Additional Compilation of Studies Identified by EPA Office of Water for the SAB Drinking Water Committee Lead Review Panel Meeting (March 29, 2011)

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The initial communication is needed to inform the general public of steps they may take to reduce their exposures. Repeating the information every 6 or 12 months is needed to remind homeowners that they should still be aware of potential problems. EPA agrees with commenters that young children and pregnant women should be targeted and, therefore, is requiring water systems to deliver information to locations frequently visited by these sensitive populations as outlined above. Guidance to assist water systems in implementing a successful public education program can be found in "A Primer: Developing a Community-Based Public Education Program on Lead in Drinking Water" (EPA, 1990i). Copies will be available from EPA Regional Offices and State Health Departments.

In communities where a significant proportion of the population speaks a language other than English, public education materials prepared for distribution through print or electronic media must be communicated in the appropriate language. To further facilitate the dissemination of public information concerning lead and copper in drinking water, the PWS should enlist the support of local elected public officials, the professional staff in local departments of public health and environmental protection, and members of both the business and academic communities.

6. Non-Transient, Non-Community Water Systems

The proposed rule would have required NTNCWS to publicly post informational posters on lead in drinking water in a public place, hold at least one public meeting annually to educate water consumers about lead in drinking water to answer any questions on the subject, and distribute brief informational pamphlets at least quarterly.

Several commenters argued that NTNCWS deliver water to different customers than community water systems and that the public education requirements were excessive. They recommended substantial reductions in these requirements. EPA agrees with commenters that NTNCWS deliver water to people whose exposure patterns are different than community water systems and has accordingly modified the public education program to better serve that constituency's needs.

The final rule requires NTNCWS to deliver the information contained in § 141.85(a) (1), (2), and (4) of the final rule within 60 days of exceeding the lead action level. The information is required to be delivered as follows:

(1) Posters hung in a public place or common area in each of the buildings served by the system.

(2) Pamphlets and/or brochures distributed to each person served by the NTNCWS.

NTNCWS are required to deliver the materials at least once during each calendar year in which the system exceeds the lead action level for as long as the lead action level is exceeded.

H. Lead Service Line Replacement

While the proposed rule did not contain provisions that would have required the replacement of lead service lines, the preamble to the proposal discussed in some detail, and solicited comment on, a lead service line replacement program that the Agency was considering adopting. The program adopted in the final rule resembles in large part the program discussed in the preamble to the proposal. The Agency did not formally propose lead service line replacement because of difficulties with quantifying on a national basis the contributions of lead service lines to lead levels at the tap, because of difficulties in estimating changes in lead levels after corrosion control treatment and lead service line replacement, and because of the potential risks associated with partial pipe replacement.

While there continues to be limited quantitative information regarding contributions from lead service lines to levels at the tap, EPA believes that a lead service line replacement program, as structured in the final regulation, will be an effective means for reducing excessive lead exposures. As discussed further below, the final rule requires systems to institute a replacement program if, after installing optimal corrosion control treatment (and when applicable, source water treatment), the system continues to exceed the lead action level. Replacement of individual lines in the system may be waived where the lead concentration in the service line sample is below 0.015 mg/L. EPA believes that the current lack of extensive data should not delay implementation of the lead service line replacement program. This is because information necessary to determine levels at the tap attributable to lead service lines will be collected on a case-by-case basis, and replacement of service lines will occur where lines are shown to contribute to elevated levels at the tap.

1. Comments on Lead Service Line Program

Numerous commenters supported a removal program proposing different ideas on how it should be implemented. Some commenters suggested requiring the removal of only those service lines that contribute lead above a specific level, such as 0.020 mg/L. Other commenters supported the removal of lead lines if the removal program was extended over 20–30 years, while others advocated removal as lead services are encountered during routine replacement of water lines.

Numerous commenters opposed requiring lead service lines replacement based on one or more of the following beliefs: (1) EPA does not have the authority to require replacement of lead service lines that are not under the water system's ownership or control; (2) the costs derived from lead service line replacement would outweigh the benefits, especially considering that water systems can only replace the portion of the line that they own/control and that may vary from system to system; (3) other methods, such as corrosion control, public education, or enforcing the lead ban, would be more effective for reducing an individual's exposure to lead from drinking water compared to partial lead line replacement; and (4) implementation would be a burden because records do not exist to locate lead lines and because monitoring lead lines will be difficult.

2. Authority to Replace Service Lines

EPA acknowledges that ownership and/or control of lead service lines is often split between the public water system and the property owner. Depending on State law or regulations, or local ordinances, some public water systems control and/or own connections up to the property line, others control and/or own the service line and other connections up to the building (especially if the water meter is located inside the building), and still others control and/or own the service connections only up to the curb.

A recent survey conducted by the American Water Works Association (AWWA, 1989, 1990) indicates that there are approximately 10 million lead service connections currently in use in the United States and that about 20 percent of all public water systems have some lead service connections. The actual number of lead service lines as a percentage of total service connections varies from system to system. EPA estimates, based on the AWWA survey, that the average length of a lead service line is 42 feet. About 70 percent of systems indicated that they own part of the service connection, 20 percent reported they owned no part, 9 percent reported ownership over only the gooseneck/pigtail, and 1 percent reported ownership over the entire service connection. According to the survey, ownership is determined in the majority of systems by ordinance (72 percent), with about 10 percent determined by informal agreements, 6 percent by contract, and 6 percent by either building codes or building codes and ordinance (EPA, 1990c).

A study discussed in the preamble to the proposal evaluated the extent of authority over service connections in publicly owned water systems in Boston, Chicago, Dallas, Denver, the District of Columbia, Los Angeles, New York, Pittsburgh, San Diego, and San Francisco, and other investor-owned utilities in various States. In the majority of cases evaluated, the water system was found to retain access to virtually all property serviced by the system and to reserve the right to perform work on privately owned service lines (usually at the expense of the property owner). To varying degrees, most of the systems also require property owners to meet certain specifications relating to service line location, size, and material composition. For investor-owned utilities, access to privately owned service connections is often restricted by municipal ordinance.

The study concluded that to the extent public water systems prescribe standards for construction, repair, and maintenance of service lines and reserve the right of entry onto private property to perform necessary work, it could be argued that the entire service line is under the system's control.

As discussed in the preamble to the proposal, requiring lead service line replacement involves determining the obligation of the public water system where jurisdiction over the service line is split between the water system and the user. Because the SDWA defines "public water system" as including "distribution facilities under the control of the operator" (SDWA section 1401(4)), the Agency concluded that it had the authority to hold public water systems responsible only for conditions under their "control." As noted above and discussed in the preamble to the proposal, where ownership is split between the utility and the user, utilities sometimes retain authority to prescribe the standards for construction, repair, and maintenance of service lines, and a right of entry to perform work deemed necessary (usually billing the user for the work on its portion of the line). Based upon this authority of public water systems, the preamble to the proposal discussed the option of establishing a rebuttable presumption that the entire lead service line was owned or controlled by the water system and, therefore, could be replaced by the system. This presumption could have been rebutted by the public water systems' citing appropriate legal authority (such as local ordinances, State statutes, or contractual provisions) limiting its control or ownership.

As noted elsewhere in today's notice, EPA believes its authority to impose regulatory requirements on public water systems extends only to those distribution facilities under the control of the system. Therefore, under the final rule, systems replacing lead service lines are required to replace the portions of lines that are under their control. Control is defined in § 141.84(e) of the final rule as being indicated by one of the following forms of authority: authority to set standards for construction, repair, or maintenance of the line, authority of the system to replace, repair, or maintain the service line, or ownership of the line. The final rule includes essentially the same substantive criteria for determining control as was discussed at proposal, including the "rebuttable presumption" procedure. The rebuttable presumption assumes that the water system controls and, therefore, can replace the lead components up to the wall of the building served (building inlet). As in the proposal, this presumption could be rebutted by the water systems by citing local ordinances or State statutes, or in the case of private systems, the contract between the systems and their customers, that limit the extent of control of the water system.

EPA decided to include a definition of "control" in the final rule to explain clearly the extent of public water systems' responsibilities under the lead service line replacement program. The statutory term, "control," is not defined in the SDWA, and the legislative history does not contain any guidance as to what Congress intended by the use of this term. EPA believes that, in the context of lead service line replacement, it is reasonable to interpret "control" to include those authorities listed in § 141.84(e) of the final regulation. Water systems generally retain authority to specify standards for construction, maintenance, and composition of service lines to be able to safeguard the integrity of the distribution system and, thereby to ensure the delivery of safe water to the consumer. Where a lead service line is demonstrated to be contributing to elevated lead levels at the tap, such a condition is similarly threatening the quality of the water consumed by the public. The Agency believes, moreover, that it is reasonable to interpret "control" as being present in cases where a system has authority to replace or repair or maintain the line since lead service line replacement under the final rule is a form of "repair" or "maintenance" which is necessary to prevent further exposures to elevated levels of lead. Thus, EPA believes that requiring public water systems to replace problem lead service lines that the systems "control" (as the term is defined in the rule) is consistent with the underlying purpose of the SDWA to protect public health as well as with practices of the water supply industry designed to maintain the integrity of water distribution systems.

Systems that do not replace the entire service line are required to submit to the State within the first year of their replacement schedule a letter demonstrating that their control is limited (see section VI(C)(1) of the preamble), so that States can review whether the system's interpretation correctly interprets relevant legal authority (see § 141.90(e)(4)). EPA believes that allowing States to review a system's basis for contending that its control is limited is important to ensure that systems apply correctly the regulatory definition of control to the specific facts of their system. In order not to delay prompt implementation of service line replacement and not to burden the States unduly, the final rule does not require States to affirmatively approve the system's interpretation of its legal authority prior to commencement of replacement. However, the State may determine that a system has incorrectly interpreted the extent of its "control" over lead service lines as the term is defined in the final rule. In these cases, the State is required to make its determination in writing and explain the basis for its decision. The system is then required to replace the portion of the lead line under the system's control as determined by the State.

Where a system's control does not extend to the entire service line, the rule requires systems to offer to replace the portion of the line controlled by the homeowner. The rule, however, does not explicitly address how the costs of replacing the homeowner's portion of the service line should be allocated. In the study discussed above, most cities charged the customer for work on privately owned piping. Systems may choose to incur the costs of replacing the entire line and spread the costs across the ratepayers, if the system believes that this would be appropriate. The incremental cost of replacing the privately controlled portion of the service line should not be substantial, however, since the largest component of the cost is the expense of mobilizing the equipment and labor to the replacement site, a cost that would be incurred by the system anyway. Because this provision of the rule does not impose any additional costs upon the system, and systems are required to replace only portions of lines they control, the Agency believes that the requirement for systems to offer assistance with replacement of privately controlled service lines is an efficient and effective means of maximizing the public health benefits achieved by the rule.

EPA has also adopted a second rebuttable presumption, discussed in the preamble to the proposal, that lead service lines must be replaced unless they contribute less than a specified amount of lead, although, as discussed below, the level requiring replacement has changed.

3. Cost and Effectiveness of Lead Service Line Replacement

EPA believes that corrosion control will remain the primary method for the majority of water systems to reduce lead levels. Although corrosion control has been shown to be effective in minimizing the corrosion of lead service lines by "insulating" the interior surface of the lines, the chemical reactions responsible for formation of these protective deposits are reversible (over days-months) if the passivation layers on the lines are not maintained. The buildup of these protective films can vary from one house to another depending on plumbing age, physical disturbances such as ground freezing or nearby road repair, and the length and diameter of the pipe.

a. *Contributions of Service Lines to Lead Levels at the Tap.* While corrosion control can be an effective treatment for preventing or slowing the dissolution of lead from lead service, in many cases it will not be sufficient to reduce lead levels below the action levels. Data from Boston, MA, Bennington, VT, and Fall River, MA, cities that contain relatively large numbers of lead service lines, illustrate that high levels that would not be protective of public health persisted despite significant reductions in lead levels achieved with corrosion control treatment. Results summarized in Table 7 also indicate that systems with lead service lines have substantially higher lead levels than those without. These results further suggest that many systems with lead service lines may not be able to reduce lead at the tap to levels below the action level using corrosion control alone. In addition, Table 10 indicates that lead levels in homes with lead service lines compared to homes without lead service lines, in the same system, had higher lead levels. EPA believes that the information presented in Tables 7 and 10 suggests that lead service lines can contribute significant amounts of lead at consumers' taps.

TABLE 10.—AVERAGE LEAD LEVELS (MG/L) BY TYPE OF SERVICE LINE (EPA, 1990d)

City	Pipe type	Number of samples	First draw	Fully flushed
Bridgeport.	Lead	10	12	7
	Non-Lead	12	7	5
Champaign.	Lead	6	18	16
	Non-Lead	16	3	4
Chicago	Lead	512 (FD)	13	9
		466 (FF)		
	Non-Lead	110	5	4
Fairfield	Lead	19	15	7
	Non-Lead	19	7	5
Louisville.	Lead	51 (FD)	11	11
		49 (FF)		
	Non-Lead	10 (FD)	10	2
		18 (FF)		
New Haven.	Lead	5	215	34
	Non-Lead	14	10	34
Newport News.	Lead	41	10	
	Non-Lead	448	11	
Phila/Suburb.	Lead	290	12	
	Non-Lead	22	6	

FD—First-draw, FF—fully flushed

b. *Partial Lead Service Line Replacement.* As discussed above, only that portion of the lead service line controlled by the PWS is required to be replaced by the system. Many commenters did not believe that replacing only that portion of the lead service line under their control would be an effective method for reducing lead levels at the tap and that replacing only part of the service line could actually increase the lead levels at the tap because of the disruption of the protective coating on the inside of the pipe.

In practice, EPA believes that many systems required to replace lead lines will receive consent to remove any privately controlled portions since it is in homeowners' interest to remedy completely this source of lead in their drinking water. In those cases where the water system cannot obtain permission to remove the entire line, EPA still believes there are benefits to partial replacement.

Partial removal of a lead service line will reduce the likelihood of exposure to lead from drinking water because there will be a smaller volume of water in contact with the lead service line. For example, a lead service line 40 feet in length and 3/4 inch in diameter will contain about 4 liters of water, and a service line 20 feet in length and 3/4 inch diameter will contain about 2 liters of water. If the lead concentrations in the service line are the same (i.e., 0.020 mg/L), consumers are more likely to consume water with elevated lead levels from longer lines because a larger volume of water will have elevated lead levels. Data collected by Pocock (1980) from over 2,000 homes in the United Kingdom support the view that the likelihood of elevated lead levels varies in relation to the length of the lead service line. The study found that within pH ranges reflecting relatively low corrosive water, tap water lead levels were significantly related not only to the presence of lead piping, but to the length of the piping as well. These findings are also consistent with Kuch and Wagner's (1983) mass transfer modeling, which predicted the dependence of lead levels on the length and diameter of a lead pipe (i.e., higher lead with longer lead pipe).

EPA shares the concern of commenters that partial replacement could increase lead levels, but believes that increased levels, if they occur, will be temporary and will decrease over time. One study cited in the proposal (Britton and Richards, 1980) showed a temporary rise in lead levels at the tap. One week after service line replacement the lead levels were as low as 0.1 mg/L and as high as 4.25 mg/L. Of the 10 samples collected, only one measured (4.25 mg/L) was above 0.1 mg/L; two were above 0.05 mg/L; and the remaining seven were below 0.05 mg/L. Two months after replacement, lead levels further declined to concentrations ranging from 0.05 mg/L to 0.2 mg/L. Four months after replacement, lead levels declined even further; 9 of the 10 samples were below 0.05 mg/L, and the 10th was below 0.09 mg/L. The Agency believes that the temporary rise in lead levels indicates not only the presence of lead materials in the distribution system (i.e., service lines, probably lead pipe), but also poor corrosion control. As noted by the authors, pH adjustment had only recently been implemented in the area and any passivation films on the interior walls of the pipe were probably thin. By the time replacement would be required under the final rule, corrosion control will have been fully implemented and should therefore reduce the potential for temporary increases in lead levels. This provides another justification for requiring lead service line replacement only after corrosion control treatment has been optimized.

Data collected since the proposal from Newport News as reported in the American Water Works Association report "Lead Service Line Replacement: Benefit-to Cost Analysis" (AWWA, 1990), indicate that replacement of service lines can result in temporary increases in lead levels. However, these increases lasted only 1–2 weeks and followed replacement of lines that initially had low levels (indicating an effective passivation film). Replacement of lead service lines with lead levels above 0.015 mg/L generally resulted in decreased levels immediately after removal, followed by substantial decreases after 2 weeks.

Newport News Waterworks began a program in 1987 to replace existing lead service lines in their system. Samples were collected at the meter, before and immediately after the service line was replaced, and 2 weeks after the replacement. The results in Table 11 indicate that of the nine locations sampled, four sites had initial lead levels above 0.015 mg/L, one site had lead levels between 0.010 to 0.015 mg/L, and four sites had lead levels below 0.005 mg/L. Immediately after removal of the lead lines, the lead levels in three of the four locations with initial lead levels above 0.015 mg/L declined, and all four locations showed substantial reductions when sampled 2 weeks after replacement.

TABLE 11.—LEAD LEVELS IN HOMES BEFORE AND AFTER REPLACEMENT OF LEAD SERVICE LINES IN NEWPORT NEWS, VA (AWWA, 1990)

Location	Lead levels (ppb)		
	Before replacement	Immediately after replacement	1–2 weeks after replacement
7	4	88	1
10	4	16	2
11	1050	6	4
14	2	106	2
16	4	10	4
18	37	44	<1
19	2350	45	6
21	76	66	13
25	13	27	6

EPA conducted a study on the effects of partial lead service line replacement on seven homes in Oakwood, Ohio (EPA, 1991c). First-draw samples and service line samples were taken before and after replacement. First-draw and service line samples were taken (two to four samples collected at each home) during a 1 week period before the service lines were replaced, and follow-up samples were collected over a 2 week period (one to three samples were collected at each home), after service line replacement. Only that portion of the lead service line owned by the water utility, main to curb, was replaced, even though four homes had lead service materials from the main to the house. The water system offered to replace the section of the service line owned by the homeowner, curb to house, but all four homeowners declined the offer. The results presented in Table 12 indicate that the lead levels in service line samples before and after replacement were very similar, and were below 0.015 mg/L, with one exception. Even though the results indicate very little change in lead levels before and after service line replacement and some increases in some cases, these data are not directly relevant to the replacement requirements in the final rule since levels at these lines were already below the replacement level in the final rule of 0.015 mg/L and would not be required to be removed under the final rule. These data do appear to indicate, however, that requiring replacement of lines where tap levels are already low (i.e., below 0.015 mg/1) might not result in improvements in lead levels.

TABLE 12.—LEAD LEVELS IN HOMES BEFORE AND AFTER REPLACEMENT OF LEAD SERVICE LINES IN OAKWOOD, OH (EPA, 1991c)

Location	Lead levels (ppb)	
	Before replacement	1–2 Weeks after replacement
4	9	6
5	6	3
6	10	4
7	8	22
8	9	11
11	10	7
12	6	8

To ensure that increased exposures do not occur because of partial line replacement, systems are required to notify affected residents that the system is replacing the lead line and that the potential exists for increased lead levels during an interim period after removal. Systems are also required to collect a lead service line sample from the consumer's tap within 14 days after replacing the line to determine whether any increase has occurred. The purpose of collecting the follow-up sample is to inform residents of precautions that may be needed temporarily such as flushing water at taps to avoid potential increases in lead levels.

In conclusion, while partial replacement could in some cases result in transitory increases in lead levels at the tap, EPA believes that such increases will be minimized due to the fact that effective corrosion control should be in place by that time, and because homeowners will be informed of necessary precautions. Finally, even if temporary increases do occur, EPA believes that such concerns are outweighed by the importance of having lead levels reduced over the long term. Except at extremely high exposure levels not found in drinking water (exceptions may occur where there is stagnant water in a lead-lined water cooler), lead is primarily of concern because of its capacity to accumulate in the body and result in chronic health effects, rather than acute toxicity. Thus, EPA believes that it is most important that longterm exposures to elevated levels due to lead service lines are avoided, even if this can mean short-term exposures in some cases to higher levels immediately after partial replacement.

c. *Current Replacement Programs and Cost.* EPA estimates that about 8,300 of the 15,000 water systems with lead service lines will be required to replace some lead service lines after corrosion control has been installed. Costs are estimated to range from about $900 to $1800 dollars per line depending on the local circumstances and the replacement method (EPA, 1991a). Most of these expenses will be fixed costs associated with mobilizing utility work crews and preparing the site to replace the line. Consequently, the costs of replacing lead service lines of different lengths will be comparable. The annual increase in household water bills for large metropolitan water systems (over 50,000) is estimated to range from $2 to $9 (EPA, 1991a). EPA believes that these costs are reasonable.

Costs for lead service line replacement could be substantially lower in the future than those estimated above with more widespread use of low cost pipe replacement technology currently available. This new technology can pull old pipes out without excavating entire streets. The only constraint on the use of this technology is that it cannot be used in clay soils or "river rock." EPA estimates that such conditions exist in less than 25% of the U.S. Assuming that such technology will be used for replacement of 75% of the problem lead service lines, annual household costs estimated for large systems would be reduced to as low as <$1 to $4 (EPA, 1991d).

Several cities currently have programs to accelerate the replacement of lead service lines. Since the early 1960s San Francisco, California, has replaced about 10,000 lines, representing 95 percent of the lead service lines at a cost of approximately $1200–1400/line. The service line from the water main to the water meter is replaced with polybutylene, copper, or ductile iron, depending on line diameter. In 1964, Akron, Ohio, began replacing each year about 1,000 lead and galvanized steel service lines from the water main to the curb. In all of these cases, the service line replacement was funded by operating revenues paid by the customers. Washington, D.C., has replaced an estimated 500 service lines with a program in which the city will replace its portion of the lead service lines provided that the building owner pays for replacement of his or her portion (AWWA–RF, 1990).

EPA believes corrosion control will reduce the leaching of lead from lead service lines in many cases, but high lead levels will persist in some cases and service lines will need to be replaced. EPA believes that available information suggests that the replacement of lead service lines is effective in reducing lead levels at the tap and that the costs are reasonable for large metropolitan water systems. The technology to replace lead service lines is available, and many cities across the country have been implementing lead service line replacement programs. The Agency will, during the next 3 years, use the data from these systems to assess fully the effectiveness (i.e., in terms of lead levels at the tap or other potential effects) of the lead service line replacement requirements in this regulation, and consistent with this review, make changes, if appropriate, to the service line replacement requirements described below.

4. Final Replacement Program

The lead service line program discussed in the preamble to the proposal would have required systems to replace all lead service lines that contribute measurable lead levels (i.e., 0.003 mg/L) after corrosion control was implemented where the levels of lead in 5 percent of service line samples collected at the tap exceeded 0.020 mg/L. All lead services would have been required to be replaced within 15 years from the date the replacement program was triggered.

The lead service line replacement program in the final rule is premised on five principles: (1) Corrosion control can reduce lead levels from lead service lines in some instances, but high lead levels may persist after treatment; (2) water systems should only be responsible for removing that portion of the lead lines they control; (3) a system is triggered into a lead service line replacement program if the system exceeds the lead action level after installing corrosion control and/or source water treatment; (4) a system is not required to replace individual lead service lines if the service line sample is 0.015 mg/L or less; and (5) water systems must each year replace 7 percent of their total number of lead service lines in place at the beginning of the program (i.e., complete replacement over 15 years). The first two principles have been discussed in the previous section. The final three requirements and the rationale for the remaining components are discussed below.

a. *Criteria for Triggering Replacement Program.* All public water systems that exceed the lead action level in tap water samples after installation or improvement of corrosion control or source treatment (whichever treatment is installed later), or during any subsequent monitoring period, are required to initiate a lead service line replacement program. Obviously, no such program would be required in communities where no lead service lines have been used.

The Agency decided to use the lead action level to trigger lead service line replacement for consistency with other components of the treatment technique (i.e., corrosion control for small and medium systems, source water treatment, and public education). Given the technical complexity of this regulation, and the large number of water systems possessing varying degrees of technical expertise subject to these regulatory requirements, the Agency believes it is extremely important that the requirements be easily implemented by the industry and understood by the public. Use of a single action level for all the regulatory requirements helps achieve this objective. Moreover, for reasons explained elsewhere in this preamble, the Agency believes that use of 0.015 mg/L as a trigger for action will ensure substantial public health protection.

After a water system is triggered into the lead service line replacement program, it is required to take three steps: (1) Complete a materials evaluation, if this has not already been done, to identify all homes or buildings served by lead service lines, (2) establish a replacement schedule for replacing lead service lines, and (3) replace all lead service lines controlled by the system except for those that do not contribute more than 0.015 mg/L. Water systems with lead service lines may simply choose to remove them without conducting any monitoring. This could reduce the monitoring costs for systems, especially if a system believes that lead levels from the service lines are likely to exceed 0.015 mg/L.

b. *Materials Evaluation.* One year after a water system is triggered into the replacement program, it is required to submit to the State a revised materials evaluation identifying the total number of lead service lines in its distribution system. EPA believes that 1 year is more than an adequate period of time since water systems should have obtained this type of information either when they were required to determine whether their distribution system contained lead or copper pipes (§ 141.42(d)), or when they established their sampling pool for tap monitoring under this rule (see § 141.86(a)). EPA understands that some cities may have very poor records of lead service line location and may not be able to initially identify each line. However, systems are not required by the final rule to provide this information until 8–10 years from today (i.e., after installation of corrosion control and/or source water). Given this extended period, EPA anticipates that even those systems with poor records initially should be able to locate their lead service lines and that systems with monitoring results indicating that lead service lines may be a problem should plan this work accordingly.

c. *Replacement Schedule.* The lead service line replacement program discussed in the preamble to the proposed rule would have required replacement of all lead service lines on a schedule to be determined in each system's treatment plan, but in no case more than 15 years. Some commenters argued that the maximum period was too short and that lines should only be replaced in accordance with system's routine maintenance activities. EPA does not believe it would be appropriate to allow systems to replace lines as part of normal maintenance since this could take as long as 50 years before all the problem lead lines are replaced in some systems. EPA believes that it is necessary to accelerate the rate at which systems would otherwise replace lead service lines in order to ensure that public health will be adequately protected.

EPA received other comments arguing that the maximum replacement schedule discussed in the proposal was either too short or too long. Commenters suggested alternative schedules ranging from 10 years to 30 years. While these commenters disagreed with a maximum 15-year replacement schedule, they did not articulate why it would be feasible for systems to replace lines in a shorter period of time, or why it would only be feasible for systems to replace lines on a longer schedule. Indeed, it is difficult to determine a uniform, national replacement schedule applicable to all public water systems because the circumstances faced by systems can vary substantially, depending upon the number of lead lines in a system and system size. EPA estimates that lead service lines can comprise between 10 and 50% of the total service lines in systems which have them. In some systems, this percentage may be even higher. Large systems with few lines would be capable of replacing the lines on the fastest schedule, whereas a system comprised of a high percentage of lead lines would take the longest period of time to complete replacement. A city like Chicago, which required use of lead service lines until 1986, would require the longest period of time to feasibly replace all of its lead lines.

EPA considered alternative ways of taking into account both system size and the number of lead service lines in establishing a replacement schedule. One such alternative would have required systems to replace the number of lead service lines each year which corresponds to a fixed percentage of the total number of lines (lead and non-lead) in the system. For example, if 10% of the total number of lines were required to be replaced each year, a system with a total of 10,000 lines and 5,000 lead lines would be required to replace 1,000 lines per year (10% of 10,000), leading to replacement of all lines within 5 years. A system of the same size with all lead lines would be given a longer period of time (10 years) to complete replacement under the above scenario. While such an approach would take into account the various factors affecting the feasibility of replacement schedules for individual systems, it can yield inappropriate results in the case of the larger systems, which may be required to complete replacement on an inordinantly fast schedule which would not be feasible (e.g., a city containing a total of 200,000 lines and 50,000 lead lines would be required to replace all the lead lines within only 2 and 1/2 years).

After considering the public comments and the difficulties associated with establishing a uniform replacement requirement for all systems, EPA has decided to retain the approach discussed in the proposal of establishing a maximum replacement schedule of 15 years for all systems. Under the proposed rule, the exact schedule for each system would have been established by the State in each treatment plan for the system. The final rule does not provide for the establishment of treatment plans, as discussed above; the rule simply requires States, and EPA in states without primacy, to place systems on a replacement schedule shorter than 15 years where this is feasible. States will be in the best position to assess the factual circumstances of each individual system to determine the schedule which the system can feasibly meet. In no case, however, can a system take more than the maximum 15-year schedule contained in the final rule.

Water systems required to conduct a lead service line replacement program are therefore required to replace each year at least 7 percent of the total number of lead service lines with lead concentrations above 0.015 mg/L. For example, a system that has a total of 10,000 lead service lines would be required, at a minimum, to replace 700 lead service lines per year (unless the systems could demonstrate that specific lines had concentrations less than 0.015 mg/L, as discussed below). Addressing and, if necessary, replacing all lead lines would, therefore, take 15 years unless the State specified a shorter schedule.

d. *Replacement of Individual Service Lines.* In the preamble to the proposed rule, the Agency considered a lead service line replacement program that would have contained a rebuttable presumption that all lead service lines contribute measurable amounts of lead to the tap and, therefore, should be replaced. That presumption could have been rebutted if the system conducted monitoring that compared a lead service line sample with a fully flushed sample and found that the service line contributed to no measurable increase in lead levels at the tap. The Agency continues to believe that a rebuttable presumption that all lines should be removed is appropriate, but has changed the lead level at which systems will be allowed to avoid replacing specific service lines.

The proposal would have required the replacement of a service line if it contributed lead levels of 0.003 mg/L or more. Several commenters stated that this was unreasonable and that a higher trigger level should be established. EPA agrees that a higher trigger level is appropriate and has selected 0.015 mg/L for an individual line for three reasons: (1) It is consistent with the lead action level that triggers the system into lead service line replacement, as well as other components of the treatment technique; (2) use of a low trigger level may not reliably indicate whether the source of the lead contamination is the service line versus other components of the distribution system; (3) some data indicates that partial replacement of lines where the levels are already below 0.015 mg/L may not consistently reduce those levels; and (4) replacing lines where the level is above 0.015 mg/L provides substantial public health protection.

The first reason for requiring replacement of only those lines contributing above 0.015 mg/L is administrative simplicity. The lead service line replacement program, as well as public education, source water monitoring, and corrosion control for small and medium-sized systems, are triggered by exceedance of the action level of 0.015 mg/L at the 90th percentile. The Agency believes that using the same number as a trigger for removing lead service lines will be less confusing to the public and the regulated community and will enhance expeditious compliance with the rule, thereby improving the rule's effectiveness in protecting public health.

The second reason for using 0.015 mg/L as a trigger for lead service line replacement is recognition of the difficulties in ascertaining whether the service line is actually a significant source of lead contamination. Determining the concentration of lead in drinking water attributable to service lines on a case-by-case basis is complicated by differences in interior plumbing configurations and varying lengths of lead service lines. EPA believes that a trigger level as low as 0.003 mg/L (which is lower than the PQL for lead), and even somewhat higher values, would not provide a reliable indication that the service line (as opposed to other components of the distribution system, such as interior plumbing or brass faucets) was contributing lead to tap levels. The Agency believes it is appropriate to have a reasonable degree of certainty that the service line is, in fact, contributing to elevated levels of lead at the tap (after corrosion control and source water treatment have addressed all other sources of contamination within the PWS's control) before requiring systems to incur the costs of replacing the line. The higher the amount of lead detected in a service line sample, the greater certainty that the line is the source of the lead problem. Also, as noted above, EPA conducted a study on lead levels before and after partial pipe replacement which showed inconsistent results when the initial levels were below 0.015 mg/L. In sum, given the uncertainties associated with determining whether low levels of lead in service line samples are attributable to service line contamination and whether replacement can further reduce already low tap levels, the benefits in terms of ease of implementation associated with a consistent action level, as well as the substantial public health protection provided by an action level of 0.015 mg/L (see discussion in section IV(E)(2)(a), above), the Agency has selected 0.015 mg/L to trigger replacement of individual lead service lines.

Thus, under the final rule, the rebuttable presumption in favor of replacing lead service lines would operate as follows. As discussed above, a system is required to replace annually the number of lead service lines equal to seven percent of the total number of such lines identified in the system's materials evaluation. The system may seek to rebut the presumption requiring replacement of this number of lines by taking a service line sample at each site scheduled for replacement. If the concentration in the service line sample is less than or equal to 0.015 mg/L, then the system is not required to replace that individual line. However, the system may count that service line towards the seven percent replacement requirement which it is required to meet that year. Thus, in effect, the rule requires systems either to replace and/or rebut the presumption for replacement (by demonstrating that levels are below 0.015 mg/L) for a total of seven percent of its lead service lines each year.

e. *Discontinuing Replacement Program.* Under the final rule, water systems can discontinue the lead service line program if they can demonstrate that the lead levels in first-draw water at the tap are below the lead action level for two consecutive 6 month monitoring periods. It is conceivable that systems, through improvement of corrosion control or source water treatment, or because they obtain an alternative source of water that is naturally less corrosive, can achieve the action level even though they had previously exceeded it. The Agency decided to require systems to meet the action level during the monitoring periods conducted over the course of an entire year in order to ensure that the lower levels genuinely reflect a lowering of lead levels and not normal variability in lead levels at the tap. If a system subsequently exceeds the action level again during any single monitoring period, then it would have to recommence the replacement program.

f. *Annual Letter Certification Process.* For each year of the lead service line replacement program, each water system must submit a letter certifying that they have completed replacement, or monitored lead levels to rebut the replacement presumption, for at least seven percent of their service lines. The annual letter must include information on the number and location of each lead service line scheduled to be replaced during the most recent year, the service lines that were replaced, and the lines where service line samples were collected. The information must include the lead concentrations and the date and methods used to collect the samples. EPA believes that this information is necessary to ensure that the system is properly conducting the lead service line program.

V. MONITORING

A. Analytical Methods

1. Analytical Methods for Lead and Copper

The 1988 notice proposed the graphite furnace atomic absorption technique (GFAA) for conducting compliance monitoring for lead and either the GFAA, direct aspiration atomic absorption technique (DAAA), or the inductively coupled plasma (ICP) technique for conducting compliance monitoring for copper. Neither the DAAA nor the ICP technique were proposed for lead because the method detection limits for these two techniques were too high. All of these analytical methods were considered technically and economically feasible. On October 19, 1990, EPA published a **Federal Register** notice (55 FR 42409) soliciting comment on several new methods for lead and copper along with updates on the methods in the proposal. The new methods for lead and copper included a new inductively coupled plasma mass spectrometry (ICPMS) technique and the graphite furnace platform atomic absorption technique (GFPAA). In addition, the notice proposed analytical methods for calcium, conductivity, alkalinity, orthophosphate, silica, and water temperature and updated methods for pH, which are discussed in section 6, below.

Several commenters supported EPA's decision not to approve the DAAA or the ICP technique for lead in the proposal. Other commenters expressed concern that very few laboratories, other than State laboratories, currently had the analytical equipment or capability to test for lead at the MDL or PQL and that the costs for these lead analyses would be excessive. EPA received no substantive comments on the new methods proposed in the October 19, 1990, **Federal Register** notice (55 FR 42409).

EPA is concerned that the increase in the number of samples requiring analyses may require certification of more laboratories. Based on EPA's most recent Water Supply Performance Evaluation Studies (WS #22 and 23) EPA estimates that there are about 400 laboratories nationwide that currently have the capability to analyze for lead using the GFAA technique within #30 of the Practical Quantitation Level (PQL). However, a large majority of these systems are not EPA- or State-certified laboratories and some may need to obtain certification before completing analysis for lead. Because of this concern, the final rule is phasing in the monitoring requirements by system size to ease the burden on analytical laboratories and to allow some States the opportunity either to expand their current laboratory capacity or initiate a program to certify independent laboratories to analyze for lead (see section C(1)(c) below for a discussion of phased-in monitoring).

The cost for analyzing lead and copper is estimated at about $15 per metal per sample, with collection costs of $20. The proposal estimated the cost of analyzing lead and copper samples at about $6 to $30 per metal per sample. EPA changed its cost estimates based on public comments, although contacts with several school districts and laboratories across the country indicate that lead samples can be analyzed for as low as $5. EPA concludes that the analytic methods listed in table 13 are both technically and economically feasible for routine use in compliance monitoring for lead and copper. These methods are therefore designated as the prescribed analytical methods for conducting monitoring under the final rule.

Final Report:

Lead Service Line Replacement A Benefit-to-Cost Analysis

Prepared for
The American Water Works Association

Sponsored by
The Water Industry Technical Action Fund

Prepared by
Roy F. Weston, Inc.
and
Economic and Engineering Services, Inc.

LEAD SERVICE LINE REPLACEMENT

A BENEFIT-TO-COST ANALYSIS

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American Water Works Association
National Association of Water Companies
Association of Metropolitan Water Agencies
National Rural Water Association
National Water Resources Association

This unique coalition of water industry organizations combined forces in 1988 to create a source of funding to gather technical information concerning the water industry. The primary focus is to provide information to aid the U.S. Environmental Protection Agency in the development of protective and practical Federal drinking water regulations.

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SECTION 1

SUMMARY AND CONCLUSIONS

SECTION 1

SUMMARY AND CONCLUSIONS

1.1 INTRODUCTION

The objective of this study is to assess the benefit-to-cost relationship of the development of a national lead service line replacement program. Regulations calling for a mandatory program requiring public water supplies to replace lead service lines and connections that are within their responsibility have been under consideration by the U.S. Environmental Protection Agency (EPA) and Congress. This is despite the concerns that the actual extent to which lead service lines contribute to levels of lead in drinking water is uncertain and that the majority of lead service lines are the responsibility of water consumers and will not be affected by such a program.

The benefits of a lead service line replacement program will be the reduction of lead concentrations in water at the consumers' taps and the accompanying reduction in exposure to lead. The adverse health effects of high levels of lead in the blood of humans, especially small children, infants, and fetuses, is well documented. Lead is pervasive in the environment. Water is one of several routes of human ingestion (air, dust, food, and lead paint exposure are others). Lead service lines and service connections are one source of lead in drinking water. Lead was commonly used as a material for water lines because of its availability, flexibility, and durability. Other sources include lead in source water that is not removed by treatment, bronze and/or brass fixtures, and lead solder joints in customer plumbing. Lead in source water can be eliminated or reduced by appropriate treatment. Leaching from other sources can be minimized by corrosion control techniques. However, only the elimination of the contact with water from lead services, fixtures, and solder can completely eliminate potential exposure. Water systems and customers are gradually eliminating lead services over time. This study considers the costs and benefits of an accelerated mandatory replacement program.

1.2 TECHNICAL APPROACH

The study was conducted in six tasks. These are shown in Figure 1-1 and are related to the following objectives:

- Task 1 -- Determine the occurrence of lead service lines on a national basis. This includes estimating the number of lead service lines and connections, their geographic location, and the jurisdiction and ownership of these service lines and connections.

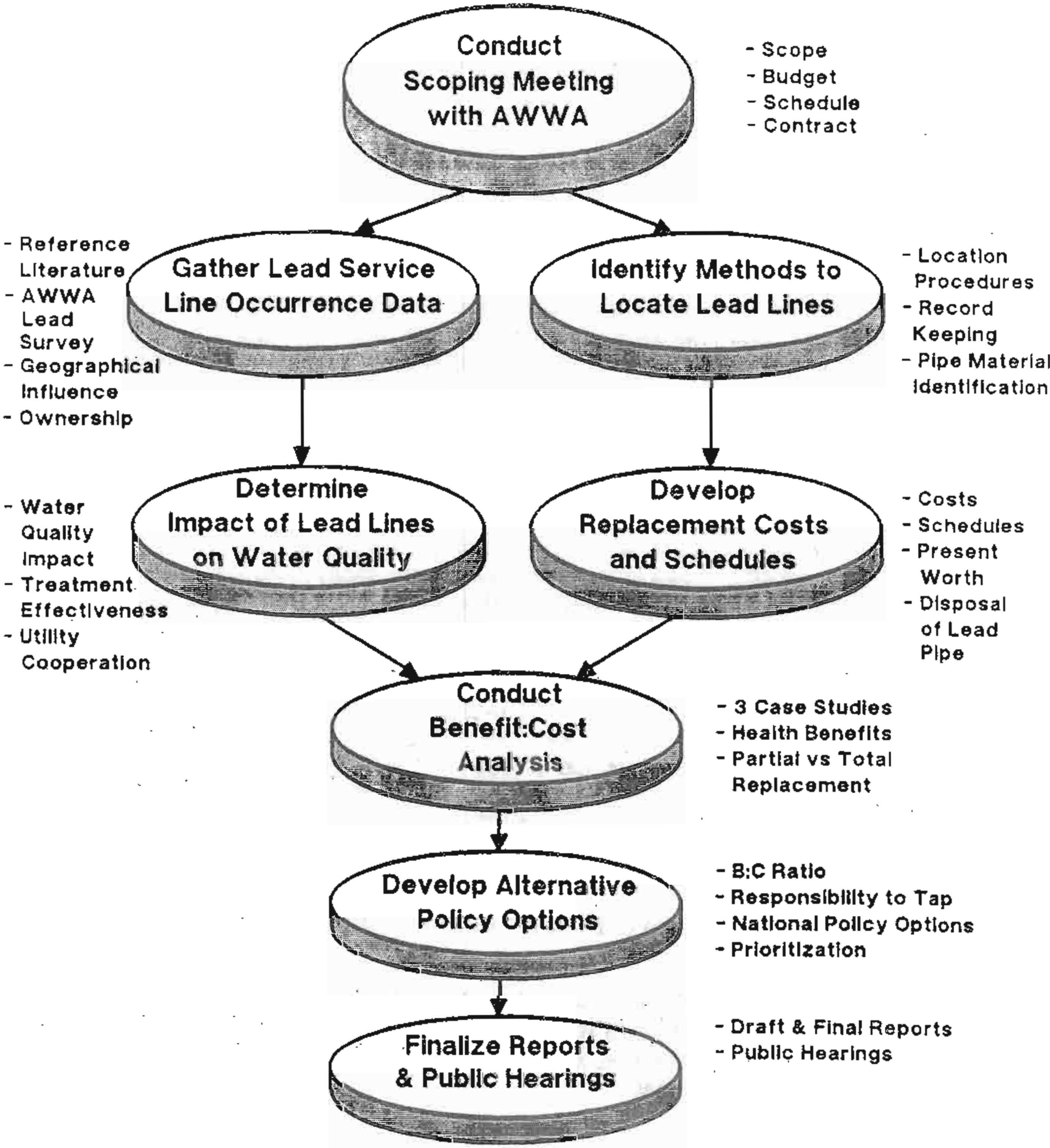


FIGURE 1-1 PROJECT FLOW CHART

- Task 2 -- Determine the means available to water utilities to locate and identify lead services. To replace these services, utilities must be able to specifically locate individual lead service lines and connections.

- Task 3 -- Estimate the contribution of lead services to elevated lead levels at the tap. Lead services are one of several sources contributing to this problem (others being fixtures, fittings, lead-based solder). The benefits of an accelerated mandatory removal program depend on the contribution of these lead services to elevated lead levels at the tap.

- Task 4 -- Estimate the costs of a mandatory replacement program over time and compare it to baseline conditions. An economic analysis was conducted considering 10-, 15-, 20-, and 25-year replacement programs.

- Task 5 -- Conduct a benefit-to-cost analysis after evaluating the benefits of the reduction in lead exposure because of the mandatory replacement program. This includes evaluating the health benefits to be achieved by lead service replacement and quantifying these benefits in monetary terms. The analysis also is based on the differences in benefits and costs from the ongoing replacement under baseline conditions.

