ($1890 \text{ m}^3/\text{d}$) serving 2000 customers (about 7,300 persons). The water is a shallow well source. There are 4 wells about 30 ft. (9.1 m) deep.

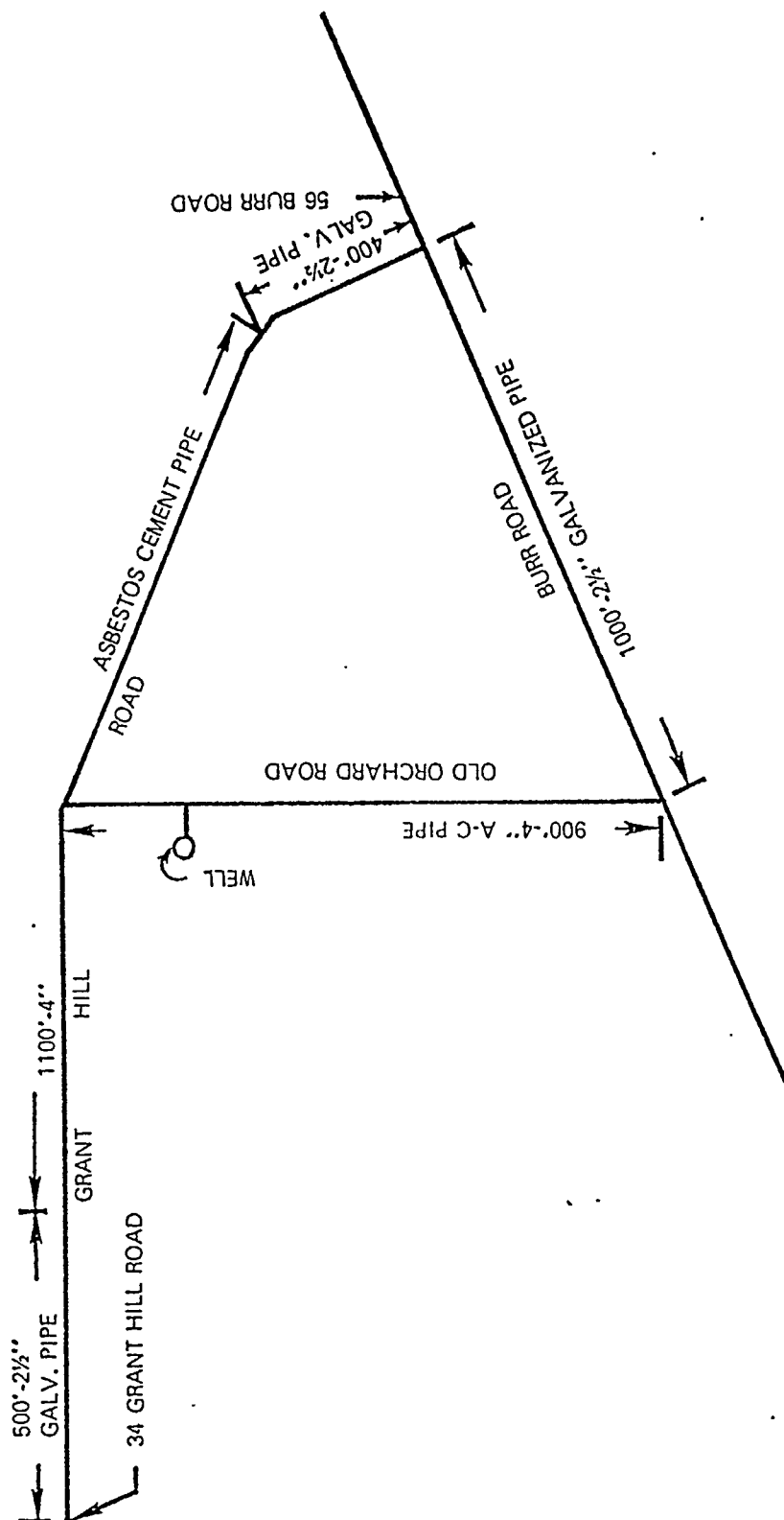


Figure 3. Grant Hill Associates, Inc. Bloomfield, Conn.

