United States Environmental Protection Agency
Research and Development
Risk Reduction Engineering Laboratory Cincinnati, OH 45268
EPA/600/S2-90/056 Feb. 1991

EPA **Project Summary**

Impact of Lead and Other Metallic Solders on Water Quality

Norman E. Murrell

A study of the relationship between water quality at the consumer's taps and the corrosion of lead solder was conducted under actual field conditions in 90 homes supplied by public water in the South Huntington Water District (New York) and at 14 houses supplied by private wells in Suffolk County on Long Island (New York). The South Huntington Water District water supply is composed of wells that feed water to a series of storage tanks from which water is distributed to individual homes. The 90 homes were selected to provide 10 sites of 9 house construction age groups—from new to those more than 20 years old.

The study was done in three phases at three different pH ranges (5.0-6.8, 7.0 to 7.4, and 8.0 and greater). The phase I study was performed without any pH adjustments on the water sources. The pH range of the water from the South Huntington District was 5.1 to 6.4, whereas the water from the private wells in Suffolk County had a pH range of 5.6 to 6.8. Phase II study consisted of raising the pH to the 7.0 to 7.4 range by the addition of caustic soda and maintaining the pH for 30 days prior to the sampling. Only the South Huntington Water Supply district participated in this phase; the private wells in Suffolk County were not treated. Similarly, the pH was increased to 8.0 and greater for the Phase III study. It was difficult to hold the pH at 8.0 due to the unbuffered water source. Water samples were collected from an inside faucet within each home after an overnight period of nonuse. Eight 125-mL samples were collected at specific time intervals in order to evaluate the effect of time on the leaching rate of lead. All eight samples were analyzed for lead and the first draw sample was analyzed for cadmium and copper. Water that was collected between the 125-mL samples was analyzed for pH, alkalinity, hardness chlorides, and total dissolved solids. The Langelier Saturation Index was calculated from these parameters.

In the second phase of the investigation, a more controlled, four-pipe loop study was conducted with the same corrosive Long Island water. Each pipe loop consisted of approximately 60 ft of copper pipe with 22 solder joints, each loop having a different type of solder: (1) tin/lead, (2) tin/antimony, (3) silver/copper, and (4) tin/copper. The four loop solder test results indicate that tin/antimony, silver/copper, and tin/copper can be used with only minor metal leaching.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In October 1982, a western Suffolk County (New York) Water District consumer in Smithstown, NY, complained of lead poisoning. At that time, water as a source of lead was discounted since the Water

District had a 15-yr record of lead-free distribution samples—a record obtained by using the standard procedure of running the water 3 to 5 min before sampling. Two separate water samples obtained by the complainant without flushing the system showed lead levels of 1900 and 1600 µg/L. An additional water sample, collected after running the water for 3 to 5 min, showed a lead level of 27 µg/L. Another series of water samples was collected after a 4-hr nonuse period and the results of the lead analysis on these samples are shown in Figure 1. By this time, lead solder in the copper plumbing was suspected as the source of the lead. Tests of nearby homes indicated that lead was also present in these plumbing systems. As a result of this information, a lead solder ban was approved and made effective immediately in the town of Smithtown on December 26, 1982.

Additional testing for lead (done for the Nassau and Suffolk County Health Departments and the Town of Hempstead) produced data showing high lead concentrations in first draw samples. These data along with suggestions for further research focusing on the effect of age of the plumbing, and the pH and hardness of the water supply on leaching lead from lead solder resulted in this cooperative study of the U.S. Environmental Protection Agency and the South Huntington Water District.