- Task 6 -- Evaluate alternative national policy options. These included replacement, treatment for inhibiting corrosion, nonmandatory options, and combinations of these. These evaluations have been discussed directly with AWWA; recommendations are to be provided in a separate memorandum.

Lead in drinking water is a basic public health issue. Throughout this study, when it was necessary to make assumptions, they were made on the side of public health. That is, they were made in a way that maximized the benefit side of the service line replacement question.

Many data sources were used, but several proved to be particularly useful. As part of this study, a telephone survey was taken of 35 utilities, and case studies of three utilities were conducted. The 1988 American Water Works Association Lead Information Survey (AWWA-LIS), which summarized data from over 1,000 water utilities, was most helpful. The 1984 EPA Lead Product Use Survey provided important information; and the 1986 EPA report, Reducing Lead in Drinking Water: A Benefit Analysis, was used to derive monetary benefits. It is important to note that this last report was used as a methodology developed by and acceptable to EPA even though AWWA and the water industry have questioned some of its determinations. Its use in this study does not imply any endorsement of its findings by AWWA, the water industry, Economic and Engineering Services, and WESTON.

1.3 FINDINGS AND CONCLUSIONS

1.3.1 Benefit-to-Cost Analysis

In general, the study found that, if you had only one dollar to spend to reduce lead levels in drinking water, lead service line replacement would not be the place to spend it. Service line replacement, however, does have a place in a systematic program to reduce lead levels. In the most common case where a home or property owner owns two-thirds of the service line, the water supplier's most effective use of that dollar could be in providing water treatment that will reduce lead leaching in the owner's line as well as in his brass plumbing fixtures. Only when more cost-effective solutions have failed to meet public health objectives should lead service line replacement on an accelerated schedule be considered.

This study has concluded that the benefit of a mandatory lead service replacement program is very low relative to the cost. The benefit-to-cost ratio varies from about 0.025 to 0.020 for programs carried out between 10 to 25 years. A benefit-to-cost ratio of 1.0 or higher is generally considered necessary to consider a program viable and worthy of implementation.

1.3.2 Occurrence

Lead service lines and connections were found to be most prevalent in the eastern and upper-midwestern portions of the U.S. This study has estimated that approximately 6.4 million lead connections and 3.3 million lead service lines exist nationwide. Water utilities with lead service lines typically own only a portion of these lines. Approximately 70% have partial jurisdiction (usually main to curb line or curbstop, or about one-third of the service line), while 20% have no jurisdiction, 9% have responsibility for the connection to the main only, and 1% accept jurisdiction over the entire service line. Ownership is established most often by a local ordinance (75% of the time), while other methods of establishing jurisdiction include informal agreement, contracts, building codes, and utility rules and regulations. In a mandatory lead service replacement program, water utilities would remove only that portion under their jurisdiction, leaving the remainder for the customer to address.

1.3.3 Identification

Most water utilities do not have information that would allow them to readily locate those service lines and connections that are lead. Even those systems with the best record-keeping systems cannot locate all of their lead services. It has been estimated that approximately 20% of the water utilities would be able to use a combination of their existing record sources in combination with prediction techniques (such as geographic location, known lead services on the same block, date of installation, maintenance records, etc.) to effectively locate their lead services. Inspection within premises, such as by water meter readers on their routine duties, would be used by approximately 57% of the systems to identify potential lead services, even though the internal pipe material may not always match that within the utilities jurisdiction. The remaining 23% of systems, unless they knew that they did not have any lead services, would have to excavate to determine service material in order to comply with a mandatory program. During this study, several other methods for identifying the material of buried pipe were found to be ineffective, including water sampling.

1.3.4 Contribution

The contribution of lead services to the total level of lead exposure at the tap was assessed. Although there has been a great deal of interest in the issue of lead in drinking water, only a limited number of studies have evaluated the contribution from lead service lines. These have been summarized with other sources of lead in a water quality matrix presented in Section 4 of this report. Water qualities nationwide were categorized as having a lead leaching potential of high, medium, and low. Lead levels associated with lead service lines were also categorized as high, intermediate, and low. With the concurrence of the AWWA Lead Subcommittee of the Inorganic Contaminant Technical Advisory Workgroup (IOC TAW), this study has used the intermediate concentration of 10 ug/L lead to represent the exposure concentration of lead to be ingested when drinking water that has been in contact with lead service lines.

Reports in the United Kingdom (Britton and Richards, 1981) and data gathered in the United States (Hulsmann, 1990) raise a concern that physical disturbance of lead service lines can cause high lead levels. Investigations report that partial replacement of lead piping can produce dramatic, short-term increases in water lead levels. Levels up to 4250 ug/L have been measured. They hypothesize that particulate lead dislodged by physical disturbance of the pipe as well as exposure of fresh metallic lead surfaces may be the causes of the increased levels. There are enough data available to raise this issue to a high level of concern, especially if lead service lines nationwide are to be disturbed and partially removed. Many customers who are currently exposed to very low lead levels in noncorrosive areas could be exposed to high lead levels on a short-term basis. Based on this concern, EPA should be asked to investigate the potential for this problem before mandating a partial replacement program nationwide.

1.3.5 Cost

Examination of present utility practice shows that about 61,000 lead services are being replaced each year without a mandatory program. This represents a baseline condition of removing lead services over a 55-year period. The costs to be evaluated are those associated with the acceleration of replacement beyond this baseline condition as part of a mandatory program. Costs were determined for mandatory replacement programs occurring over a 10-, 15-, 20-, and 25-year period, with the method of replacement being determined by how the water utilities would be able to identify and locate their lead services. Costs included programmatic costs (those related to finding the services and scheduling their replacement), replacement costs (material, excavation, etc.), and excess excavations for those occasions when an assumed lead service line turned out to be another material. Based on investigation of disposal and recovery techniques, it has been evaluated that all of the lead removed could be recycled by the lead smelting industry and a recovery value has been assumed. The present value costs of the 10- to 25-year mandatory replacement programs

1.3.6 Benefits

To maximize the public health benefits of such a mandatory program, the highest potential exposure to the subject population was assumed. Thus, the benefits analysis proceeded assuming that of a two-liter daily adult ingestion of water, one liter was from the first draw in contact with plumbing fixtures in the home, and the second liter was from water in contact with lead service lines. A child was assumed to ingest one liter of water daily, also half being first draw and half in contact with lead service lines. Based on the study's determination of typical service lengths, jurisdiction, water quality, and this exposure, it was determined that, the mandatory lead service replacement program would reduce an adults lead intake from drinking water by 2.5 ug/day and a child's by 1.25 ug/day. Drawing from EPA's derivation of monetary benefits from lead reduction this would be equivalent to benefits upon the completion of the program of about $14 million annually. Comparing this benefit to the 10-, 15-, 20-, 25-year time periods, over the period until the baseline conditions would also remove all lead services, resulted in benefit-to-cost ratios (Table 1-1) of between 0.020 to 0.025 for the accelerated mandatory programs.

1.3.7 Recommendations

Based on this study and utility experience with corrosion control, the water industry should not support a mandate to accelerate the removal of all lead service lines nationwide.

Table 1-1

Summary of Benefit-to-Cost Ratios

Replacement Program	Present Value Costs	Present Value Benefits	Benefit-to-Cost Ratio
10 Year	$5,114,000,000	$128,000,000	0.025
15 Year	$4,436,000,000	$104,000,000	0.023
20 Year	$3,860,000,000	$ 84,000,000	0.022
25 Year	$3,369,000,000	$ 66,000,000	0.020

All costs are shown in 1990 dollars.

SECTION 2

OCCURRENCE OF LEAD SERVICE LINES/CONNECTIONS

SECTION 2

OCCURRENCE OF LEAD SERVICE LINES/CONNECTIONS

2.1 HISTORICAL LEAD PIPE USE

The use of lead piping to convey water has been common since Roman times. Its soft, malleable qualities and its resistance to serious physical deterioration often made lead the plumbing and piping material of choice when available. The detrimental effects to health from lead leaching out of pipes were recognized at the end of the eighteenth century in Wurttemberg, Germany, and by 1845 in the United States. A 1924 survey by Donaldson of 539 cities throughout the U.S. indicated that half were using lead or lead lined pipes. By 1940, most cities had stopped installing lead service piping; however, the desirable physical qualities and apparent economic benefits of lead and lead-containing materials in plumbing contributed to the continued use of lead in some areas of the United States into the 1980's. New installation of lead materials in plumbing systems has been banned since 1986.

2.2 PURPOSE AND OVERVIEW

The overall purpose of this portion of the study was to 1) document the location of lead service lines and lead connections on a national basis, 2) assess how prevalent they are within a geographic area, and 3) identify typical service line ownership characteristics. A survey of potential data sources from the U.S. Environmental Protection Agency (EPA) yielded little recent information on lead materials occurrence; however, several historical data sources were identified and reviewed, including:

- The 1988 AWWA Lead Information Survey (completed by T. David Chinn, P.E., Assistant Director for Governmental Affairs, AWWA, Washington).
- U.S. EPA's 1984 Lead Product Use Survey.
- Information gathered from two AWWA Research Foundation projects: Economics of Internal Corrosion Control (1989), and Lead Control Strategies (1990).
- The 1987 AWWA Lead Information Survey (AWWA-LIS).
- District of Columbia Lead Study (1990).
- U.S. EPA's Office of Drinking Water Lead Survey (1987).

Review of these current data sources identified two major databases that provide the most complete information on lead services and lead gooseneck connection occurrence:

- The 1984 EPA Lead Product Use Survey (EPA Survey).
- The 1988 AWWA Lead Information Survey (AWWA-LIS).

A description of these two databases, the technical approach used in determining occurrence and ownership characteristics, and results of the evaluation are summarized below.

2.3 DATABASE DESCRIPTION

The EPA Survey was conducted by the Water Supply Branches of each of the 10 EPA Regions. Questionnaires or telephone interviews of 143 public water systems in the United States were completed. Information obtained included total number of service connections, number of lead gooseneck connections, and number of lead service lines. Figure 2-1 displays the database information used from this survey.

In 1988, the American Water Works Association (AWWA) conducted a survey to obtain information on lead service lines and connections in the United States. The survey was accomplished by mailing questionnaires that asked utilities to specify whether they had lead service lines or lead connections in their system and to estimate the number of lead connections and/or feet of lead service line. They were also asked to describe their jurisdictional authority over service lines. A total of 1,006 utilities, located throughout the United States, responded to the AWWA Survey. Figures 2-2 and 2-3 display the database information used for this survey. A copy of the survey form appears in Appendix A.1.

The distribution of utilities by population served for each of these surveys is as follows:

Population Served	Number of Utilities EPA Survey	AWWA-LIS
≤ 3,300	--	241
3,301 - 10,000	--	251
10,001 - 50,000	25	317
> 50,000	118	191
	143	1000

Although the AWWA-LIS has a much higher percentage of utilities serving less than 10,000 people than the EPA Survey, neither survey reflects the population distribution for all public water systems throughout the United States, which is heavily weighted towards very small systems.

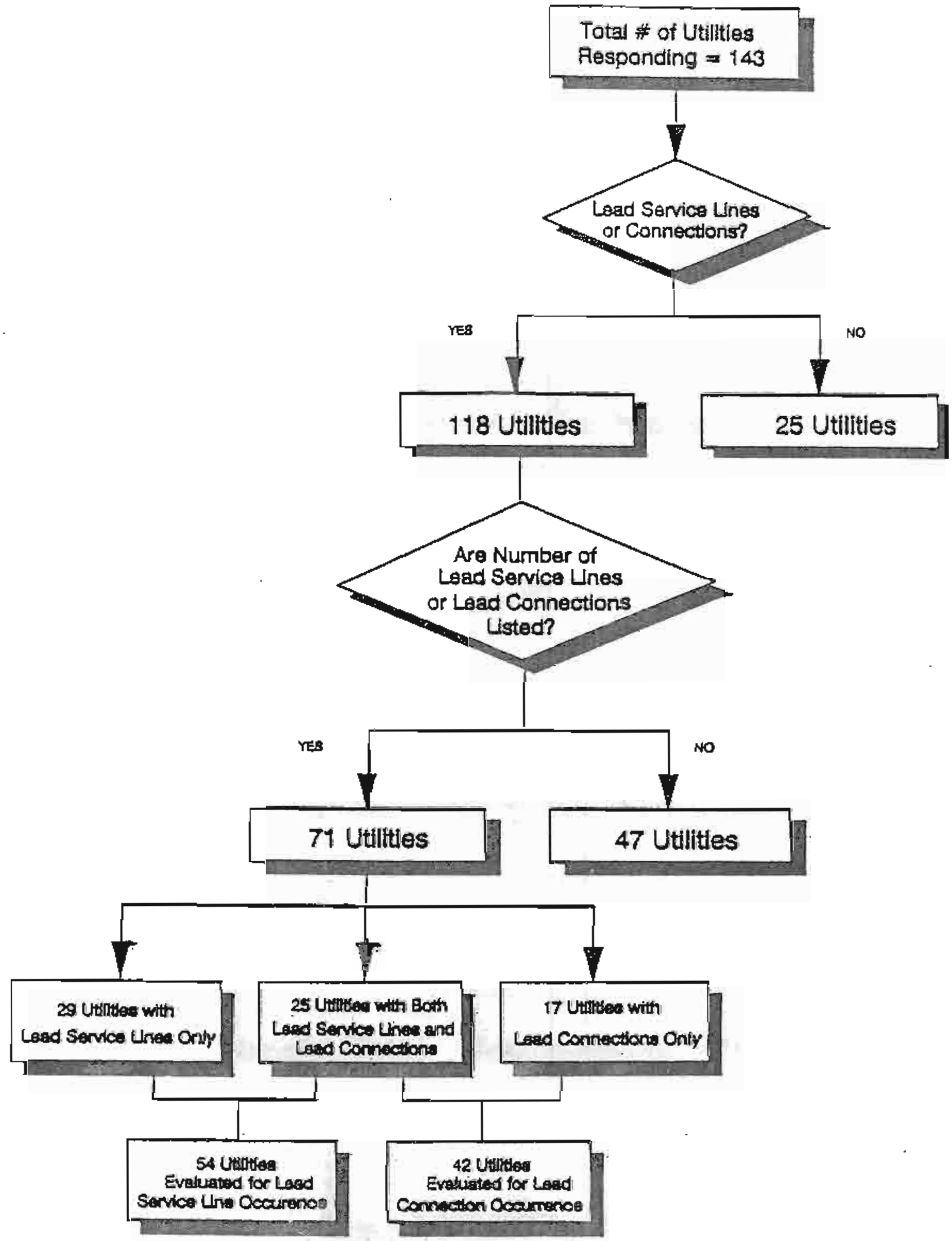


FIGURE 2-1 OCCURRENCE DATABASE DESCRIPTION:
EPA LEAD PRODUCT USE SURVEY

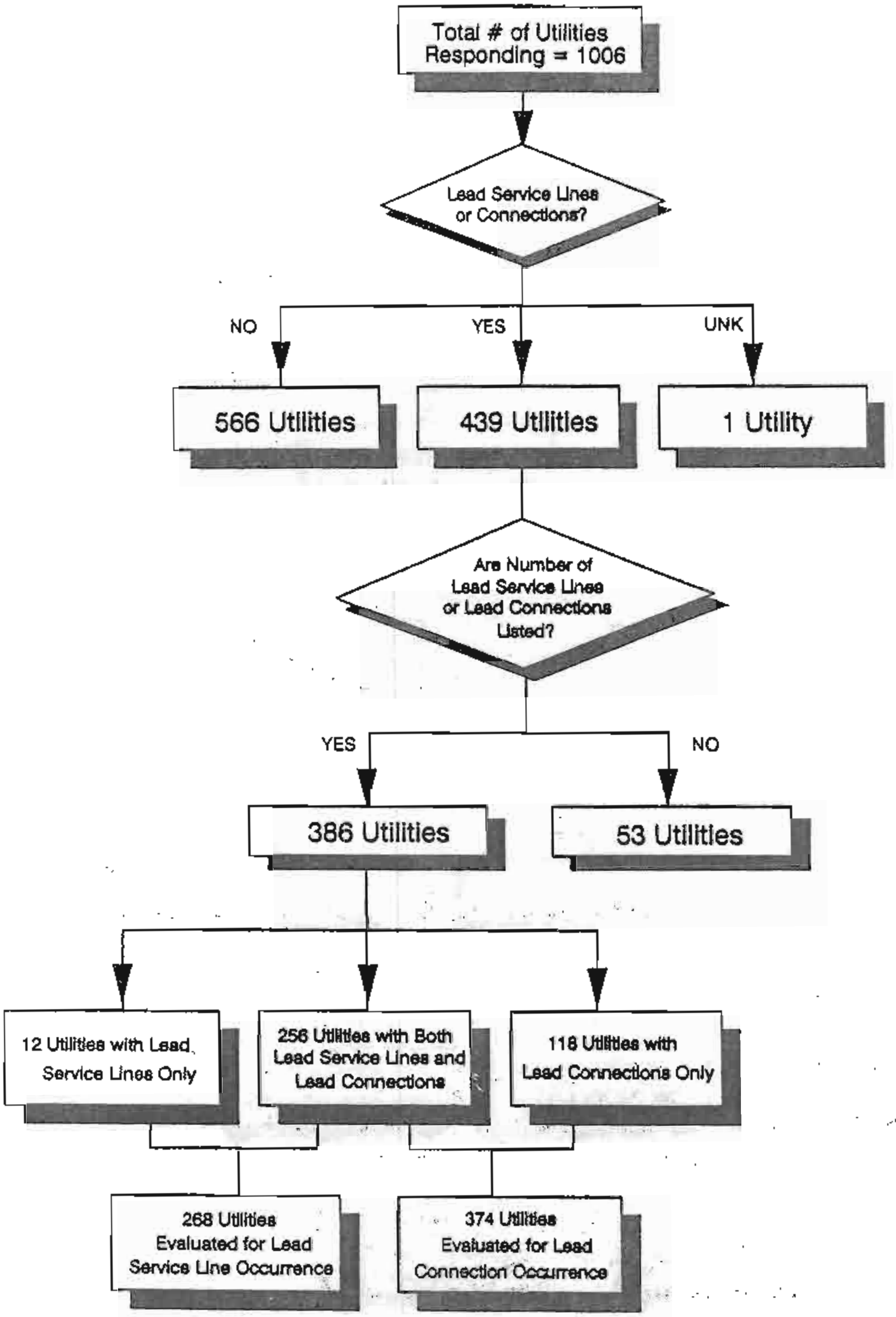


FIGURE 2-2 OCCURRENCE DATABASE DESCRIPTION: AWWA-LIS

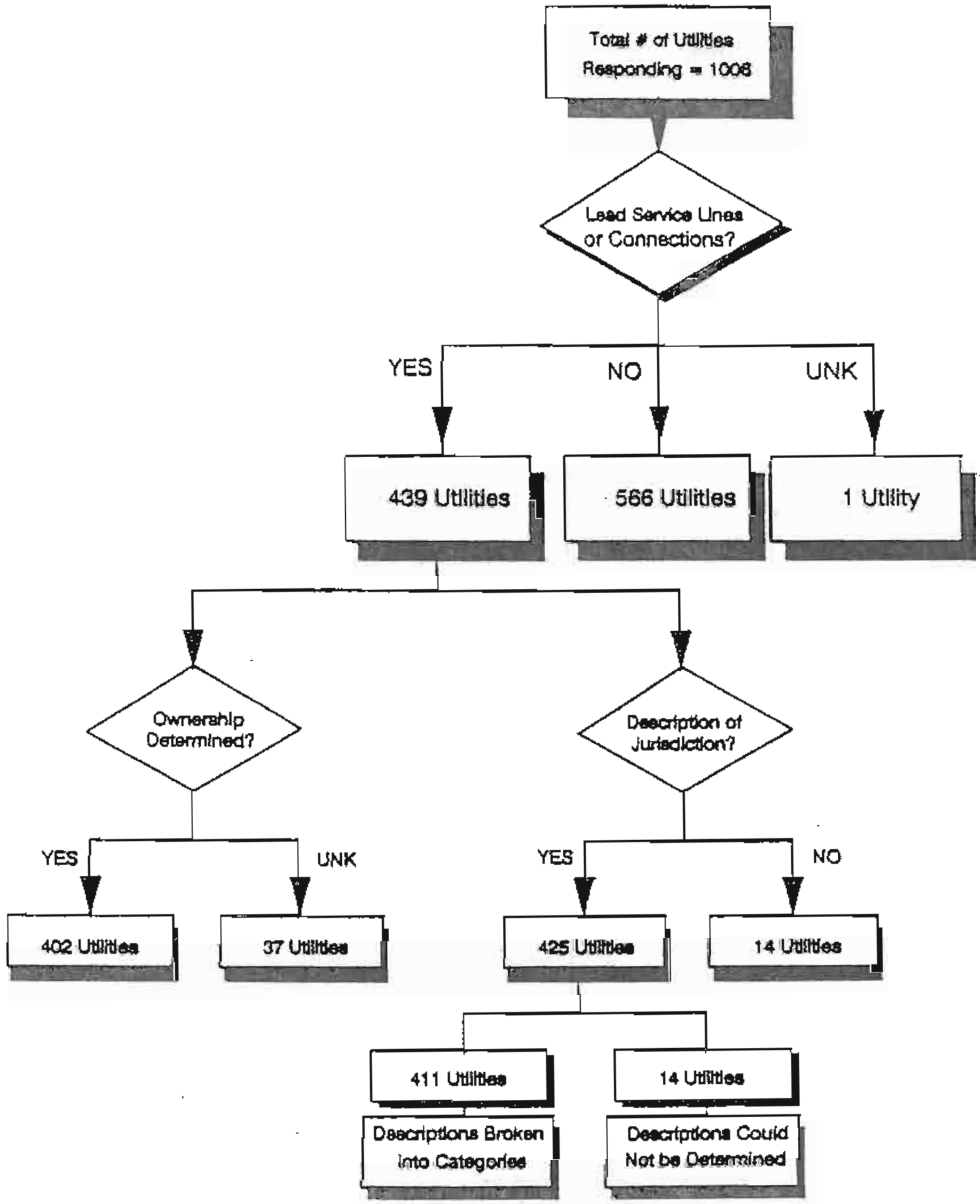


FIGURE 2-3 OWNERSHIP DATABASE DESCRIPTION: AWWA-LIS

The breakdown of total utility responses by EPA Region and the number of utilities with lead materials were as follows:

		Number of Utilities			
		EPA Survey		AWWA-LIS	
Region	States in Region	Total	Lead Matls.	Total	Lead Matls.
1	CT, ME, NH, RI, VT, MA	24	21	40	26
2	NJ, NY	15	6	72	40
3	DE, MD, PA, VA, DC, WV	22	15	87	37
4	AL, MS, KY, FL, GA, NC, SC, TN	16	--	111	41
5	IL, MN, WI, IN, MI, OH	5	4	244	156
6	AR, LA, NM, OK, TX	9	4	63	16
7	IA, KS, MO, NE	23	12	81	56
8	CO, MT, ND, SD, UT, WY	12	3	65	36
9	AZ, CA, HI, NV	2	2	152	17
10	AK, ID, OR, WA	15	4	91	14

This equates to the following percentages of utilities with lead materials for each database:

Region	EPA Survey, %	AWWA-LIS, %
1	87.5	65.0
2	40.0	55.6
3	68.2	42.5
4	0	36.9
5	80.0	63.9
6	44.4	25.4
7	52.2	69.0
8	25.0	55.4
9	100	11.2
10	26.7	15.4

These percentages show relatively good agreement between the two surveys, with the exception of Regions 4, 8, and 9 where the AWWA-LIS had a much larger number of utility responses.

2.4 TECHNICAL APPROACH FOR LEAD MATERIALS OCCURRENCE AND OWNERSHIP EVALUATION

Occurrence information was evaluated from each of the databases separately for comparison purposes. Figures 2-4 and 2-5 present the approaches used to determine percent lead service lines and lead connections by state for each database. Total service connections for the utilities in the AWWA-LIS were estimated based on population served since data on total connections were not available from the survey. In addition, the AWWA-LIS contained data on total footage of lead service line rather than number of lead services. The total number of lead service lines for each state within the survey was estimated using typical service line lengths, according to the following example calculation:

$$\text{\# of Lead Service Lines} = \frac{\text{Feet of Lead Service Line from Survey}}{\text{Typical Length (Feet)/Service Line}}$$

These typical lengths are described in more detail in Subsection 2.5. The lead service line occurrence evaluation discussed in Subsection 2.6 is based on these typical lengths.

Nationwide occurrence of lead service lines and lead connections was estimated using the percentages for each state obtained from the AWWA-LIS. This database provided the most recent and most complete source of information for extrapolation. Figure 2-6 displays the approach used in estimating total numbers of lead service lines and lead connections.

The AWWA-LIS was also used to evaluate ownership and jurisdiction of lead service lines and connections. The survey contained descriptions of jurisdiction over the service lines/connections, which were categorized according to how much of the service line over which they indicated that they had authority. These categories were:

- <u>Complete:</u> The utility owns the service line from the main, including the connection, all the way into the building or house. (The meter, then, is usually inside the basement.)

- <u>Partial:</u> The utility owns a portion of the service line. In most cases, the authority extends to the meter box or curb stop/control valve and includes the connection to the main. Utilities indicated their authority over the service line normally extended to the right-of way or owner's property line.

- <u>Connection:</u> The utility does not own the service line; however, they do own the connection to the main, i.e., the lead gooseneck.

- <u>Nothing:</u> The utility does not own the service line or the connection between the service line and the main. In essence, this indicated that they only own the main.

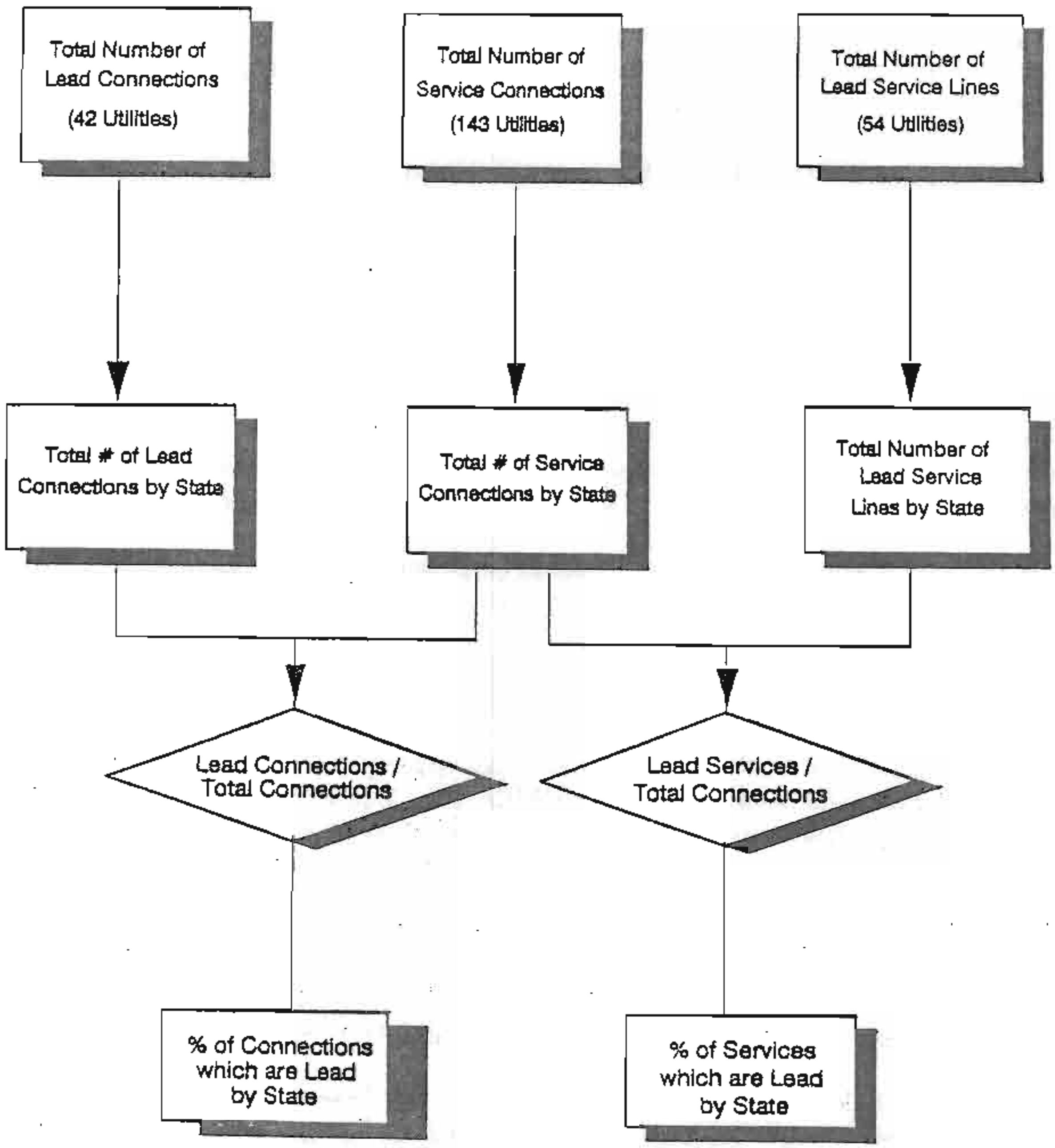


FIGURE 2-4 TECHNICAL APPROACH FOR OCCURRENCE:
EPA LEAD PRODUCT USE SURVEY

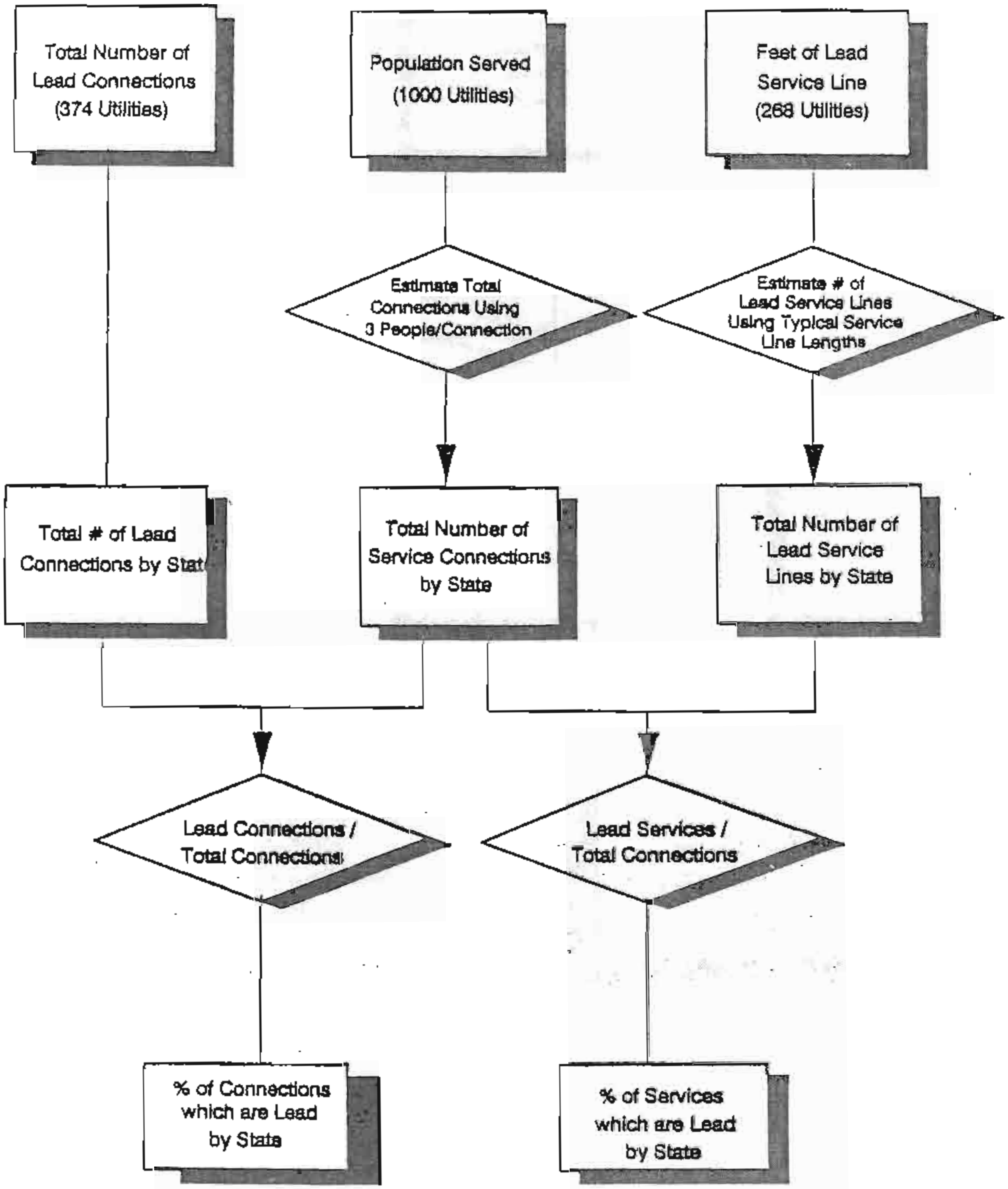


FIGURE 2-5 TECHNICAL APPROACH FOR OCCURRENCE: AWWA-LIS

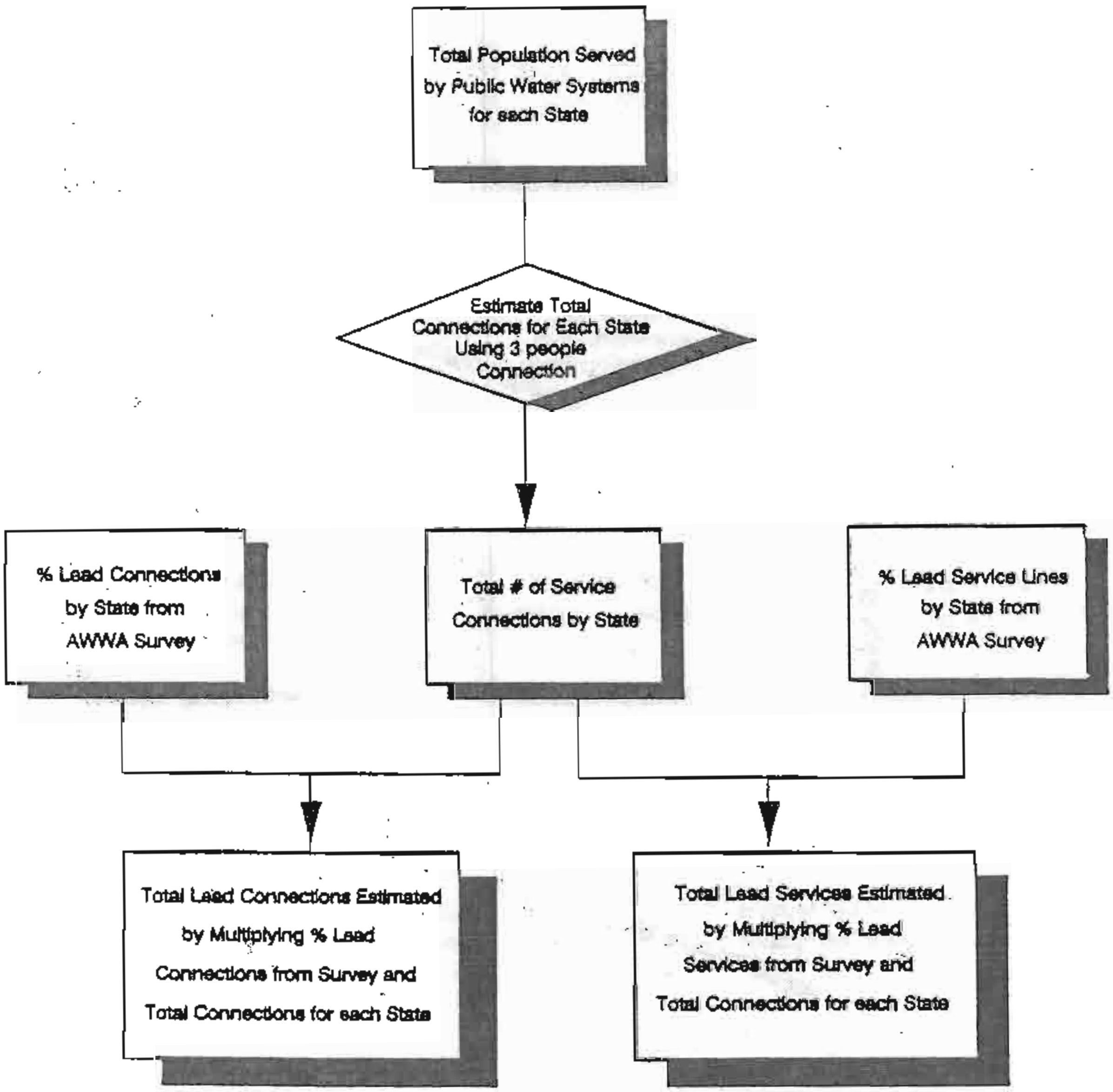


FIGURE 2-6 TECHNICAL APPROACH FOR ESTIMATING TOTAL NATIONWIDE LEAD SERVICE LINES AND CONNECTIONS

Of the 439 utilities responding that they had lead service lines or connections in their system, 411 provided descriptions of their ownership that could be placed in one of the above categories.

In addition, 402 utilities provided information on how ownership was determined. The major categories were:

- Ordinance.
- Informal agreement.
- Contract.
- Building code.
- Some combination of these methods.

Figure 2-7 summarizes the approach used to evaluate ownership and jurisdictional information.

2.5 SERVICE PIPE CHARACTERISTICS

Typical service pipe characteristics were determined based on review of existing information from the data sources listed in Subsection 2.2 and through results of a telephone survey of 35 utilities conducted by WESTON. Table 2-1 contains a summary of the information obtained during the telephone survey. Although it is difficult to determine specific information from so few data, general conclusions can be inferred. Those utilities that provided service line characteristics for older, more urban parts of their system generally had shorter lines than the newer, more suburban areas. For those utilities in the telephone survey which identified typical line lengths associated with older parts of their city, the average main-to-curb distance was 13 feet. For the remainder of the utilities, this distance was 25 feet. In order to determine the total service line length, the curb-to-house distance was added to this main-to-curb length. For the utilities that provided curb-to-house lengths, the average total length for service lines was between 50 to 58 feet. For the utilities that provided a curb-to-meter distance, the total length was estimated based on an assumption that the meter was located in the house when the curb-to-meter length was greater than 20 feet. For the remainder of utilities from the telephone survey that provided curb-to-meter lengths of 1 or 2 feet, the curb-to-house distance was estimated to be 30 feet. Using this approach, the average total service line lengths were 48 feet for older, more urban areas, and 73 feet for other utilities that provided an average lengths for their system. Figure 2-8 is a schematic of typical service line lengths based on the average main-to-curb and curb-to-household lengths for both urban and suburban systems. The typical main-to-curb distances provided by the telephone survey indicate that utilities with partial jurisdiction over service lines may control only 25 to 30 percent of the total length.

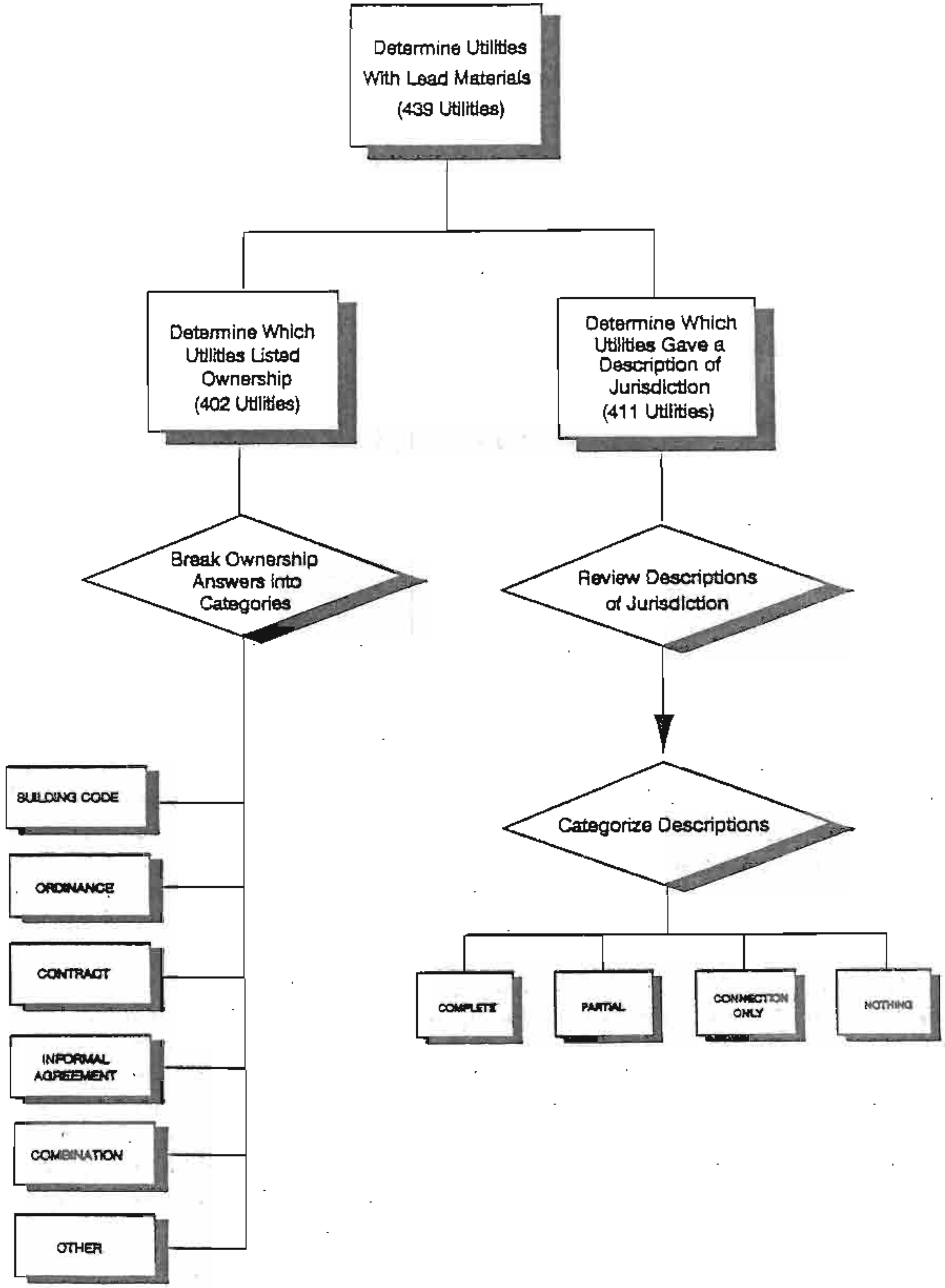


FIGURE 2-7 TECHNICAL APPROACH FOR OWNERSHIP/JURISDICTION: AWWA-LIS

Table 2-1

Results of Telephone Survey on Typical Service Line Lengths

EPA Region	City	State	* Area	Service Line Distance in Feet			Total Service Line Length	Estimated Total Service Line Length
				Main to Curb	Curb to Meter	Curb to House +		
1	Norwich	CT	-	20	-	30	50	
2	White Plains	NY	-	25	-	20 - 50	55 - 75	
	Elmira	NY	-	30	-	15 - 40	45 - 70	
3	Wheeling	WV	-	25	-	30	55	
	Clarksburg	WV	-	20 - 25	-	25 - 30	45 - 55	
	Morgantown	WV	-	30	-	20 - 40	60	
	Virginia Beach	VA	-	20	-	30	50	
4	Winona	MS	A	20	1			50
5	Marion	OH	-	15	-	30	45	
	Willmar	MN	O	8	50	-	-	58
	Fairmont	MN	A	16	60	-	-	76
	Kenosha	WI	A	30	45	-	-	75
7	Mission	KS	O	25	1	-	-	56
	Falls City	NE	A	30	70	-	-	100
	Cape Girardeau	MO	A	30	2	-	-	62
8	Salt Lake City	UT	A	30	30	-	-	60
	North Ogden	UT	A	60	1	-	-	90
9	El Centro	CA	O	10	1	-	-	40
10	Seattle	WA	O	10	2	-	-	40

* Area:
O = Older Part of City
N = Newer Part of City
A = Average

+ Curb to house distance was estimated to be 30 feet for utilities where curb to meter distance was two feet or less. For remainder, curb to meter distance was assumed to be identical to curb to house distance (i.e. meter located inside the house).