Table 4. Asbestos Fiber Counts* for Grant Hill System,
Bloomfield, Conn.
A.I. = 11.56

Date of Sample	Sample Stations					
	Well Pump		34 Grant Hill Road		56 Burr Road	
	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile
2/6/75	BDL	0.13	BDL	BDL	BDL	NSS
3/4/75	BDL	BDL	BDL	0.17	BDL	NSS
4/30/75	BDL	BDL	BDL	NSS	BDL	NSS
7/31/75	BDL	BDL	BDL	NSS	BDL	0.17
10/7/75	BDL	BDL	BDL	BDL	BDL	NSS
12/9/75	BDL	BDL	BDL	BDL	BDL	BDL

*All data in Fibers per liter X 10⁶

The raw well water hardness is 580 mg/l. This causes some instances of calcium carbonate deposition in water heaters and fixtures but causes no difficulties in operating the treatment facilities and the distribution system. The raw water contains iron in excess of 1.5 mg/l and at times enough manganese to be troublesome. The treatment given the water is aeration, filtration for iron and manganese removal, and chlorination for disinfection. The iron is reduced to about 0.3 mg/l in the finished water. The finished water quality is pH 7.8, calcium hardness of 250 mg/l, and alkalinity of 220 mg/l, which results in an aggressive index of 12.54. The water plant and sample point locations are indicated on the attached map (Figure 4).