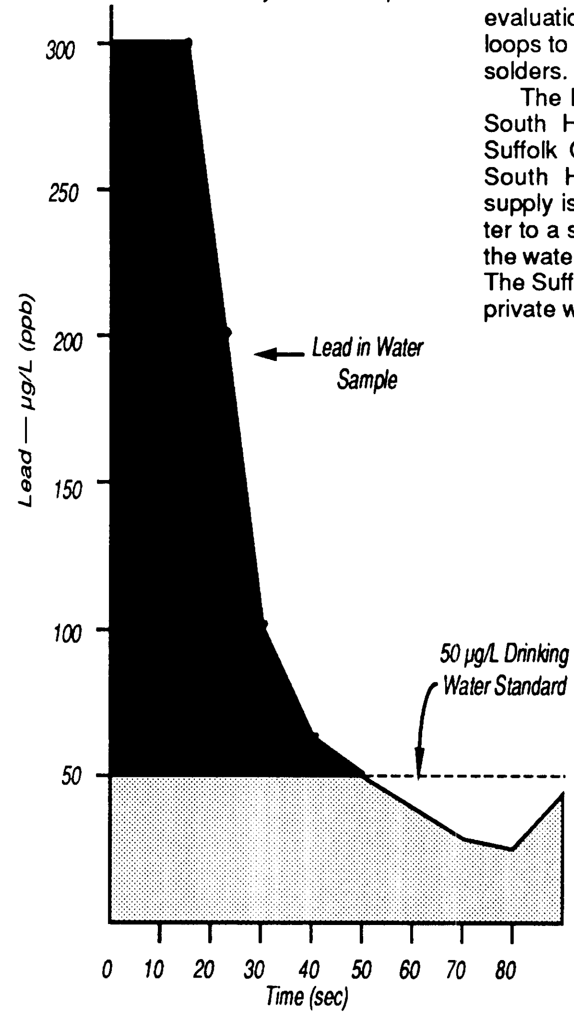

Figure 1. *Time series lead sample in upstairs bedroom bathroom Smithtown residence.*

Procedures

To develop an understanding of the effects of water chemistry, plumbing system age, and solder type on lead leaching, a work plan was developed to observe these effects in individual homes that were chosen in various age categories. The solder in the plumbing system of each house was analyzed for the presence of lead. Since copper plumbing systems are almost exclusively connected by lead solder, the field sampling was supplemented with an evaluation of specially constructed pipe loops to evaluate leaching from alternative solders.

The homes tested were located in the South Huntington Water District and in Suffolk County on Long Island, NY. The South Huntington Water District water supply is composed of wells that feed water to a series of storage tanks from which the water is distributed to individual homes. The Suffolk County homes were served by private wells. Household water testing was conducted in three phases at three different pH values to test the effect of pH changes on lead leaching. In Phase I, 63 homes in the South Huntington Water District and 14 homes in Suffolk County were tested at the pH range of 5.0 to 6.8. The water in Suffolk County had a pH range of 5.6 to 6.8, whereas the pH in the South Huntington was pH 6.4 and less (see Table 8). Because the pH of the private wells in Suffolk County could not be modified, 27 more homes in the South Huntington Water District were added to the 63 homes for the Phase II study. The pH was raised to between 7.0 and 7.4 for the Phase II study. In Phase III, the pH was raised to greater than 8.0. Four households declined to participate in the Phase III study so that the total sampled was reduced to 86. Homes were selected so that approximately an equal number of homes fell into the following nine age categories: 0-1; 1-2; 2-3; 3-4; 4-5; 6-7; 9-10; 14-17; >20 yr of age. These homes were also selected to provide a reasonable geographic distribution of the customers in South Huntington.

To evaluate the lead leaching with respect to length of sampling time at each home, eight 125-mL samples were collected from a continuously flowing faucet after first removing the faucet strainer. The sampling sequence is shown in Table 1.