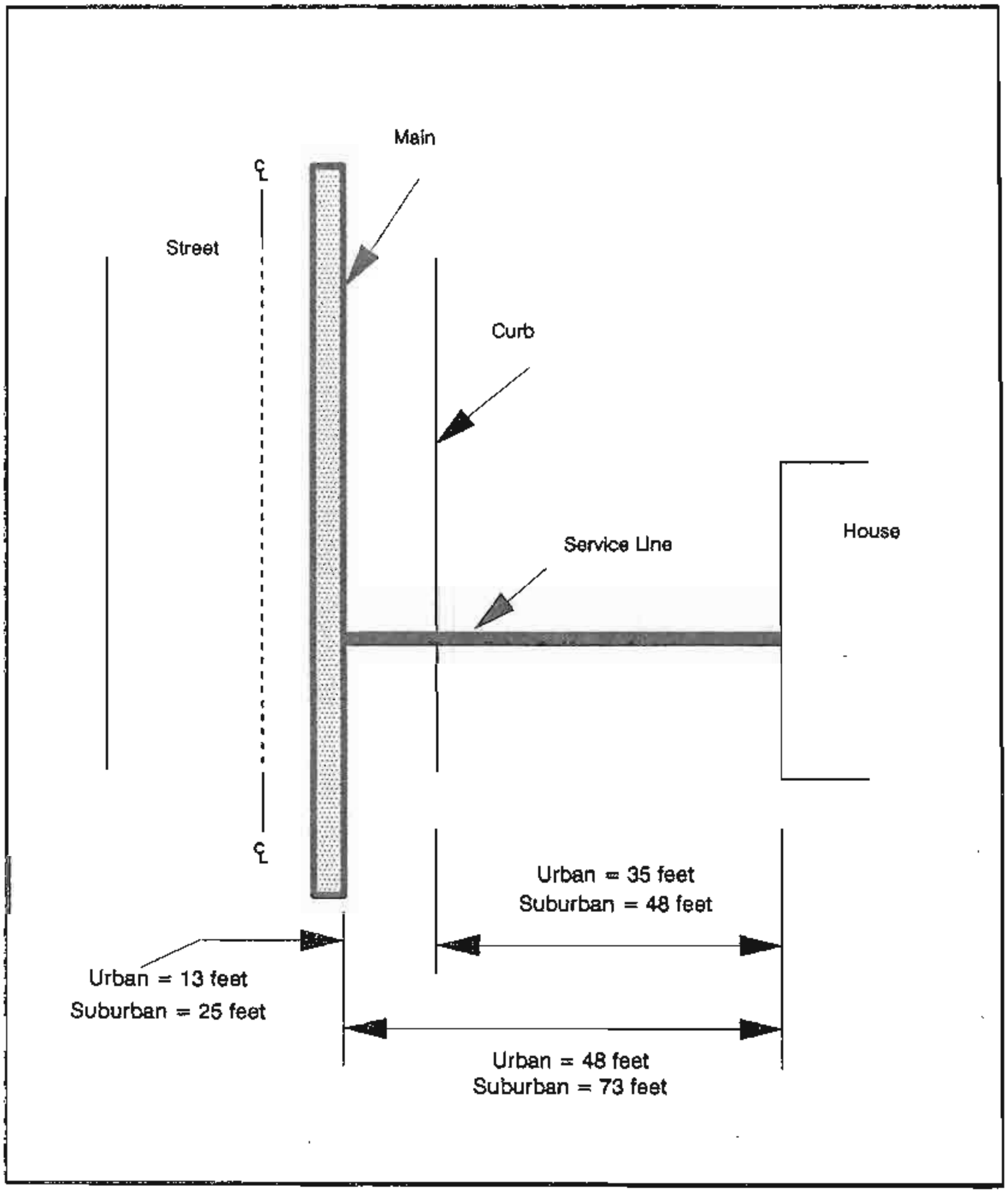


FIGURE 2-8 SCHEMATIC OF TYPICAL SERVICE LINE CHARACTERISTICS

The average service line lengths were also used to identify typical service lengths by region to be used in estimating total lead services from the AWWA-LIS data. Based on information obtained in the telephone survey, the following typical service line lengths were used for each EPA Region:

Region	Typical Length Used
1,3,4,5,6,9,10	50 feet
2	60 feet
7,8	75 feet

The typical lengths were then used to calculate total number of lead service lines for each state. Estimating total lead service lines from the AWWA-LIS in this manner is highly sensitive to the assumptions used for typical service lines. Using shorter typical lengths will increase the number of estimated lead service lines, whereas longer lengths will decrease the number.

2.6 OCCURRENCE OF LEAD MATERIALS

The information used in this occurrence analysis reflects only the information contained in each of the databases. Although information is shown statewide, in some instances very little data were available for a particular state. This is true for North Dakota, Rhode Island, Oklahoma, Montana, Vermont, Alaska, and Idaho.

2.6.1 Lead Connections

Results of evaluating lead connection occurrence information from the EPA Survey and the AWWA-LIS can be seen in Figures 2-9 and 2-10, respectively. These figures depict the prevalence of lead connections in each survey. Geographically, the AWWA-LIS information indicates that lead connection occurrence is higher in the eastern and upper midwestern regions of the United States. When comparing the two surveys, the percentage of lead connections for each state either remained the same or were higher for the AWWA-LIS data. The exceptions are the higher percentage of lead connections in the states of Idaho, Massachusetts, and New Mexico in the EPA Survey. This is most likely because the utilities that were surveyed in these states varied between the two databases, and the utilities in the EPA Survey contained more lead connections.

Nationwide occurrence of lead connections was extrapolated from results of the AWWA-LIS. The geographic distribution of lead connections is shown in Figure 2-11. Significant numbers of lead connections occur in the upper mid-west, east, and many of the states bordering the Gulf of Mexico. Also, the estimated number of total lead connections for the state of Washington is as much as 30,000 higher than surrounding states in the western U.S.

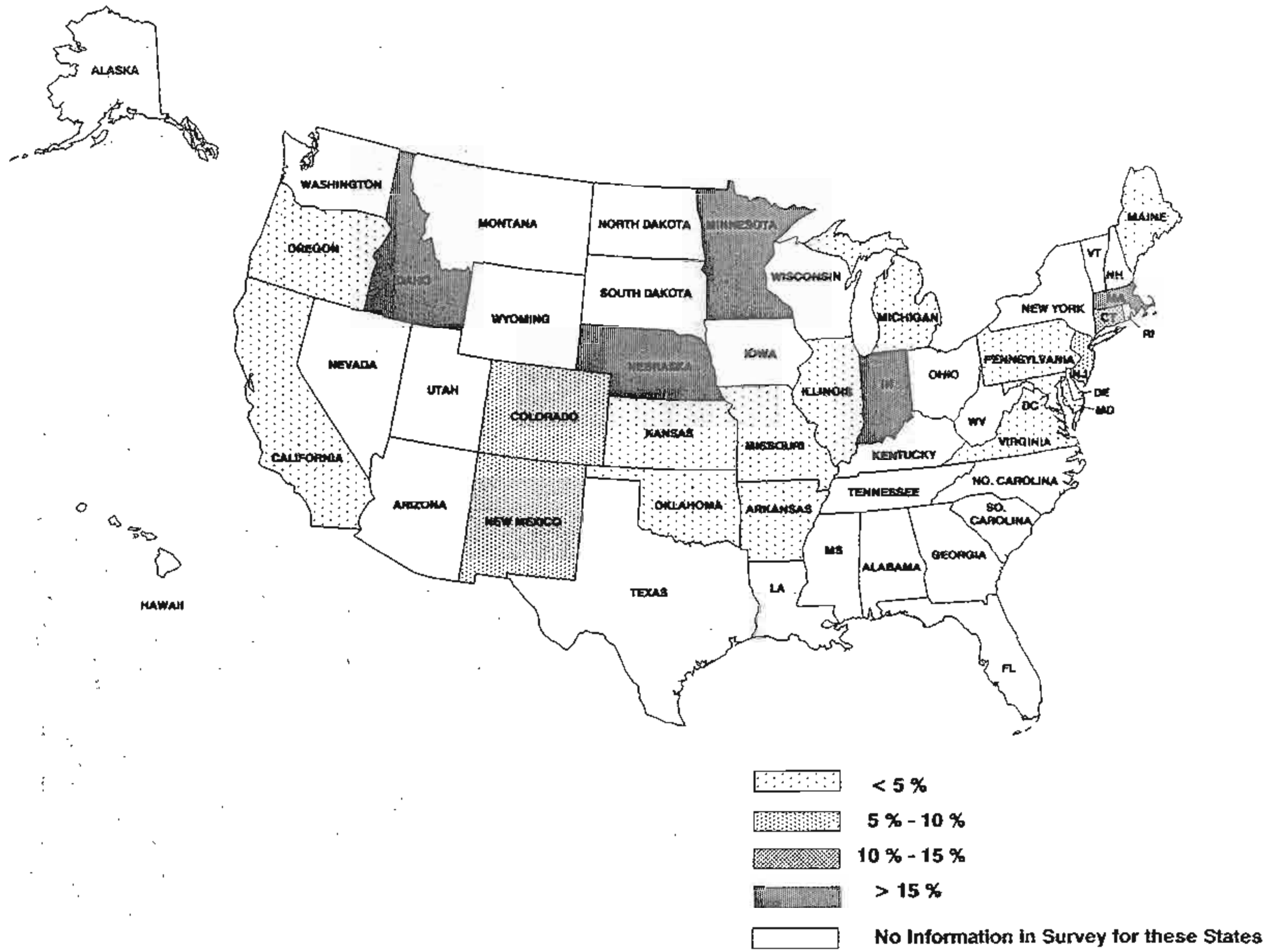


FIGURE 2-9 PERCENT OF CONNECTIONS IN SURVEY WHICH ARE LEAD: EPA LEAD PRODUCT USE SURVEY

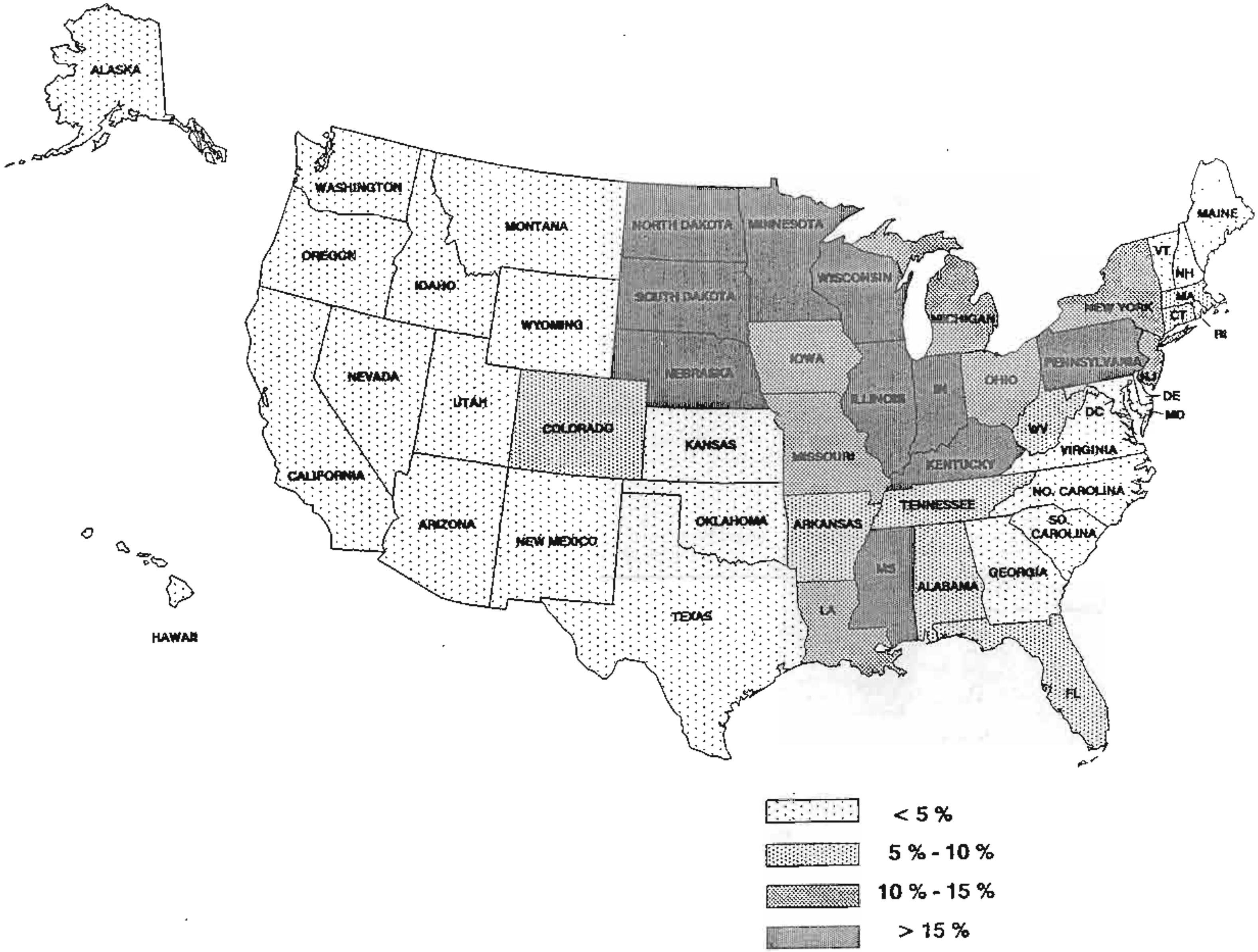


FIGURE 2-10 PERCENT OF CONNECTIONS IN SURVEY WHICH ARE LEAD: AWWA-LIS

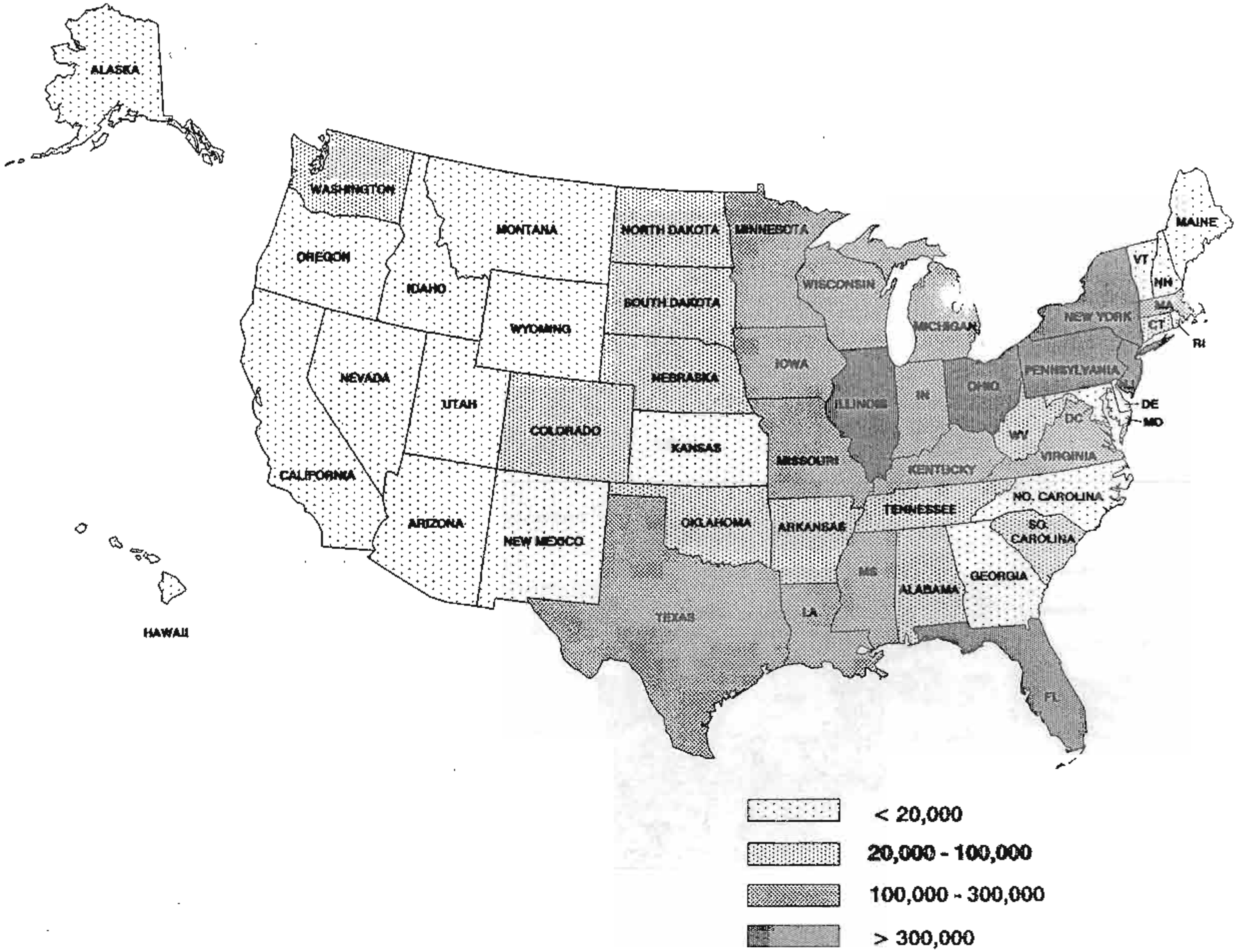


FIGURE 2-11 NATIONWIDE EXTRAPOLATION - ESTIMATED TOTAL NUMBER OF LEAD CONNECTIONS: AWWA-LIS

2.6.2 Lead Service Lines

Results of evaluating lead service line occurrence from the EPA Survey and the AWWA-LIS are presented in Figures 2-12 and 2-13. These figures depict the percentage, or prevalence of service lines that are lead based on the total number of connections in each survey. In general, both databases exhibit a higher percentage of lead materials in the eastern and upper midwestern regions of the United States. As with lead connection occurrence, a comparison of the two databases indicates that the percentages either remained within the same range or became higher in the AWWA-LIS. In comparing lead service line prevalence between the two surveys, the states of Minnesota, Iowa, Indiana, Virginia, New Jersey, New Mexico, and Massachusetts all exhibited higher percentages of lead service lines in the EPA Survey than what was estimated in the AWWA-LIS. For the states of Minnesota, Iowa, Indiana, and Virginia, the AWWA-LIS contained a significantly higher number of utilities and is probably more representative of these states as a whole than the EPA Survey. The utilities representing the states of New Jersey, Massachusetts, and New Mexico were similar in number between the two surveys; however, the utilities included were not the same, accounting for the discrepancy in lead service line percentages. Generally, states with higher numbers of lead service lines exhibit even higher lead connection occurrence.

Nationwide occurrence of lead service lines was extrapolated from results of the AWWA-LIS Survey. The geographic distribution of lead service lines is shown in Figure 2-14. Lead service lines occur in greater numbers in the midwestern and northeastern half of the United States, particularly around the Great Lakes region.

2.6.3 Summary

In general, both databases exhibit higher percentages of lead materials in the eastern and upper midwestern regions of the United States. Based on the technical approach described previously, the total number of lead connections and lead service lines in the United States is estimated at:

Lead Connections - 6.4 Million
Lead Service Lines - 3.3 Million

Sensitivity of Assumptions

These estimated numbers are dependent on and highly sensitive to the assumptions made for (1) typical service line length, and (2) the total number of connections for each state. For example, varying the typical service line lengths by plus or minus 20% will impact the estimated number of lead service lines by the following percentages:

% Change in Assumption of Typical Service Line Length	Change in Estimate of Total Number of Lead Service Lines
− 20 %	4.1 million (+24%)
+ 20 %	2.7 million (−18%)

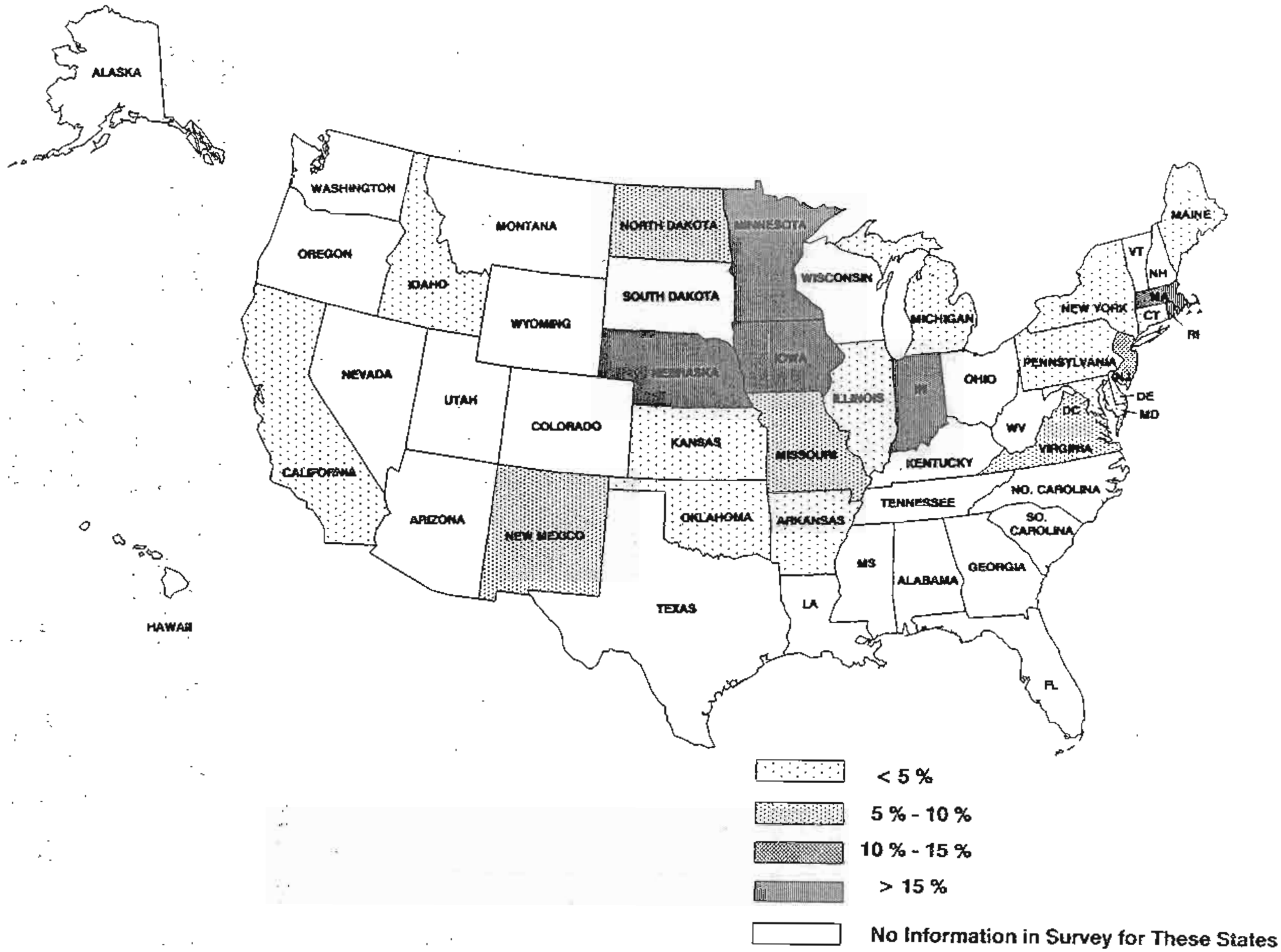


FIGURE 2-12 PERCENT OF SERVICE LINES IN SURVEY WHICH ARE LEAD: EPA LEAD PRODUCT USE SURVEY

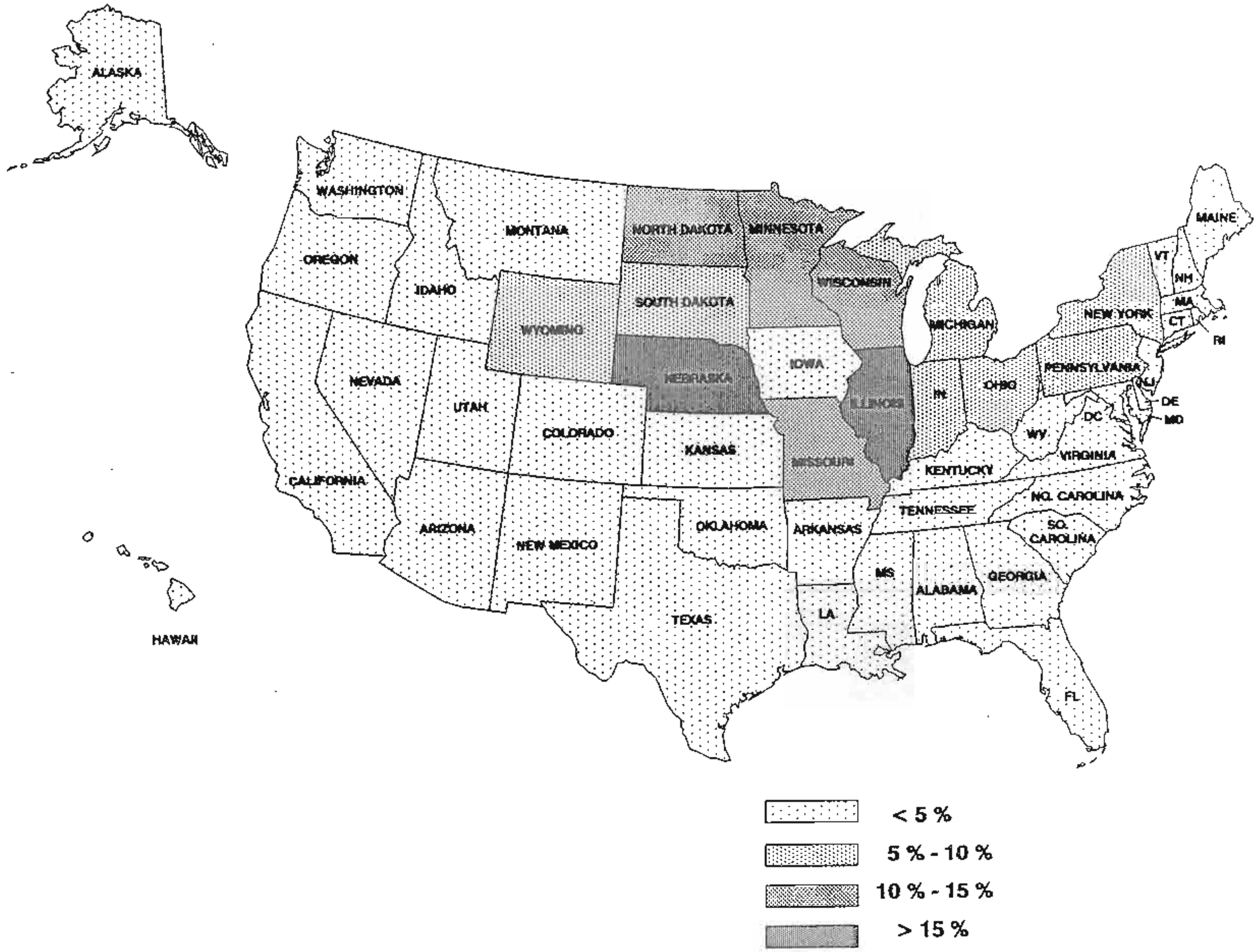


FIGURE 2-13 PERCENT OF SERVICE LINES IN SURVEY WHICH ARE LEAD: AWWA-LIS

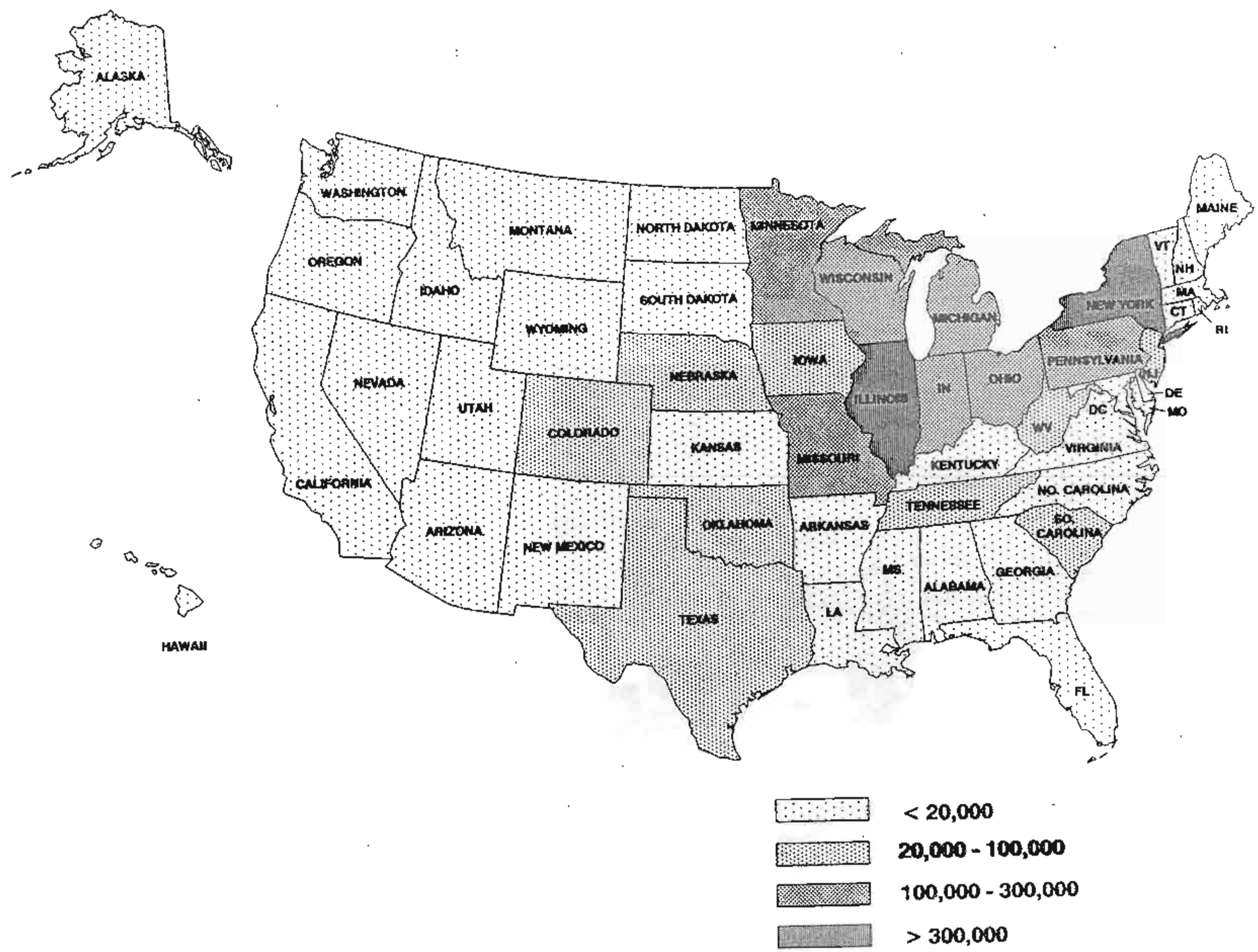


FIGURE 2-14 NATIONAL EXTRAPOLATION - TOTAL NUMBER OF LEAD SERVICE LINES: AWWA-LIS

By decreasing the assumption for typical service line length, the total number of lead service lines estimated will increase. This is a result of using the following equation to estimate total lead service lines:

$$\text{\# Lead Service Lines} = \frac{\text{Feet of Lead Service Line from Survey}}{\text{Typical Length/Service Line}}$$

Adjusting the assumption for total service connections in each state will impact the estimates for both total lead service lines and lead gooseneck connections. Total service connections were estimated using the total population served by public water systems and assuming that 3 people were served per connection, i.e.:

$$\text{Total Service Connections} = \frac{\text{Population Served}}{\text{3 People/Connection}}$$

Changing the assumption of number of people served per connection by plus or minus 20 % (3.6 or 2.4 people per connection) would change the estimate of total lead service lines and lead connections by the following percentages:

% Change in Assumption of # People/Connection	Change in Estimates of Lead Service Lines	Lead Connections
− 20 % (2.4 per connection)	4.1 million (+24%)	8.0 million (+25%)
+ 20 % (3.6 per connection)	2.7 million (−18%)	5.4 million (−16%)

Using an assumption of fewer people per connection (2.4 rather than 3 or a change of −20 %) will increase the total number of connections estimated. This will also increase the estimates of total lead service lines and lead goosenecks because they are based on the total connections multiplied by the percentage of connections which have either a lead gooseneck or a lead service line.

Adjusting both the typical service line length and the assumption for number of people served per connection will impact the estimate for total number of lead service lines as follows:

% Change in Assumptions: # People per Connection	Typical Service Line Length	Change in Estimate of Lead Service Lines
+ 20 %	+ 20 %	2.3 million (−30%)
+ 20 %	− 20 %	3.4 million (+30%)
− 20 %	− 20 %	5.1 million (+55%)
− 20 %	+ 20 %	3.4 million (+ 3%)

This analysis demonstrates the sensitivity in the estimates of total lead service lines and lead goosenecks to the assumptions made to arrive at these numbers. Other estimates are, or will be, available for comparative purposes. The U.S. EPA has estimated that there are 4.4 million lead service lines in the United States (U.S. EPA, 1988). The American Water Works Association is in the final stages of completing a database of the water industry, which will also provide information on the number of lead services and connections. This database will contain information from approximately 450 utilities throughout the United States and specifically requested information on lead materials.

2.7 OWNERSHIP AND JURISDICTIONAL ISSUES

The method of determining ownership of service lines was evaluated from the AWWA-LIS. Figures 2-15 and 2-16 display the categories for ownership determination, the number of utilities in each category, and the percentage of the total. The majority of utilities indicated that an ordinance, or ordinance in combination with either a building code, contract, or informal agreement, was the method of determining ownership of service lines. Eight utilities listed some other method for determining ownership, such as standard details, state law, or tariff. The number of utilities in each category is:

Ownership Category	# of Utilities	% of Total
Ordinance (alone or in combination with other methods)	308	76.6
Informal Agreement	38	9.5
Contract	25	6.2
Building Code	13	3.2
Rules and Regulations	10	2.5
Other	8	2.0

The results of categorizing the descriptions of jurisdiction are contained in Figures 2-17 and 2-18. While the vast majority of utilities listed some form of partial jurisdiction, i.e., jurisdiction of the service line to the meter, curb stop, right-of-way etc., 20% of the utilities in the AWWA-LIS indicated they had no authority over the service line. The following table summarizes the percentage of utilities from the AWWA-LIS in each category:

Jurisdictional Category	% of Utilities
Complete	1.0
Partial	69.8
Connection	9.2
None	20.0

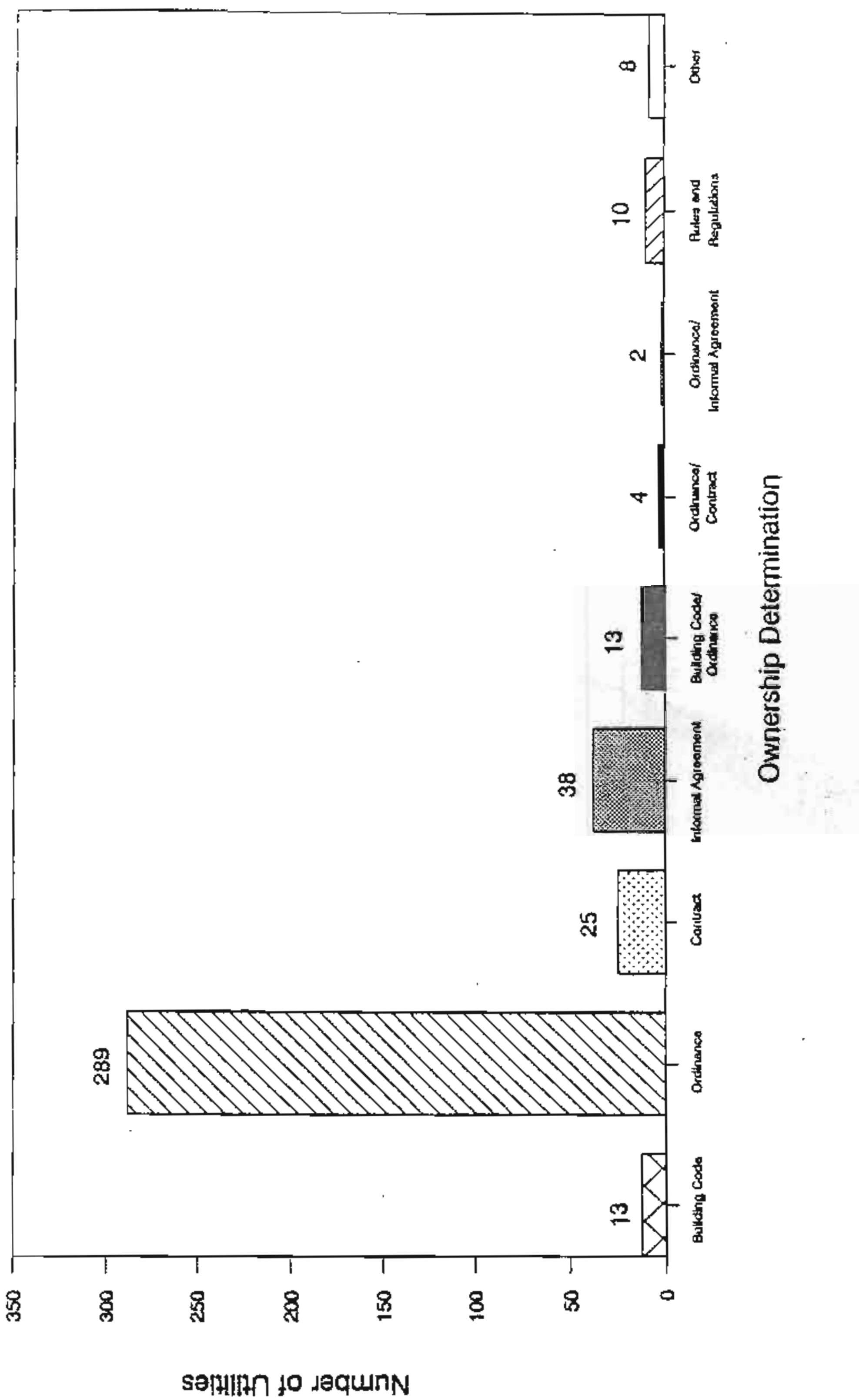


FIGURE 2-15 RESULTS OF THE AWWA-LIS: HOW OWNERSHIP IS DETERMINED AND THE NUMBER OF SYSTEMS IN EACH CATEGORY

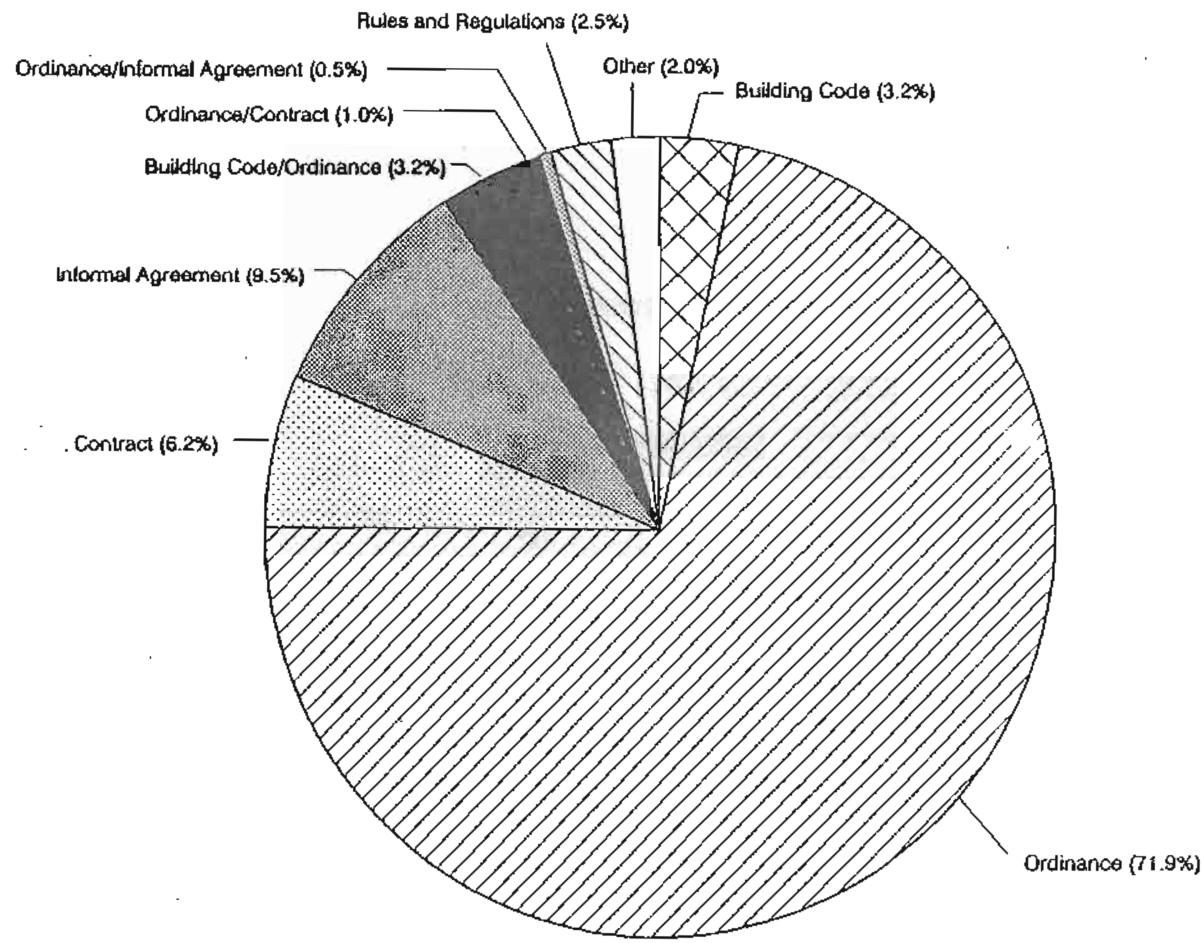
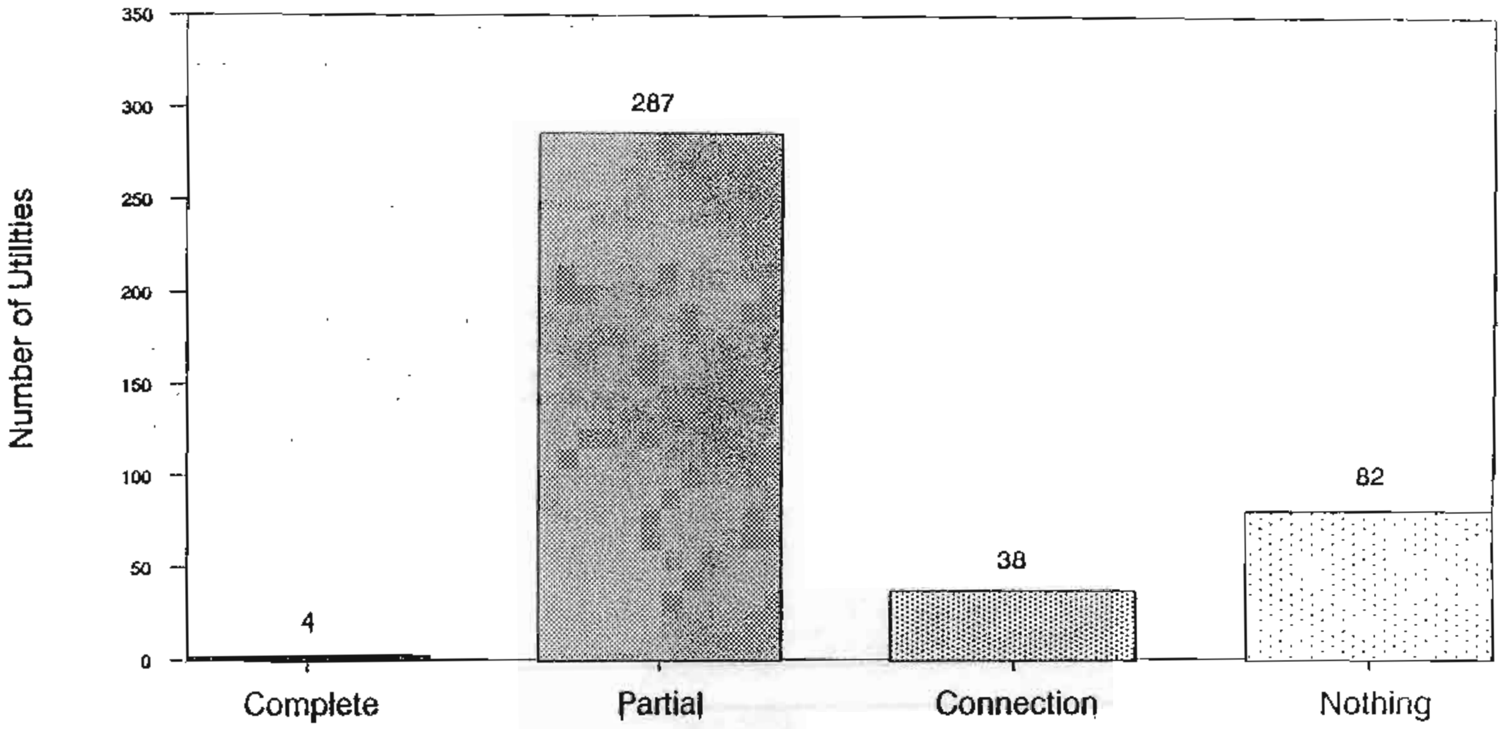


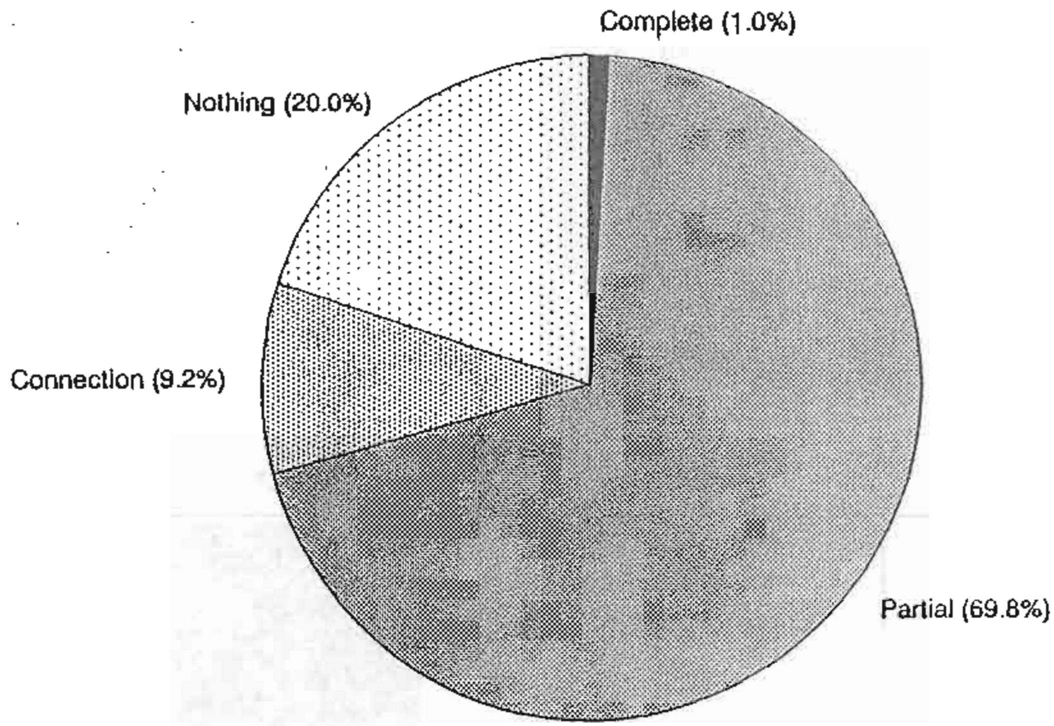
FIGURE 2-16 RESULTS OF THE AWWA-LIS: HOW OWNERSHIP IS DETERMINED AND THE PERCENT OF SYSTEMS IN EACH CATEGORY



KEY

Complete	- Entire Service Line
Partial	- Service Line for a Specified Distance (meter box, curb stop, ROW, property line, etc.)
Connection	- Jurisdiction over the Connection Only
Nothing	- No Jurisdiction over the Service Line (Utility owns only the Main and/or Meter)

FIGURE 2-17 RESULTS OF THE AWWA-LIS: SERVICE LINE JURISDICTION AND THE NUMBER OF SYSTEMS IN EACH CATEGORY



KEY

Complete	- Entire Service Line
Partial	- Service Line for a Specified Distance (meter box, curb stop, ROW, property line, etc.)
Connection	- Jurisdiction over the Connection Only
Nothing	- No Jurisdiction over the Service Line (Utility owns only the Main and/or Meter)

FIGURE 2-18 RESULTS OF THE AWWA-LIS: SERVICE LINE JURISDICTION AND THE PERCENT OF SYSTEMS IN EACH CATEGORY

Table 2-2 contains a state breakdown of jurisdictional issues obtained from the AWWA-LIS. All the utilities that indicated they had complete jurisdiction over the service line (from the main to the house) were from EPA Region 5; however, this Region also contained a large number of utilities with no jurisdiction over the service line. Region 6 also contained a relatively large percentage of utilities with no authority over any portion of the service line.