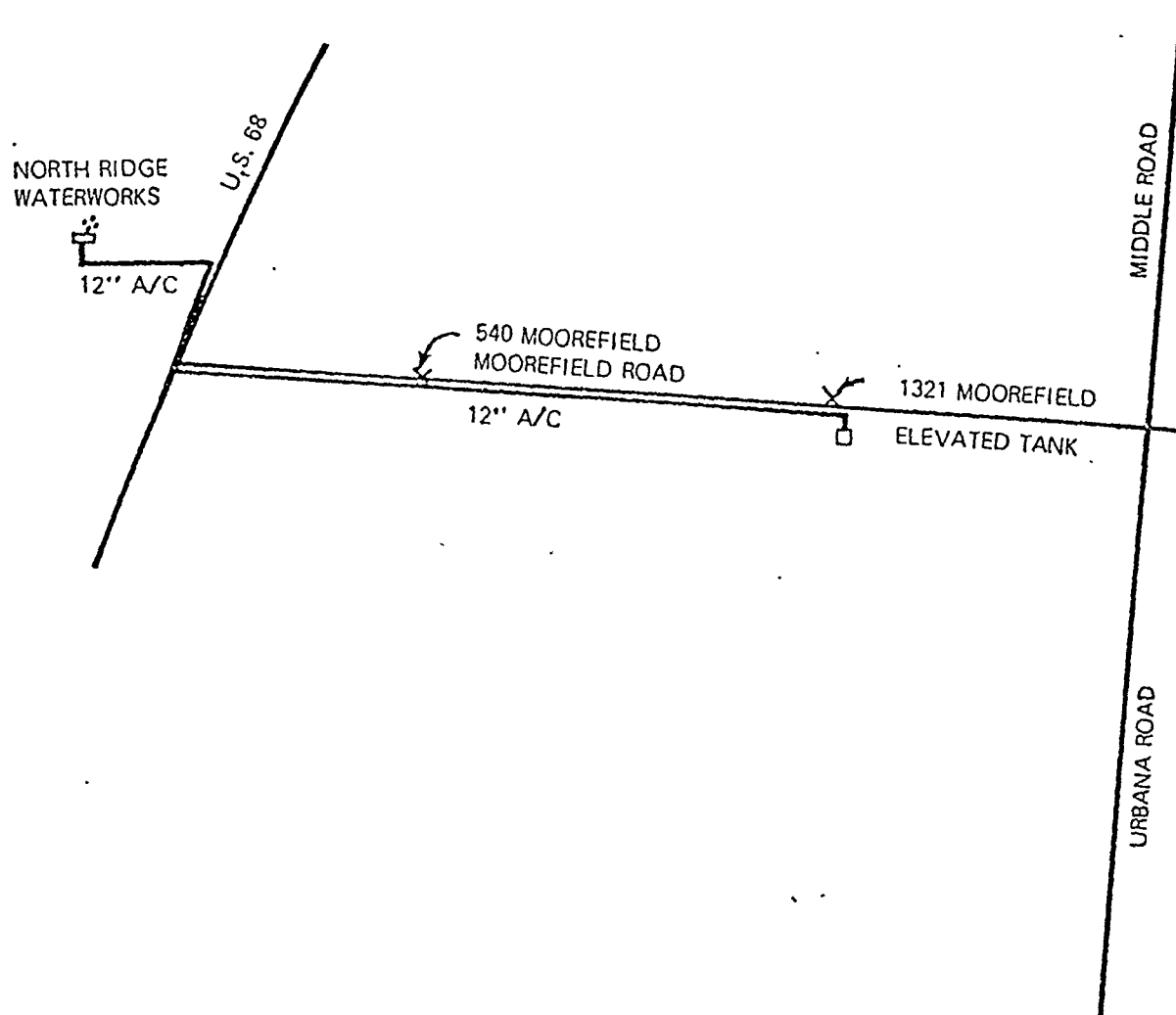


Figure 4. Northridge, Clark County, Ohio

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The 12 in. (30.5 cm) A/C main from which the samples are taken is principally a transmission line from the treatment plant to elevated storage. Only a few residential taps come off this main and no service laterals. The A/C pipe is Johns-Manville class 150, Type II installed in 1956. The water passes through 5,400 ft. (1650 m) of 12 in. (30.5 cm) A/C pipe to reach the 540 Moorefield Road sample point and 9,800 ft. (2,990 m) of 12 in. (30.5 cm) A/C pipe to reach the 1321 Moorefield Road sample point.

The absence of asbestos fibers (Table 5) in the samples from this system is because of the non-aggressive water that has deposition rather than corrosive tendencies.

Table 5. Asbestos Fiber Counts from Northridge
Water System, Clark County, Ohio
A.I. = 12.54

Date of Sample	Sample Stations					
	Northridge Water Treatment Plant		540 Moorefield Road		1320 Moorefield Road	
	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile
6/4/75	BDL	NSS	BDL	BDL	BDL	BDL
7/8/75	BDL	BDL	BDL	BDL	BDL	BDL
9/26/75	BDL	BDL	BDL	BDL	BDL	BDL
11/24/75	BDL	BDL	BDL	BDL	BDL	BDL
4/27/76	BDL	BDL	NSS	NSS	BDL	NSS

Lockhart, Texas

The Lockhart, Texas water system has an average water use range of 1 - 1.5 mgd (3,790 - 5,680 m³/d) and serves a population of about 7,200. The water source is 4 wells ranging from 302 to 365 ft. (92 to 111 m) in depth. Some of the pertinent water quality parameters for these wells are in the following Table 6:

Table 6. Water Quality of Lockhart Wells

Well Number	pH	Mn mg/l	Fe mg/l	Total Alk. mg/l as CaCO ₃	Hardness mg/l as CaCO ₃
3	7.7	0.19	1.80	191	304 (Total)
4	7.5	0.15	1.24	171	216 (Total)
5	7.3	0.20	1.06	188	263 (Total)
6	7.9	<0.05	<0.02	320	46 (Total)
Finished Water					
	9.4	-	-	50	44 (Calcium) 12.74 (A.I.)

As can be noted, well No. 6 has different characteristics than the other three wells. It is located 6 miles (9.7 km) east of the city while the other three are about 10 miles (16.1 km) east of the city. The better mineral quality of well No. 6 is offset by a hydrogen sulfide problem.

The water from the 4 wells is pumped to a treatment facility at the outskirts of the city. The treatment consists of aeration, lime softening, filtration and disinfection. The tray type aeration was originally used for hydrogen sulfide removal but now serves in the iron and manganese removal process as well. Lime softening with ferric sulfate addition to aid coagulation does not perform satisfactorily. Sedimentation is

incomplete and deposition of calcium carbonate occurs in the filters and the distribution system. Treatment plant improvements are planned to better this situation. Disinfection is accomplished by chlorination with the addition of ammonia to obtain a combined chlorine residual. The treated water with a pH 9.4, calcium hardness of 44 mg/l, and alkalinity of 50 mg/l results in an aggressive index of 12.74.

A map of the area is shown in Figure 5. The Lockhart State Park sampling station is at end of a three mile (4.8 km) combination of 6 and 8 inch (15.2 and 20.3 cm) diameter A/C pipe. The pipe is Johns-Manville class 150, Type II installed in 1954-55. Some services are tapped off this line but mainly it serves the park where it dead ends. Not much flow occurs in this line most of the time.

The 619 Wassa Street sampling station has an assortment of cast iron pipe, 8 and 12 inch (20.3 and 30.5 cm) plus a short section of 10 inch (25.4 cm) composing the 3 1/2 miles (5.6 km) of pipe to the sampling point from the treatment plant. The water passes through no A/C pipe before reaching this sampling station.