Table I. *Sampling Sequence*

Sampling Sequence	*Time After First Draw (Sec)*
1	*0 (first draw)*
2	*10*
3	*20*
4	*30*
5	*45*
6	*60*
7	*90*
8	*120*

Water coming out of the faucets between each 125-mL sample was caught in a container to obtain a volume figure and for some of the chemical analyses. Figure 2 shows a schematic of the time series of samples that were utilized in the study. The flow rate for sampling was 1800 mL/min. The length of time for each sample and period of time between samples is shown in this figure. All of the samples were analyzed for lead with the use of the atomic absorption graphite furnace technique. Cadmium and copper were determined in the first draw samples; the water caught between samples (2600 mL) was used to determine other water quality parameters such as pH, Langelier Saturation

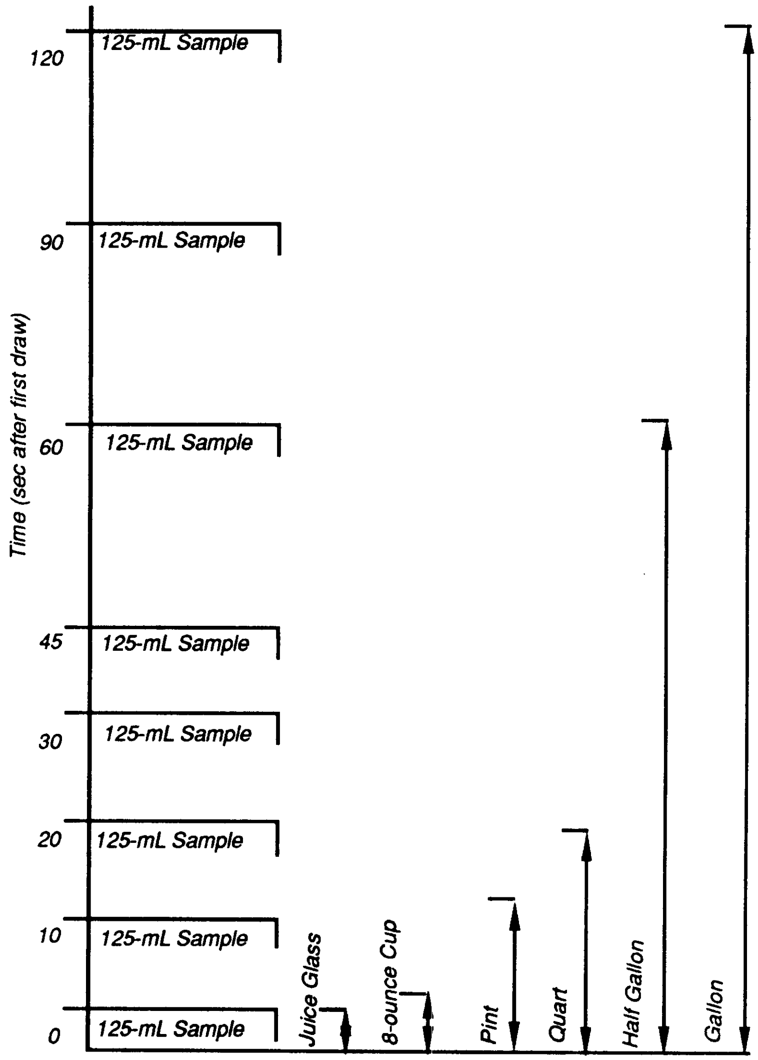

Figure 2. Time series schematic at 1800 mL/min rate of sampling.

Index, and halogen + sulfate over alkalinity ratio, known as the Larson Index.

Four copper pipe loops were constructed (Figure 3) to evaluate leaching of contaminants from the four solders: tin/lead, tin/antimony, silver/copper, and tin/copper. Eleven elbow joints provided a total of 22 solder connections for each loop. Piping material from the source to the test loop apparatus was plastic. After construction, each loop was flushed with approximately 100 gal of raw water (approximately 5.1 pH). This volume of water approximates the maximum amount of water that a plumber uses to flush a new installation.