Table 2-2

Jurisdictional Categories by State from the AWWA-LIS

State	Number of Utilities				Totals
	Nothing	Connection Only	Partial	Complete	
CT	1	3	5		9
ME		2	2		4
NH		1	3		4
RI			1		1
VT	1		1		2
MA	1	1	2		4
REGION 1 - TOTAL	3	7	14	0	24
NJ			4		4
NY	8	1	25		34
REGION 2 - TOTAL	8	1	29	0	38
DE					
MD			2		2
PA	4	1	12		17
VA			11		11
DC			1		1
WV			4		4
REGION 3 - TOTAL	4	1	30	0	35
AL	1		2		3
MS		2	2		4
KY	1		4		5
FL		1	7		8
GA			1		1
NC			3		3
SC			3		3
TN		2	6		8
REGION 4 - TOTAL	2	5	28	0	35
IL	5		16		21
MN	8		10	1	19
WI	3	1	30	2	36
IN	4	3	19		26
MI		4	19	1	24
OH	2		20		22
REGION 5 - TOTAL	22	8	114	4	148
AR		1	3		4
LA		1	2		3
NM		1			1
OK		1	1		2
TX			5		5
REGION 6 - TOTAL	0	4	11	0	15

Table 2-2
(continued)

State	Number of Utilities				Totals
	Nothing	Connection Only	Partial	Complete	
IA	11		6		17
KS		1	7		8
MO	7	1	5		13
NE	7		9		16
REGION 7 - TOTAL	25	2	27	0	54
CO	7	1	7		15
MT	1				1
ND	1		1		2
SD	5		1		6
UT		1	4		5
WY	3		2		5
REGION 8 - TOTAL	17	2	15	0	34
AZ			2		2
CA	1	3	7		11
HI					0
NV					0
REGION 9 - TOTAL	1	3	9	0	13
AK					0
ID					0
OR		2	5		7
WA		1	2		3
REGION 10 - TOTAL	0	3	7	0	10

SECTION 3

IDENTIFYING AND LOCATING LEAD SERVICE LINES

SECTION 3

IDENTIFYING AND LOCATING LEAD SERVICE LINES

3.1 INTRODUCTION

To conduct an effective lead service line replacement program, a water utility must be able to identify the pipe or connection material and the specific location of these services so that they can be efficiently excavated and replaced. A utility's ability to replace lead services depends upon a utility's ability to find those lead services. For example, the most desirable identification method is a database that lists each customer's address and the service material. In practice, however, these data are rarely available to the utility because recording the material used for customer services has not always been done. Most water utilities have no direct records linking service type and location; these utilities must rely on indirect predictive methods and/or employ a program of direct observation by meter readers or other employees.

This section describes the potential methods that water utilities can use to identify and locate lead service lines. A total of 35 utilities were surveyed via telephone to obtain their estimates of the number of lead service lines and to assess their ability to locate them. Also described in this section is the current state-of-the-art equipment for locating buried pipe and an assessment of the ability to determine material type by using this equipment. Additional information on identification and location techniques was obtained by visiting the three case study utilities: Washington, DC (population served: 650,000); Kenosha, WI (90,000); and Philadelphia, PA (1,690,000) and investigating their records management systems. Finally, the information obtained was used to create three typical scenarios for identifying service materials that we believe would be used by utilities (see Subsection 3.4). All utilities contacted during this task were placed into a category based on various factors, including condition of service records and whether or not the utility was metered. The distribution of the sample (see Tables 3-4 through 3-7) was compared to that of all systems throughout the country, thus generating an initial list of the country's current ability to identify, locate and replace lead service lines.

3.2 OBJECTIVES

The objectives of this task were to:

- Determine water utilities' recordkeeping methods by conducting a telephone survey of systems across the country known to have lead services.
- Estimate the percentage of lead services that cannot be identified by assessing the ability of systems to specifically identify their services.
- Document techniques for locating buried pipe and identifying pipe material.

- Determine how utilities would carry out a replacement program by evaluating all potential identification techniques.

- Identify three case study utilities and make a detailed assessment of their identification and location methods and determine how they would conduct a replacement program.

3.3 TELEPHONE SURVEY DESCRIPTION

To evaluate the ability of water utilities to identify and locate specific lead service lines and connections and the cost of such a process, the project team conducted a telephone survey of 35 systems across the country. The 1988 AWWA Lead Information Survey (AWWA-LIS) was the source of utility contacts.

A questionnaire was prepared and administered to each contact. Its main purposes were to determine the level of information available for identifying lead service lines and connections and to obtain additional information on replacement costs and service line characteristics. Appendix A presents the questionnaire used in this study. Table 3-1 lists the 35 contacted utilities.

Care was taken to ensure that the utilities contacted were representative of the 439 systems which responded to the AWWA-LIS and indicated the presence of lead service lines and/or connections. Table 3-2 compares the population distribution of the utilities contacted for the Project Telephone Survey with the AWWA-LIS. Table 3-3 compares the geographic distribution of utilities contacted for both surveys.

3.4 LEAD SERVICE LINE IDENTIFICATION TECHNIQUES

The findings of the project telephone survey and the three case studies indicate that there are a limited number of options available to a water system in attempting to specifically identify which customers have lead service lines. None of the water systems investigated were aware of any viable sophisticated techniques for identifying a lead service line. All would have to rely on: 1) the use of existing records of service line installation; 2) a subjective judgment based on the age and general locale of the particular address; 3) physical inspection of the service line; or 4) a combination of the above.

3.4.1 Use of Existing Records

Some water systems have maintained detailed records of service line installations. These records usually contain, at a minimum, the address and date of installation of the service line. They often also contain an indication of the material used. If this is the case, a water system can easily identify the original service line material at a particular address. If the records are incomplete, (and all systems examined had some data gaps), the service lines for which the material is known can be used to statistically determine the probability of other addresses in the system having a lead service line. Computerization of manual paper

Table 3-1
Water Systems Surveyed

Location	Population Category	EPA Region
Fair Haven, VT	1	1
Winona, MS	2	4
Falls City, NE	2	7
Crossett, AR	2	6
Willmar, MN	3	5
Fairmont, MN	3	5
North Ogden, UT	3	8
Allouez, WI	3	5
El Centro, CA	3	9
Norwich, CT	3	1
Wheeling, WV	3	3
White Plains, NY	3	2
Cape Girardeau, MO	3	7
Kenosha, WI	4	5
Clarksburg, WV	4	3
Morgantown, WV	4	3
Marion, OH	4	5
Elmira, NY	4	2
Green Bay, WI	4	5
Mission, KS	4	7
Clearwater, FL	4	4
Virginia Beach, VA	4	3
Philadelphia, PA	4	3
Washington, DC	4	3
Seattle, WA	4	10
San Francisco, CA	4	9
Salt Lake City, UT	4	8
Lansing, MI	4	5
Peoria, IL	4	5
Madison, WI	4	5
Sioux Falls, SD	4	8
Flint, MI	4	5
Gary, IN	4	5
Des Moines, IA	4	7
Independence, MO	4	7

Population Categories:

1: 25-3,300 customers
2: 3,301 - 10,000 customers
3: 10,001 - 50,000 customers
4: > 50,000 customers

Table 3-2

Coverage of AWWA-LIS and Project Telephone Survey Distribution by Population

Category	Population Served	Percent of Systems	
		AWWA-LIS	Project Survey
1	< 3,300	20	3
2	3,301 - 10,000	24	9
3	10,001 - 50,000	31	26
4	> 50,000	25	62

Table 3-3

Coverage of AWWA-LIS and Project Telephone Survey Distribution by EPA Region

EPA Region	No. of Utilities Reporting Lead (AWWA-LIS)	Percent of Total	No. of Utilities Contacted (Project Survey)	Percent of Total
1	26	6	2	6
2	40	9	2	6
3	37	8	6	17
4	41	9	2	6
5	156	36	11	31
6	16	4	1	3
7	56	13	5	14
8	36	8	3	9
9	17	4	2	6
10	14	3	1	3
	Total 439		Total 35	

data records would generally be required to carry this out and the development of a predictive technique would require follow-up inspections or excavation for verification.

3.4.2 Use of Subjective Judgment

Water utilities that do not maintain such detailed records of their service lines often still have an intuitive "feel" for their system. Often this is due to previous experience replacing entire sections of main in particular areas of the system. Usually, the older sections of the system are known, and these can usually be given a higher probability of lead service. Although this technique may not be able to identify the service material for specific addresses, it can be used to focus attention on those areas most likely to have lead service lines.

3.4.3 Physical Inspection

Finally, some utilities have no means of identifying lead service lines, either at specific addresses or by general area. These utilities must rely on a physical inspection of the service line. There are two basic means of accomplishing this: 1) excavating at the service line or 2) observing the line where it enters the customer's home. A simple way of doing the latter, for those systems with inside meters, is to have meter readers examine the line as part of their duties. A major drawback of this method is that the pipe material identified is the portion which typically belongs to the homeowner and which may differ from the utility's portion.

A final possible identification technique is the use of water quality sampling. However, relying on the homeowner to correctly collect a water sample representative of water standing in the service line would be highly unreliable. Using water system personnel to collect the samples would decrease, but not eliminate, this problem, but would also greatly increase the cost of such a program. Finally, depending on the specific local water quality conditions, a lead service line may not be contributing any lead into the water. It is extremely difficult to collect a sample that can pinpoint a lead service line. Thus, although it may be possible to identify some lead service lines, water quality sampling would not be allow pinpointing all lead service lines.

3.5 BURIED PIPE DETECTION TECHNIQUES

All of the above techniques require a water system to have on hand certain information or to perform lengthy and possibly costly physical investigations. Therefore, a study was made of existing technology to determine if it was possible to identify service line material in the field without excavation and without entering the customer's home.

Water utility system files are probably the most cost-effective means of locating lead service lines. In many cases, however, there is insufficient data to locate lead services; therefore, physical methods must be used to ascertain the presence of buried lead pipes. Service lines cannot be directly examined without access to the customer's premises and/or excavation. Therefore, the use of remote sensing techniques would be of substantial benefit.

An investigation of the following geophysical methods was conducted:

- Ground Penetrating Radar.
- Electrical Conductivity.
- Metal Detectors.
- Resistivity Survey.
- Magnetometer Survey.
- Fiber Optic Instruments.

Each method was researched to determine its effectiveness and expected accuracy in locating and identifying buried lead pipes.

3.5.1 Description of Techniques

3.5.1.1 Ground Penetrating Radar

Ground Penetrating Radar is a surface interface radar which transmits an electromagnetic pulse into the subsurface. The time the pulse takes to travel from the antenna to the buried object and back to the antenna is dependent on the depth of the object and the properties of the media through which the pulse travels.

This method can be used to determine the location of a buried metal object, but cannot be used to obtain information on the nature of the metal object. The depth of radar penetration is very site specific. This depth is reduced if water or fine-grained materials are encountered. In some cases the radar pulse and penetration may not exceed three feet.

3.5.1.2 Electrical Conductivity

The instrumentation consists of a transmitter coil that radiates an electromagnetic field, which includes current loops in the earth, and which acts as a conductor.

Electrical conductivity is mostly used to find lateral and vertical variations of soil in the subsurface, to locate buried materials, and to determine the presence of plumes and distribution of contaminants in groundwater.

Metals are of much higher conductance and are readily visible because of the higher currents generated. Unfortunately, the differences in conductivity of lead, copper, and iron are not large enough to furnish a characteristic profile for each material.

An alternative electrical conductivity method consists of directly measuring the electrical conductance of the pipe. This requires access to two points in the service line either by excavation or by entry to the residence.

3.5.1.3 Metal Detectors

The metal detector responds to changes in electrical conductivity caused by the presence of metallic objects, both ferrous and nonferrous. The magnitude of response from a metal detector is a function of several variables including target to sensor distance, target size, and type of metal.

Among the various types of metal detectors, the detector used for locating buried drums may also be used for locating utilities, but, in general, these detectors have been found to be insensitive to buried objects of small cross-section.

Based on a survey of over 20 leading metal detector manufacturers in the country, the permeabilities of lead and copper are too similar to distinguish between the two with any degree of certainty by metal detectors presently on the market. Additional research, and a market for the product, could result in metal detectors capable of identifying and locating buried lead pipe.

3.5.1.4 Resistivity

This method provides similar data as using the electrical conductivity method. It measures the electrical resistivity (or its inverse conductivity) of the subsurface or geohydrologic section.

The limitations of this method are similar to those of the electrical conductivity method. In this case, the differences in the electrical resistivity of lead, copper, and iron are not large enough to furnish a characteristic profile for each material.

3.5.1.5 Magnetometer

The magnetic method detects variations in magnetic susceptibility within the subsurface environment. The magnetometer is commonly used to locate ferrous metals. The response is proportional to the mass of the ferrous target.

Magnetometers detect only ferrous metals such as underground iron pipes or tanks. They do not respond to nonferrous metals such as lead and copper, and will not distinguish among them.

3.5.1.6 Fiber Optic Instruments

A fiberscope is comprised of a light source unit, an eyepiece, and a flexible probe containing optical fibers that transmit the image. Fiberscopes have been used as inspection tools in boiler tubes and to verify remedial work such as pipe linings. Commonly used to acquire information on the condition of pipelines, fiberscopes provide a practical way of visually inspecting inaccessible pipelines without having to cut a short sample of pipe.

Fiberscopes have been used in the water industry to inspect water mains. Access to the mains is gained by feeding the scope through a hydrant. It is possible to apply this method to determine the service line material, although the scope would be required to negotiate sharp bends in a small diameter space. External inspection is also a possibility. A small hole could be quickly bored next to the service line, giving the scope a chance to view the outside of the pipe.

Several difficulties arise when attempting to apply fiberscopes to water systems:

- Requires steering through hydrant to main and then to 3/4" connection service line for internal inspection.
- Requires negotiation of severe bends in cases where access via the water meter is possible.
- Involves the risk of damaging the service line when excavating for external inspection.
- Requires disruption of service for internal inspection because few fiberscopes are able to withstand the main's pressure.

3.5.2 Applicability to Lead Service Line Identification

After investigating the various methods of buried pipe detection and identification techniques, it was determined that none of the methods are currently able to discern a lead service line from another buried metallic object, especially in an urban or suburban setting. The typically deep location of the services (3 to 5 feet) and the proximity of other buried utilities combine to exceed the current state-of-the-art in detection techniques.

Several manufacturers of metal detectors indicated that it is theoretically possible to develop an instrument of suitable power and material distinction capabilities if there were a large enough market to justify the research and development costs. Such a market could exist if a nationwide lead service line and connection replacement program was ordered. However, the uncertainty of the amount of research required and the cost of development does not allow for considering such devices as part of an anticipated mandatory replacement program.

3.6 CASE STUDIES

3.6.1 Washington, DC Case Study

This water utility serves a major metropolitan area on the east coast of the United States, providing water to approximately 650,000 people. The utility purchases its water wholesale, and is responsible only for its distribution and storage. There are approximately 126,000 single-family residential service connections in the system. Average daily demand in 1989 was 181 million gallons per day (mgd).

The utility maintains an extensive database of service line installation information. At the present time, this information is recorded on paper records, some dating back to the late 1880s. Information on the records, called tap cards, includes the address of the service line installation, the date, a geographic reference known as the square, the service line diameter, property owner and installer name, location and size of main, and location of curbcock. There is no specific place on the tap card to record the service line material. However, for an extended period of time from the mid-1920s to about 1970, the installer of the service line usually made some indication of pipe material somewhere on the tap card.

As part of an ongoing project, information from the tap card file has been input into a computer database. The ultimate goal of this project is to determine the number and geographic distribution of lead service lines throughout the system. Information taken from the tap cards included the address, date, square, service line diameter, and service line material when available. The final database consisted of information on 126,099 service lines. Some of these service lines, however, had been abandoned or were no longer in use for residential service.

Once the basic tap database had been established from the tap card file, other sources of information were used to enhance this data and to fill in any gaps in the data.

- Meter Relocation Program. The utility has an ongoing meter relocation program intended to move meters from inside customers' homes to curbside. The crews performing this work record the service line material, both on the utility side as well as the homeowner side. This information on service line material was used to update the information already in the computer database for the particular address.

- Street Replacement Program. Under this program all service lines along a street are replaced when the street is being redone. Service line materials are recorded and used to update the database.

- Lead Service Line Replacement Program. Under this program lead service lines (utility portion) are replaced as they are discovered. This information is useful not only in identifying what were existing lead service lines, but also in accounting for service lines that have been replaced.

- Meter Location Program (Project Locator). Several years ago the utility undertook a major effort to locate all water meters in the system (i.e., inside or outside the house) prior to beginning their meter relocation program. When the meter was inside, the service line material could be identified and was recorded. This information was added to the database, but kept separate from other information on service line material, since it could document only the customer portion of the service line.

The completed tap database was then used to determine the number and distribution of lead service lines in the system. First, the addresses which had an indication of service line material, either lead or nonlead, were examined. In this case, almost two-thirds of the

126,099 addresses had an indication of service line material. Thus, the number of "known" lead and "known" nonlead service lines could be determined.

For the remaining addresses that had no indication of service line material, a statistical approach was used. It was believed that the use of lead service lines in the system was prevalent in the early part of this century and basically ended around 1950. Also, it was known that entire blocks of homes often had their service lines installed at the same time by the same contractor. Thus, if one of these was known to be lead, there was some probability that most or all would be lead. Listings of lead service line installations by date and geographic area were done for "known" lead and "known" nonlead service lines. These breakdowns were then used to calculate the number and distribution of lead service lines among the addresses that had no indication of service line material.

From this work, a methodology was developed for the utility to follow in determining whether or not a particular address had a lead service line. This methodology is illustrated in Figure 3-1.

3.6.2 Kenosha, Wisconsin Case Study

The Kenosha Water Utility serves a total population of 90,000, which includes wholesale service to other surrounding districts. The utility draws its water from Lake Michigan and has a purification plant on the lake's shoreline. The average daily demand in 1989 was 40 mgd.

The utility has documented in their main system files a total of 24,000 service line accounts, from as early as 1894. In addition to this file, there are four other independent files where information on the service line is stored:

- The main file cards contain the address, with a system map page number, the service line diameter, and date of permit.

- The streets and avenues file lists (between two cross-streets), the main size and date installed. It also indicates if a main has been replaced and the date of replacement.

- The services per year file is set up by year, starting in 1946 to today. It lists the number of services installed in a particular year, the service line diameter, the pipe material, and costs of installation.

- The service line retirements file is recorded since 1946. It lists the number of service lines that were "retired" in a year, the service line diameter, the pipe material, and costs information.

- The maintenance file was set up by address in 1978. It describes in detail the nature of the repair, the service line pipe material, and if replaced, the material used to replace the original line.

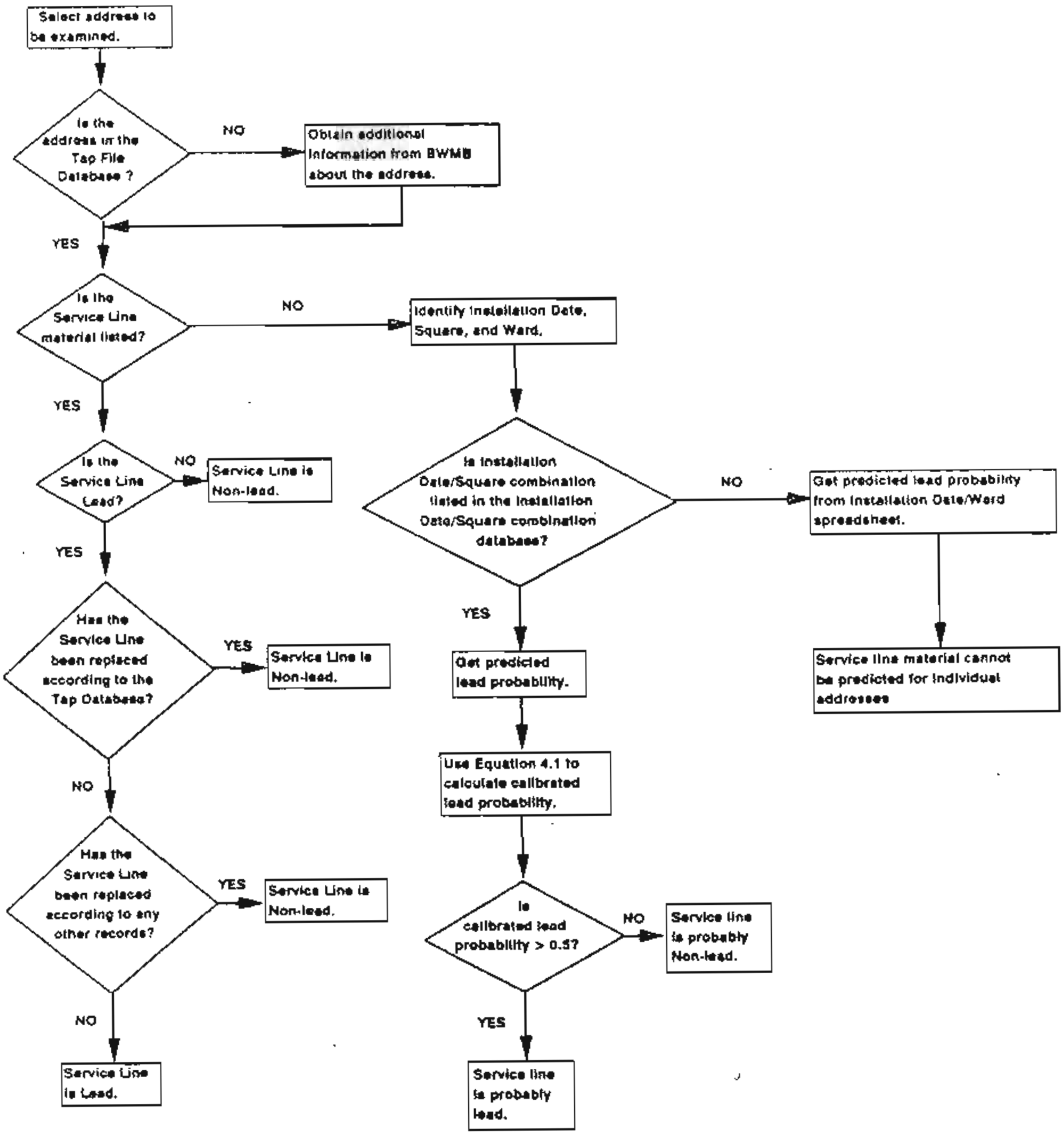


FIGURE 3-1 METHODOLOGY FOR IDENTIFYING SERVICE LINE MATERIAL

A database of service line installation information has been set up on a mainframe computer and is currently used only for billing purposes. The goal is to computerize all system data files. The address, the account number, the date of permit, service line diameter, and billing information are currently stored in the database. The pipe material is not indicated.

The water utility owns the main and service line up to the city right-of-way line. The property owner owns the service line from the curb-stop to the building and all interior plumbing. The meter is owned by the utility and located within one foot of the basement wall on the interior side.

In general, the mains are located offset from the center with respect to the street right-of-way, and the average length of a service line from the main to the curb-stop is 30 feet and from the curb-stop to the meter is 45 feet. All service line connections are currently metered and they are inspected once a year. Additionally, there is an on-going maintenance and building inspection program.

The main system files indicate that the last lead service connection from the main to the curb-stop was installed in 1946. Since the utility ownership stops at the curb-stop, there is no pipe material information on the service lines from the curb-stop to the meter.

In response to concern over lead in water, last year the utility published an article in the newspaper and offered to do free lead testing of the water for their customers. The utility received at least 700 responses attributed to the notice (which included services known to be lead), and first-draw water samples at the customer taps were tested for lead. The water quality results (available on a personal computer in dBASE III), indicate that three samples exceeded lead levels of 50 ppb. About 10 of them were between 20 and 50 ppb and the rest were lower than 20 ppb. However, comparisons of lead levels at the tap for lead services before and after replacement are not available.

Presently, there is no proactive lead replacement program. The general policy is that lead service lines are replaced as they are encountered, either during maintenance work or at customer's request. The typical replacement costs incurred by the utility, including pavement repairs, are $1,500 per service line. Replacement done from the main to the curb-stop is at no charge to the customer.

3.6.3 Philadelphia, Pennsylvania Case Study

The Philadelphia Water Department serves a total population of 1.69 million which includes other wholesale water customers. The utility draws and filters their water from the Delaware and Schuylkill Rivers.

The utility has documented in their system files a total of 500,000 active service line accounts, from as early as 1840. There are two file systems.

- The main file cards. "Ferrule" records are indexed by address in alphabetical order. They contain the date and number of the original permit, house number, pipe material, and service line diameter. Whenever maintenance is performed on a line, the "Ferrule" card is updated which, in turn, indicates that the information has been transferred into a database.

- A database of service line maintenance and newly installed lines has been implemented on a microcomputer, but is currently used only for billing purposes. The on-going project was initiated in 1985, and the goal is to computerize all system data files. The database maintains information on 78,398 accounts. Each record contains the account number, permit number, address, installation or repair date, service line size and pipe material, main size and depth, main location, curb-stop location, sidewalk width, and street width.

The water utility owns the main and the meter. The property owner owns the service line from the main to the curb-stop, from the curb-stop to the building, and all interior plumbing.

The utility manages 3,200 miles of mains with an average 500 services per mile in the older, more densely populated areas. The main replacement program currently replaces approximately 12 to 18 miles of main per year.

The mains are offset from the center with respect to the street right-of-way. The average length of a service line, from main to curb-stop, is 15 feet and 40 feet from curb-stop to meter. All service line connections are currently metered and inspected approximately once a year. Meters are typically located within two feet of the basement wall on the interior side.

The main system file cards indicate the presence of cast iron mains with lead goosenecks dating as far back as 1840. It is believed that lead service connections from main to curb-stop were phased out in the 1940's. There is no pipe material information on the service line from curb-stop to meter.

Philadelphia Water Department authorities estimate that the percentage of lead service lines remaining in service varies between 25% and 33% across the system. An estimated 50% of the original lead services have been replaced with nonlead material.

A water quality monitoring program was initiated by the utility in response to concern over lead in water. Approximately 200 randomly selected first-draw water samples (which included services known to be of lead) were tested for lead. For first-draw water samples collected from the lead service line, lead levels ranged from 15-25 ug/L.

Since the lead service lines are privately owned, there are no city-sponsored programs for the general replacement of lead service lines. The general policy is that lead service lines are replaced at the customer's request or, if necessary, during maintenance work. Replacement lines are of copper. Typical replacement costs incurred by the customer, including pavement repairs, are approximately $1,300 per service line.

There is, however, an on-going replacement program of lead goosenecks and service lines at main-service line connections. These are replaced whenever encountered during maintenance procedures and water main re-lays. The replacement is done up to the curb-stop at no cost to the customer.

Currently, the system data does not permit the specific identification of lead services. If a mandatory replacement program were implemented, additional information would be required. This could be collected by pipe inspection during meter readings, main re-lays, gooseneck replacement, or by conducting a customer survey.

3.7 SCENARIOS FOR IDENTIFICATION

After completing the telephone survey and examining the findings of the three case studies, two scenarios for identifying lead service lines as part of a mandatory replacement program were developed. A third scenario, for those systems with no ability to identify lead service lines other than through excavation, was also considered.

3.7.1 Scenario I

Water systems which fit this scenario would be able to identify the service line material for most, if not all, of the addresses in their system. The scenario is characterized by an existing recordkeeping system in which data on the service line materials are maintained. If the records are incomplete, the probability of a lead service line existing at a given address can be assigned based on the distribution of the service lines with known material. (A test excavation program would be necessary to verify these probabilities.) A computerized database, while not absolutely necessary in small systems, would certainly facilitate this sort of program. Case Study 1 would fit this scenario.

3.7.2 Scenario II

Water systems in this scenario would rely on meter readers or internal inspection of the line entering the customer's premises to identify service line material, since no other data sources exist. Because meters are typically read two to four times per year (and not all addresses can be accessed every time), it is expected that a program of this type could take over one year to complete. In addition, meter-readers would need to be trained to identify different pipe materials, and a procedure for recording and maintaining these data would have to be established. Finally, the identification of service line material would be valid only for the customer's portion of the line. The utility's portion may not always be the same material, and lead goosenecks may exist with a variety of service line materials. Case Studies 2 and 3 would fall under this scenario.

3.7.3 Scenario III

Those water systems which have little or no data on service line installations, are not metered, and would not choose to enter into a program of gaining entrance to private property to inspect the customer's service at point-of-entry, would fall under this scenario.

These water systems would have to rely on service line excavations to identify service material.

3.7.4 Additional Identification Technique

One other possible technique for identifying lead service lines was considered but not used in the final scenarios. Water quality sampling was rejected as being too costly and unreliable for service line identification purposes.

3.7.5 Scenario Distribution

The 35 systems which were part of the telephone survey on the case studies were segregated into the three replacement scenarios. A summary of the scenario distribution by system size is given in Table 3-4.

3.8 UTILITY DISTRIBUTION

The distribution of the 35 contacted water systems (32 by phone survey plus 3 case studies) across the three replacement scenarios was used as a guideline for determining the number of water systems throughout the country that would fall into each replacement scenario (Table 3-5). The percentage of systems in each scenario was adjusted to account for the likelihood that systems of all sizes could be found to fit each of the scenarios. For example, 1 of 35 contacted systems had a population less than 3,300 persons, and it fell into Scenario III. It would be inappropriate to say, however, that all of the water systems serving less than 3,300 persons throughout the country also fell into Scenario III.

The mechanism for adjusting the national distribution of water systems into the three replacement scenarios was to use the percentage of systems in each size category that are metered. This allowed for placing an appropriate percentage of systems into Scenario III (which by definition are nonmetered) and into Scenario II (for systems with populations less than 3,300 persons). The number of systems in Scenario I was determined using the results of the 35 contacted systems for the larger population categories (> 10,000) with the assumption being that the smaller population categories (< 10,000) would have a corresponding smaller number of systems with the capabilities needed for Scenario I. The final nationwide analysis of water systems into the three replacement categories is given in Table 3-6 by population and in Table 3-7 by number of water systems.

Table 3-4

Scenario Distribution by Population Category

System Size	City, State	Scenario I	Scenario II	Scenario III
< 3,300	Fair Haven, VT			1
	% in Scenario	0.00%	0.00%	100.00%
3,301-10,000	Winona, MS		1	
	Falls City, NE		1	
	Crossett, AR		1	
	% in Scenario	0.00%	100.00%	0.00%
10,001-50,000	Willmar, MN		1	
	Fairmont, MN		1	
	North Ogden, UT		1	
	Allouez, WI		1	
	El Centro, CA		1	
	Norwich, CT	1		
	Wheeling, WV		1	
	White Plains, NY		1	
	Cape Girardeau, MO		1	
	% in Scenario	11.11%	88.88%	0.00%
>50,000	Kenosha, WI		1	
	Clarksburg, WV	1		
	Morgantown, WV	1		
	Marion, OH	1		
	Elmira, NY	1		
	Green Bay, WI		1	
	Mission, KS		1	
	Clearwater, FL		1	
	Virginia Beach, VA		1	
	Philadelphia, PA		1	
	Washington, DC	1		

Table 3-4
(continued)

System Size	City, State	Scenario I	Scenario II	Scenario III
> 50,000 (continued)	Seattle, WA		1	
	San Fransico, CA		1	
	Salt Lake City, UT		1	
	Lansing, MI		1	
	Peoria, IL		1	
	Madison, WI		1	
	Sioux Falls, SD		1	
	Flint, MI	1		
	Gary, IN	1		
	Des Moines, IA		1	
	Independence, MO		1	
	% in Scenario	31.82%	68.18%	0.00%

Table 3-5

Scenario Distribution of Contacted Systems

System Size	% Nation	Percent of Systems Contacted Scenario I	II	III
< 3,300	11%	0.00%	0.00%	100.00%
3,301-10,000	11%	0.00%	100.00%	0.00%
10,001-50,000	24%	11.11%	88.88%	0.00%
> 50,000	54%	31.82%	68.18%	0.00%

Table 3-6

Extrapolated Nationwide Distribution by Population

System Size	Total Population Served (Million)	Extrapolated Population (Million) Scenario		
		I	II	III
< 3,300	25.2	0.3	6.0	18.9
3,301-10,000	24.0	1.2	10.8	12.0
10,001-50,000	54.8	4.3	34.1	16.4
> 50,000	122.3	36.2	77.5	8.6
	226.3	42.0	128.4	55.9

Table 3-7

Extrapolated Nationwide Distribution by Number of Systems

System Size	Total Number of Systems	Extrapolated Number of Systems by Scenario		
		I	II	III
< 3,300	52,283	523	12,548	39,212
3,301-10,000	4,210	211	1,895	2,105
10,001-50,000	2,534	197	1,577	760
> 50,000	619	183	392	43
	59,646	1,114	16,412	42,120

SECTION 4

CONTRIBUTION OF LEAD SERVICE LINES AND CONNECTIONS TO ELEVATED LEAD LEVELS IN DRINKING WATER

SECTION 4

CONTRIBUTION OF LEAD SERVICE LINES AND CONNECTIONS TO ELEVATED LEAD LEVELS IN DRINKING WATER

4.1 OVERVIEW

The purpose of this section of the study was to evaluate the contribution of lead service lines and/or goosenecks to measured lead levels in drinking water. The specific subtasks were:

- Evaluate the impacts of water quality parameters on lead levels.
- Examine lead levels at the tap before and after lead pipe excavation or replacement.
- Tabulate water quality data as it relates to lead solubility by geographic area.
- Estimate potential lead reduction with effective water treatment.
- Develop a matrix table(s) for lead summarizing the major factors that influence lead levels at the tap.

The following discussion contains information on water quality impacts on lead levels, an evaluation of the estimated geographic distribution of water quality characteristics and the potential for lead leaching, material sources of lead and their relative contribution to measured lead concentrations, impact of replacement or removal of lead service lines and/or connections on lead levels, and the potential impact of water treatment on lead levels.

4.2 IMPACT OF WATER QUALITY ON LEAD LEVELS

4.2.1 Theoretical Discussion

The most important factors influencing lead levels in drinking water are: 1) the water quality characteristics, 2) the sources of lead in the system, 3) the physical properties of the piping system, 4) the sample collection procedures, and 5) stagnation time, i.e., the length of time the water has been standing in the pipe. The following discussion focuses on the water quality characteristics considered to have the greatest impact on lead levels. These parameters are pH, alkalinity, dissolved inorganic carbonate (DIC), and orthophosphate. These chemical characteristics are very much interrelated, and a change in one will directly or indirectly change the form or effectiveness of the others. Other parameters may also be important; however, the basic research to establish their relationships to lead solubility has not been done. A discussion of these important water quality characteristics, their relationship to various lead containing materials, and to lead levels in drinking water is presented below.

pH. pH is probably the most important water quality characteristic in lead mobilization and its control. pH is the negative logarithm (base 10) of the hydrogen ion concentration. On the pH scale of 0-14, a value of 7 represents a neutral condition (at 25°C). The effect of pH on lead solubility is very strong. Figure 4-1 is a 3-dimensional solubility surface of lead solubility in a system containing only DIC and H_2O (Schock & Wagner 1985; Schock 1985). In practice, lead levels in the field are often lower than computer model predictions though laboratory experiments produce levels that are very close to predicted values. These differences are likely caused by a multitude of factors including the impact of temperature on solubility and dissolution rates and the presence of protective films on the pipe which may not contain lead compounds.

Alkalinity. Alkalinity is defined as the capacity of water to neutralize acid. It is typically expressed in terms of mg/L of $CaCO_3$. Waters with low alkalinities, <25 mg/L as $CaCO_3$, have very little capacity to neutralize acids; waters with high alkalinities, >100 mg/L as $CaCO_3$, have a greater capacity to neutralize acids. Generally, soft, low mineral waters will have low alkalinities and harder, more mineralized waters will be associated with higher alkalinities, although there are certainly exceptions.

Dissolved Inorganic Carbonate. DIC is a parameter that has not been commonly used by most water supply professionals; however, its impact on lead mobilization has been well documented. The level of dissolved inorganic carbonate (DIC) is an important parameter in lead solubility. DIC is the total concentration of all dissolved inorganic carbonate species, including carbonic acid $H_2CO_3^\circ$ {where $H_2CO_3^\circ = H_2CO_3^\circ + CO_2(aq)$}, bicarbonates, carbonates, and complexes and ion pairs such as $CaHCO_3^+$, $CaCO_3^\circ$, $MgCO_3^\circ$, $MgHCO_3^+$, $PbCO_3^\circ$, $Pb(CO_3)_2^{-2}$ plus others. The formation of effective carbonate films (usually one of the solid "basic lead carbonates," mineral names "hydrocerussite" or "plumbonacrite") depends on both DIC and pH levels.

DIC can be calculated from total alkalinity, pH, temperature, and ionic strength. The predominant factors are total alkalinity and pH. Figure 4-2 displays the relationship between DIC, alkalinity, and pH for a water with an ionic strength of 0.005 and a temperature of 25°C. Figure 4-1 illustrates that the effect of the interrelationship between pH and DIC on lead solubility is extremely important. The predicted absolute minimum lead solubility point is at a pH of 9.8 and DIC concentration of approximately 4.8 mg C/L for a model where hydrocerussite is the controlling solid. This would translate into a total alkalinity of approximately 28 mg $CaCO_3$/L (depending on the temperature and ionic strengths used for the DIC to alkalinity conversion). The exact point of minimum lead solubility will change with various differences in assumptions of equilibrium constants, solubility constants, and the presence of other complexing agents or competing actions in real systems. Figure 4-1 also shows that systems with high DIC are theoretically capable of dissolving as much or more lead as systems with less DIC at lower pH values.