The absence of asbestos fibers in the samples taken from this system (Table 7) is because the water is non-aggressive as indicated by the index. Further, the low numbers of fibers from the case-iron line demonstrates that in this situation, at least, the jointing materials are not a source of fibers.

Cleburne, Texas

The Cleburne, Texas Water system has an average water use of 2 mgd (7.570 cu m/d) and serves a population of about 20,000. The water source is a man-made reservoir (Nolands River Reservoir). Pretreatment

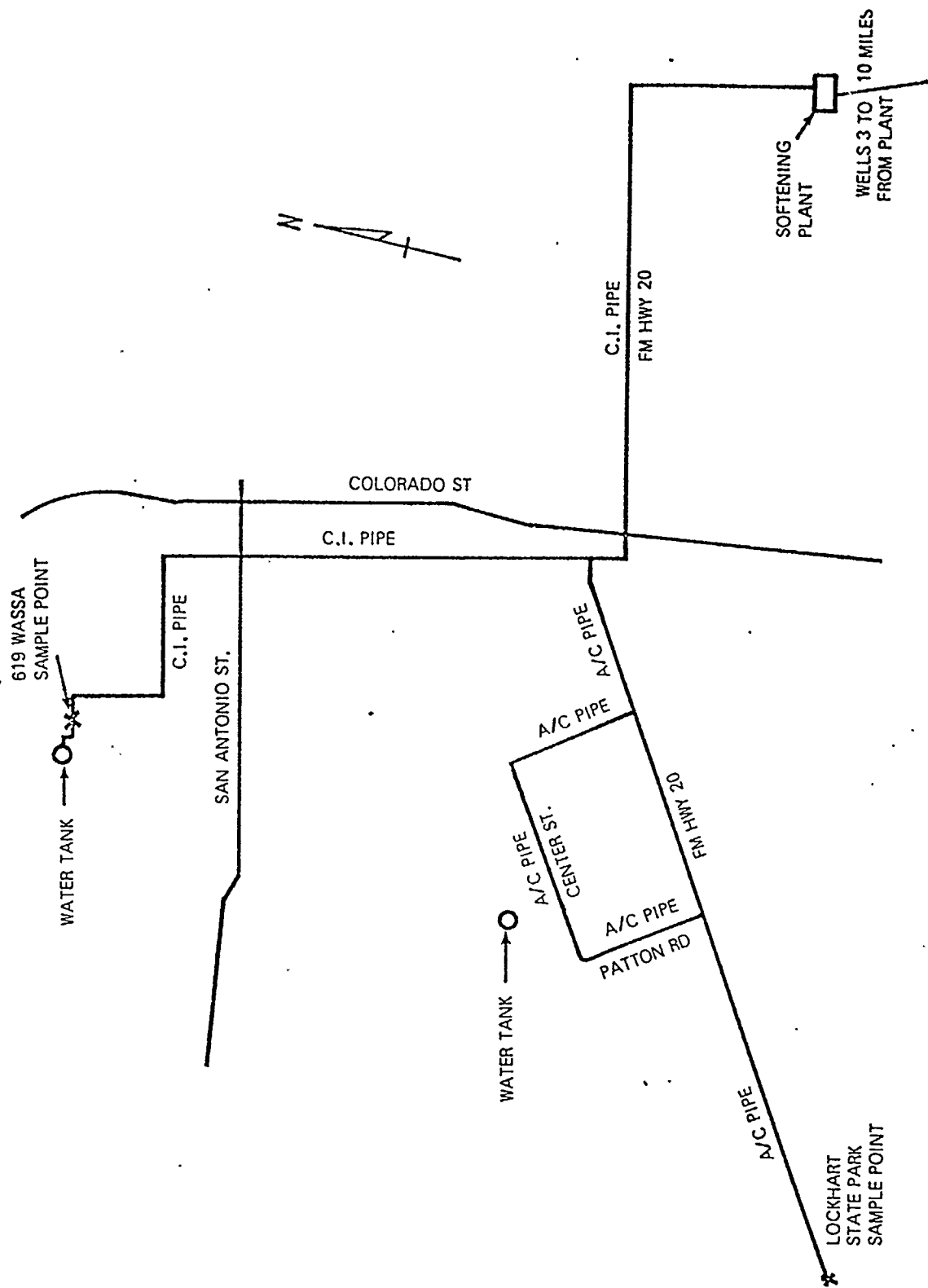


Figure 5. City of Lockhart, Texas.