To stabilize leaching conditions in the piping, water was left in each loop for 4 weeks. Water was added at the top of the loop, held for a specific period of time, and sampled from the bottom of the loop. Samples were taken after 4, 8, 12, and 24 hr at a pH of 5.1. Six 125-mL were obtained from each loop as near to a joint as possible. This was done by calculating the amount of water between joints and measuring the effluent. A similar approach, including the 4-wk stabilization period, was used for waters of approximately pH 6.5, 7.5, and 8.5. Each sample obtained from the tin/lead solder loop was analyzed for lead, while only one sample from each of the three loops was analyzed for lead. One sample from each loop at each pH was analyzed for cadmium. In addition, one test sample in each loop was analyzed for copper, hardness, pH, alkalinity, total dissolved solids, sulfate, chloride, and arsenic. The metals were determined by standard atomic adsorption procedures and the other components were determined by standard EPA procedures.

Results and Discussion

Ninety-six test homes in the Huntington Water District had the solder of their household plumbing system analyzed for the lead content. With the exception of one household which was plumbed with tin/antimony solder, all of the households used a lead/tin solder with more than 40% lead. No apparent relationship between the lead content of the solder and the age of the test homes was found to exist. The lead content of the lead/tin solder varied from 41.9% to 73.1%. For each of the nine age categories of homes, the average lead content of the solders varied from 54.5% to 61.5%. The Suffolk County Department of Health Services personnel obtained drinking water samples from 14 homes with private wells and solder samples from 11 of these homes. For the 11 homes where solder samples were obtained, the lead in the solder ranged from 42.4% to 64.3%, with an average lead content of 56.7%. Table 2 contains water quality values obtained during the study.

To evaluate the effect of household plumbing age, pH, and flushing time on leaching of lead, the percentage of test homes having water samples exceeding 50 µg lead/L water and 20 µg/L lead was calculated. The effect of these variables on lead leaching is presented in Tables 3, 4, and 5. There are approximately ten homes in each age category.

The information in these tables indicated that increased pH reduces lead leaching and that this effect was more pronounced in older homes. This is seen more clearly by categorizing the households according to 0-1, 1-5, 6-20 and older, as shown in Table 6.

Alkalinity was monitored. The values varied from an average of 8 mg/L as $CaCO_3$ for the untreated (low pH) water to an average of 30 mg/L for the treated (high pH) water. Of the 250 samples tested, only 3 samples had an alkalinity between 40 and 51 mg/L as $CaCO_3$. The other values were less than 40 mg/L. When these data were categorized into 10 mg/L increments, there appeared to be a general trend of reduced leaching of lead with increased alkalinity. This trend appeared only in the 0- to 40-mg/L range. This does not exclude changes in pH.

In many cases, the first draw samples had a high value when compared with the second draw. This indicates that lead was being leached from the faucets. Of the eight test sites in the South Huntington Water District and eight private well sites, only one site had water with a significant amount of cadmium in the first draw sample. The pH was 5.6. A time series experiment