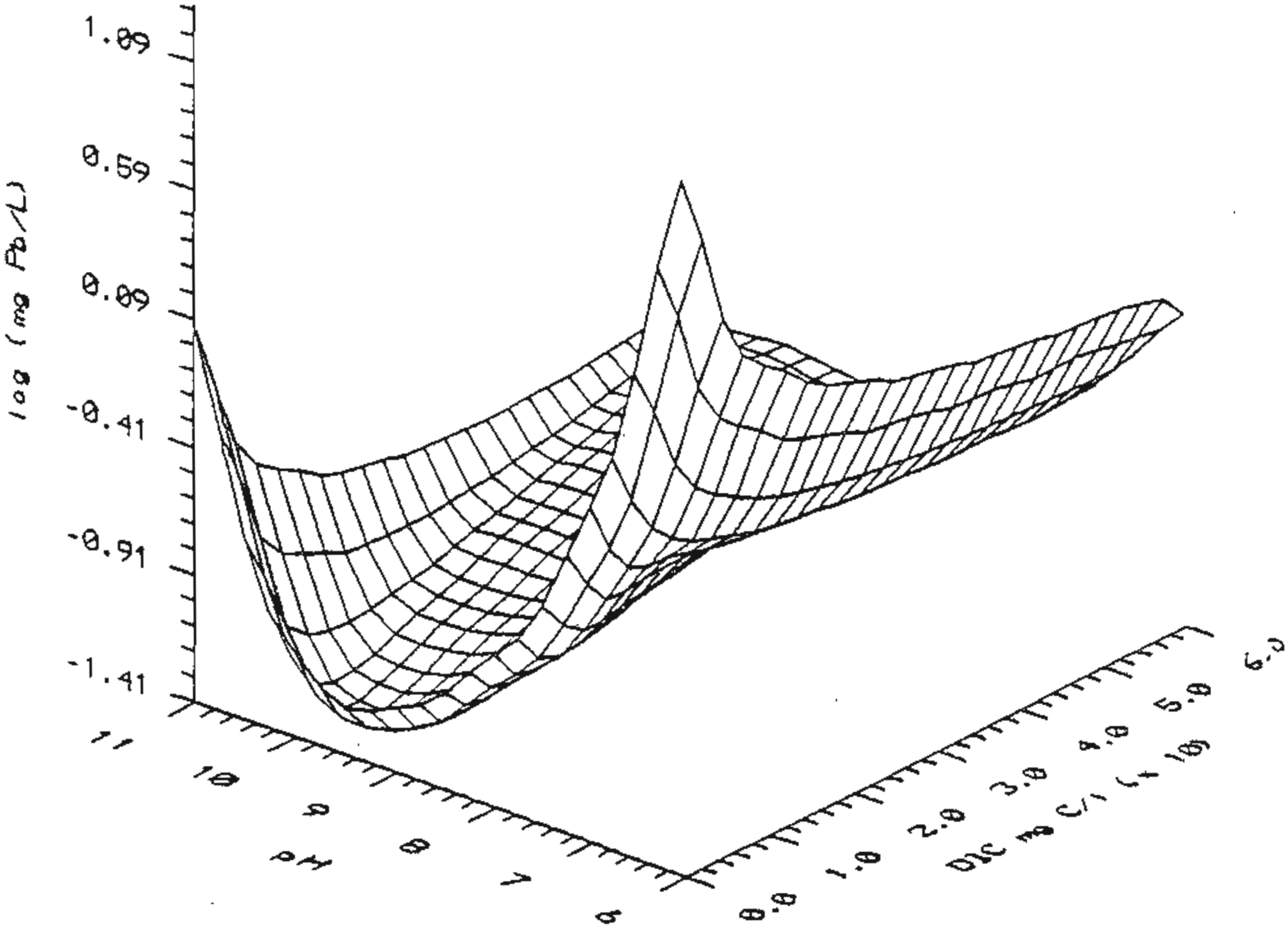


FIGURE 4-1 3-DIMENSIONAL DIAGRAM FOR LEAD SOLUBILITY - NO PHOSPHATE ADDED
IONIC STRENGTH = 0.005, TEMPERATURE = 25°C

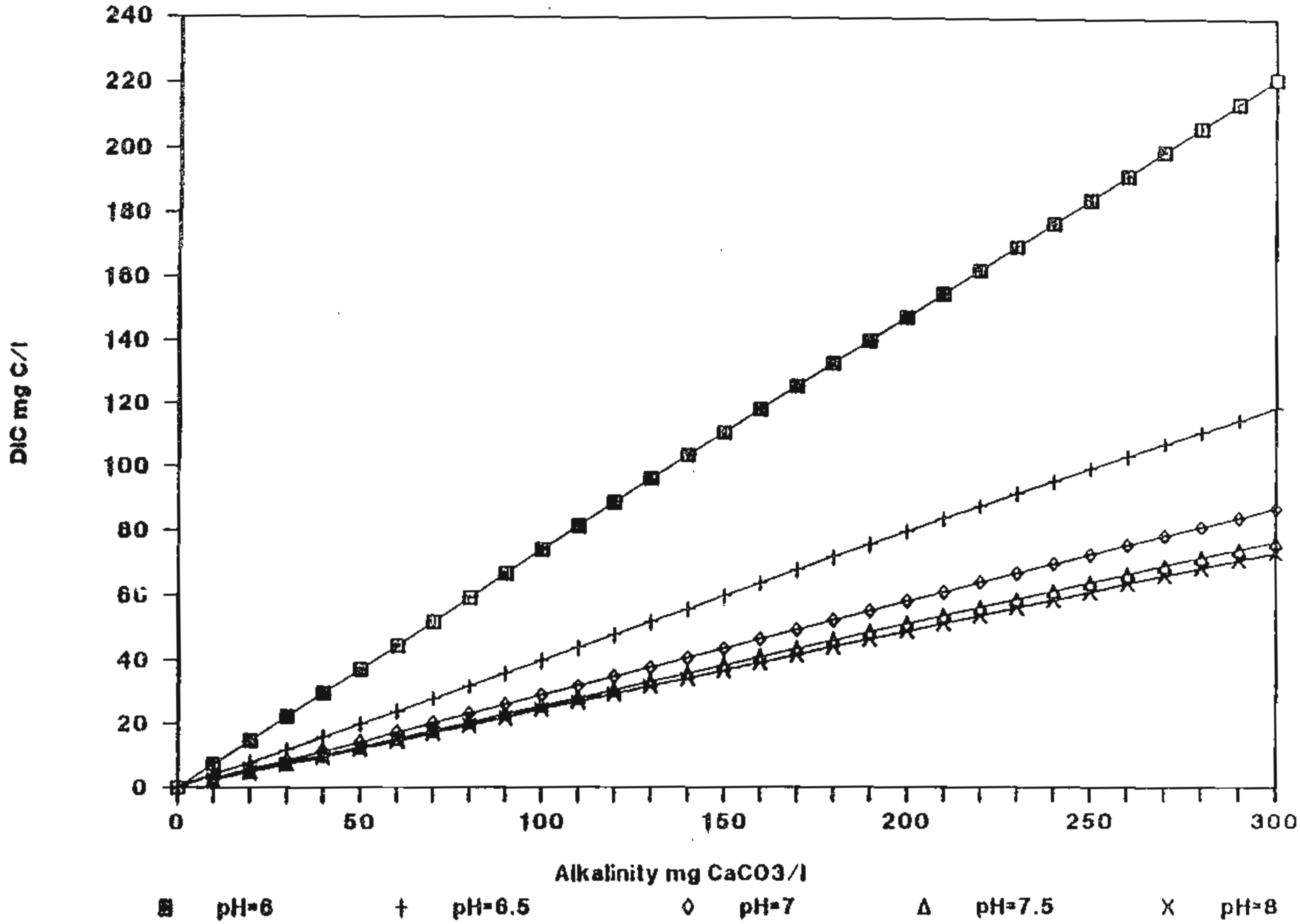


FIGURE 4-2 RELATIONSHIP BETWEEN ALKALINITY AND DIC FOR pH LEVELS 6-8
IONIC STRENGTH = 0.005, TEMPERATURE = 25°C

Orthophosphate. Orthophosphate have been found to be quite effective at reducing lead solubility. Lead forms several orthophosphate solids that are even less-soluble than basic lead carbonate over a wide pH range. The formation of lead orthophosphate films depends on the DIC concentration, as well as the pH, temperature, and orthophosphate concentration. Figure 4-3 depicts a typical 3-dimensional diagram of lead solubility with orthophosphate added assuming the formation of $Pb_5(PO_4)_3OH$ to control lead. A comparison of Figures 4-1 and 4-3 indicates that the range of optimum pH levels for lead reduction is lower and much wider if orthophosphate are present.

4.2.2 Lead Levels Measured for Various Water Quality Characteristics

Several utilities around the country have initiated volunteer lead monitoring at the customer's kitchen tap. Most of these surveys collected 1 liter standing samples at the tap for lead levels, pH, and in some cases, alkalinity, hardness, or phosphate levels. Table 4-1 summarizes the results of several of these studies which correlated water quality characteristics with measured lead levels.

pH. The majority of surveys related pH and alkalinity to first flush lead levels collected at the kitchen faucet, and therefore does not necessarily correlate to lead levels measured from lead service piping. Most studies (AWWSCo, Karalekas 1976, Frey 1989) found that at lower pH levels, higher lead levels were measured. This observation is in agreement with the theoretical impact which pH has on lead solubility, i.e., lower pH levels can potentially cause increased lead levels.

Alkalinity. The correlation between measured lead levels and alkalinity was not as straight forward in the studies listed in Table 4-1. In the American Water Works Service Company study, alkalinity exhibited no influence on lead levels at the tap. Monitoring completed by the South Central Connecticut Regional Water Authority (SCCRWA) showed a decrease in lead levels with increasing alkalinity when evaluating lead levels for all pH ranges. When measured lead levels were categorized by both pH and alkalinity however, no correlation was noted.

Dissolved Inorganic Carbonate. DIC was estimated for both the Nova Scotia study (Maesson 1985) and the five cities in the Karalekas study (Karalekas 1978). The finished water quality characteristics from Providence, RI (pH = 10.1, DIC estimated at 3 mg C/L) in the Karalekas study, were closest to the predicted minimum lead solubility pH and DIC concentration (9.8 and 4.8 mg C/L), and standing lead levels measured here were also the lowest.

Orthophosphate. The AWWSCo study found significantly lower average lead levels when zinc orthophosphate inhibitor was used for corrosion control, than when no inhibitor was used.

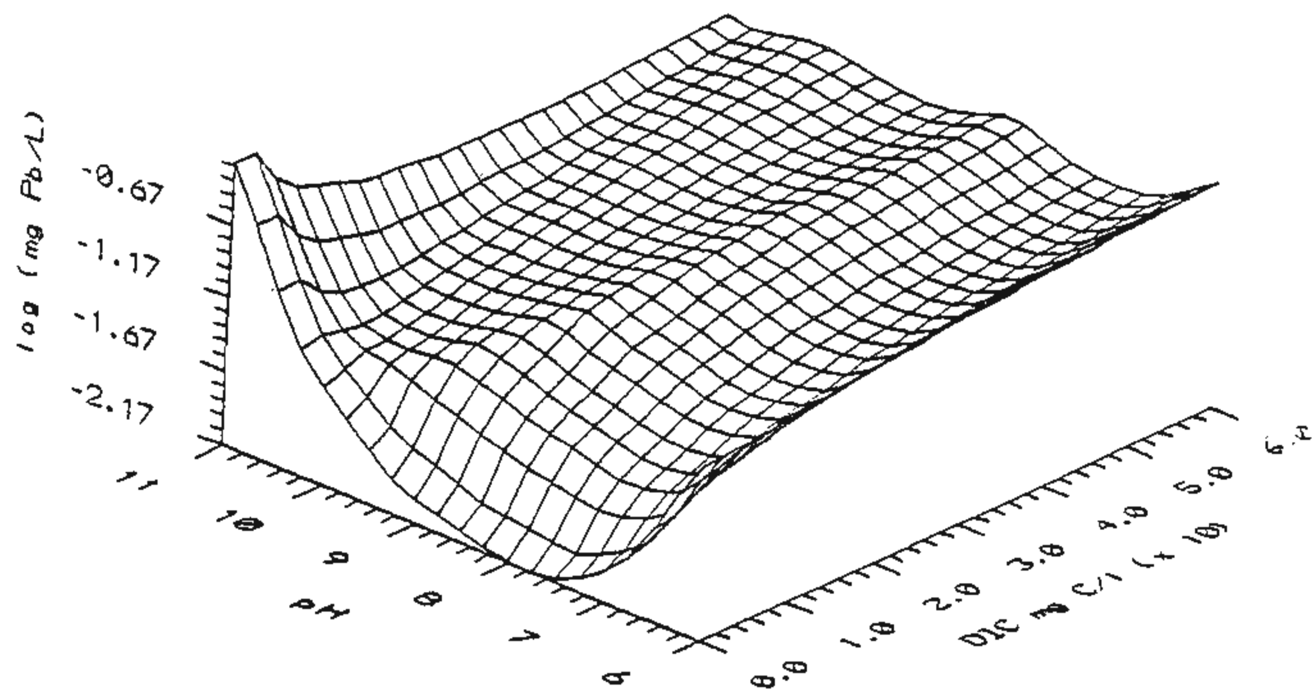


FIGURE 4-3 3-DIMENSIONAL DIAGRAM FOR LEAD SOLUBILITY - 1.5 mg/L PO_4 ADDED
IONIC STRENGTH = 0.005, TEMPERATURE = 25°C

Table 4-1

Comparison of Measured Lead Levels and Water Quality Characteristics

Study/Utility	Sample Collection Procedure: Protocol	Sample Collection Procedure: Volume	Water Quality Characteristics	Results
American Water Works Service Company (AWWSCo)	Standing at tap from houses with copper plumbing (no inhibitor)	1 Liter equivalent	pH Range	Average Lead Level, ug/L
			< 7	19
			7 - 7.5	13
			7.5 - 8	12
			> 8	5
	Standing at tap from houses with copper plumbing (no inhibitor)	1 Liter equivalent	Alkalinity, mg/L CaCO3	Average Lead Level, ug/L
			< 30	8
			30 - 100	14
			100 - 200	13
			> 200	8
			pH / Alkalinity, mg/L CaCO3	Average Lead Level, ug/L
			7 - 8 / < 30	8
			7 - 8 / > 30	13
			> 8 / < 30	5
			> 8 / > 30	5
	Standing at tap from houses with copper plumbing with zinc orthophosphate treatment	1 Liter equivalent	Contained orthophosphate	3.6

Table 4-1
(continued)

Study/Utility	Sample Collection Procedure: Protocol	Sample Collection Procedure: Volume	Water Quality Characteristics	Results
AWWA Lead Information Survey (Frey 1989)	First flush at the tap	1 Liter		% of Measured Lead Levels Greater than 20 ug/L (Age of House, years): ≤ 2 / 2 - 5 / ≥ 5
			pH < 8	48 / 20 / 8
			pH > 8	25 / 10 / 7
			Alkalinity, mg/L CaCO3 < 30	66 / 0 / 19
			Alkalinity, mg/L CaCO3 > 30	32 / 20 / 3
Boston, Somerville, Cambridge (Karalekas 1976)	Standing sample collected after bottle was rinsed.	1 Quart	City / pH / Hardness, mg/L CaCO3	Percent of Samples Greater than 50 ug/L
			Cambridge / 6.9 - 8.0 / 56	7.6 %
			Boston / 6.0 - 7.0 / 14	17.8%
			Somerville / 6.0 - 7.0 / 14	19.0 %
Nova Scotia (Maesson 1985)	Standing sample at tap 55 homes	250 mL	City / pH / Alk. (mg/L CaCO3) / Hard. (mg/L CaCO3)	Average Lead Levels, ug/L
			Hackets Cove / 6.4 / 25 / 41.5	40 ug/L
			East Dalhousie / 6.03 / 66 / 86	140 ug/L
			Cole Harbour / 6.3 / 93 / 69	41 ug/L
			Pleasant Valley / 7.7 / 138 / 200	27 ug/L

Table 4-1
(continued)

Study/Utility	Sample Collection Procedure: Protocol	Volume	Water Quality Characteristics				Results	
					(mg/L CaCO3)		Average Lead Levels, ug/L	
Several Utilities in the Northeast U.S. (Karalekas 1978)	Standing sample at tap and service line sample at the tap (by flushing until a temp. change)		City	pH	Alk.	Hard.	Tap	Service
			Bridgeport	7.1	18	48	10	11
			Marlborough	6.5	6	14	14	37
			Chatham	6.3	3	20	17	18
			New Bedford	7.3	24	12	76	90
			Providence	10.1	20	40	< 5	6
South Central Connecticut Regional Water Association (SCCRWA)	Standing at tap	1 Liter	pH				Average Lead Levels, ug/L Alk. < 30	Alk. > 30
			< 6.5				1	NA
			6.5 - < 7.0				5.6	2.3
			7.0 - < 7.5				3.4	2.1
			7.5 - < 8.0				2.4	4.4
			8.0 - < 8.5				4.0	2.0
			Alkalinity, mg/L CaCO3				Average Lead Levels, ug/L At All pH Ranges	
			< 30				3.8	
			30 - < 100				2.5	
			100 < 150				1.3	

4.3 GEOGRAPHIC DISTRIBUTION OF WATER QUALITY CHARACTERISTICS AND POTENTIAL FOR ELEVATED LEAD LEVELS

4.3.1 Technical Approach

The purpose of this subtask was to obtain nationwide water quality data, specifically pH, alkalinity, and hardness, in order to:

- Estimate and display typical water quality characteristics geographically.
- Determine an estimated potential for lead solubility based on these parameters.

A more detailed discussion of the approach for nationwide water quality characteristics and potential for lead solubility follows.

4.3.1.1 National Water Quality Characteristics

The following national surveys of water quality data were reviewed:

- "Chemical Quality of Public Water Supplies of the U.S. and Puerto Rico," U.S. Geological Survey, 1962.
- "Public Water Supplies of the 100 Largest Cities in the U.S.," U.S. Geological Survey, 1962.
- "Corrosion in Water Distribution Systems," Patterson, 1981.
- AWWA 1984 Water Industry Database (AWWA-WIDB).

The 1984 AWWA-WIDB was found to be the most recent and most complete set of finished water quality data for utilities in the United States, and was used to estimate water quality characteristics geographically. The total number of utilities in the AWWA-WIDB which contained finished water quality data was approximately 400. The number of utilities by EPA Region are:

Region	# Utilities
1	18
2	38
3	43
4	62
5	73
6	36
7	26
8	17
9	72
10	16

Data on finished water hardness, alkalinity, and pH levels for each utility were entered into a database, and each of the parameters were population weighted to arrive at one value for each state. Results of this analysis are displayed in Figures 4-4 through 4-6.

4.3.1.2 Estimated Potential for High Lead Levels

Using theoretical lead solubility relationships for fresh lead pipe (Figure 4-1), three categories indicating the relative potential for lead solubility were developed based on pH, DIC, and the calculated theoretical lead level which results. These potential categories are:

Potential for Lead Solubility	pH	DIC, mg C/L
High	<8	<5
	<8	5-30
	<8.5	>30
Intermediate	8-8.5	<30
	8.5-10.5	>30
Low	8.5-10.5	<30

A category for pH levels greater than 10.5 was not included in this evaluation since the theoretical solubility relationships and corresponding solids formations have not been adequately developed. DIC levels were estimated from the population weighted pH and alkalinity values for each of the states in the nationwide water quality evaluation described above. Each state was then placed in one of the three potential solubility categories depending on the pH and DIC level. These results are shown graphically in Figure 4-7.

4.3.2 Discussion

While the 1984 AWWA-WIDB provides the most recent finished water quality data for utilities nationwide, several items should be kept in mind when evaluating Figures 4-4 through 4-7:

- The statewide estimates of pH, alkalinity, hardness, and potential solubility used in this evaluation are based on finished water quality data as reported in the AWWA-WIDB. These characteristics may change in the distribution system, and those chemical changes, along with the physical characteristics of the specific piping system (i.e., diameter, length, surface area of exposed lead source, flow) and the protocol for collecting samples will ultimately determine the lead levels measured at the tap.

- The categories for potential lead solubility are based on a simple system containing only DIC and water. The interrelationship of other constituents in the water, their scale-forming properties, and the presence of inhibitors is not taken into account.

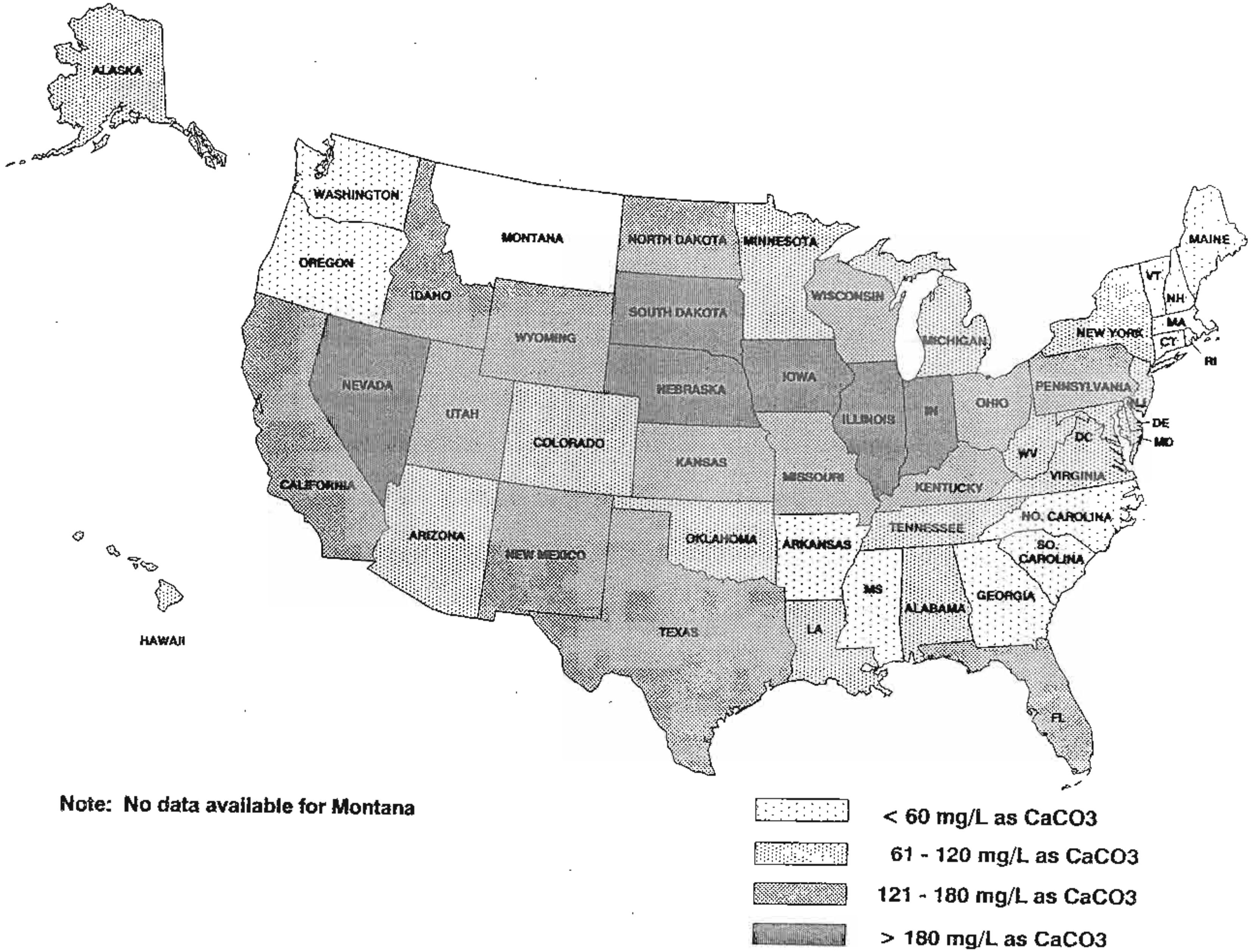


FIGURE 4-4 POPULATION WEIGHTED HARDNESS LEVELS BY STATE FROM THE 1984 AWWA WATER INDUSTRY DATABASE

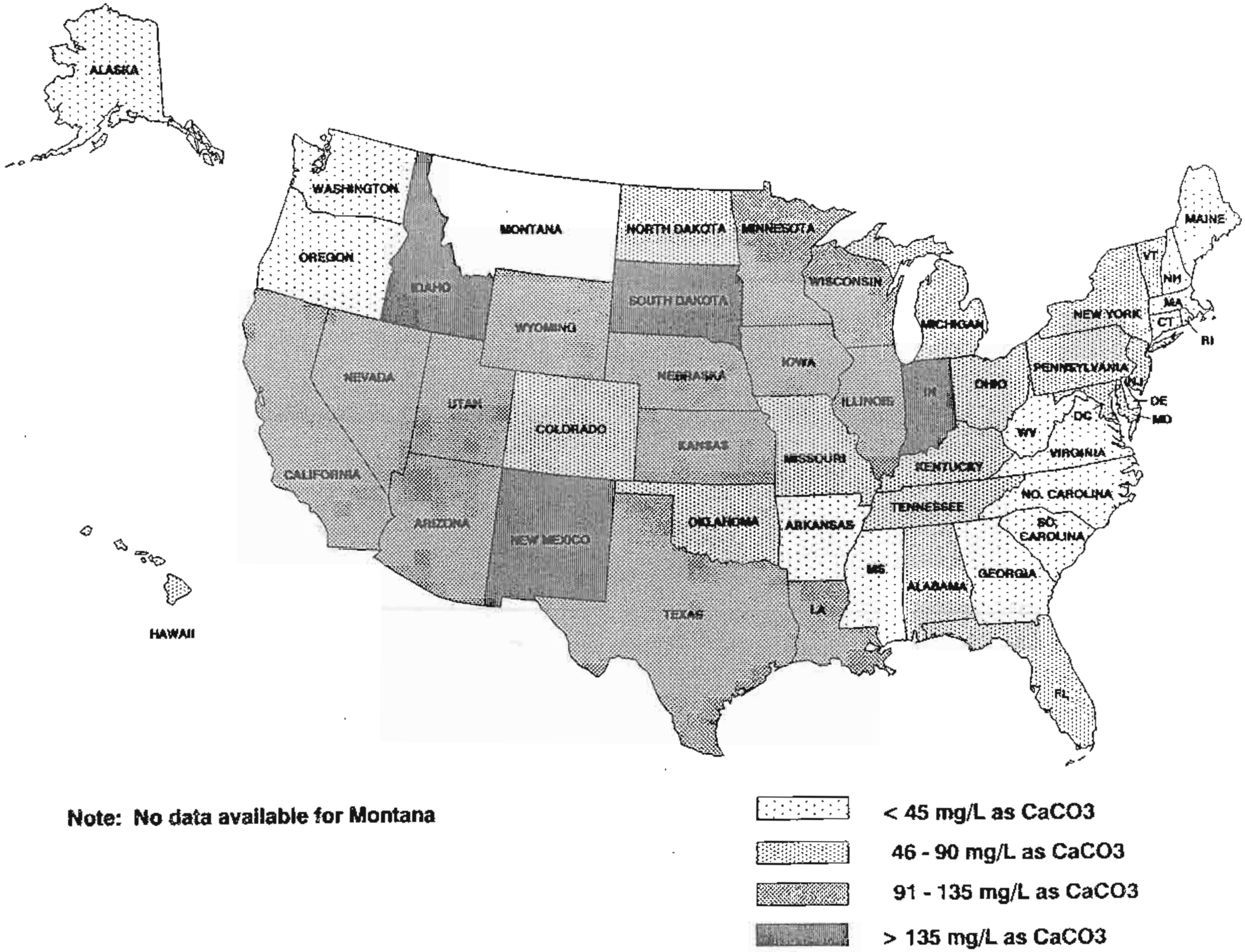


FIGURE 4-5 POPULATION WEIGHTED ALKALINITY LEVELS BY STATE FROM THE 1984 AWWA WATER INDUSTRY DATABASE

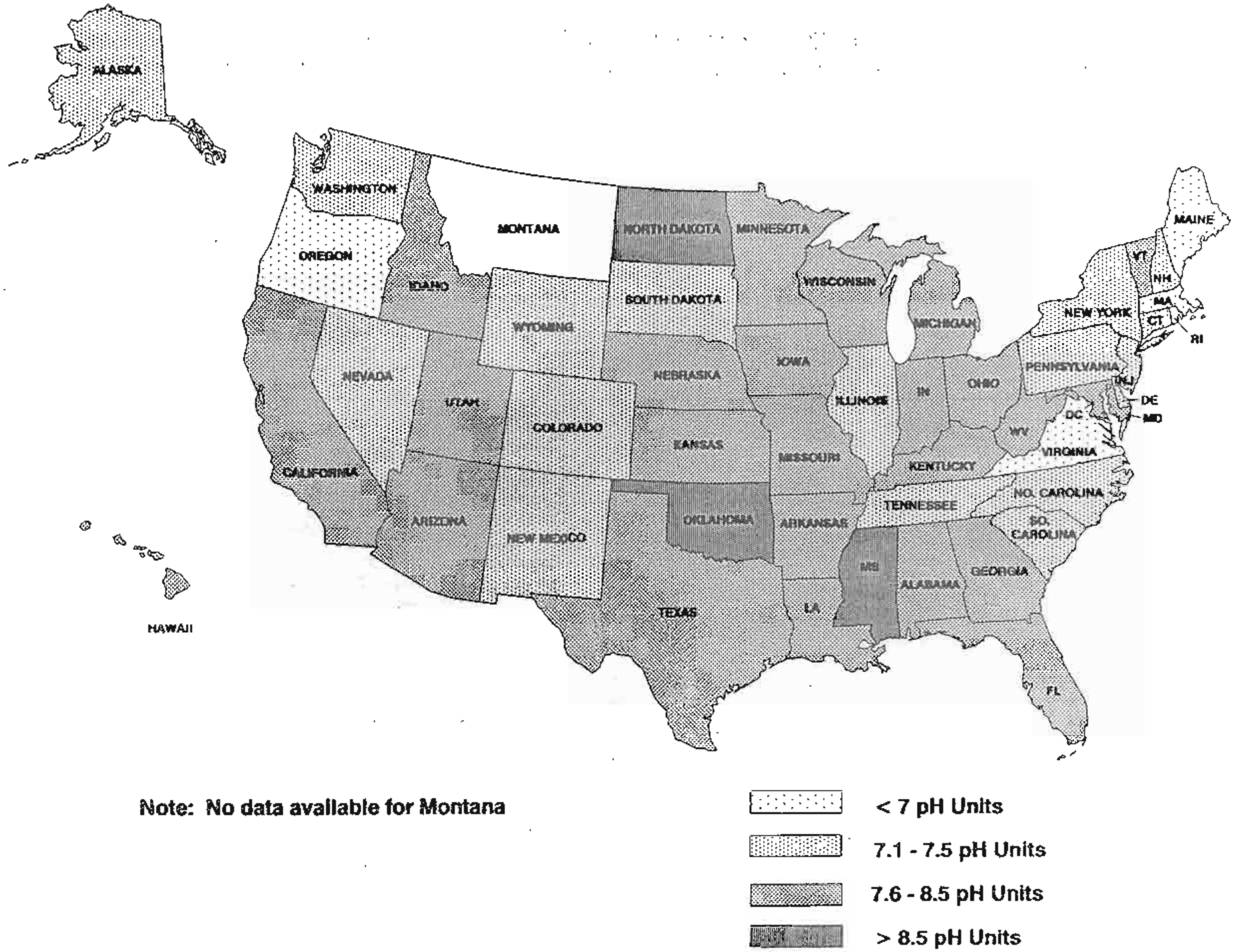
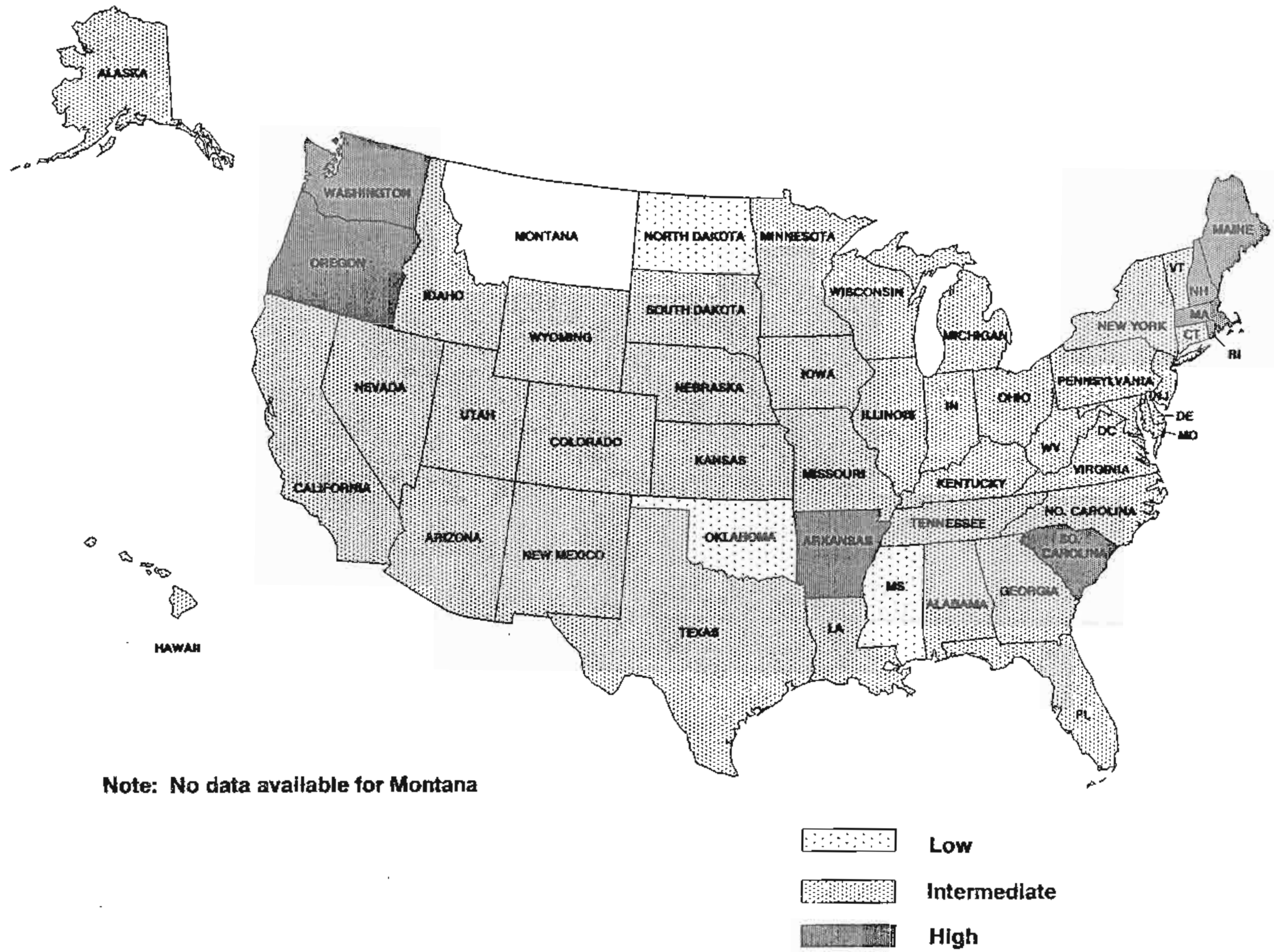


FIGURE 4-6 POPULATION WEIGHTED pH LEVELS BY STATE FROM THE 1984 AWWA WATER INDUSTRY DATABASE



Note: No data available for Montana

FIGURE 4-7 ESTIMATED POTENTIAL LEAD SOLUBILITY BY STATE FROM THE 1984 AWWA WATER INDUSTRY DATABASE

- This analysis is meant only as an estimate of the location of water quality characteristics which might cause a higher potential for lead leaching to occur, and is based only on those utilities which provided data to the AWWA-WIDB. For some states in the AWWA-WIDB, data from only one or two utilities were available.

- Finally, the population weighting of the parameters ensures that utilities serving larger populations will be more heavily represented in the final average than those serving smaller populations. It is entirely possible that a utility with a relatively small service population could have a high potential for lead solubility using the technical approach described; however, a larger utility with a low potential would outweigh their impact in the overall average.

Figures 4-4 through 4-6 display the results of population weighting the hardness, alkalinity, and pH levels from the AWWA-WIDB. The hardness evaluation, Figure 4-4, displays relatively soft waters along the eastern seaboard, the southeast, and the extreme northwest portions of the U.S., while the center of the country is generally higher in hardness. These results are very similar to a geographic distribution of hardness completed by the U.S. Geological Survey (USGS 1964). The USGS used finished hardness levels for 600 water utilities throughout the U.S. Differences in the two surveys can probably be attributed to the inclusion of different utilities in each database and the changes in water treatment which may have occurred over the past 25 years.

The geographic distribution of alkalinity, Figure 4-5, displays low values (< 45 mg/L $CaCO_3$) for the east coast, particularly the extreme northeast, and for the northwest. The remainder of the country fell predominantly into the two higher alkalinity categories. Concerning pH, no noticeable geographic pattern could be determined from the pH level distribution (Figure 4-6) throughout the U.S.

When each of the states was categorized for potential lead solubility, the extreme northeast and northwest regions of the U.S. were evaluated as having a high potential for lead solubility. It can be noted that actual historical monitoring in the northeastern portion of the United States has also exhibited high lead level measurements.

4.4 LEAD MATERIAL CONTRIBUTIONS TO LEAD LEVELS IN DRINKING WATER

4.4.1 Major Material Sources of Lead

Based on the review of available literature on potential lead sources, lead service piping, lead plumbing, lead goosenecks, high lead solders, and household plumbing fixtures are the most likely material contributors to high lead levels at the tap. These sources are described in more detail below.

Lead Pipe. Lead service lines are common in water distribution systems in the U.S. Lead service pipe has a useful life expectancy of much greater than 50 years, therefore, many of these pipes will be in operation well into the future. Lead pipe has also been used for plumbing inside homes.

Lead Goosenecks. A gooseneck or pigtail is pipe that connects the service line to the distribution main (Figure 4-8). Lead goosenecks have also been widely used because lead's malleable qualities were suited to the wide variety of shapes required to connect the service pipe to the distribution main.

Tin-Lead Solder. A common use of lead in water piping systems in addition to lead service pipes has been lead-based solders that are used to join copper pipes. The percent ratios of lead to tin for commonly used plumbing solders are usually 50:50 and 60:40. Premise piping containing lead solder that is two years old or less is of particular concern as the lead leaching rates from newer lead solder are considerably higher than in older solders (AWWSCo, 1988). The 1986 Amendments to the Safe Drinking Water Act prohibit the use of lead solders which contain more than 0.2 percent lead. Alternative lead-free solders such as tin/antimony are readily available, several of which have been used for many years.

Brass Fixtures and Fittings. Brass is a copper-zinc alloy commonly used in potable water systems and is found in valve parts, faucets, and some water meters. Lead is found in brasses in the 0.1-12 percent range (Uhlig, 1948), however, the brasses most commonly used in household fixtures contain between 1.5 to 7.5 percent lead.

4.4.2 Typical Lead Levels Associated with Material Sources of Lead

Several studies have focused on the relative contribution of various lead sources to measured lead concentrations at the tap. A summary of results from these studies is presented in Table 4-2. Many collection protocols were designed to evaluate a one liter standing sample, which would be representative of both the faucet (brass fixtures) and the household plumbing (lead solder). However, for those cases where the protocol was designed to segment these two components, the faucet lead concentration was higher than the home plumbing concentration. Several of these studies were further analyzed to evaluate water quality characteristics (i.e., potential for lead solubility) in relation to lead material contributions. This information is summarized for each potential lead material source in Tables 4-3 to 4-6. The studies included in these tables were chosen because they were either specifically designed to evaluate a particular lead source, or the information could be evaluated based on the collection protocol used.