Table 7. Asbestos Fiber Counts* for
Lockhart, Texas System

Date of Sample	Sample Stations					
	Water Plant A.I. = 12.74		Lockhart State Park 3 mi (4.8 km) A/C		619 Wassa 3 1/2 mi (5.6 km) C.I.	
	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile
6/17/75	BDL	BDL	BDL	NSS	BDL	NSS
9/3/75	BDL	BDL	BDL	0.13	BDL	NSS
11/11/75	BDL	BDL	BDL	BDL	BDL	BDL
2/18/76	BDL	BDL	BDL	BDL	BDL	BDL
4/27/76	BDL	NSS	BDL	NSS	BDL	BDL

*All data in Fibers per liter X 10^6

given the water is aeration of the reservoir for taste and odor control purposes. The aeration provides an additional benefit by reducing the total hardness from about 130 mg/l to 96 mg/l as CaCO_3 . The in-plant treatment consists of lime softening, ferric sulfate coagulant, polymer coagulant aid, sedimentation, filtration and disinfection with chlorine gas. The softened water leaves the plant with a total hardness of 40-48 mg/l as CaCO_3 and a turbidity of less than 0.1 NTU.

The treated water has a pH of 9.7, a calcium hardness of 39 mg/l as CaCO_3 and an alkalinity of 36 mg/l as CaCO_3 resulting in an aggressive index of 12.85, which places it in the non-aggressive water category.

Figure 6 is a map of the system. One of the distribution system sampling points is located after 3 miles (4.8 km) of 12 in. (30.5 cm) and 16 in. (40.6 cm) A/C pipe. The pipe is Johns-Manville, Class 150, Type II installed in 1973. There are a few services tapped off this line but it serves mainly as a transmission line to an industrial user.

The other distribution system sample point is located after 0.4 mile (0.64 km) of 12 in. (30.5 cm) C.I. pipe. Possibly some water at this sample point could be through A/C pipe returning from a storage tank. The general absence of asbestos fibers (Table 8) in the samples taken from this system is because the water is non-aggressive water as indicated by the Index. As with the Lockhart, Texas system, few fibers were present in water flowing through the cast-iron pipe.

Table 8. Asbestos Fiber Counts* from
Cleburne, Texas Water System

Date of Sample	Sample Stations					
	Water Plant A.I. = 12.85		3 mi. (4.8 km) A/C pipe		0.4 mi. (0.64 km) C.I. pipe	
	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphobile	Chrysotile
6/26/75	BDL	0.21	NSS	0.27	BDL	NSS
9/4/75	BDL	BDL	NSS	NSS	BDL	BDL
11/18/75	BDL	BDL	BDL	BDL	BDL	BDL
2/18/76	NSS	BDL	BDL	NSS	BDL	BDL
4/26/76	BDL	BDL	BDL	NSS	BDL	BDL