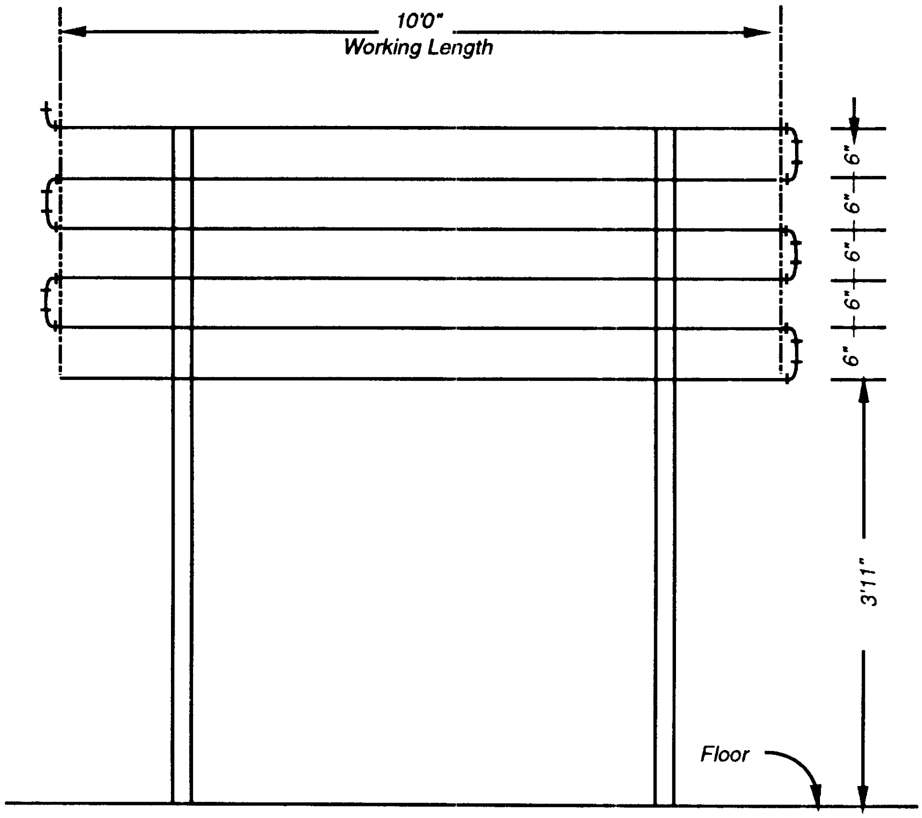

Figure 3. Schematic Drawing of typical loop in four loop study.

was done in which the water had 42.5 µg/L in the first draw sample and 3.0 µg/L for the second draw sample. Subsequent samples reached the detection limit of 1 µg/L by the sixth draw. The results suggest that the cadmium came from the faucet.

Copper leaching studies were also done on the test sites. At a pH of 6.4 and less, 82.4% exceeded the proposed maximum contaminant limit (MCL) of 1.3 mg/L on the first draw sample from the South Huntington Water District. Only one exceeded 1.3 mg/L at a pH above 7.0.

In the pipe loop studies, four loops employing four types of solder were constructed to provide a means of comparing the leaching of tin/lead solder with that of three possible substitute solders. The four control loops were constructed by the same plumber with the same number of joints at the same spacing. The same corrosive Long Island groundwater was used as in the home testing program. Water was left standing in the loops for varying periods of time. The average lead content and major components of the solders used in the pipe loop study are listed in Table 7.

The general loop testing procedure begins with adding water to the top of the loop. The water is allowed to stand for a specific period of time and then removed at the bottom. The pH is checked on the influent water after the time period has elapsed. Based on calculation of the amount of water between joints and measurement of the effluent, six 125-mL samples are obtained from each loop as near to a joint as possible. The average of six samples at each pH for each time period of standing water is reflected in Table 8.

In a 4-wk time standing period, the average lead leached into water was 1900 µg/L at 5.0 pH. Note in Table 8 that in all time periods, except for 1-hr sample, the lead leaching decreased with an increase of pH. Also, in each pH range, nearly all values of lead leaching increased with time.

The highest lead values in the three substitute solder loops were also determined. In the silver/copper solder loop, the highest lead in 23 loop samples was 15 µg/L lead at 5.3 pH in 4 hr. In the tin/copper solder loop, the three highest leads in 25 loop samples were (1) 42 µg/L lead at 7.4 pH in 4 hr; (2) 20.5 µg/L lead at 5.2 pH in 12 hr, and (3) 18.3 µg/L lead at 5.1 pH in 8 hr. In the tin/antimony solder loop, the three highest leads in 27 loop samples were (1) 57.5 µg/L lead at 5.3 pH in 4 hr; (2) 17.3 µg/L lead at 5.1 pH in 4 wk, and (3) 11 µg/L lead at 5.1 pH in 8 hr.