For the faucet contribution, most studies evaluated a standing 125-mL sample at the tap (Table 4-3). Two studies which evaluated lead leaching from faucets under controlled environments were also included. The studies which identified home plumbing contributions

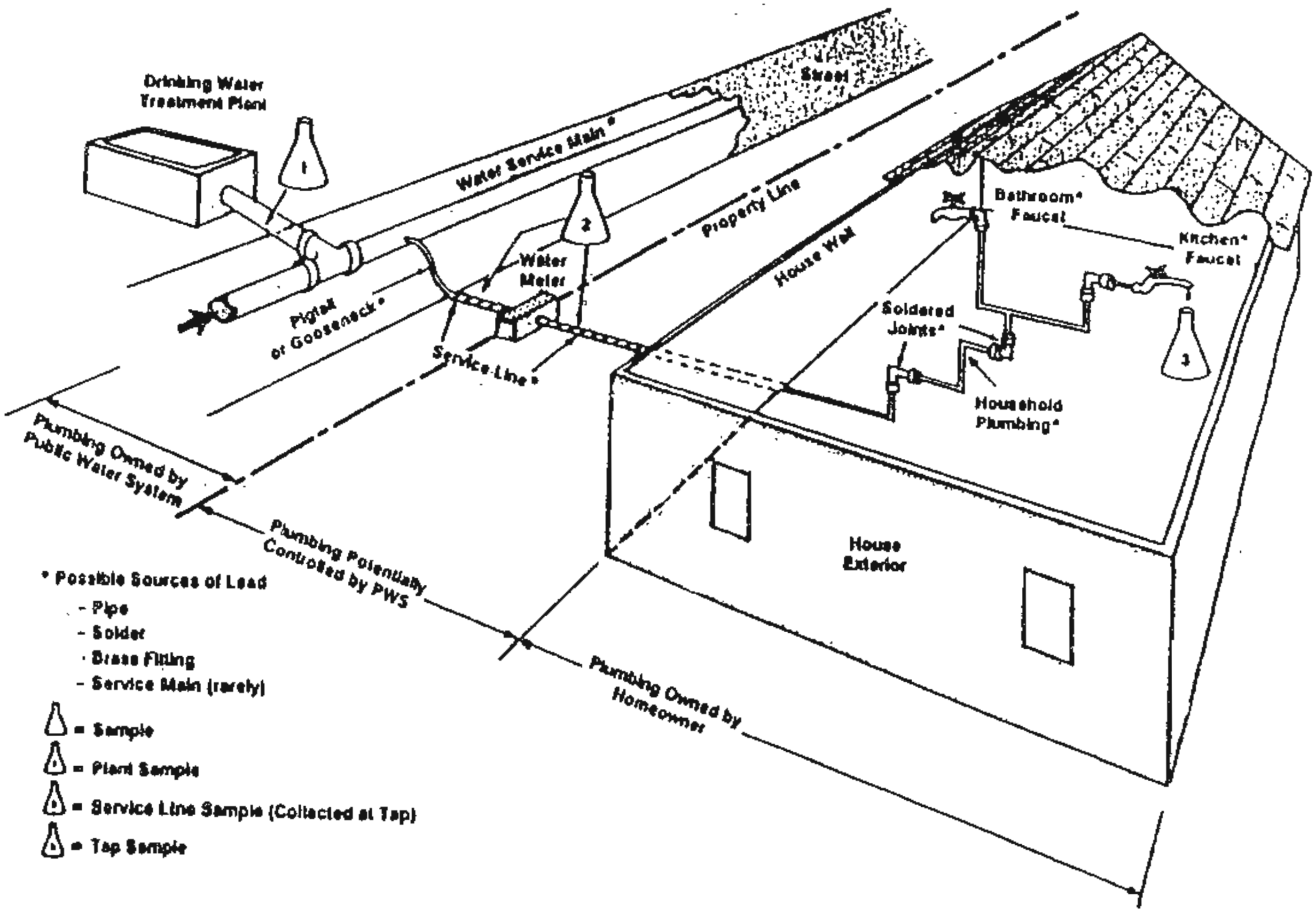


FIGURE 4-8 SERVICE AND PREMISE PIPING DIAGRAM
(USEPA, 1988)

Table 4-2

Contribution of Lead Service Materials to Measured Lead Levels

Study/Utility	Sample Collection Protocol	Sample Collection Volume	Representative of	Results		
American Water Works Service Co. (AWWSCo)				Average Lead Level, ug/L (Type of Home Plumbing)		
				Plastic	Galv.	Copper
	First flush standing sample at tap	100 mL	Faucet	4	6	12
	Next 1000 mL	1000 mL	Household plumbing	2	2	6
	Calculated first draw 1000 mL (combination of above)	N/A	Faucet and Household plumbing	4	9	9
	Directly from lead service line	1000 mL	Lead Service Line	9.2 ug/L		
1987 AWWA Lead Information Survey (Frey 1989)				% of Utilities with Lead Levels Greater than 20 ug/L (House Age, years)		
				< 2	2 - 5	> 5
	First flush standing sample at tap	1000 mL	Faucet and Household plumbing	38 %	17 %	8 %
	Various methods, but water representative of service line		Service Line	3 %	0	2 %

Table 4-2
(continued)

Study/Utility	Sample Collection Protocol	Sample Collection Volume	Representative of	Results	
Greater Vancouver Water District (GVWD) Vancouver, B.C.				Lead Levels, ug/L	
				Average	Range
	First flush standing	125 mL	Faucet	50	7 - 260
	Next Liter	1000 mL	Household plumbing	10	< 1 - 28
	Flushed for 10 minutes then collected	1000 mL	Main	1	< 1 - 4
Northern Illinois Water Company				Average Lead Levels, ug/L	
Champaign	First flush standing	125 mL	Faucet	4	
	Flush until temperature change	125 mL	Service Line	1.1	
Sterling	First flush standing	125 mL	Faucet	34.5	
	Flush until temperature change	125 mL	Service Line	30.0	
Boston, Cambridge, Somerville, Mass. (Karalekas 1976)				Average Lead Level, ug/L	
	Standing sample after container was rinsed	1 Quart	Faucet and Household plumbing	53	
	Flushed for 4 minutes	1 Quart	Main	31	
	"Early Morning" Samples Collected after a temperature change.	1 Quart	Service Line	104	

Table 4-2
(continued)

Study/Utility	Sample Collection Protocol	Sample Collection Volume	Representative of	Results		
Several Utilities in the Northeast				Average Lead Levels, ug/L		
				Bridgeport	Marlborough	Chatham
(Karalekas 1978)	First flush standing		Faucet and Home Plumbing	10	14	17
	Flushed until a temperature change		Service Line	11	37	18
	Flushed for 3 minutes		Main	< 5	10	15
				New Bedford	Providence	
			Faucet and Home Plumbing	76	< 5	
			Service Line	90	6	
			Main	13	< 5	
Portland Water Bureau	Standing overnight samples from three homes with lead goosenecks. Samples collected at meter box.		Lead Gooseneck	Lead Levels, ug/L 120 260 2500 Standing samples at the tap from these homes were all less than 50 ug/L		

Table 4-2
(continued)

Study/Utility	Sample Collection Protocol	Volume	Representative of	Results
Portland Water Bureau	After 8 hour standing time, consecutive samples taken at tap until water in contact with lead gooseneck was reached.	60 mL	Lead Gooseneck	Average Lead Level, ug/L 7.3

Table 4-3

Measured Lead Levels Representative of the Faucet Contribution

Study/Utility	Sample Collection Procedure: Protocol	Volume	Water Quality Characteristics	Results	Category for Potential Lead Solubility
American Water Works Service Co. (AWWSCo)	Standing at tap (copper plumbing)	100 mL	Various (see Table 4.5)	Average Lead Levels, ug/L: 12	Intermediate
Greater Vancouver Water District (GVWD) Vancouver, B.C.	Standing at tap	125 mL	Average Characteristics: pH 6.2; Alkalinity (mg CaCO3/L) 2.6; Calcium (mg Ca/L) 1.4	Average Lead Levels, ug/L: 50 (7 - 260)	High
Champaign, IL	Standing at tap	125 mL	pH 9.0; Alkalinity (mg CaCO3/L) 110; Hardness (mg CaCO3/L) 80	Average Lead Levels, ug/L: 4	Low
Portland, ME	Standing at Tap	125 mL	pH 8.6; Alkalinity (mg CaCO3/L)	Average Lead Levels, ug/L: 15.4	Intermediate
USEPA-ODW (Gardels 1989)	11 Different Faucets 1 Day Standing Time Cincinnati Tap Water	125 mL	pH 8.1 - 8.4; Alkalinity (mg CaCO3/L) 43 - 51; Hardness (mg CaCO3/L) 105 - 132	Lead Level Range, ug/L: 10 - 100 (Est. Average = 25 ug/L)	Intermediate

Table 4-3
(continued)

Study/Utility	Sample Collection Procedure Protocol	Volume	Water Quality Characteristics pH	Alkalinity (mg CaCO3/L)	Calcium, mg/L	Results Lead Levels, ug/L Mean	Median	Category for Potential Lead Solubility
Illinois State Water Survey (6 Different Water Supplies in IL)	Pipe Loops with brass sample valves. New Faucets, Copper Plumbing.	125 mL						
Site 305			8.1 - 9.1	82 - 126	10 - 14	17	9	Intermediate
Site 308			7.3 - 9.4	215 - 336	1 - 75	42	11	Intermediate
Site 310			7.5 - 8.6	215 - 305	8 - 52	10	7	Intermediate
Site 318			9.5 - 10.3	25.3 - 57.4	12.9 - 32	71	17	Low
Site 301			6.9 - 9.0	30.6 - 66	10.6 - 22.8	82	23	Intermediate
	Pipe Loops with brass sample valves. New Faucets, Galvanized Plumbing.	125 mL						
Site 302			6.7 - 8.9	30.6 - 66	10.6 - 23.5	7	1	Intermediate
Site 306			8.1 - 9.1	82 - 118.5	10.8 - 14.5	13	5	Low
Site 309			7.3 - 9.4	215 - 336	1.4 - 76.8	17	9	Intermediate
Site 311			7.5 - 8.6	215 - 305	8.7 - 67.8	16	4	Intermediate
Site 317			9.0 - 10.4	25.0 - 60.0	14.6 - 33.7	15	6	Low

Table 4-4

Measured Lead Levels Representative of Home Plumbing

Study/Utility	Sample Collection Procedure Protocol	Volume	Water Quality Characteristics			Results	Category for Potential Lead Solubility
Boston, Somerville, Cambridge (Karalekas 1976)	Standing at tap after container was rinsed (no inhibitor)	1 Quart	City	Hardness (mg CaCO3/L)	pH	Average Lead Level, ug/L from all 3 Cities	
			Boston	14	6.0 - 7.0		High
			Cambridge	56	6.9 - 8.0	53	High
			Somerville	14	6.0 - 7.0		High
American Water Works Service Co. (AWWSCo)	Standing at tap after 100 mL sample collected (copper plumbing)	1 Liter		Various (see Table 4.)		Average Lead Level, ug/L 6	Intermediate
Greater Vancouver Water District (GVWD) Vancouver, B.C.	Standing at tap after 125 mL sample collected	1 Liter	pH	Average Characteristics Alkalinity (mg CaCO3/L)	Calcium (mg Ca/L)	Average Lead Level, ug/L	High
			6.2	2.6	1 4	10 (1 - 28)	
Seattle Water Dept. Seattle, WA (Chapman et al 1989)	Standing at tap after coliform sample collected (200 ml)		pH		Alkalinity (mg CaCO3/L)	Average Lead Levels, ug/L	
Cedar River Supply			7.2		16	9.5	High
			8.2		19	3.7	Intermediate
Tolt River Supply			6.0		2.5	11.8	High
			8.2		13.5	3.8	Intermediate
Portland, ME	Standing at tap after 125 mL sample collected	950 mL		pH		Average Lead Level, ug/L	
				8.3		2.4 (2 - 10)	Intermediate

Table 4-5

Measured Lead Levels Representative of Home Plumbing and Faucet Contributions

Study/Utility	Sample Collection Procedure: Protocol	Volume	Water Quality Characteristics: pH	Alkalinity (mg CaCO3/L)	Hardness (mg CaCO3/L)	Results: Average Lead Levels, ug/L	Category for Potential Lead Solubility
American Water Works Service Company (AWWSCo)	Standing at tap from houses with copper plumbing (no inhibitor)	1 Liter equivalent	7 - 8	< 30		8	Intermediate
			7 - 8	> 30		13	Intermediate
			> 8	< 30		5	Intermediate
			> 8	> 30		5	Intermediate
South Central Connecticut Regional Water Association (SCCRWA)	Standing at tap	1 Liter	< 6.5	< 30		1	High
			6.5 - < 7.0	< 30		5.6	High
			7.0 - < 7.5	< 30		3.4	Intermediate
			7.5 - < 8.0	< 30		2.4	Intermediate
			8.0 - < 8.5	< 30		4.0	Intermediate
			< 6.5	> 30		NA	High
			6.5 - < 7.0	> 30		2.3	Intermediate
			7.0 - < 7.5	> 30		2.1	Intermediate
			7.5 - < 8.0	> 30		4.4	Intermediate
			8.0 - < 8.5	> 30		2.0	Intermediate
Several Utilities in the Northeast U.S. (Karalekas 1978)	Standing sample at tap						
Bridgeport			7.1	18	18	10	High
Marlborough			6.5	6	14	14	High
Chatham			6.3	3	20	17	High
New Beford			7.3	24	12	76	High
Providence			10.1	20	40	< 5	Low

Table 4-5
(continued)

Study/Utility	Sample Collection Procedure: Protocol	Sample Collection Procedure: Volume	Water Quality Characteristics	Results	Category for Potential Lead Solubility
Boston, MA (Karalekas et al 1983)	Standing sample at tap		pH; Alkalinity (mg CaCO3/L)	Average Lead Levels, ug/L	
			5.9 to 6.8; 8	128	High
			8.3	35	Intermediate
Fairbanks, AK	Standing sample at tap (standing times varied from 24 to 67 hours)	1 Liter	pH; Alkalinity (mg CaCO3/L); Calcium (mg CaCO3/L)	Average Lead Level, ug/L	
			6.8; 193; 108	77	Intermediate
Covewood Lodge	Standing sample at tap	1 Liter	pH; Alkalinity (mg CaCO3/L); Calcium (mg Ca/L)	Average Lead Level, ug/L	
			6.34; 7.5; 4.1	46	High
Portland, OR	Standing sample at tap Houses built in 1984	1 Liter	pH; Alkalinity (mg CaCO3/L); Hardness (mg CaCO3/L)	Average Lead Level, ug/L	
			6.8; 10; 12	25	High
Milwaukee, WI	Standing sample at tap		pH; Alkalinity (mg CaCO3/L); Hardness (mg CaCO3/L)	Average Lead Level, ug/L	
			7.54; 98; 86	40	Intermediate

Table 4-6

Measured Lead Levels Representative of Lead Service Line Contribution

Study/Utility	Sample Collection Procedure: Protocol	Volume	Water Quality Characteristics			Results	Category for Potential Lead Solubility
American Water Works Service Co. (AWWSCo)	Standing sample directly from service line	1 Liter	Various (see Table 4.5)			Average Lead Levels, ug/L	
						9.2	Intermediate
Serveral Utilities in the Northeast U.S. (Karalkeas 1978)	Standing at Tap (Flushed until a temperature change)		pH	Hardness (mg CaCO3/L)	Alkalinity (mg CaCO3/L)	Average Lead Levels, ug/L	
Bridgeport			7.1	18	18	11	High
Marlborough			6.5	14	6	37	High
Chatham			6.3	20	3	18	High
New Bedford			7.3	12	24	90	High
Providence			10.1	40	20	6	Low
Chicago, IL (EPA 1987)	Standing sample at the tap aft estimated volume of inside plumbing was flushed (or temperature change). 23 locations with lead service lines.	500 mL	pH	Hardness (mg CaCO3/L)	Alkalinity (mg CaCO3/L)	Average Lead Levels, ug/L	
			8.3	130	109	15	Intermediate
Boston, Cambridge, Somerville, MA (Karalekas 1976)	Standing at Tap (Flushed until a temperature change)	1 Quart	City	pH	Hardness (mg CaCO3/L)	Average Lead Level, ug/L	
			Boston	6.0 - 7.0	14		
			Cambridge	6.9 - 8.0	56	104	High
			Somerville	6.0 - 7.0	14		

Table 4-6
(continued)

Study/Utility	Sample Collection Procedure: Protocol	Volume	Water Quality Characteristics			Results	Category for Potential Lead Solubility
Boston, MA (EPA 1987)	Standing sample at tap after temperature change detected. 24 sample locations with lead service lines, before and after treatment.	250 mL	6.3			121	High
Louisville, KY (EPA 1987)	Standing sample at the tap after a temperature change was detected.		8.5			5	Intermediate
St. Louis, MO (EPA 1988)		1 L	9.0		50	< 1	Low
Oakwood, OH (EPA Cincinnati 1990)	Standing at Tap (Flushed until estimated volume of water in the home plumbing had been wasted) 7 Houses with Lead Service Lines Samples taken prior to Replacement	250 mL	Avr. pH	Avr. Alkalinity (mg CaCO3/L)	House		
			7.05 - 7.14	285 - 367	House #4	8.9	Intermediate
			"	"	House #5	5.8	Intermediate
			"	"	House #6	9.8	Intermediate
			"	"	House #7	8.6	Intermediate
			"	"	House #11	9.9	Intermediate
			"	"	House #12	6.0	Intermediate
			Avr. pH	Avr. Ca, mg/L			
			7.05 - 7.14	96	House #8	12	Intermediate
			7.05 - 7.14	1.5	House #8	8.0	High

(Table 4-4) were based on samples collected immediately after a small volume of standing water was collected at the tap. The relative ages of the home plumbing could not be identified, however. All of the studies listed in Table 4-5 were based on a standing 1-liter sample at the tap, with the exception of the Massachusetts and Milwaukee data where total volume was not given. These 1-liter samples would be representative of both the home plumbing and the faucet. In order to evaluate the contribution of lead service lines, several monitoring protocols were identified where samples were either indicative of the service line or were taken directly from the service line. These studies are listed in Table 4-6. The sampling protocols for most of these studies relied on detecting a temperature change at the tap to determine when water from the service line should be collected. Only the AWWSCo sampled directly from a lead service line.

4.4.3 Matrix of Lead Levels at the Tap

In order to evaluate the contribution of lead source materials to lead levels at the tap and to possible human ingestion of lead in drinking water, a matrix for lead ingested in drinking water was developed. This matrix was based on assumptions for typical plumbing characteristics, water quality characteristics (i.e., lead concentrations), and water use patterns.

4.4.3.1 Approach

Typical Plumbing Characteristics. The typical home plumbing scenario used in this evaluation was a single family residence with a lead gooseneck, lead service line, copper plumbing in the home with 50:50 lead:tin solder, and a brass faucet. The typical service line and gooseneck used in the matrix evaluation were based on the service line characteristics gathered in Section 2.4. A total service line length of 48 feet was used to represent older, more urban service areas. Lead goosenecks are typically 2 to 4 feet in length; therefore, a conservative 4-foot length was assumed for the matrix.

The diameters and lengths for the home plumbing characteristics in the matrix were derived from actual measurements of four houses in the Washington, DC area. These home plumbing measurements consisted of the piping distance from the basement wall to just under the kitchen sink, plus the length of piping directly under the sink to the faucet. The measurements for length of plumbing from the basement wall to under the kitchen sink ranged from 27 to 54 feet with diameters of 3/4 inch or 1 inch. The length of plumbing measured directly underneath the sink ranged from 2 feet to just over 3 feet with diameters of 1/2 inch. One home had both 3/4 inch and 1/4 inch piping underneath the sink. A summary of the actual measurements, and the average values are displayed in Table 4-7. The home plumbing measurements used in the matrix were based on these average measurements.

Table 4-7

Home Plumbing Measurement from Washington, DC

Location		House #1	House #2	House #3	House #4	Averages *
Basement Wall to Under Sink in Kitchen	Diameter, inches	N/A	3/4	1	3/4	3/4
	Length, feet	45	54	27	38	41
Under Sink in Kitchen to Faucet	Diameter, inches	N/A	1/2	1/2	3/4 and 1/4	1/2
	Length, feet	N/A	2	3	1.67 and 1.5	2.7

* These values were used to represent typical home plumbing in the matrix

The typical plumbing characteristics used in the matrix evaluation are summarized below:

Major Material Source of Lead	Typical Plumbing Characteristics Diam., in.	Length, ft.	Vol., L
Brass Faucet	-	-	0.10
Home Plumbing			
Under Sink	0.50	2.7	0.10
Basement Wall to under sink	0.75	41.0	3.56
TOTAL			3.66
Service Line	0.75	48.0	4.17
Gooseneck	0.75	4.0	0.35

Water Quality Characteristics. The measured lead levels for various lead material sources listed in Tables 4-3 through 4-6 were used to estimate typical lead concentrations for three categories of potential lead solubility. Actual standing lead levels measured for lead service line, faucets, and home plumbing contributions were bracketed according to their corresponding water quality characteristics, i.e., high, intermediate, and low potential solubility. In addition, the data from several 1 liter standing samples which represent a combination of both the faucet and the home plumbing were included in the evaluation of individual faucet and home plumbing contributions.

Faucet and Home Plumbing Contributions. Individual faucet and home plumbing contributions from 1-liter standing samples (from Table 4-5) were calculated by assuming that the faucet contributed 33 percent of the lead in a one liter sample. This was the percentage of lead determined from the AWWSCo survey to be contributed by the faucet. The calculated values are shown in Table 4-8, and the ranges are summarized below:

Category for Potential Solubility	Range of Calculated Contributions, ug/L Faucet	Home Plumbing
High	3.3 - 422	0.7 - 95
Intermediate	6.6 - 254	1.5 - 57
Low*	16.5	3.7

*Note: Only one value for the Low Category.

Table 4-8

Summary of Home Plumbing and Faucet Contribution

Category For Potential Lead Solubility	Actual Average Lead Levels in 1 Liter Sample, ug/L *	Calculated Faucet Contribution ** (ug/L)	Calculated Home Plumbing Contribution ** (ug/L)
High	1	3.3	0.7
	5.6	18.4	4.2
	10	33.0	7.4
	14	46.2	10.4
	17	56.1	6.2
	76	250.8	56.6
	128	422.4	95.3
	46	151.8	34.2
	25	82.5	18.6
Intermediate	8	26.4	6.0
	13	42.9	9.7
	5	16.5	3.7
	5	16.5	3.7
	3.4	11.2	2.5
	2.4	7.9	1.8
	4.0	13.2	3.0
	2.3	7.6	1.7
	2.1	6.9	1.6
	4.4	14.5	3.3
	2.0	6.6	1.5
	35	115.5	26.1
	77	254.1	57.3
	40	132.0	29.8
Low	< 5	16.5	3.7

* From Table 4.5

** Assuming Faucet Contributes 33% of Lead in a 1 Liter Sample

These calculated values were then used along with actual data representing faucets and home plumbing (from Tables 4-3 and 4-4), to estimate typical lead level contributions from these sources. The actual average lead levels from faucets in the surveys were measured from 100- to 125-mL standing samples at the tap. The actual home plumbing values were measured from a standing sample collected at the tap after a small volume of water had either been wasted or collected to determine the faucet contribution. Tables 4-9 and 4-10 contain the values used to estimate the faucet contribution and the home plumbing contribution, respectively. These tables contain both actual average lead levels measured from faucets and home plumbing, and the calculated faucet and home plumbing contributions from one liter samples. The average value for faucet and home plumbing lead levels for each potential lead solubility category was calculated as follows:

Category for Potential Solubility	Average Value, ug/L	
	Faucet	Home Plumbing
High	111.5	24.5
Intermediate	38.1	9.8
Low	23.9	3.7

Lead Service Line and Gooseneck. Measured lead levels from samples representative of a lead service line (Table 4-6) were categorized according to potential lead solubility category. These values were then averaged to arrive at an estimate of the lead levels from the service line and the gooseneck. Table 4-11 contains the values used to estimate the lead service line contribution. Following is a summary of the range of lead concentrations measured from lead service lines:

Category for Potential Solubility	Range of Lead Levels, ug/L	Average Lead Levels, ug/L
High	8 - 121	55.6
Intermediate	5 - 15	8.7
Low	<1 - 6	3.5

Estimated Lead Levels for Matrix. The average values described above for each of the major material sources of lead were used to estimate lead levels for the matrix. A final summary of these estimated lead concentrations used in the matrix evaluation is as follows:

Category for Potential Lead Solubility	Estimated Lead Concentrations (ug/L)		
	Faucet	Home Plumbing	Service Line
High	112	25	56
Intermediate	38	10	9
Low	24	4	4

Table 4-9

Summary of Faucet Contribution

Category for Potential Lead Solubility	Actual Average Lead Levels* (ug/L)	Calculated Faucet Contribution** (ug/L)	Summary Statistics (ug/L)	
High	50	3.3	Avg. =	111.5
		18.4	Max. =	422.4
		33.0	Min. =	3.3
		46.2	Std. =	125.0
		56.1	Med. =	53.1
		250.8		
		422.4		
		151.8		
		82.5		
Intermediate	12	26.4	Avg. =	38.1
	15.4	42.9	Max. =	254.0
	25	16.5	Min. =	6.6
	17	16.5	Std. =	55.8
	42	11.2	Med. =	16.0
	10	7.9		
	82	13.2		
	7	7.6		
	17	6.9		
	16	14.5		
		6.6		
		115.5		
		254.1		
		132.0		
Low	4	16.5	Avg. =	23.9
	71		Max. =	71.0
	13		Min. =	4.0
	15		Std. =	23.9
			Med. =	15.0

* From Table 4.3
** From Table 4.8

Table 4-10

Summary of Home Plumbing Contribution

Category for Potential Lead Solubility	Actual Average Lead Levels* (ug/L)	Calculated Home lumbing Contribution* (ug/L)	Summary Statistics (ug/L)	
High	53	0.7	Avg. =	24.5
	10	4.2	Max. =	95.3
	9.5	7.4	Min. =	0.7
	11.8	10.4	Std. =	26.9
		6.2	Med. =	10.4
		56.6		
		95.3		
		34.2		
		18.6		
Intermediate	6	6.0	Avg. =	9.8
	3.7	9.7	Max. =	57.3
	3.8	3.7	Min. =	1.6
	2.4	3.7	Std. =	14.3
		2.5	Med. =	3.7
		1.8		
		3.0		
		1.7		
		1.6		
		3.3		
		1.5		
		26.1		
		57.3		
		29.8		
Low		3.7	Avg. =	3.7

* From Table 4.4
** From Table 4.8

Table 4-11

Summary of Lead Service Line Contribution

Category for Potential Lead Solubility	Average Lead Levels* (ug/L)	Summary Statistics (ug/L)	
High	11	Avg. =	55.6
	37	Max. =	121.0
	18	Min. =	8.0
	90	Std. =	44.4
	104	Med. =	37.0
	121		
	8		
Intermediate	9.2	Avg. =	8.7
	15	Max. =	15.0
	5	Min. =	5.0
	8.9	Std. =	2.8
	5.8	Med. =	8.9
	9.8		
	8.6		
	9.9		
	6.0		
Low	6.0	Avg. =	3.5
	< 1	Max. =	6.0
		Min. =	1.0
		Std. =	2.5

* From Table 4.6

These values were then used to calculate lead mass contributions from the typical home plumbing scenario. Figure 4-9 displays the total mass of lead and percent of total mass contributed by each component using these lead concentrations and plumbing characteristics.

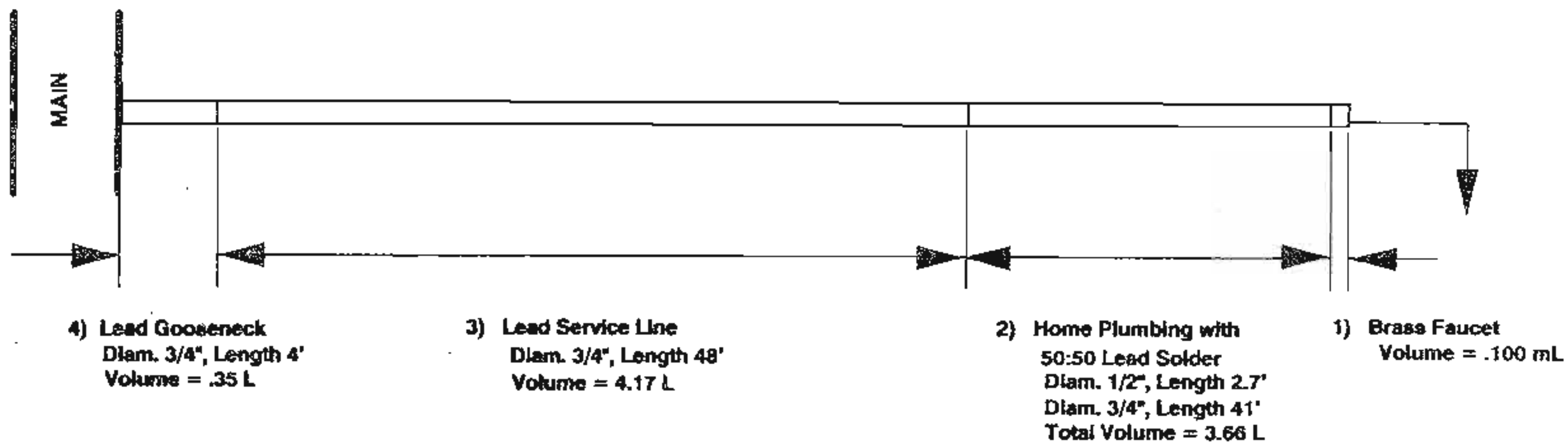
Water Use. Two different water use scenarios were evaluated to estimate adult human ingestion of 2 liters of drinking water from the kitchen tap. Both scenarios assumed a continuous flow rate of 1.75 gpm at the tap. This flow rate was estimated from a range of 0.5 - 3.0 gpm. The high end of this range was arrived at by using the National Association of Corrosion Engineers' (NACE) recommendation that a maximum design velocity of 4 fps (2.9 gpm) be used for Type K copper tube (commonly used in household applications) to prevent erosion of the pipe materials. The low end of the range was established in order to prevent particulate matter from accumulating in pipe loop experiments (AWWARF 1990).

The first water use scenario assumed that eight 250-mL samples would be ingested with a 10 second flush between each sample. Plug-flow was assumed in order to carry the lead contributions from each lead component through to the outlet. This is probably not a reasonable assumption, however, there is little information available to equate the effect of mixing on lead levels at the tap or lead contributions from particular material sources. Water use scenario #1 is an extremely conservative estimation which increases the impact of the lead service line on the total mass of lead ingested. It is highly unlikely that someone would drink 2 liters of water, all of which has been in contact with a lead source material overnight. This scenario is presented merely as an example of the type of analysis which can be performed in order to estimate the amount of lead ingested in drinking water. The contribution of various lead material sources to the total mass of lead ingested is dependent on the water use pattern estimated (i.e., volume ingested, volume of water flushed in between drinking water samples), the lead concentrations estimated for each material source, and how these concentrations change due to mixing and short stagnation times in the pipe or faucet.

The second water use scenario assumes that a 1-liter first flush standing sample at the tap and a 1-liter volume directly from the service line would be ingested. This is also an extremely conservative assumption; however, it relates to both the sample collection protocol in the proposed regulation as well as the impact of removal or replacement of all or part of the service line. This scenario was carried through to the remainder of the lead service line replacement benefit-to-cost analysis.

4.4.3.2 Results

A matrix for total lead ingested was completed for each of the two water use scenarios. These matrices combined the following assumptions to arrive at total lead ingested in a 2-liter sample:



		High Potential			Intermediate Potential			Low Potential		
	Volume, L	Conc., ug/L	Mass, ug	% of Total	Conc., ug/L	Mass, ug	% of Total	Conc., ug/L	Mass, ug	% of Total
1) Brass Faucet	.100	112	11.2	3.2 %	38	3.8	4.7 %	24	2.4	6.8 %
2) Home Plumbing with 50:50 Lead Solder	3.66	25	91.5	25.7 %	10	36.6	45.1 %	4	14.6	41.6 %
3) Lead Service Line	4.71	56	233.5	65.6 %	9	37.5	46.3 %	4	16.7	47.6 %
4) Lead Gooseneck	.35	56	19.6	5.5 %	9	3.2	3.9 %	4	1.4	4.0 %
Total	8.28 Liters		355.8 ug	100 %		81.1 ug	100 %		35.1 ug	100 %

FIGURE 4-9 TYPICAL HOME PLUMBING CHARACTERISTICS AND TOTAL MASS FROM EACH COMPONENT

- A typical home plumbing scenario consisting of a lead gooseneck, lead service line, home plumbing with 50:50 lead solder, and a brass faucet. The diameter, length, and total volume characteristics for these lead material components were also estimated.

- Estimated lead concentrations from each of the lead material components for three potential lead solubility categories.

- Water use assumptions to arrive at the total mass of lead ingested in a two liter sample.

The matrices for water use scenarios #1 and #2 can be seen in Figures 4-10 and 4-11, respectively. The mass of lead contributed from the lead service line for each scenario is as follows:

Category for Potential Lead Solubility	Mass from Lead Service Line, ug Scenario #1	Scenario #2
High	42.5	56
Intermediate	6.8	9
Low	3.0	4

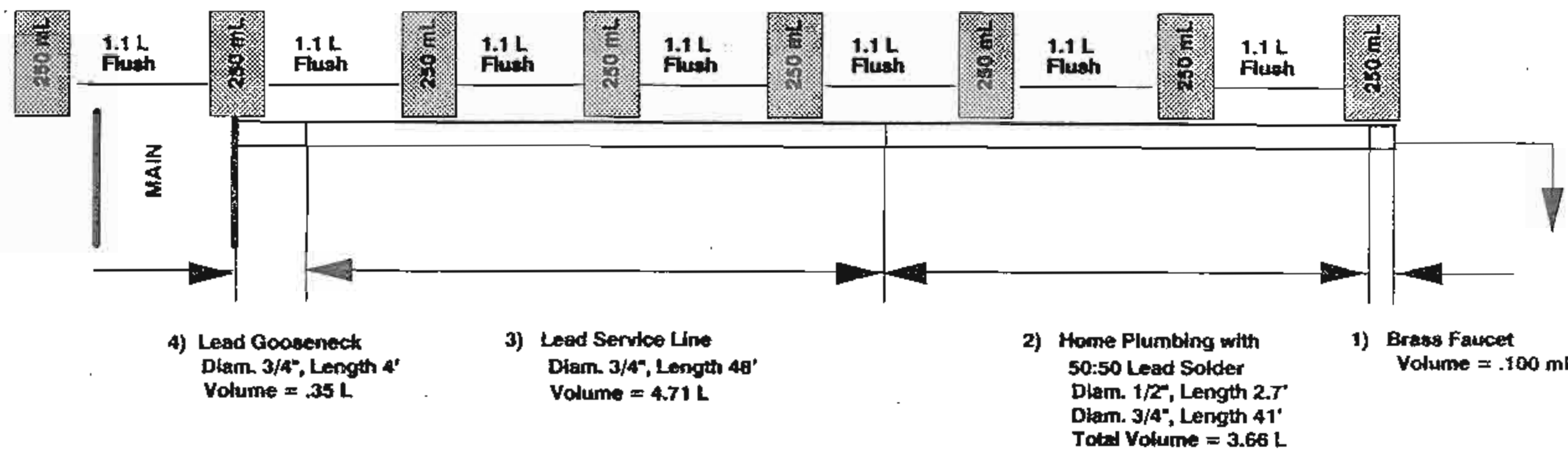
These mass contributions represent a percentage of the total mass of lead ingested from all lead sources related to drinking water. The percentages vary from 35 to 53 percent for water use scenario #1, and from 40 to 62 percent for water use scenario #2.

4.5 IMPACT OF REPLACEMENT OR REMOVAL OF LEAD SERVICE LINES AND CONNECTIONS ON LEAD LEVELS

In order to evaluate replacement or removal of lead services and/or goosenecks, the matrix for ingested lead was used to determine a theoretical percent reduction in lead. Both the impact of removing the entire service, or a portion of the service are discussed. Actual field data gathered both before and after lead service lines was also summarized. These results are discussed below.

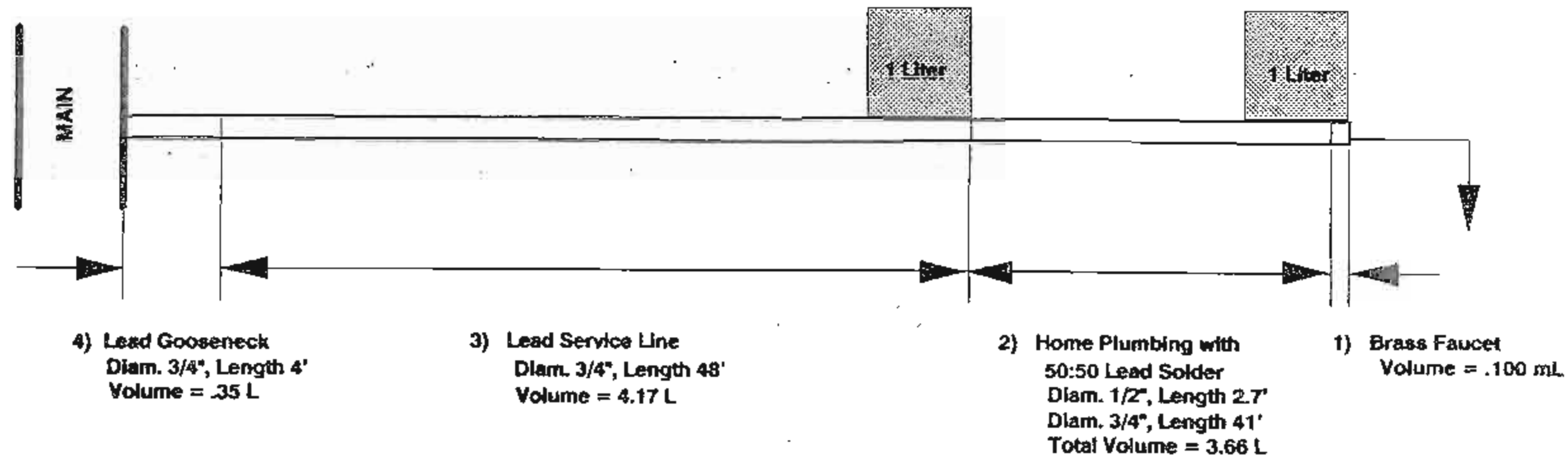
4.5.1 Estimated Impact on Lead Levels Based on Matrix

Using water use scenario #2, the total mass of lead ingested from 2 liters was estimated for high, intermediate, and low potential lead solubility categories, respectively. Replacement of the lead gooseneck would have no impact on lead ingested under this scenario. Replacement or removal of the entire lead service line would however, reduce these mass amounts. Figure 4-12 presents the matrix for lead levels at the tap after the entire lead service line has been removed.



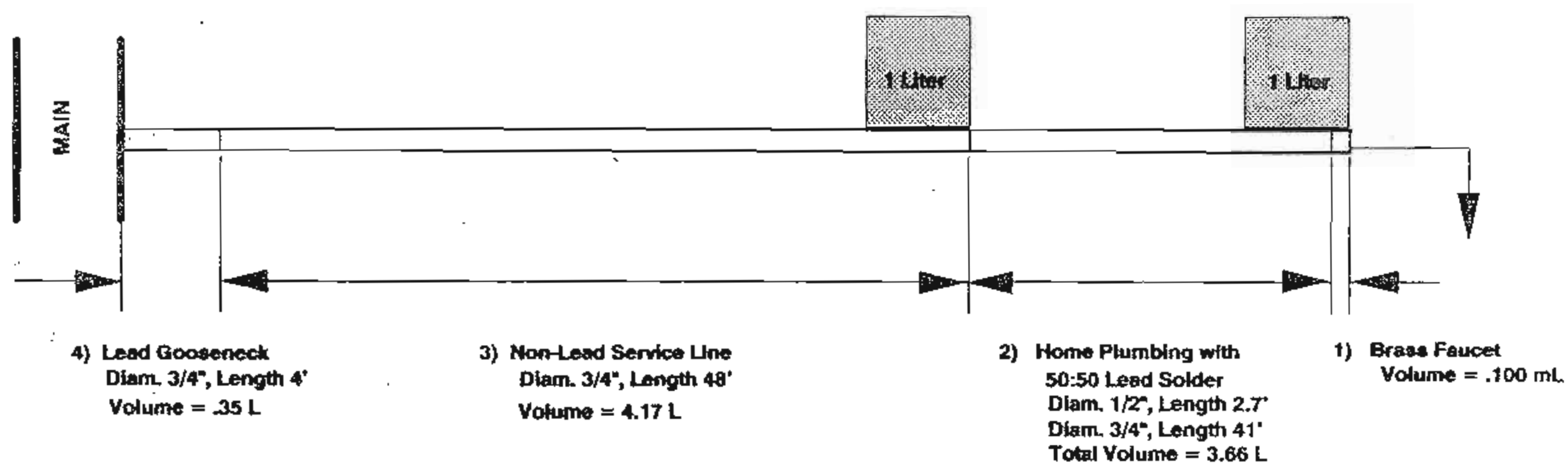
		High Potential			Intermediate Potential			Low Potential		
	Volume, L	Conc., ug/L	Mass, ug	% of Total	Conc., ug/L	Mass, ug	% of Total	Conc., ug/L	Mass, ug	% of Total
1) Brass Faucet	0.10	112	11.2	14.1 %	38	3.8	20.3 %	24	2.4	27.5 %
2) Home Plumbing with 50:50 Lead Solder	0.65	25	16.3	20.4 %	10	6.5	34.8 %	4	2.6	29.8 %
3) Lead Service Line	0.75	56	42.0	52.8 %	9	6.8	36.2 %	4	3.0	34.4 %
4) Lead Gooseneck	0.18	56	10.1	12.7 %	9	1.6	8.7 %	4	0.7	8.3 %
Total	1.68 Liters		79.6 ug	100 %		18.7 ug	100 %		8.7 ug	100 %

FIGURE 4-10 WATER USE SCENARIO #1 MATRIX FOR LEAD LEVELS AT THE TAP



		High Potential			Intermediate Potential			Low Potential		
	Volume, L	Conc., ug/L	Mass, ug	% of Total	Conc., ug/L	Mass, ug	% of Total	Conc., ug/L	Mass, ug	% of Total
1) Brass Faucet	0.10	112	11.2	12.5 %	38	3.8	17.4 %	24	2.4	24 %
2) Home Plumbing with 50:50 Lead Solder	0.90	25	22.5	25.1 %	10	9	41.3 %	4	3.6	36 %
3) Lead Service Line	1.00	56	56	62.4 %	9	9	41.3 %	4	4	40 %
4) Lead Gooseneck	0	56	0	0 %	9	0	0 %	4	0	0 %
Total	2.0 Liters		89.7 ug	100 %		21.8 ug	100 %		10.0 ug	100 %

FIGURE 4-11 WATER USE SCENARIO #2 MATRIX FOR LEAD LEVELS AT THE TAP



		High Potential			Intermediate Potential			Low Potential		
	Volume, L	Conc., ug/L	Mass, ug	% of Total	Conc., ug/L	Mass, ug	% of Total	Conc., ug/L	Mass, ug	% of Total
1) Brass Faucet	0.10	112	11.2	33.2 %	38	3.8	29.7 %	24	2.4	40 %
2) Home Plumbing with 50:50 Lead Solder	0.90	25	22.5	66.8 %	10	9	70.3 %	4	3.6	60 %
3) Lead Service Line	1.00	0	0	0 %	0	0	0 %	0	0	0 %
4) Lead Gooseneck	0	56	0	0 %	9	0	0 %	4	0	0 %
Total	2.0 Liters		33.7 ug	100 %		12.8 ug	100 %		6.0 ug	100 %

FIGURE 4-12 MATRIX FOR LEAD LEVELS AT THE TAP ASSUMING THE ENTIRE SERVICE LINE IS REPLACED

Percent reductions in total lead mass ingested for each potential lead solubility category would be:

Reduction in Total Mass of Lead Ingested Due to Replacement of Entire Lead Service Line

Potential Lead Solubility Category	Total Mass Before (ug)	Total Mass After (ug)	% Reduction in Total Lead Mass
High	89.7	33.7	62
Intermediate	21.8	12.8	41
Low	10.0	6.0	40

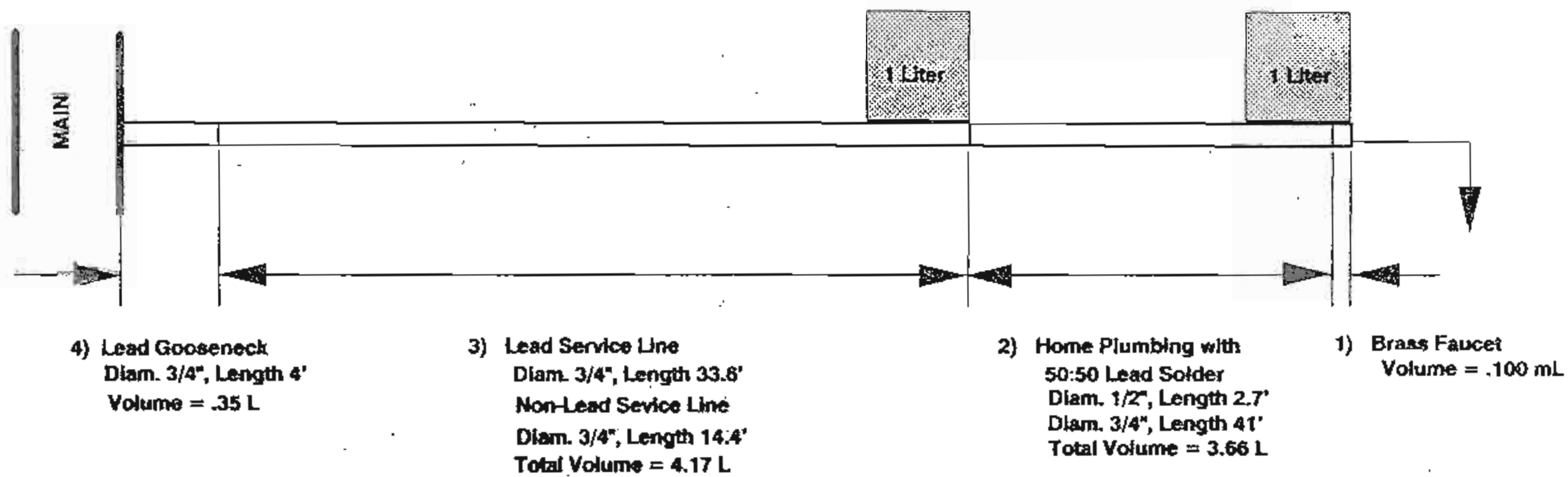
These reductions would be less if only a portion of the service line were removed. In order to evaluate the impact of partial replacement, it was assumed that the percentage of service line replaced would equal the same percentage reduction in the lead mass contributed by the service line. Figure 4-13 displays the lead matrix assuming that 1/3 of the service line has been replaced. Percent reductions in total lead mass ingested would be:

Reduction in Total Mass of Lead Ingested Due to Replacement of 30% of the Lead Service Line

Potential Lead Solubility Category	Total Mass Before (ug)	Total Mass After 30% Replaced (ug)	% Reduction in Total Lead Mass
High	89.7	72.9	18.7
Intermediate	21.8	19.1	12.4
Low	10.0	8.8	12.0

4.5.2 Utility Experience of Partial Replacement on Lead Levels

Very little data exists on the impact of lead service line or lead gooseneck replacement on lead levels measured at the tap. While the estimated impact of partial lead service line replacement would be a decrease in lead levels as described above, there is the potential for immediate, short term increases in lead concentrations. Britton and Richards observed high lead concentrations from both first draw and random daytime samples after partial lead pipe replacement (Britton and Richards, 1981). The lead concentrations rose to a maximum of 4,250 ug/L after replacement, but eventually decreased to the prereplacement levels of less than 50 ug/L. More recently, a study on particulate lead was completed in which 8 lead service lines were removed, placed in a pipe rig, and sampled during the stabilization period (Hulsmann, 1990). The disturbance of the internal corrosion layer was found to have significantly increased lead concentrations, and these higher lead levels were caused by particulate lead. Higher lead level concentrations after lead pipe replacement or disturbance are most likely due to both the increase in particulate lead from disturbance of the pipe films and the corresponding surface of pipe exposed to electrochemical corrosion.