*All data in Fibers per liter X 10⁶

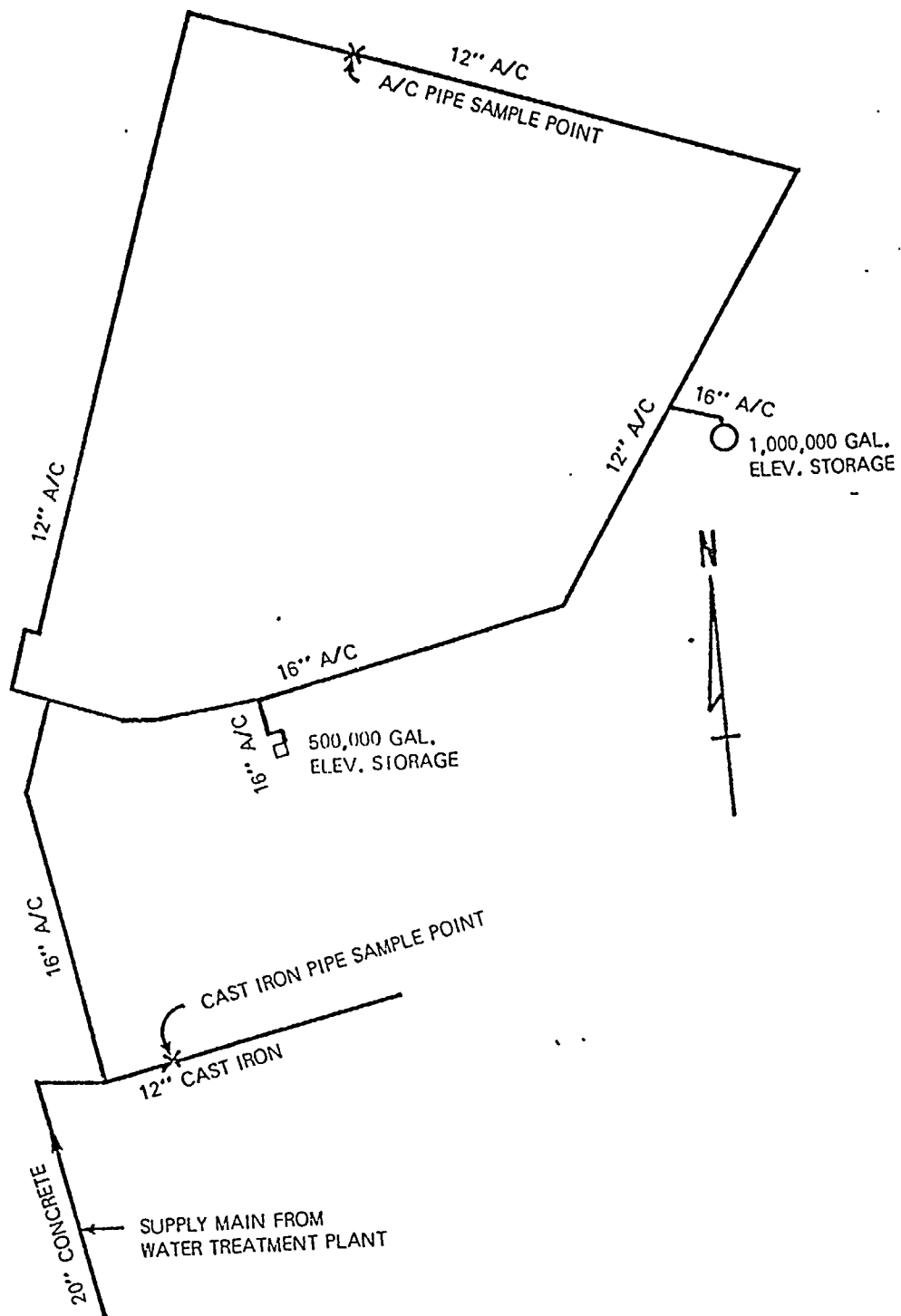


Figure 6. Cleburne, Texas.

Other Systems

As previously mentioned, a third phase of this study is to conduct a field investigation of various control measures that might be useful in preventing the release of fibers from A/C pipe. In an attempt to locate suitable systems for study, data on some additional systems (Table 9) have been obtained. These not only fortify previous findings, but also indicate some of the complexities that might be encountered (see the data for Amherst). At first glance this system seems to be an exception to the expected pattern; namely, although the water is very aggressive very few fibers were found at most points in the system (471 N.E. St. and Cherry Hill).

As indicated in Table 9, however, the system contains an intermix of cast iron and asbestos-cement pipe, and the raw water is also naturally high in iron. As was observed in the first attempted A/C pipe loop study, iron from the system is believed to be plating out on the A/C pipe and protecting it from corrosion. The Water Supply Research Division is now (1977) in the process of arranging for excavation of some of the pipe to verify this. Furthermore, at the end of the line (Montague Rd.) where there is very little water flow and where, presumably no plating has occurred, the fiber count is very high. Also note that the reason for the lower pH in the system at 471 N.E. St. sampling point is because it is at this point that the system is chlorinated.

The chrysotile fiber lengths in these three systems ranged from 0.3 to 72 μm in length. Approximately 75%, however, were under 5.0 μm in length and the median length was 3.0 μm . The amphibole (crocidolite) fiber lengths varied from 2.0 to 3.9 μm in length, with a median length of 3.0 μm and with diameters of 0.1 to 0.3 μm .