The tin/antimony solder contained 6.0% antimony, 86.2% tin and 0.1% lead. Antimony leaching studies on this solder were performed at four pH values (5.3, 6.3, 7.4, and 8.5) at various time intervals. Six samples were used at each test. Most of the values (88 of 96) were below the detectable limit of 4 µg/L antimony for leaching time of up to 24 hr. Eight of 12 samples had antimony values between 4 and 10 µg/L for a detention time of 4 days at pH values of 7.4 and 8.5. At a pH of 8.5 and a detention time of 4 days, 5 of 6 samples had antimony values in the 8 to 11 µg/L range. In a 4-wk period, only 8 of 24 samples had antimony values less than 4 µg/L. The highest value of 68 µg/L was obtained at a pH of 7.4.

The tin/copper solder used in constructing the tin/copper loop contained 3.0% copper, 94.7% tin, and 0.04% lead. Copper leaching studies were performed on each of the loops at various standing times ranging from 4 to 24 hr. The copper leaching increased only slightly (<50%) with time, but increased greatly (factor of 10 to 40) when pH was reduced to less than 7.0. Six water samples were taken for copper analysis in each tin/copper solder loop test. Only one sample was tested for copper in each of the other three loop tests. In general, the copper leaching was slightly greater (<50%) in the silver/copper solder loop than in the tin/copper solder loop, which is probably explained by the higher percentage of copper in the silver solder (88.0%). In general, copper leaching in the tin/lead solder loop and the tin/antimony solder loop was only slightly (<50%) less than that in the tin/copper solder loop. It appeared that little or no copper leached from the copper solder, and nearly all the copper leaching was from the copper piping itself.

The silver/copper solder contained 6.9% silver and 88.0% copper. Twenty-three water samples were collected on the silver/copper solder loop, included four ranges of pH (5.3, 6.3, 7.4 and 8.5) and nine time intervals of standing water (4 hr through 4 wk). In 138 samples, only two showed silver above the detectable limit of 2 µg/L. Two of six samples at pH 8.5 in the 12 hr standing water test indicated 104 µg/L and 3.1 µg/L of silver.

Conclusions and Recommendations

Several field and laboratory studies have shown the effect of pH on lead solubility and corrosion rates from lead pipes and from lead solders. This project was

Table 2. Water Quality Parameters and Values of Tested Waters

Parameter	*Mean*	*Average*	*Range*
Private Wells (pH 5.6 - 6.8)			
pH (units)	6.2	6.2	5.6-6.8
Alkalinity (mg/L as $CaCO_3$)	18	16.4	6-33
Langelier Saturation Index	-3	-3.2	(-4.4)-(-2.1)
Total Dissolved Solids	137.5	144.4	35-415
Chlorides (mg/L)	16.5	15.5	4-32
Sulfates (mg/L)	22	28.9	3-101
South Huntington (pH 6.4 & less)			
pH (units)	5.8	5.9	5.1-6.4
Alkalinity (mg/L as $CaCO_3$)	7	8	1-25
Langelier Saturation Index	-4.3	-4.2	(-5)-(3)
Total Dissolved Solids	46.5	53.8	22-131
Chlorides (mg/L)	3	3.3	<2-15
Sulfates (mg/L)	<2	0.8	<2-12
South Huntington (pH 7.0-7.4)			
pH (units)	7.1	7.1	7.0-7.4
Alkalinity (mg/L as $CaCO_3$)	27	27.7	0-51
Langelier Saturation Index	-2.4	-2.4	(-2.1)(-1.6)
Total Dissolved Solids	71	72.4	6-168
Chlorides (mg/L)	7	8.1	4-27
Sulfates (mg/L)	3	4.7	<2-27
South Huntington (pH 8.04 & greater)			
pH (units)	8.5	8.5	8.0-9.1
Alkalinity (mg/L as $CaCO_3$)	28	29.5	5-46
Langelier Saturation Index	-1.0	-1.0	(-1.9)-(-0.3)
Total Dissolved Solids	154.5	130.2	8-229
Chlorides (mg/L)	8.5	9.6	3-21
Sulfates (mg/L)	3	5.0	1-17