		High Potential			Intermediate Potential			Low Potential		
	Volume, L	Conc., ug/L	Mass, ug	% of Total	Conc., ug/L	Mass, ug	% of Total	Conc., ug/L	Mass, ug	% of Total
1) Brass Faucet	0.10	112	11.2	15.4 %	38	3.8	19.9 %	24	2.4	27.3 %
2) Home Plumbing with 50:50 Lead Solder	0.90	25	22.5	30.9 %	10	9	47.1 %	4	3.6	40.9 %
3) Lead Service Line	1.00	39.2	39.2	53.7 %	6.3	6.3	33.0 %	2.8	2.8	31.8 %
4) Lead Gooseneck	0	56	0	0 %	9	0	0 %	4	0	0 %
Total	2.0 Liters		72.9 ug	100 %		19.1 ug	100 %		8.8 ug	100 %

FIGURE 4-13 MATRIX FOR LEAD LEVELS AT THE TAP ASSUMING 30% OF THE SERVICE LINE IS REPLACED

Several utilities were contacted to determine if they had lead level measurements at the tap before and after removal of lead materials (Table 4-12). None of the utilities listed had collected this type of data. One east coast utility was contacted which had collected this type of data. The Newport News Waterworks supplies water to over 350,000 customers in an area of Virginia which encompasses three cities and major portions of two counties. In 1987, they initiated a program to replace existing lead service lines in their system. Samples were collected at the meter, both before and just after the lead service was replaced, as well as a few weeks after replacement. One of the streets in this program exhibited the following lead level results:

Location Code	Lead Levels, ug/L		
	Before	After	2 Weeks After
7	4	88	1
10	4	16	2
11	1050	6	4
14	2	106	2
16	4	10	4
18	37	44	<1
19	2350	45	6
21	76	66	13
25	13	27	6

The utility believes the high lead levels in the "before" samples resulted from disturbance of the passivation layer during excavation. The services were exposed prior to sampling.

In several instances, the samples collected immediately after replacement were higher than samples taken before. Significantly lower lead levels were measured at these locations after a two week period however. An ongoing study being completed by the U.S. EPA in Cincinnati is currently evaluating data from seven houses in the Midwest where portions of lead service lines were replaced (EPA Cincinnati 1990). Several service line samples were taken both before and after a portion of the lead service line was replaced. Samples were collected by drawing 3 consecutive 250-mL samples from the tap after flushing a calculated volume of water representing the home plumbing. The difference in before and after replacement lead levels was not found to be statistically significant, however.

In summary, there is enough data available to raise this issue to a high level of concern, especially if lead service lines nationwide are to be disturbed and partially removed.

4.6 IMPACT OF WATER TREATMENT ON LEAD LEVELS

4.6.1 Theoretical Discussion

Many systems that have elevated lead levels can significantly reduce lead levels by simply treating the water to raise pH. A change in solubility of lead of a factor of approximately ten from pH 6 to 7 would not be improbable, depending on the water composition. Sizeable

Table 4-12

Utilities Contacted for Before and After Data Related to Lead Service Line Replacement

City	State
Mission	Kansas
Willmar	Minnesota
Falls City	Nebraska
Seattle	Washington
Fairmont	Minnesota
Cape Girardeau	Missouri
Winona	Mississippi
Salt Lake City	Utah
North Ogden	Utah
Kenosha	Wisconsin

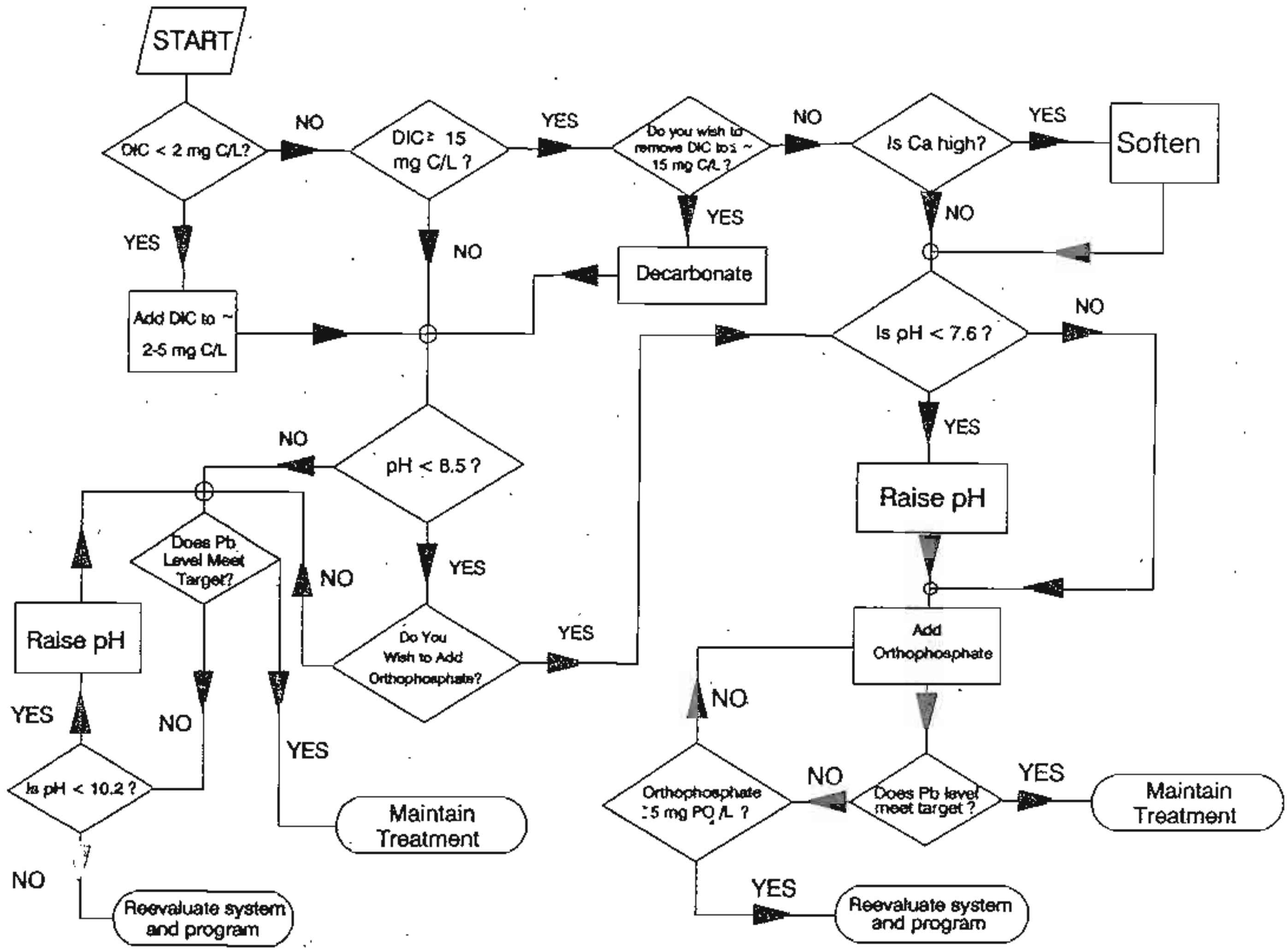
changes could be obtained for different combinations of solution chemistries and pH ranges (particularly below a pH of about 8 or 8.5). The best range for lead solubility reduction would appear to be Dissolved Inorganic Carbonate (DIC) concentration of approximately 1 to 8 mg C/L in the pH range of 8.8 to 10.

It is not possible to devise a fool-proof approach for selecting the best treatment scheme for a given water system. There are simply too many complicated chemical and physical interrelationships that exist and there is a lack of laboratory and field experience to document theoretical models. Even though there are some limitations that must be considered, Figure 4-14 is an initial suggestion of a sequence of decisions that provides guidance for the selection of treatment alternatives. The levels of DIC and pH presented in Figure 4-14 for decision points are approximate, and will require revision as the understanding of lead solubility mechanisms increases. The driving philosophy behind Figure 4-14 is that the chemical models can provide a useful qualitative guide of water chemistry impact, but that the levels of adjustment to be made should be determined through feedback from the specific pilot test and monitoring programs.

The strategy outlined by Figure 4-14 starts with a division of water systems into those containing two levels of DIC. A concentration of 2 mg C/L is chosen as an approximate minimum value for enough DIC present to provide some pH buffering at the pipe surface and the ability to form a protective film of basic lead carbonate. The value of 15 mg C/L as an approximate upper limit was chosen based on what was obviously a deterioration of protection observed in laboratory experiments.

Utilities with waters containing "too much" DIC could use pH adjustment to reduce lead solubility, but in that case, DIC must be removed through some process such as stripping, ion exchange, or lime softening. Conceivably, even after some DIC removal and pH adjustment, lead solubility could still be too high. Also, the effect of the ultimate pH on the calcium carbonate precipitation potential must be anticipated, so that softening could be used, if necessary, to prevent excessive scaling. For high alkalinity and probably high hardness systems, Figure 4-14 does not include an explicit iterative loop for cycles of DIC removal and subsequent pH adjustment. It is implicitly contained in the system reevaluation option.

A second choice for systems with high alkalinity or limited pH adjustment latitude would be the direct application of orthophosphate to the system. Some pH adjustment may be necessary, and the potential for calcium orthophosphate or calcium carbonate precipitation, especially in hot water, must be taken into account, before the orthophosphate dosing program is initiated. Some softening might be necessary in certain hard waters. The selection of pH 7.6 in Figure 4-14 is an estimate of what would be necessary to get the most lead solubility reduction from orthophosphate in systems with moderate to high DIC, based on theoretical predictions.



Note: DIC = Dissolved Inorganic Carbonate

FIGURE 4-14 APPROXIMATE DECISION TREE FOR THE SELECTION OF TREATMENT OPTIONS AMONG pH, DIC, AND ORTHOPHOSPHATE DOSAGE

Systems containing a low, but adequate level of DIC, 2 to 15 mg C/L, could choose to either go with pH adjustment or to use orthophosphate. Orthophosphate addition can be effective at high DIC levels and will do more to reduce lead solubility in high DIC situations than most other water quality alterations, short of major decarbonation or pH adjustment. Because carbonate complexation raises lead solubility in systems with high DIC, lower lead solubility levels generally can be obtained in the water with lower DIC. At very low DIC levels, such as less than approximately 1 mg C/L, the optimum pH for lead orthophosphate film formation is approximately 8. As the orthophosphate dose is increased, the optimum pH slowly decreases, but it remains above 7 for virtually all but the highest DIC concentrations and orthophosphate doses that would ever be encountered. Figure 4-14 presumes the addition of orthophosphate in higher concentrations at a pH of around 7.6 to be more desirable than lower concentrations of orthophosphate dosed at a higher pH, based on the assumption that the selection of orthophosphate addition is most likely to be made by systems trying to avoid a pH of approximately 8 or above.

Systems containing extremely low levels of DIC would require supplementation of carbonate through the addition of such chemicals as sodium bicarbonate or sodium carbonate.

4.6.2 Utility Experience with Corrosion Control

Several utilities have instituted corrosion control treatment, but few have designed, implemented, and evaluated their programs specifically for control of leaching from lead containing materials. Table 4-13 provides a summary of several historical treatment programs and it contains information on programs designed to reduce tap lead levels, as well as programs where this reduction was a beneficial side effect of general corrosion control. Four of these treatment programs are described in more detail below.

Seattle, WA. The Seattle Water Department (SWD) provides drinking water for approximately 1.2 million people. The major supplies are the Cedar and Tolt Rivers from the Cascade mountains, which are low pH, soft surface waters. After comprehensive studies of internal corrosion in their water system were completed, SWD initiated a corrosion treatment program. The goal of this program was to modify the characteristics of both supplies to reduce corrosion and related aesthetic and economic problems, while maintaining a high level of overall water quality.

Water treatment to increase the pH and alkalinity to control corrosion was initiated in 1982. This treatment included addition of calcium oxide (1 to 2 mg/L) at both the Cedar and Tolt supply, and sodium carbonate addition (9 mg/L) on the Tolt supply. In order to measure the effect of treatment on metals leaching, SWD established a monitoring program, the "Residential Water Quality Monitoring Program" or RWQM. Sampling sites were chosen throughout their service area with an equal number from both the Cedar and Tolt supplies. Approximately half the sites were chosen at random and half were chosen based on customer complaints of rust stains, yellow water, and metallic taste. Overnight standing and flushed tap samples were drawn. Results from the monitoring can be seen on Table 4-13. Reductions in standing tap lead levels were 61 percent to 68 percent, and cadmium, copper, and zinc levels were also reduced significantly after treatment was initiated.

Table 4-13

Impact of Water Treatment on Lead Levels: Utility Experience

Utility	Treatment Approach and Water Quality Characteristics	Before Treatment: No. Sites and Samples	Before Treatment: Avr. Pb	After Treatment: No. Sites and Samples	After Treatment: Avr. Pb	% Reduction and/or Comments
Boston, MA (Karalekas et al 1983)	Zinc orthophosphate (6/76 to 12/76) Initial = 13 mg/L Maint. = 3.2 - 4.5 mg/L Initial pH = 5.9 to 6.8 Alkalinity = 8 mg CaCO3/L Hardness = 12 mg/L	11 - 14 sites 3 samples per site, 11 times from 2/76 to 5/76	All > 50 ug/L	11 - 14 sites 3 samples per site, 5 times from 2/76 to 12/76	All > 50 ug/L	Initial treatment with zinc orthophosphate was not deemed successful at pH = 6.8.
	followed by: pH adjustment to 8.3 with NaOH (5/77 to present)	11 - 14 sites 3 samples per site, taken 4/77	128 ug/L	11 - 14 sites 3 samples per site, 23 times from 6/77 to 8/81	35 ug/L	72.6% Reduction pH adjusted to 7.3 initially then to 8.3. Substantial decrease in lead levels noted.
New England Municipalities (Karalekas 1978)						Comparison of 5 typical treatment methods and their impact on tap lead levels.
Bridgeport, CN	Lime addition to pH = 7.1, zinc orthophosphate Alk. = 18 mg CaCO3/L Hardness = 48 mg/L	N/A		10 sites 30 samples	7 ug/L	3 samples/site: Morning first draw Flushed to temp. change, Flushed 3 minutes.
Marlborough, MA	Sodium zinc phosphate glass Alk. = 6 mg CaCO3/L pH = 6.5	N/A		9 sites 27 samples	20 ug/L	

Table 4-13
(continued)

Utility	Treatment Approach and Water Quality Characteristics	Before Treatment: No. Sites and Samples	Before Treatment: Avr. Pb	After Treatment: No. Sites and Samples	After Treatment: Avr. Pb	% Reduction and/or Comments
New England Municipalities (cont.)						
Chatham, MA	Sodium hexameta-phosphate, 0.4 mg/l Alk. = 3 mg CaCO3/L pH = 6.3	N/A		10 sites 30 samples	17 ug/L	
New Bedford, MA	Soda ash addition to pH = 7.3 Alk. = 24 mg CaCO3/L	N/A		10 sites 30 samples	60 ug/L	
Providence, RI	Lime addition to pH = 10.1 Alk. = 20 mg CaCO3/L	N/A		10 sites 30 samples	< 5 ug/L	
Fairbanks, AK (Townsend & Pollen 1988)	Sodium polyphosphate Dose: Initial = 6.9 mg/L Maint. = 2.3 mg/L Alk. = 193 mg CaCO3/L pH = 6.8 Hardness = 172 mg/L Calcium = 108 mg/L	15 sites 15 samples	77 ug/L	15 sites 15 samples	34.8 ug/L	54.8% Reduction Morning first draw One Liter samples. Treatment in place for one month prior to sampling.

Table 4-13
(continued)

Utility	Treatment Approach and Water Quality Characteristics	Before Treatment: No. Sites and Samples	Before Treatment: Avr. Pb	After Treatment: No. Sites and Samples	After Treatment: Avr. Pb	% Reduction and/or Comments
Portland, ME (Boissonneault 1989) (Perkins 1989)	Sodium hydroxide addition pH = 8.6	25 sites: 31 samples 4 samples 1 sample 1 sample 1 sample	 < 50 ug/L 50 ug/L 60 ug/L 70 ug/L 150 ug/L	6 sites 494 samples	15.4 ug/L	Morning first draw 125 mL samples Before treatment samples taken anywhere from 2-10 years prior. Treatment in place approx. four months prior to start of after treatment sampling. Lead levels for the 31 samples under 50 ug/L is unknown.
	Zinc orthophosphate addition and sodium hydroxide: Dose: Initial - 1.0 mg/L Maint. - 0.4 mg/L pH = 7.4			6 sites 162 samples (initial dose) 6 sites 237 samples (maint. dose)	23.3 ug/L 24 ug/L	Morning first draw 125 mL samples Treatment in place approx. two months prior to start of sampling For 3 of the 6 sites, caustic alone to pH 8.6 was more effective than zinc orthophosphate plus caustic to pH 7.4.
American Water Works Service Company (AWWSCo 1988) (Lee et al 1989)						
District 230 Davenport, IA	Zinc orthophosphate addition Initial = 0.3 mg/L (2 weeks) 0.6 mg/L (2 weeks) Maint. = 1.0 mg/L	9 sites 9 samples	40 ug/L	9 sites 9 samples	5 ug/L	87.5% Reduction Morning first draw One Liter samples Treatment in place for one month prior to start of sampling

Table 4-13
(continued)

Utility	Treatment Approach and Water Quality Characteristics	Before Treatment No. Sites and Samples	Before Treatment Avr. Pb	After Treatment No. Sites and Samples	After Treatment Avr. Pb	% Reduction and/or Comments
American Water Works Service Company (cont.)						
District 340	Zinc orthophosphate addition Initial = 0.2 mg/L Maint. = 1.7 mg/L	4 sites 4 samples	53 ug/L	4 sites 4 samples	5 ug/L	87% Reduction
District 130	Zinc orthophosphate addition Initial = 0.2 mg/L Maint. = 1.7 mg/L	5 sites 5 samples	90 ug/L	5 sites 5 samples	12 ug/L	91% Reduction
Nationwide (comparison of various treatment methods from member districts)	Zinc orthophosphate			218 samples	3.6 ug/L	Morning first draw one liter samples. Zinc Orthophosphate more effective than pH increase to 8.0 alone.
	Sodium zinc hexametaphosphate			25 samples	25.1 ug/L	
	Other polyphosphates			86 samples	6.3 ug/L	
	pH greater than or equal to 8.0			200 samples	5.2 ug/L	

Table 4-13
(continued)

Utility	Treatment Approach and Water Quality Characteristics	Before Treatment: No. Sites and Samples	Before Treatment: Avr. Pb	After Treatment: No. Sites and Samples	After Treatment: Avr. Pb	% Reduction and/or Comments
Covewood Lodge Resort, Upstate New York (Letterman 1986)	Limestone contactor					
	Spring source: Alk. = 7.5 mg CaCO3/L pH = 6.34 DIC = 3.7 mg/L	1 site 3 samples	46 ug/L	2 sites: 7 samples 13 samples	 18 ug/L 8.4 ug/L	 60.8% Reduction 82% Reduction Morning first draw one liter samples
	Lake source: Alk. = -1.5 mg CaCO3/L pH = 4.64	1 site 3 samples	26 ug/L	1 sites 26 samples	15 ug/L	42.3% Redution Morning first draw one liter samples
	DIC = 0.99 mg/L	1 site 3 samples	13 ug/L	1 sites 5 samples	11 ug/L	15.4% Reduction Morning first draw one liter samples.
Seattle Water Department (Chapman et al 1989)						Residential water quality monitoring program. Half of samples chosen at random, half chosen from complaint calls
Cedar River Supply	Before Treatment pH = 7.2 Alk. = 16 mg CaCO3/L	163 samples	Standing: Avr. = 9.5 ug/L Max. = 137 ug/L	214 samples	Standing: Avr. = 3.7 ug/L Max. = 42.5 ug/L	61% Reduction standing samples.
	Lime addition to pH = 8.2 Alk. = 19 mg CaCO3/L (1982)		Running: Avr. = 1.54 ug/L Max. = 16.5 ug/L		Running: Avr. = 0.55 ug/L Max. = 11 ug/L	

Table 4-13
(continued)

Utility	Treatment Approach and Water Quality Characteristics	Before Treatment: No. Sites and Samples	Before Treatment: Avr. Pb	After Treatment: No. Sites and Samples	After Treatment: Avr. Pb	% Reduction and/or Comments
Seattle Water Department (cont.)						
Tolt River Supply	Before Treatment pH = 6.0 Alk. = 2.5 mg CaCO3/L	136 samples	Standing: Avr. = 11.8 ug/L Max. = 133 ug/L	165 samples	Standing: Avr. = 3.8 ug/L Max. = 62 ug/L	68% Reduction standing samples.
	Lime and sodium carbonate addition to: pH = 8.2 Alk. = 13.5 mg CaCO3/L (1982)		Running: Avr. = 1.19 ug/L Max. = 16.5 ug/L		Running: Avr. = 0.37 ug/L Max. = 6.5 ug/L	

Boston, MA. Boston, Massachusetts purchases drinking water from a surface water supply owned by the Metropolitan District Commission. Prior to 1976, treatment consisted of chlorination and ammoniation. Chemical characteristics of the finished water prior to distribution were approximately:

pH	5.8-6.8
Alkalinity	8 mg/L $CaCO_3$
Hardness	12 mg/L $CaCO_3$

Extensive monitoring at home taps revealed that 15.4 percent of samples had lead levels above 50 ug/L (Karalekas 1976). Boston initiated lead corrosion treatment in June 1976 with addition of zinc orthophosphate. The initial dosage was 13 mg/L which was maintained for several weeks before it was lowered to 3.2-4.5 mg/L for the remainder of the six month period that it was tried full scale. Lead levels during this period were almost all above 50 ug/L and increased algal growth was observed in distribution system reservoirs. Boston stopped this treatment when these results indicted that addition of orthophosphate alone was ineffective in reducing tap lead levels and produced undesirable side effects.

In 1977, Boston initiated a pH adjustment program with addition of 14 mg/L sodium hydroxide. This treatment raised the pH and alkalinity levels to 8.5 and 12 mg/L as $CaCO_3$ respectively. Samples taken at the same home taps over a five year period indicated a significant reduction in average lead levels after the sodium hydroxide treatment was initiated (Karalekas 1983). Average lead levels were reduced from an untreated level of 128 ug/L to 35 ug/L after treatment. In Boston's case, the increase in pH levels as measured at the plant appears to be directly responsible for reducing lead concentrations at the tap. Also, average pH levels measured at consumers' taps demonstrated that lower pH levels resulted in a concurrent increase in measured lead levels.

Portland, ME. The Portland Water District supplies drinking water to approximately 160,000 customers (46,000 service connections) in the Portland, Maine area. The major water supply is Sebago Lake, which is supplemented by three well systems. In April 1984, chemical addition of zinc orthophosphate was started, at an initial dose of 1 mg/L. Liquid caustic was also added to raise the pH level to a 7.4 to 7.6 range. A maintenance dosage of 0.3 mg/L was started in June and continued until September, 1984. The decision to stop orthophosphate treatment was based on excessive zinc levels in wastewater sludge which would prohibit land spreading. Although tap lead levels were not measured prior to treatment, standing copper levels were measured at five sites several times before and after treatment. Results indicated that treatment reduced standing copper levels by 36 percent to 72 percent.

In July, 1986, the Portland Water District began addition of caustic to raise the pH to 8.3 and again evaluated standing copper levels from the same five sites. Reductions in standing copper levels ranged from 61 percent to 85 percent. The lead levels measured at six sites (494 samples) after this treatment averaged 15.4 ug/L.

Addition of zinc orthophosphate was started again in June, 1988 at an initial dose of 1 mg/L for two months, and then a maintenance dose of 0.4 mg/L. Caustic was also added to adjust the pH to 7.4. Of the 6 sites sampled almost daily over the next 2 month period, lead levels increased in three of the sites and the overall average from all sites was higher than with caustic alone. The average lead level measured was 24 ug/L. The Portland Water District has since discontinued the zinc orthophosphate treatment since caustic treatment alone was more effective in reducing lead levels.

Covewood Lodge, NY. Covewood Lodge is a resort in upstate New York. The resort contains several cabins and a central lodge which are served by low pH, low alkalinity springs as their major water supply. In 1981, a baffled limestone contactor was placed in one of the springs and its effectiveness in reducing corrosion was evaluated over the next few years (Letterman 1986). The limestone contactor was a packed bed of crushed limestone which measured 0.6 x 0.6 x 1.2 m. The entire unit was placed in the spring and the effluent served the entire west side of the resort. The raw water passing through it dissolves the calcium carbonate, resulting in an increase in pH, calcium ion, and alkalinity.

Twenty-three samples were taken over a two year period to evaluate the effectiveness of the limestone contactor in reducing lead levels measured at the tap. Three cabins were involved in the testing, one which was supplied by untreated water and two receiving water from the contactor. Lead levels from the cabins with treated water were significantly lower than those receiving untreated water.

In addition to the contactor, a wound fiberglass, ion-exchange type column containing limestone particles was used to treat water at two cabins. The lake supply was extremely acidic (pH = 4.6) with negligible alkalinity. Use of the column caused the pH to be increased to approximately 7.0 and lead levels at the tap were reduced by 15 percent to 42 percent.

Although both the spring and lake supplies were still relatively corrosive after treatment with the contactor and column, there were significant reductions in lead levels measured at the tap.

American Water Works Service Company (AWWSCo). District 230, in Davenport Iowa, is a member district of the AWWSCo. They began corrosion control treatment in May 1988 using zinc orthophosphate at an initial passivation dose of 0.3 ppm for 2 weeks, 0.6 ppm for two more weeks, followed by a control dosage of 1.0 ppm (as phosphate). Tap samples were collected from 9 sites both before and after treatment was initiated. Results indicated a significant reduction in lead levels (87.5 percent) after treatment was started. Districts 340 and 130 of the AWWSCo system also evaluated lead levels both before and after zinc orthophosphate treatment and found similar percentage reductions (87.5 percent and 91 percent, respectively).

4.6.3 Summary

The theoretical basis for effective water treatment to reduce lead levels as well as tap water quality data associated with various chemical treatments for corrosion control have been summarized. Lead levels and other corrosion by-products indicate that in some cases, substantial reductions in metal leaching can be achieved by proper adjustments to water chemistry in water systems. It is also abundantly clear that corrosion control is an art and not an exact science. Based on the available literature, lead level reductions have ranged from 0 percent up to 95 percent or more, but a more typical range is from 35 percent up to 75 percent. Sometimes treatments have actually increased the potential for leaching of lead. The most common treatments used are pH and alkalinity adjustments and orthophosphate inhibitors. Higher lead level reductions due to treatment were generally seen in very corrosive waters, where initial lead levels were very high. In some instances, lead levels measured were still relatively high when compared to the proposed regulatory levels even though a large percent reduction may have been reported. Thus, while water treatment can reduce tap lead levels significantly, it may not always reduce the levels to meet a level of 10 to 20 ug/L in first flush samples from the tap.

SECTION 5

LEAD SERVICE REPLACEMENT - SCHEDULING AND COST

SECTION 5

LEAD SERVICE REPLACEMENT - SCHEDULING AND COST

5.1 INTRODUCTION

The national costs for implementing an accelerated mandatory lead service replacement program have been developed based on the cost information available from the 1988 AWWA Lead Information Survey (AWWA-LIS), this study's utility telephone survey, and the three case studies. This cost information has been analyzed to determine its variation by utility system size and geographic location. Methods for water utilities to respond to a mandatory program were evaluated and found to be dependent upon how a utility would be able to locate the lead services within its system.

Costs for three different methods by which water systems could carry out the program were calculated; these correspond to the three identification/location methods described in Section 3. For each of these methods, both programmatic costs (those additional costs incurred by the utilities to locate and schedule services for replacement) and actual excavation and replacement costs were developed. Not surprisingly, the ability to accurately locate lead services minimizes the number of nonlead services that would be excavated in attempting to find all the lead services. Based upon information from our three case studies, we have estimated the number of erroneous excavations that would be expected to occur under each replacement method.

The implementation of the mandatory replacement program has been scheduled over four different completion periods (10, 15, 20, and 25 years). These have been compared to ongoing replacement practices, which are considered to be baseline conditions. The potential for using cost-saving techniques has been evaluated, but is limited due to the nature of lead service lines. The quantities of lead accumulated by this program have been estimated, and there is a strong potential for cost recovery through recycling.

5.2 OBJECTIVES

The objectives of this task were to:

- Evaluate the baseline conditions of ongoing water utility lead service replacement practices.
- Investigate the potential for use of innovative cost-saving replacement techniques.
- Develop national costs for an accelerated mandatory lead service replacement program. Such costs would include the additional programmatic costs necessary for the water utility industry to identify and locate lead services and to schedule, mobilize, and carry out the program.

necessary for the water utility industry to identify and locate lead services and to schedule, mobilize, and carry out the program.

- Provide cost estimates for programs to be completed over 10-, 15-, 20-, and 25-year periods.
- Compare the accelerated program to baseline conditions using 50 percent and 90 percent completion dates.
- Determine the impact of removed lead services if they are recycled, disposed of, or stockpiled.

5.3 BASELINE CONDITIONS

The AWWA-LIS of more than 1,000 water utilities nationwide provided information on the actual replacement of lead service lines occurring annually. Based on the information provided by AWWA-LIS, and extrapolating to the water industry nationwide, we have estimated that 61,000 lead service lines are presently being replaced each year. In Section 2, we have estimated the total number of lead service lines nationally as 3,350,000. If the present rate of replacement is maintained, a 55-year period would be required for complete removal of lead service lines.

There are two major considerations that might significantly alter the present rate of lead service line replacement:

- The emphasis and concern now being placed upon lead exposure and the part that service lines may have in the total exposure will probably accelerate the rate of replacement, even without a mandated program. In fact, many of the water systems contacted in the case studies or in the telephone survey indicated they are already proactively stepping up replacement efforts.
- As lead services continue to be replaced, the remaining services will be less frequently encountered and more difficult to find.

These two factors will, to varying degrees, counteract each other; therefore, until the present replacement rates can be tracked more closely, it would seem reasonable to consider them as representing baseline conditions.

5.4 COST SAVING REPLACEMENT TECHNIQUES

5.4.1 Historical Method

For years, the accepted method for replacing a service line was to excavate along the entire length of the line, remove the old service line, and install a new pipe. This often meant digging up a major portion of the roadway, and, of course, required costly roadway repair.

To avoid this, water utilities in recent years have used two alternate methods to replace service lines. These methods do not require extensive excavation.

5.4.2 Pull-Through Technique

First, an excavation is made at each end of the service line. Typically, this is at the corporation stop at the main, and at whatever point the utility's ownership of the service line ends (usually at the curb-stop). The service line is then disconnected at these two points. Next, a new service line is connected to the old service line, and the old line is pulled out. As the old line is removed, the new line is pulled in behind it. The new line is then connected at both ends, and the service restored.

The success of this method depends on the type and condition of the old service line, as well as local soil conditions. For lead service lines, a modification to the basic pull-through technique is suggested. In this case a metal cable is first inserted through the length of the service line and attached to the new pipe length. Then, as the cable is pulled through, it will remove the old line, as well as pulling in the new pipe. The cable prevents problems arising from the lead pipe breaking apart.

5.4.3 Hydraulic Pusher Technique

In cases where the pull-through technique will not work, utilities may make use of a hydraulic pusher. This is a device which is placed in the excavation at one end and, as its name implies, pushes a new length of pipe through to the excavation at the other end of the service.

5.5 COST FOR A MANDATORY REPLACEMENT PROGRAM

The ability of water utilities to identify and locate their lead services (both service lines and connections) will have a significant impact on the cost of implementing a mandatory replacement program. In Section 3 the water utilities across the nation were divided into three scenarios as to how they would be able to locate lead services to be replaced.

- The first group consisted of those systems whose information, data sources, or knowledge of their systems and customer services would allow them to identify and locate services by address.

- The second group would be metered systems where, over a period of time, likely services could be located by visual inspection at the meters. Also included would be nonmetered systems who would choose to gain entrance to private customer's premises to inspect pipe material at the point-of-entry.

- The third group would be unmetered systems where, unless a system was known not to include lead services, determination of the material of a service line could be made only by excavation.

The distribution of the nation's water systems into these categories was provided in Section 3. By using the same procedures described in Section 2 to show the occurrence of lead services nationally by state, the distribution of lead services by system size and by these three scenarios is shown in Table 5-1 for lead service lines and lead connections. Thus, about 17 percent of the lead services are considered located in systems categorized in Scenario I, 55 percent in Scenario II, and 28 percent in Scenario III.

5.5.1 Programmatic Costs

In the course of carrying out a mandatory lead replacement program, water utilities would incur certain costs related to locating and identifying lead services, as well as scheduling and mobilizing the replacement program. These costs will be dependent on the utility's size and its ability to locate lead services. The three scenarios for identifying lead services described in Section 3 will be used as the basis for estimating programmatic costs.

5.5.1.1 Scenario I

Water utilities in Scenario I are considered to have good records of where lead service lines and/or lead connections are located. Based on the three case studies as well as the telephone survey, however, it appears that even those utilities that have data on service line material often do not have it in a form that is easily accessed for use in a replacement program. Also, the records may be incomplete or outdated. For this reason, a programmatic cost has been included for these systems to produce a computerized database of service line material by address, as well as to develop "predictive" techniques for those addresses for which the service line material is unknown. The predictive technique would be based on an analysis of the addresses for which the service line material is known in an attempt to identify factors, such as installation date, or geographic area, which would indicate a high probability that a lead service was located at a particular address.

The cost to computerize service line records and to develop a predictive technique has been estimated based on one of the case study utilities that has undertaken such a program. The cost for this large (> 50,000 person) utility was approximately $300,000. The development of the predictive technique, including a 3-month data entry effort, took approximately 9 months. Since smaller systems would have to deal with a much smaller set of data, the cost of such a program would be significantly less. For this study, the cost for the smallest systems was estimated at $10,000 per system. The costs for intermediate size systems were extrapolated in a linear fashion between the $10,000 per system and $300,000 per system figures.

Since this predictive technique could not be expected to be 100 percent accurate, utilities in Scenario I would be likely to undertake a study to determine the validity of the technique. Thus, a programmatic cost has been added for Scenario I systems for such a verification program. The cost of such a program was again based on the experience of the case study utility, who carried out 120 test excavations, and was estimated at $60,000 per system for large utilities. This cost is primarily the cost of the test excavations to verify the validity of

Table 5-1

Summary of Nationwide Lead Service Lines and Connections by Replacement Scenario

SYSTEM SIZE	SCENARIO I		SCENARIO II		SCENARIO III		TOTAL	
	LEAD SERVICES	LEAD CONNECTIONS	LEAD SERVICES	LEAD CONNECTIONS	LEAD SERVICES	LEAD CONNECTIONS	LEAD SERVICES	LEAD CONNECTIONS
<= 3,300	3,444	10,509	82,665	252,224	258,327	788,201	344,436	1,050,935
3,301 - 10,000	19,435	41,379	174,918	372,409	194,353	413,788	388,706	827,575
10,001 - 50,000	48,820	119,331	390,562	954,648	188,325	460,323	627,707	1,534,302
> 50,000	589,422	840,096	1,262,942	1,800,056	139,425	198,721	1,991,789	2,838,873
TOTAL	661,122	1,011,315	1,911,086	3,379,337	780,431	1,861,033	3,352,638	6,251,685

the predictive technique. The cost for a verification program for smaller utilities would be significantly less. It has been estimated at $5,000 per system for the smallest utilities, with intermediate size utilities estimated between the $5,000 per system and $60,000 per system figures.

The final programmatic cost for Scenario I systems was to re-evaluate the predictive technique based on the results of the verification program, and to develop a cost-effective service replacement schedule. Utilities of all sizes would be required to take this step with slight differences in cost based on system size. The costs for this re-evaluation and scheduling step are primarily staff labor and bid preparation and ranged from $2,500 per system for the small utilities to $10,000 per system for the largest systems.

5.5.1.2 Scenario II

Water utilities which fall under Scenario II would rely on meter readers to identify lead services. Since this should involve little or no extra work on the part of the meter reader, the only programmatic costs to be incurred by these systems are the data entry of the information collected into a computer database and the scheduling of replacements. There would be no verification program necessary as there is with the Scenario I systems.

The data entry work can be expected to be spread over an entire year, at least, as the meter readers make their way through the system. The cost will differ with system size, ranging from $3,500 per system for small systems to $5,000 for the largest utilities, based upon the amount of data that needs to be processed.

The cost of scheduling will also vary with system size. The cost of scheduling lead replacement was estimated at $1,250 for small systems and at $5,000 for large systems.

5.5.1.3 Scenario III

Programmatic costs for water utilities in Scenario III are minimal. These utilities are not metered and have no way of identifying the locations of lead services without excavation. Therefore, the only programmatic cost considered is the scheduling of excavations. The same costs were used as for the Scenario II systems.

The per system programmatic costs were then multiplied by the number of systems in each scenario to get a total programmatic cost for the mandatory lead replacement program. Table 5-2 summarizes these costs by system size and replacement scenario.

5.5.2 Replacement Costs

Three sources of information were used to develop the costs applicable for replacing services:

Table 5-2

Summary of Programmatic Costs

PROGRAMMATIC COST ITEM	POPULATION CATEGORY <= 3,300 COST PER SYSTEM	3,301 - 10,000 COST PER SYSTEM	10,001 - 50,000 COST PER SYSTEM	> 50,000 COST PER SYSTEM	TOTAL COST FOR ALL SYSTEMS
SCENARIO I					
- Computerize database and develop a predictive technique	$10,000	$110,000	$205,000	$300,000	$59,726,411
- Verification program	$5,000	$25,000	$40,000	$60,000	$12,690,707
- Re-evaluate predictive technique and schedule replacements	$2,500	$5,000	$7,500	$10,000	$2,574,279
SCENARIO II					
- Data entry into a computerized database	$3,500	$4,000	$4,500	$5,000	$23,183,563
- Schedule replacements	$1,250	$2,500	$3,750	$5,000	$11,306,179
SCENARIO III					
- Schedule replacements	$1,250	$2,500	$3,750	$5,000	$21,226,605
				TOTAL	$130,707,744

- The AWWA-LIS questioned utilities on the cost of replacing service lines. At this time, the question of jurisdiction was not brought out and the survey represents the cost of replacing service lines in general rather than specifically representing the utility's portion of the service line (which is typically under the street surface and thus more expensive to replace).

- The second source was the telephone survey conducted by this study. Because we are specifically dealing with the potential of a mandatory replacement program requiring the utility to replace the portion of the service under its jurisdiction, we specifically directed our questions to those costs.

- The third source of data was the three case study utilities with whom we discussed at length factors affecting replacement costs.

The AWWA-LIS provided the most substantive volume of information as it included over 1,000 systems. It was analyzed to determine whether replacement costs varied significantly by system size or geographic location. There was a consistent difference between replacement costs when examined by systems of population below and above 10,000. This pattern did not change by using more population categories. Table 5-3 shows the replacement costs by size of the systems reporting. All costs are reported in 1990 dollars, using ENR cost indices to account for annual inflation between 1988 and 1990.

Table 5-3

Replacement Costs by System Size

System Size	Replacement Cost ($/ft)	Average System Size	Replacement Cost ($/ft)
<=3,300	33.66	<10,000	$33.51
3,301 - 10,000	33.44		
10,001 - 50,000	44.70	>10,000	$42.61
>50,000	40.43		

As expected, the telephone survey, which specifically related to the utility's portion of the service line, and thus would generally relate to that portion of the service lines under the street surface, resulted in higher per foot costs than those in Table 5-3. The phone survey data, primarily in the >10,000 population category, yielded costs of $61.85 per foot from those systems with jurisdiction to the curb-stop or curb-line. Assuming nationwide a typical service line of 60 feet (between the 48 feet urban and 73 feet suburban reported in Section 1), and a utility jurisdiction length of 20 feet (between the 25 feet suburban and 13 feet urban mid-street to curb reported in Section 1), the cost per foot for service line replacement is shown in Table 5-4.

Table 5-4

Replacement Costs by Jurisdiction

System Size	Overall Cost ($/ft)*	Main to Curb Cost ($/ft)	Curb to House Cost ($/ft)
< 10,000	33.51	48.64	25.95
> 10,000	42.61	61.85	32.99

*From Table 5-3.

Except for the far-western states where lead services occur infrequently, there was no discernible pattern of replacement costs. Cost data for EPA Regions IX and X show lower replacement costs than for other parts of the country; however, as shown in Section 2, very few lead services occur in these regions. Therefore, no geographical variation was used in the cost analysis.

5.5.3 National Costs

Based on the distribution of lead services presented in Table 5-1, the programmatic costs described in Subsection 5.5.1, and the replacement costs in Table 5-4, the national costs by replacement scenarios can be developed. These costs for the three scenarios are presented in Tables 5-5 through 5-7.

5.5.4 Schedule of Replacement

The previous estimates of lead services replacement are based upon 1990 costs and do not reflect the time necessary to implement replacement. The actual implementation of a mandatory replacement program will occur over a significant period of time, and in the case of the first two scenarios will require completion of the identification/location portions of the program before replacement can begin. The actual costs related to the benefit-to-cost analysis are also the difference between the accelerated replacement program and the normal "baseline" replacement. For purposes of evaluating the impact of the replacement program over time and to compare it to the ongoing baseline replacement effort, the replacement costs are presented for 10-, 15-, 20-, and 25-year periods.

Figure 5-1 presents the total costs of the previously described accelerated replacement program over the four completion periods with the normal baseline replacement subtracted

Table 5-5

Summary of National Costs for Scenario I

SYSTEM SIZE	PROGRAMMATIC COST	# OF LEAD SERVICE LINES	SERVICE LINE REPLACEMENT COST	# OF LEAD CONNECTIONS	CONNECTION REPLACEMENT COST	EXTRA EXCAVATION COST (1)	TOTAL COST
<= 3,300	$3,293,829	3,444	$3,350,673	10,509	$3,436,411	$83,767	$10,164,680
3,301 - 10,000	$12,436,340	19,435	$18,906,660	41,379	$10,673,294	$472,666	$42,488,960
10,001 - 50,000	$21,645,586	48,820	$60,390,582	119,331	$43,610,925	$1,509,765	$127,156,858
> 50,000	$37,615,642	589,422	$729,115,202	840,096	$155,041,980	$18,227,880	$940,000,704
TOTAL	$74,991,397	661,121	$811,763,117	1,011,315	$212,762,610	$20,294,078	$1,119,811,202

(1) Extra Excavation Cost represents the cost of erroneously excavating nonlead service lines.