Table 9. Asbestos Fiber Counts of
Selected Aggressive Water Systems

Sampling Point	Date	pH	Alkalinity mg/l CaCO_3	Calcium Hardness mg/l CaCO_3	A.I.	Fibers/liter Amphibole Chrysotile	
Greenwood, South Carolina							
Lake Plant	3/2/76	8.3	20	7.49	10.48	BDL	BDL
	4/21/76					BDL	NSS
140 Effie Dr. after 13,000 ft. (3,970 m) of A/C pipe	3/2/76	9.25	24	17.23	11.86	BDL	0.22
	4/21/76					BDL	0.88
Corner Water Co., Clarion County, Pa.							
Treatment Plant	9/1/76	7.1	89	0.49	8.74	BDL	BDL
Booster Sta. after 1 mi. (1.6 km) of A/C pipe	9/1/76	7.2	92	1.95	9.45	0.7	19.0
Amherst, Mass.							
Atkins Reservoir	6/27/75	5.6	2	5.74	6.66	BDL	NSS
	9/12/75					BDL	NSS
	6/30/76					BDL	BDL
471 N.E. St. after 7,000 ft. (2,134 m) of C.I. followed by 12,500 ft. (3,810 m) of A/C pipe	6/27/75	4.5	1	5.99	5.28	BDL	0.12
	9/12/75					BDL	0.20
	6/30/76					BDL	0.12
Cherry Hill 11,400 ft. (3,475 m) of C.I. plus 5900 ft. (1,798 m) A/C (intermixed)	7/28/76	6.0	4.0	7.5	7.46	NSS	NSS
Montague Rd. additional 3,450 ft. (1,052 m) of A/C	7/28/76	9.0	18	22.5	11.61	9.6	190.0

SUMMARY AND CONCLUSION

A field evaluation was made of six water utilities having various water qualities and using asbestos-cement pipe. To determine the possible release of asbestos fibers from the pipe walls, samples of water as it entered the pipe and after flowing through the pipe were examined under an electron microscope. The combinations of pH, alkalinity, and calcium hardness in these six utilities produced Aggressive Indices (A.I.), as defined by ANWA Standard (C400-75¹), from 5.34 to 12.85 with three being below the recommended 12.0 and three above. Of the three above an A.I. of 12.0, one had a moderate pH (7.8) but high alkalinity and calcium hardness, while the other two had higher pH's, 9.4 and 9.7 but lower values for the other two factors in the Index. A reasonable spread of water quality factors was, therefore, covered.

Consistently quantifiable fiber counts were found only in the two systems with an Aggressive Index below 10. The distributed water in the system with an A.I. in the finished water slightly under the recommended 12.0, 11.54 did not contain many asbestos fibers. Further, all of the three systems with an A.I. over 12 produced similar low fiber counts regardless of the combinations of pH, alkalinity, and calcium hardness. Finally, in two of the systems studied, a cast-iron pipe was sampled as a companion to the samples collected from the asbestos-cement pipe. Examination of these samples revealed low fiber counts, indicating that jointing material was not contributing asbestos-fibers in these instances.

The pH and calcium content of an aggressive water increases as does the A.I. as the water passes through the A/C pipe (see Table 3) as a result of the water dissolving the cement out of the pipe. The dissolution of the cement causes deterioration of the pipe and the release of asbestos fibers. As the water is exposed to more and more of the pipe, the increase in pH and calcium cause the water to become less aggressive. Thus, the major pipe deterioration usually will occur during the period of time just after the water enters the distribution system. The travel time or time of exposure needed to stabilize the water at the expense of the A/C pipe can be achieved through either long or short lengths of pipe depending on the water velocity. Thus, it is not always the case that the farther from the water source, the less is the attack on the pipe. Specimens of A/C pipe cut out of both the King County, Washington, and the Montclair, Florida distribution systems showed the above described patterns of attack on the pipe.

FUTURE WORK

Because much is unknown concerning the health effects of inhaled asbestos fibers, the significance of fiber release found in this study cannot be assessed at this time. The study does show that the A/C pipe is deteriorated when waters of aggressive chemical quality are transported. The Health Effects Research Laboratory, U.S. Environmental Protection Agency is involved in both cell toxicology studies and epidemiology investigations of exposed populations to provide some of the needed health effects information related to fiber ingestion. The U.S. Food and Drug Administration in conjunction with the US EPA and the National

Institute of Environmental Health has started a large scale, long term animal feeding study that should provide important information. Further, the Water Supply Research Division of the U.S. Environmental Protection Agency has begun a research program designed to determine what corrective measures a water utility can take if the reduction in fiber release is desirable. Finally, further insight into the relationship of water quality and fiber release is being studied in controlled experiments with a pipe-loop of commercial asbestos-cement pipe.

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