Table 3. Percentage of Test Homes Having Water with Greater Than 50 µg/L and 20 µg/L Lead at Low pH (6.4 and less) in 9 Age Categories

Lead Level, µg/L	*Age of Plumbing, yr*	*Percentage of Homes* First Draw	10 Sec	20 Sec	30 Sec	45 Sec	60 Sec	90 Sec	120 Sec
>50	0-1	100	100	100	86	67	71	71	71
	1-2	57	57	29	29	14	29	29	14
	2-3	71	43	43	29	14	29	29	29
	3-4	86	71	29	14	43	29	29	0
	4-5	57	0	14	0	0	0	0	0
	6-7	44	22	22	0	0	0	0	0
	9-10	43	14	0	0	0	0	0	0
	14-17	57	14	0	0	0	0	0	0
	20 & older	43	29	0	0	0	0	0	0
>20	0-1	100	100	100	100	100	86	86	86
	1-2	100	71	86	71	57	29	43	29
	2-3	86	71	57	57	43	43	43	29
	3-4	100	86	85	71	71	71	29	43
	4-5	57	28	43	42	43	14	0	0
	6-7	78	44	33	33	11	11	11	0
	9-10	71	28	14	14	14	14	10	0
	14-17	71	14	14	14	14	14	14	14
	20 & older	86	29	28	0	14	0	14	0

unique in that the pH of the water delivered to the customers could be adjusted and regulated so that the effect of pH on lead leaching could be measured. Furthermore, the homes used as test sites were chosen to cover a range of ages from new homes to those over 20 yr old. As expected, lead leaching increased with a decrease in pH of the water and generally decreased with an increase in age of the home. The data obtained from this project clearly points out the role of sampling techniques and the need to draw sequential samples in order to locate the source of lead. High lead values with first draw samples followed by a sudden decrease in lead concentrations indicates that the faucet may be the major source of lead.

Since tin/lead solder was the source of lead in the drinking water, the pipe loop studies were aimed at ascertaining the alternative solders that might be used. The data obtained indicated that the alternative solders could be safely used. With a pH adjustment above 7, the metal components of the solders were below the MCL.

The water quality parameter that was deliberately changed was limited to pH adjustment with the addition of sodium hydroxide. Therefore, increasing pH may not be sufficient to reduce lead levels to an acceptable value. Other sources with other water quality parameter values may need other additives, such as inhibitors or other chemicals, for alkalinity adjustments. The results of this project indicate the need to monitor carefully, and the sampling techniques needed to find the source of the lead.

The full report was submitted in fulfillment of Cooperative Agreement CR810958-01-1 by South Huntington Water District under subcontract to H_2M Group under the sponsorship of the U.S. Environmental Protection Agency.

Table 4. *Percentage of Test Homes Having Water With Greater Than 50 µg/L and 20 µg/L Lead at Medium pH (7.0-7.4) in 9 Age Categories*

Lead Level, µg/L	Age of Plumbing, yr	Percentage of Homes First Draw	10 Sec	20 Sec	30 Sec	45 Sec	60 Sec	90 Sec	120 Sec
>50	0-1	90	60	40	20	0	0	10	0
	1-2	50	30	10	0	0	0	0	0
	2-3	10	20	10	10	0	0	0	0
	3-4	20	10	10	20	10	20	20	0
	4-5	20	10	0	0	10	0	0	0
	6-7	0	0	0	0	0	0	0	0
	9-10	10	0	0	0	0	0	0	0
	14-17	20	10	0	0	0	0	0	0
	20 & older	10	0	0	0	0	0	0	0
>20	0-1	100	90	90	60	30	20	10	10
	1-2	80	60	40	10	20	0	10	0
	2-3	30	20	10	10	10	0	0	0
	3-4	50	20	20	30	20	30	30	20
	4-5	30	10	10	0	10	0	0	0
	6-7	10	0	0	0	0	0	0	0
	9-10	20	0	0	0	0	0	0	0
	14-17	40	20	20	10	0	0	0	0
	20 & older	20	0	0	0	10	0	0	0

Table 5. *Percentage of Test Homes Having Water With Greater Than 50 µg/L and 20 µg/L Lead at High pH (8.0 and greater) in 9 Age Categories*

Lead Level µg/L	Age of Plumbing, yr	Percentage of Homes First Draw	10 Sec	20 Sec	30 Sec	45 Sec	60 Sec	90 Sec	120 Sec
>50	0-1	100	80	10	0	0	0	0	0
	1-2	22	11	11	11	11	0	11	0
	2-3	10	0	0	0	0	0	0	0
	3-4	13	0	0	0	0	0	0	13
	4-5	20	0	0	0	0	0	0	0
	6-7	0	0	0	0	0	0	0	0
	9-10	0	0	0	0	0	0	0	0
	14-17	33	11	11	10	0	0	0	0
	20 & older	20	0	0	0	0	0	0	0
>20	0-1	100	100	60	10	20	10	20	0
	1-2	67	22	11	11	11	11	11	11
	2-3	30	10	20	0	0	10	0	0
	3-4	25	0	0	0	0	0	0	13
	4-5	30	0	0	0	0	0	0	0
	6-7	20	0	0	0	0	0	0	0
	0-10	10	0	10	0	10	10	0	10
	14-17	33	22	11	11	0	0	0	0
	20 & older	20	0	0	0	0	0	0	0

Table 6. *Percentage of Test Homes Having Water With Greater Than 20 µg/L of Lead*

Age of Plumbing, yr	pH	Percentage First Draw	10 Sec	20 Sec	30 Sec	45 Sec	60 Sec	90 Sec	120 Sec
0-1	6.8 & less	100	100	100	100	100	86	86	86
	7.0 - 7.4	100	90	90	60	30	20	10	10
	8.0 & greater	100	100	60	10	20	10	20	0
1-5	6.8 & less	93	71	64	61	53	46	32	25
	7.0 - 7.4	48	28	20	13	15	8	10	5
	8.0 & greater	38	8	8	3	2	5	3	5
6-20	6.8 & less	77	30	23	16	13	10	10	3
yr &	7.0 - 7.4	23	5	5	3	2	0	0	0
greater	8.0 & greater	21	5	5	3	2	3	0	3

Table 7. *Average Lead Content and Major Component of Solders*

Solder	% Lead	% Tin	% Antimony	% Silver	% Copper
Tin/lead	60.8	—	—	—	—
Tin/antimony	0.10	86.2	6.0	—	—
Tin/copper	0.04	94.7	—	—	3.0
Silver/copper	<0.002	—	—	6.9	88.0

Table 8. *Average Lead Leached Into Water From Tin/Lead Solders in Pipe Loop Studies at Various pHs and Time Intervals*

Standing water, hr	Lead Concentration, µg/L pH 5.2	pH 6.4	pH 7.4	pH 8.6
24	983	322	42	15
12	933	200	28	14
8	900	169	33	7
4	752	140	12	8
2	NT	36	22	NT
1	NT	8	9	NT

NT = not tested

☆ U. S. GOVERNMENT PRINTING OFFICE: 1991/548-028/20165

Norman E. Murrell is with H₂M Group, Melville, NY 11747-5076.
Marvin C. Gardels is the EPA Project Officer (see below).

The complete report, entitled "*Impact of Lead and Other Metallic Solders on Water Quality,*" *(Order No. PB91-125 724/AS; Cost: $17.00, subject to change) will be available only from:*

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati, OH 45268

BULK RATE
POSTAGE & FEES PAID
EPA PERMIT NO. G-35

Official Business
Penalty for Private Use $300

EPA/600/S2-90/056