Table 5-6

Summary of National Costs for Scenario II

SYSTEM SIZE	PROGRAMMATIC COST	# OF LEAD SERVICE LINES	SERVICE LINE REPLACEMENT COST	# OF LEAD CONNECTIONS	CONNECTION REPLACEMENT COST	EXTRA EXCAVATION COST (1)	TOTAL COST
<= 3,300	$21,456,943	82,665	$80,416,162	252,224	$82,473,867	$12,062,424	$196,409,396
3,301 - 10,000	$5,196,613	174,918	$170,159,939	372,409	$96,059,647	$25,523,991	$296,940,190
10,001 - 50,000	$5,657,856	390,562	$483,124,652	954,648	$348,887,402	$72,468,698	$910,138,608
> 50,000	$2,178,330	1,262,942	$1,562,258,782	1,800,056	$332,204,972	$234,338,817	$2,130,980,901
TOTAL	$34,489,742	1,911,087	$2,295,959,535	3,379,337	$859,625,888	$344,393,930	$3,534,469,095

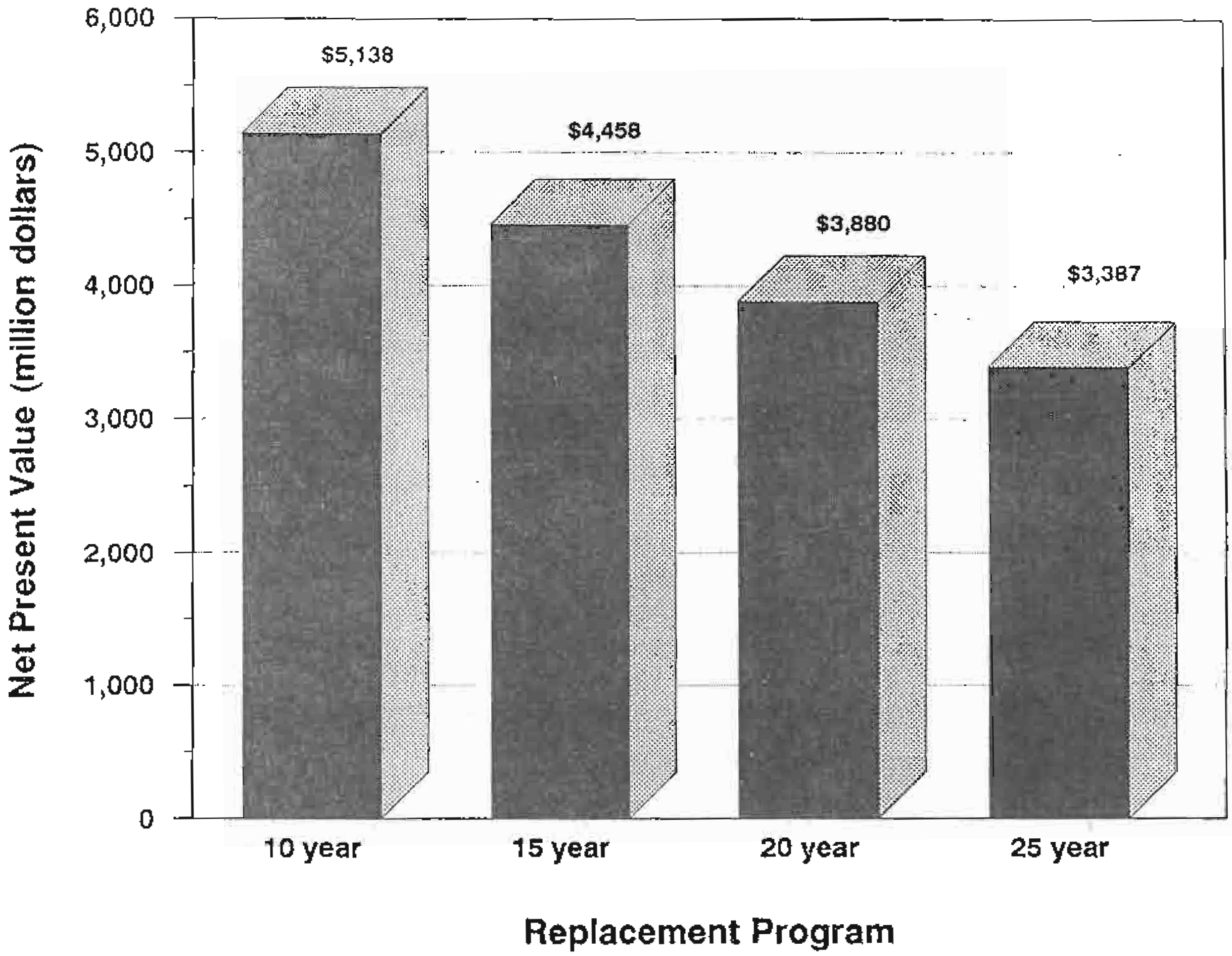
(1) Extra Excavation Cost represents the cost of erroneously excavating nonlead service lines.

Table 5-7

Summary of National Costs for Scenario III

SYSTEM SIZE	PROGRAMMATIC COST	# OF LEAD SERVICE LINES	SERVICE LINE REPLACEMENT COST	# OF LEAD CONNECTIONS	CONNECTION REPLACEMENT COST	EXTRA EXCAVATION COST (1)	TOTAL COST
<= 3,300	$17,645,513	258,327	$251,300,506	788,201	$0	$977,504,947	$1,246,450,966
3,301 - 10,000	$2,220,775	194,353	$189,066,598	413,788	$0	$726,509,901	$917,797,274
10,001 - 50,000	$1,240,076	188,325	$232,958,396	460,323	$0	$1,357,901,102	$1,592,099,574
> 50,000	$120,241	139,425	$172,469,010	198,721	$0	$893,336,518	$1,065,925,769
TOTAL	$21,226,605	780,430	$845,794,510	1,861,033	$0	$3,955,252,468	$4,822,273,583

(1) Extra Excavation Cost represents the cost of erroneously excavating nonlead service lines.



Note: Normal baseline replacement costs were subtracted.

FIGURE 5-1 SUMMARY OF ANNUALIZED COSTS

out. They range from $5.1 billion for the 10-year accelerated program to $3.4 billion for the 25-year program. These costs are based upon a 5% annual inflation rate and a 10% discount rate over these periods. A year-by-year comparison of the annualized costs and the adjustment for baseline conditions for the four completion periods are shown in Tables B-1 through B-4 in Appendix B.

5.5.5 Comparison of Mandatory Program to Baseline

Table 5-8 compares the four different mandatory replacement programs to the present baseline replacement at 50% and 90% completion.

Table 5-8

Comparison of Mandatory Program to Baseline

Program	50% Completion	90% Completion
10-Year Mandatory	5.5 Years	9.1 Years
15-Year Mandatory	8.0 Years	13.6 Years
20-Year Mandatory	10.5 Years	18.1 Years
25-Year Mandatory	13.0 Years	22.6 Years
Baseline	27.5 Years	49.5 Years

5.5.6 Costs Including Lead Service Recycling

Under RCRA (Resource Conservation and Recovery Act) regulations, the cost of operating an ultimate disposal site for metals wastes has risen sharply, and the number of sites available has been decreasing. As a result, pressure to reduce unproductive consumption and discharge of heavy metals has increased dramatically.

By design, these factors have created a strong economic incentive for conservation and recovery, and recent federal legislation has further increased the urgency of the situation. A bill signed into law on November 1984 increased the pressure on avoidance of land disposal of wastes categorized as hazardous, including metals. This legislation is expected to escalate costs for disposal of metals, and it is likely that a steady reduction in the quantity of residuals generated for ultimate disposal will be required.

There are essentially three approaches which can be taken to evaluate the recovery potential of a metal such as lead:

- Straightforward economics is best illustrated by existing plants with recycling and recovery systems in operation.

- The United States Bureau of Mines has provided a list of Secondary Lead Smelters in the United States.

- The Pennsylvania Department of Environmental Resources supplied a list of small alloyers, battery recyclers, and lead smelters around the country.

According to the U.S. Bureau of Mines, primary lead is produced in very few countries in the world, the largest producers being the United States and Morocco. In this country, most of the available lead is obtained from recycling. Large smelters produce 35% of the available lead from battery recycling with the total capacity of the industry being approximately 900,000 metric tons per year. Small size smelters produce 28% of the available lead from scrap recycling, with a total capacity of 30,000 tons per year.

The world-wide market prices for lead fluctuate between 10 to 25 cents per lb. Three battery manufacturers and smelters were contacted for prices they currently pay for lead as a raw material, their plant capacity to recycle, and the general procedures they implement when buying lead. One of them, Exide Corporation, is, in fact, the largest lead acid battery manufacturer in the world, with three manufacturing plants in the states of Pennsylvania, Texas, and Indiana. They recycle nearly 100% of the lead they buy and have an approximate total capacity of 170,000 metric tons per year. The prices they pay for lead vary between 10 and 30 cents per lb. Their only requirement to accept the raw material is that the pipe length should be less than 40 feet and in batches of up to 5,000 lbs. They predict their maximum capacity could go up to 1,000 tons per day.

Figure 5-2 presents the total costs of the four replacement programs (10-, 15-, 20-, and 25-year) including a reduction due to the salvage value of lead. The salvage value of the lead service lines and goosenecks was calculated using a value of 10 cents per lb. The low end of the price range was used conservatively and to account for any costs incurred in transporting the lead. The quantities of lead generated by the lead replacement program appear to be such that they can be absorbed into the recycle market. These costs range from $5.1 billion for a 10-year accelerated replacement program to $3.4 billion for a 25-year program. A year-by-year comparison of the annualized costs, adjusted for salvage value and baseline conditions for the four completion periods, is shown in Tables B-5 through B-8 in Appendix B.

The previous analysis has considered the replacement of those lead services under the jurisdiction of the water utilities. For comparative purposes, the cost of total lead service replacement, regardless of jurisdiction, can be estimated. This would involve considering the costs in Table 5-4 and applying them over the entire length of the service line. The estimated cost of the equivalent 10-year total replacement program would be $14.1 billion and for the 25-year program would be $10.0 billion. This represents a total replacement cost of between 2.8 to 2.9 times the evaluated jurisdictional replacement program.

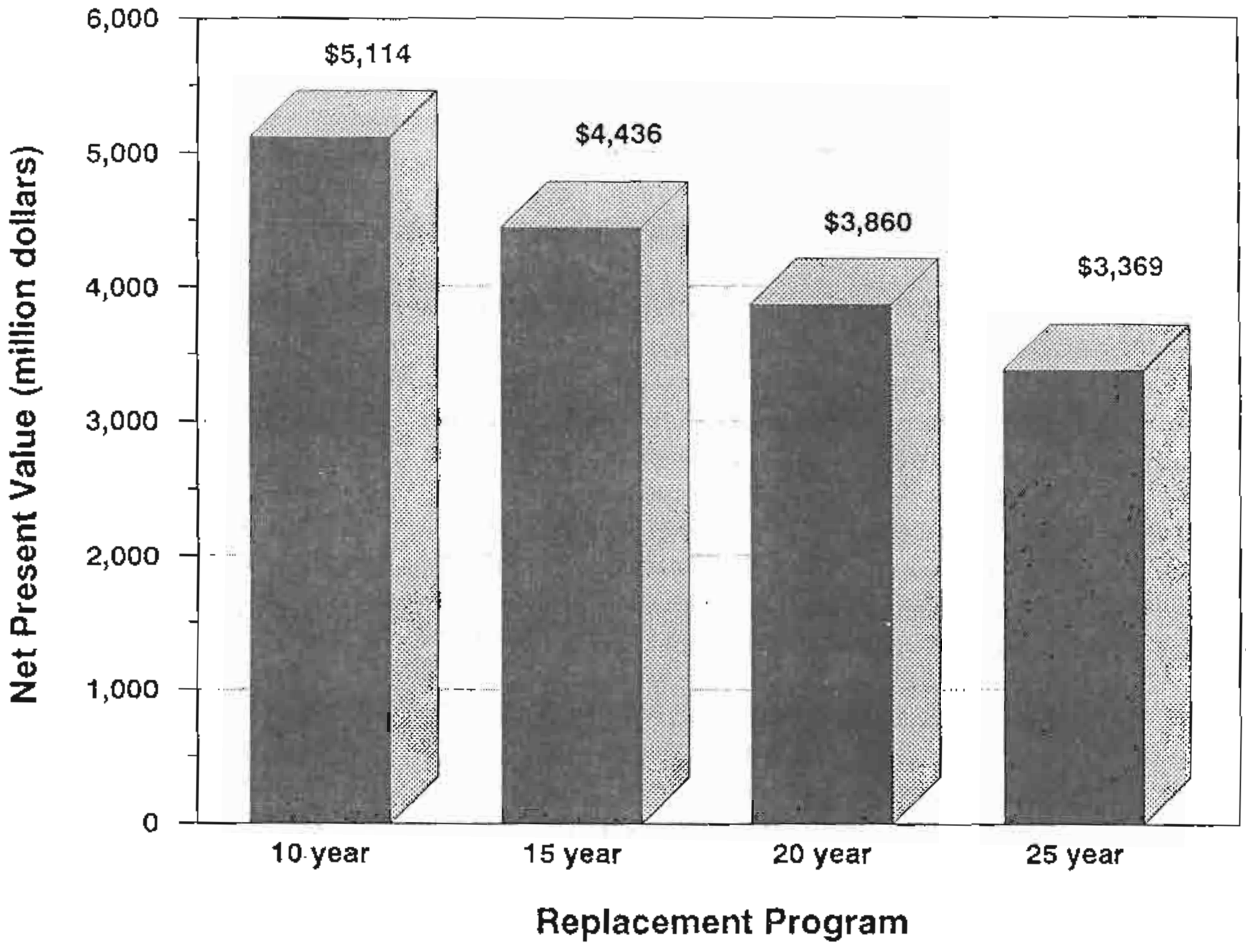


FIGURE 5-2 SUMMARY OF ANNUALIZED COSTS (INCLUDING SALVAGE VALUE)

SECTION 6

BENEFITS ANALYSIS

SECTION 6

BENEFITS ANALYSIS

6.1 INTRODUCTION

The health benefits of the replacement of the lead services impacted by the accelerated mandatory replacement program will be evaluated and compared to the costs of implementing the program. In making this comparison, the approach to determining benefits will be to assume maximum benefits. This will be done by assuming those people benefiting from replacement will have previously been receiving the maximum possible exposure to lead from drinking water in contact with lead services.

For this purpose, for homes having lead services we have assumed a two liter daily consumption of water for adults, one liter of which is from a first draw of water and the second liter has been in overnight contact with lead services. It is extremely unlikely that any individual will ever take in water in this manner but it represents a worst possible case lead exposure from drinking water. It will be further assumed that the liter of water in contact with the lead service line will have a 10 ug/L lead concentration. This was determined as the intermediate contribution from service lines (see Section 4). A child's consumption will be one-half that of an adult, also assumed to be 50 percent first draw and 50 percent in contact with lead services. Thus an adult's consumption of lead from drinking water in contact with lead services will be 10 ug/day and a child's will be 5 ug/day.

Based upon the occurrence and jurisdiction data presented in Section 1, 70 percent of water systems are responsible for partial jurisdiction (usually main-to-curb and about 30 percent of the service line); 20 percent have no jurisdiction over the service line; 9.2 percent are responsible only for the service connection; and 1 percent are responsible for the complete service line. Based upon this breakdown, and assuming 100 percent compliance with a mandatory replacement program for services under the utility's jurisdiction, about 22.5 percent of the lead service in place would be removed. Optimistically using a 25 percent removal, this would mean that the replacement program would reduce the consumption of an adult exposed to lead from a lead service line by 2.5 ug per day and that of a child by 1.25 ug per day. It is the benefits of this lead consumption reduction that will be evaluated and compared to the costs of the mandatory replacement program.

6.2 OBJECTIVE

The objectives of this task are to:

- Review available lead exposure health effects studies.
- Perform an independent analysis of health benefits.
- Evaluate increases in health risk due to different sources of lead.
- Quantify the impact on health of replacing portions of lead services.

- Calculate reduced lead exposure in relation to reduced risk.

6.3 HEALTH IMPACTS OF LEAD EXPOSURE

The purpose of this subsection is to briefly review the available literature on the health effects of lead.

The Agency for Toxic Substances and Disease Registry (ATSDR) has made available a draft version of its Toxicological Profile for Lead which provides a comprehensive examination of the toxicologic information available for lead. Included are discussions of the sources of lead in the environment, the potential for human exposure, and the health effects associated with short- and long-term exposure to lead, as well as epidemiologic evaluations that allow for a determination of the levels of significant exposure to lead. In addition, this document presents overviews of the physical-chemical properties, the production, use, and disposal of lead and lead compounds, and the fate of these compounds on release to the environment. Finally, an update of the regulatory status of lead is presented, including current and proposed maximum permissible levels of lead in air and drinking water.

6.3.1 Lead Poisoning in Children

This subsection provides an overview of the ATSDRs The Nature and Extent of Lead Poisoning in Children in the United States: A Report to Congress. This document is an extensive review of the sources of lead exposure, the numbers of individuals involved and the extent to which they are exposed, and recommendations for reducing this exposure.

Childhood lead poisoning is still recognized as a significant health problem in the United States, and as a health problem that is preventable. During early childhood development, the central nervous system is especially vulnerable to lead exposure. Severe levels of exposure to lead have produced coma, convulsions, and even death, in children while lesser exposures have been found to produce delayed cognitive development, reduced IQ scores, and impaired hearing. Exposure to lead can also produce toxic effects in the kidneys, and may affect heme synthesis in red blood cells, and the regulation of vitamin D.

Exposure to lead is uniquely characterized in that most often it is expressed in terms of the internal concentrations produced by external (environmental) exposure. A number of formulae have been developed to equate the level of environmental lead exposure to the internal concentration potentially produced. These internal levels are commonly expressed as micrograms of lead per deciliter of blood (ug/dL). Significant levels of exposure have been determined for a wide range of health effects. In 1985, the Centers for Disease Control considered 25 ug/dL (with a concurrent elevation in erythrocyte protoporphyrin) to be the level of early toxicity. In 1986, the World Health Organization identified 20 ug/dL as the maximum acceptable limit, and the U.S. EPA determined that 10 to 15 ug/dL may be associated with the onset of adverse health effects.

It is estimated that 1.5 million black and white children in Standard Metropolitan Statistical Areas (SMSAs) of greater than 1 million residents are exposed to lead levels producing blood-lead concentrations above 15 ug/dL. In SMSAs of less than 1 million residents, it is estimated that 888,000 black and white children are exposed to lead levels producing blood-lead concentrations above 15 ug/dL. This suggests that a total of approximately 2.4 million (or 17 percent) of black and white metropolitan children may be exposed to dangerous levels of lead. If the entire U.S. population, including all racial and geographical categories, is considered, the estimated number of children at risk from lead exposure is between 3 and 4 million. Furthermore, approximately 717,000 children (5.2 percent) in metropolitan areas are exposed to lead concentrations above 20 ug/dL and 197,000 (1.4 percent) to levels greater than 25 ug/dL. Some segments of the population, such as inner-city or low-income individuals, may have much higher percentages of children with dangerous levels of lead. These percentages may be overestimated due to omission of declines in lead levels in food. Underestimation is also possible because of the exclusion of the nonmetropolitan fraction of the U.S. population and the omission of Hispanic and Asiatic population segments.

All racial and economic segments of the population are at risk of exposure to dangerous levels of lead. Underprivileged inner-city children, however, continue to show the greatest prevalence of elevated lead levels.

1980 census data indicates that at least 50 percent of children live in housing built before 1950. This suggests that more than half the child population may be at a significantly increased risk due to paint with high levels of lead. The percentage of these children with lead exposures sufficient to cause adverse health effects, however, could not be estimated. In a survey of lead screening programs, it was found that 1.5 percent (11,739 of 785,285) of children screened in 1985 showed signs of lead toxicity.

The six major sources of lead exposure are: paint, gasoline, stationary sources such as smelters, dust and soil, food, and drinking water. As the ATSDR document suggests, "The total numbers of children estimated for each source and category are not comparable and cannot be used to rank the severity of the lead problem by source of exposure in a precise, quantitative way." (ATSDR, The Nature and Extent of Lead Poisoning in Children in the United States: A Report to Congress). The following figures were taken from this document.

SOURCE-SPECIFIC ESTIMATES - NUMBER OF CHILDREN EXPOSED

	Number
Paint (potentially exposed children under 7 years old)	
- all housing with some lead in paint	12 million
- oldest housing (higher lead content)	5.9 million
- oldest housing with deteriorated paint	1.8 to 2.0 million

- children with paint-lead exposure high enough to raise their blood-lead level above 15 ug/dL	1.2 million

<u>Gasoline</u>

- children under 7 years old potentially exposed to lead from gasoline at some level	5.6 million
- actual exposure to lead from gasoline projected for 1987; children up to 13 years old at blood-lead levels above 15 ug/dL	1.6 million

<u>Stationary Sources</u> (smelters, etc...)

- potentially exposed to stationary U.S. sources	230,000
- actually exposed to lead emissions from primary and secondary smelters	approximately 13,000

<u>Dust and Soil</u>

- potentially exposed to lead in dust and soil (derived from primary contributors to lead in dust and soil; i.e.: paint-lead and atmospheric lead fallout)	5.9 to 11.7 million

<u>Drinking Water</u>

<u>Potential</u> -- because of lead in old residential plumbing:

• children under 5 years old	1.8 million
• children 5 to 13 years old	3.0 million

-- because of lead in new residences (less than 2 years old):

• children under 5 years old	0.7 million
• children 5 to 13 years old	1.1 million

<u>Actual</u> -- because of drinking water lead levels that are greater than 20 ug/Liter	3.8 million
- children under 6 years old with blood-lead levels above 15 ug/dL due to elevated lead in drinking water	241,000

• with blood-lead levels above 50 ug/dL	100
• with blood-lead levels of 30 to 50 ug/dL	11,000
• with blood-lead levels of 15 to 30 ug/dL	230,000

Food

- most children under 6 years old are potentially exposed to lead in food at some level.	
- children actually exposed to enough lead in food to raise blood levels to an early toxicity risk level	1 million

MAJOR HEALTH EFFECTS - SIGNIFICANT EXPOSURE LEVELS

• Central nervous system involvement, coma, convulsions, mental retardation, seizures, death	80 ug/dL
• Peripheral neuropathy, frank anemia	40 to 80 ug/dL
• Delayed cognitive development, reduced IQ scores, impaired hearing	40 ug/dL
• Deficits in IQ scores	<25 ug/dL
• Effects on one test of intelligence	<10 ug/dL
• Impacts on heme biosynthesis and Vitamin D and calcium metabolism	15 to 20 ug/dL
• Increased severity of effects on heme synthesis reduced hemoglobin production	40 ug/dL
• Neurobehavioral and growth deficits at prenatal (maternal) exposure levels of	10 to 15 ug/dL

LEAD EXPOSURE - IMPORTANT CONSIDERATIONS

- Lead in paint, dust, and soil will be major problems into the foreseeable future.
- Leaded paint is of particular concern due to the historical and potential severity of the poisoning from this source.
- Lead levels in dust and soil result from past and present inputs and can contribute to child body burden.

- Paint and dust/soil are special problems of poor housing and poor neighborhoods.

- More emphasis should be placed on lead sources away from home, i.e., paint, dust, soil, drinking water in schools, kindergartens.

- Lead in drinking water is significant due to pervasiveness and relative toxicity risk, but not as intense as paint and dust/soil lead.

- Phasing down gasoline lead has reduced numbers of children affected as well as deposit rates to soil and dust.

- Lead in food recently has been significantly reduced.

Young children are considered to be the segment of the population at the greatest risk of being exposed to dangerous levels of lead. They also are extremely vulnerable to the adverse effects of lead during early development. The developing fetus also is at risk from excessive maternal exposure because of placental transfer of lead. Due to the potential exposure of children to high levels of lead from many sources and the highly vulnerable period of early development, the long-term consequences for public health of unabated exposure to lead has been focused on children.

METHODS FOR REDUCING CHILDREN'S EXPOSURE TO LEAD

Primary Abatement

- reduction or elimination of the entrance of lead into pathways by which people are exposed.

Secondary Abatement

- reduction or elimination of lead after it has already entered the environment or humans.

Biological Approaches

- include methods such as improving nutrition.

- may be included in both types of abatement.

Extra-Environmental Approaches

- legal action, etc....

ABATEMENT: IMPORTANT POINTS

- EPA's phasedown of lead in gasoline has been quite effective.
- From 1975 to 1984, U.S. gasoline lead consumption decreased 73 percent and estimated lead levels in ambient air showed a similar decrease.
- The reduction of lead in drinking water is necessary in public facilities as well as in homes.
- Leaded paint in housing is still an enormous problem.
- Dust and soil are still sources of potentially significant exposure; abatement of these sources has not been effective.
- Screening of children has been shown to be an effective method of reducing lead toxicity; however, screening programs for children at high risk need better organization to be more effective.
- Programs for improving nutrition play an important role in reducing lead toxicity, but are no substitute for reducing environmental lead.
- Legal action has not been shown to be an effective method of reducing lead toxicity because of lack of enforcement.
- The most effective methods for reducing environmental lead (removal from food and gasoline) have already been used.
- Considerable effort will be necessary to remove the huge amounts of lead remaining in residential and public buildings.

In summary, this document provides a detailed review of the available information concerning the health effects of lead in children. It indicates that lead in drinking water can be a significant route of exposure in children in terms of its pervasiveness, but suggests that exposure from dust and soil is a more serious problem in terms of its intensity.

6.3.2 Reducing Lead in Drinking Water

The EPA presents an extensive review of the effects of lead in drinking water in its report, Reducing Lead in Drinking Water: A Benefit Analysis. We have used this report as a guide in our evaluation of the benefits produced by the proposed mandatory replacement program. It is important to note that this report has been used as a methodology developed by and acceptable to EPA even though AWWA and the water industry have questioned some of its findings. Its use in this study does not imply any endorsement of its findings by AWWA, EES, or WESTON.

This document discusses the levels of lead commonly present in drinking water, the potentially increased lead concentrations in the blood associated with lead in drinking water, and the health effects due to these increased blood lead levels. Also provided, is a cost-benefit analysis for the reduction of lead in drinking water from the currently acceptable level of 50 ug/L to 20 ug/L. Benefits of reducing lead levels in drinking water are examined in terms of both the numbers of individuals benefiting from the reduction and the potential savings due to reduced medical costs.

Blood lead levels as low as 10 ug/dL have been found to cause slight toxicity in children, including effects on heme synthesis and possible attentional IQ deficits. No threshold level has been found for the elevation of ALA or stature effects in children. Blood lead levels (PbB) as low as 7 ug/dL have been associated with hypertension in adults.

Results of Reducing Lead in Drinking Water

The following formulae, adapted from the document described above, were used to predict the decrease in blood lead levels that could be expected to result from a reduction of lead in drinking water from 50 to 20 ug/L.

Children

$$\text{PbB (ug/dL)} = 0.16 \; \frac{\text{ug/dL}}{\text{ug/day}} \times \text{intake of lead from water (ug/day)}$$

- Assuming child drinks 1 liter per day at the proposed 20 ug/liter:

  20 ug/L x 1 liter/day = 20 ug/day

  $$(20 \text{ ug/day}) \; 0.16 \; \frac{\text{ug/dL}}{\text{ug/day}} = 3.2 \text{ ug/dL blood}$$

Adult

$$\text{PbB (ug/dL)} = 0.06 \; \frac{\text{ug/dL}}{\text{ug/day}} \times \text{intake of lead from water (ug/day)}$$

- Assuming adult drinks 2 liters per day at proposed 20 ug/liter

  20 ug/L x 2 liters/day = 40 ug/day

  $$(40 \text{ ug/day}) \; 0.06 \; \frac{\text{ug/dL}}{\text{ug/day}} = 2.4 \text{ ug/dL blood}$$

For children, a reduction of lead levels in drinking water from 50 ug/L to 20 ug/L could potentially reduce the contribution of lead from drinking water by much as 4.8 ug/dL (from 8.0 to 3.2 ug/dL). In adults, reduction of lead levels in drinking water from 50 ug/L to 20 ug/L could potentially reduce the contribution of lead from this source by as much as 3.6 ug/dL (from 6 to 2.4 ug/dL).

In estimating the numbers of individuals benefiting from this reduction, the following figures should be considered:

- 219 million people of 241 million U.S. population are served by community water systems.
- 42 million of these people are potentially exposed to drinking water exceeding 20 ug/L.

Children

- requiring medical treatment	29,000
- having IQ loss	241,000
- 1 to 2 IQ point loss	230,000
- 4 IQ points loss	11,000
- 5 IQ points loss	100
- requiring compensatory education	29,000
- at risk of stature decrement	82,000
- at risk of hematological effects	82,400
- fetuses at risk of prenatal exposure	680,000

Adults

- cases of hypertension	130,000
- heart attacks	240
- strokes	80
- deaths	240
- pregnant women (posing risk to fetuses)	680,000

Children's health benefits

- reduced medical costs	$ 27.6 million
- reduced costs of cognitive damage	
Method 1 - compensatory education	$ 81.2 million
Method 2 - decreased future earnings	$268.1 million

TOTAL:	Method 1	$108.8 million
	Method 2	$295.7 million

Adult health benefits (males only)

- reduced hypertension savings (males, aged 40-59)	$ 32.5 million
- savings from fewer heart attacks (white males, aged 40-59)	$ 15.6 million
- savings from fewer strokes (white males, aged 40-59)	$ 3.8 million
- savings from fewer deaths (white males, aged 40-59)	$240.0 million
TOTAL:	$291.9 million

In summary, this report examines the benefits of reducing lead in drinking water, including health benefits and reduced medical costs. Lead in drinking water at concentrations greater than 20 ug/L can potentially affect 42 million Americans.

6.4 SOURCES OF LEAD EXPOSURE

There are numerous sources of lead in the environment, and a number of pathways of lead exposure in man. Figure 6-1 (adapted from EPAs Air Quality Criteria for Lead, vol. 2, 1986) indicates that exposure to lead from drinking water is only one of at least five pathways of lead exposure. Other significant pathways are inhaled air, dust, soil, and food. Figure 6-1 also illustrates how several sources can contribute to lead in drinking water. These sources include fallout of atmospheric lead (from industrial and auto emissions) which directly or indirectly enters the drinking water supply, and lead in soil, which may or may not be of natural origin, as well as lead in plumbing (including solder joints and service lines). It is suggested in other words, that drinking water is responsible for only a fraction of the total lead exposure from all sources, and that lead service lines are responsible for only a fraction of the lead found in drinking water.

Table 6-1 (adapted from EPAs Air Quality Criteria for Lead, vol. 2, 1986) shows the daily intake of lead from all sources as a national average.

It is estimated that, nationally, the average 2-year-old child consumes 46.5 ug of lead per day from all sources. Total daily lead intake is estimated at 50.7 ug for adult males and 37.5 ug for adult females (ages 25 to 30 years). Table 6-1 indicates that most of the lead consumed nationally (49% for children, 82% for men, and 77% for women) comes from food and beverages (excluding drinking water). In children, exposure to lead from dust is also very significant. It is estimated that, nationally, drinking water contributes only 2.1 ug of lead per day (4.5% of total lead intake) in children, 3.6 ug per day (7.1%) in adult males, and 3.0 ug per day (8.0%) in adult females.

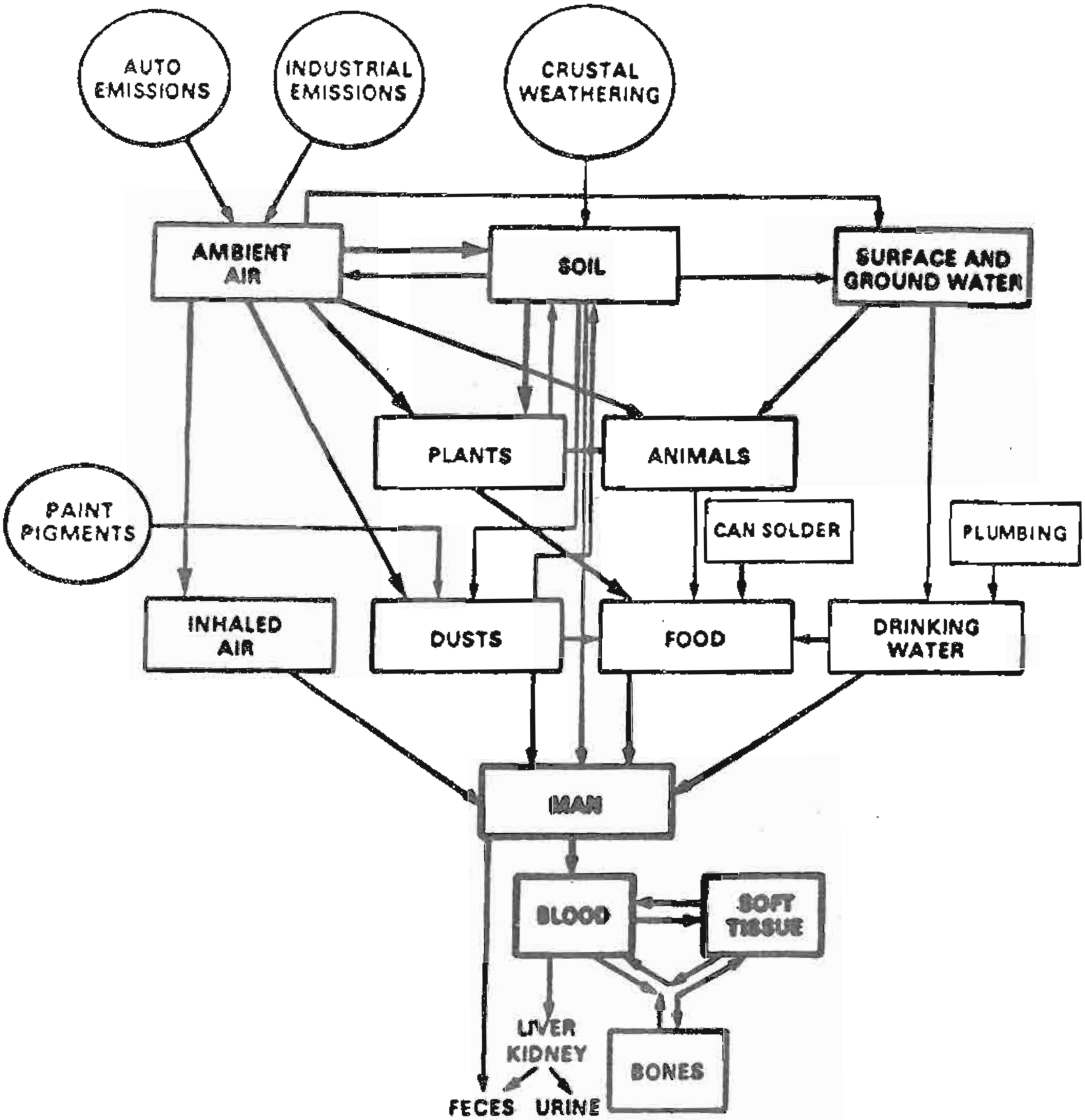


FIGURE 6-1 PATHWAYS OF LEAD FROM THE ENVIRONMENT TO MAN

Table 6-1

Daily Lead Intake From All Sources Before and After Reduction Program - National Averages (ug/day)

Source of Exposure	Child (2 yrs.)	Adult Male (25-30 yrs.)	Adult Female (25-30 yrs.)
Before Reduction Program			
Inhaled Air	0.5	1.0	1.0
Dust	21.0	4.5	4.5
Food and Beverages	22.9	41.6	29.0
Drinking Water*	2.1	3.6	3.0
Total Intake	46.5	50.7	37.5
After Reduction Program			
Inhaled Air	0.5	1.0	1.0
Dust	21.0	4.5	4.5
Food and Beverages	22.9	41.6	29.0
Drinking Water*	2.1	3.5	2.9
Total Intake	46.5	50.6	37.4

*Includes coffee, tea, powdered drink.

Source: Adapted from EPA's Air Quality Criteria for Lead, Vol. 2, 1986.

For the population segment exposed to additional lead from service lines (Table 6-2), a greater proportion of daily lead intake may be attributed to drinking water. In adults, drinking water consumption is estimated to be 2 liters per day. In children, daily consumption is about 1 liter. It has been assumed under a worst possible exposure basis that about half of the daily lead intake from drinking water comes from the lead service line, and that this portion has a concentration of 10 ug/liter.

For adults, this suggests that 1 liter per day (half the daily consumption) will contain 10 ug of lead. In other words, the service line contributes 10 ug of lead per day to the total daily intake in adults. For children, this suggests that 1/2 liter per day (half the daily consumption) will contain 5 ug of lead, which means the service line contributes 5 ug of lead per day to the average child.

Thus, it is conservatively estimated that in a worst case situation, the lead service line would contribute 10 ug/day for adults and 5 ug/day for children, in addition to the lead intake from other sources. In children, this would amount to 7.1 ug/day from drinking water or 13.8 percent of the total lead consumed from all sources prior to the proposed reduction program. In adult males (ages 25-30) prior to the reduction of lead services, this would amount to 13.6 ug/day from drinking water, or 22.4 percent of the total lead intake. In adult females aged 25-30, drinking water would contribute 13.0 ug/day, or 27.4 percent of all lead consumed daily. The proposed accelerated mandatory replacement program would eliminate approximately 25 percent of the daily lead intake due to the service line. In children, this would amount to a reduction of 1.25 ug/day or 2.4 percent of total daily consumption. In adults, the program could reduce daily lead intake by 2.5 ug/day (4.1 percent in males, and 5.3 percent in females).

6.5 BENEFITS OF MANDATORY REPLACEMENT PROGRAM

We have estimated that 3.3 million residences with lead service lines will be affected under the proposed reduction program. With an estimated 3 persons per residence, a total of 9.9 million persons will potentially benefit from the removal of 25 percent of their service lines.

This 25 percent reduction of the lead service lines translates into a 2.5 ug/day reduction of lead intake in adults, and a 1.25 ug/day reduction of lead intake in children. These reductions are estimates for the population of 9.9 million persons potentially affected by the proposed program. Since these calculations reflect benefits in a small portion of the total U.S. population, and most information available on lead exposure is for the total population, it would be of interest here to relate these effects to benefits on a national average. If figures are adjusted to reflect effects on the national population of approximately 240 million, reductions in lead intake would be estimated at 0.10 ug/day for adults, and 0.05 ug/day for children.

Table 6-2

Daily Lead Intake From All Sources Before and After Reduction Program - Population Exposed to Lead from Service Lines (ug/day)

Source of Exposure	Child (2 yrs.)	Adult Male (25-30 yrs.)	Adult Female (25-30 yrs.)
Before Reduction Program			
Inhaled Air	0.5	1.0	1.0
Dust	21.0	4.5	4.5
Food and Beverages	22.9	41.6	29.0
Drinking Water*	2.1	3.6	3.0
Lead Service Line	5.0	10.0	10.0
Total Intake	51.5	60.7	47.5
After Reduction Program			
Inhaled Air	0.5	1.0	1.0
Dust	21.0	4.5	4.5
Food and Beverages	22.9	41.6	29.0
Drinking Water*	2.1	3.6	3.0
Lead Service Line	3.8	7.5	7.5
Total Intake	50.3	58.2	45.0

*Includes coffee, tea, powdered drink.

Source: Adapted from EPA's Air Quality Criteria for Lead, Vol. 2, 1986.

6.5.1 Health Benefits

Since health effects of lead can be related to the lead concentrations found in the blood, it is necessary to know what reductions in blood lead levels could be expected under the proposed program.

In children, this reduction in lead intake (national average) could potentially reduce blood lead levels by 0.008 ug/dL (PbB = 0.16 x 0.05 ug/day). In adults, the reduced daily intake (national average) could reduce blood lead levels by 0.006 ug/dL (PbB = 0.06 x 0.1 ug/day). It is unlikely that such small reduction in blood lead concentrations would have any observable effects on health.

For the population of 9.9 million affected by the proposed service line removal, effects on blood lead levels would be more significant. In children, a reduction of 1.25 ug lead per day could reduce blood lead levels by 0.2 ug/dL. In adults, a reduction of 2.5 ug/day could reduce lead levels in blood by 0.15 ug/dL. Based on the health effects seen with significant blood lead concentrations (Subsection 6.3.1) and the fact that blood level reductions under this program would be at most 0.2 ug/dL (in children), only minimal and probably unobservable health benefits could be expected. Also, based on the fact that lead exposure from other sources responsible for a greater percentage of total lead intake would go on unabated, the benefits of removing the fraction due to drinking water could be expected to be minimal at best.

6.5.2 Monetary Benefits

The benefits of the proposed reduction program are presented monetarily in Table 6-3. These benefits are based on reduced short- and long-term medical costs, due to reduced levels of lead in the blood which are brought about by a reduction of lead levels in the drinking water. The EPA has estimated the annual benefits for children by combining reduced medical costs such as those incurred during nutritional or chelation therapy with reduced long-term costs due to cognitive damage. Benefits due to reduced cognitive damage can be assessed in two ways. Method 1 estimates the reduced costs of education needed by children to compensate for any cognitive impairment. Method 2 estimates the benefits to be significantly greater by evaluating the potential decrease in future earnings due to cognitive impairment.

EPA has estimated the annual benefits for adults by combining reduced medical costs for hypertension, heart attacks, strokes, and deaths. This represents reduced costs for males age 40-59 only, due to the high-risk nature of this group. The EPA has estimated the annual benefits of reducing lead levels in drinking water from 50 to 20 ug/L (30 ug/L), for a population of 42 million to be as much as $714.9 million. Using a proportional comparison, we have estimated the annual benefits of reducing lead levels in drinking water by 2.5 ug/L for a population of 9.9 million to be approximately $14 million. We have also adjusted for inflation over the last 5 years at an annual rate of 4 percent.

Table 6-3

Estimated Annual Monetized Benefits of Reducing Lead in Drinking Water for Sample Year 1988 (1990 dollars)

		EPA's MCL Reduction (50 ug/L to 20 ug/L)	Accelerated Lead Services Removal
	Estimated Population Benefiting From the Reduction Program	42 million*	9.9 million**
	Amount of Reduction (Drinking Water Concentration)	30 ug/L	2.5 ug/L
Children			
	- Reduced Medical Costs	$ 33.6 million	$ 659,000
	- Reduced Costs of Cognitive Damage		
	- Method 1 - Compensatory Education	$ 99.8 million	$ 1.9 million
	- Method 2 - Decreased Future Earnings	$ 326.2 million	$ 6.4 million
	Total - Using Method 1	$ 132.4 million	$ 2.6 million
	- Using Method 2	$ 359.8 million	$ 7.1 million
Adults			
	- Reduced Hypertension (males age 40-59)	$ 39.5 million	$ 776,000
	- Fewer Heart Attacks (white males age 40-59)	$ 19.0 million	$ 372,000
	- Fewer Strokes (white males age 40-59)	$ 4.6 million	$ 91,000
	- Reduced Number of Deaths	$ 292.0 million	$ 5.7 million
	Total	$ 355.1 million	$ 6.9 million
	Total Annual Monetized Benefits	$ 714.9 million (using Method 2)	$ 14 million (using Method 2)

* Total population served by Community Water Systems
** See Subsection 6.5

Source: Adapted from EPA's Reducing Lead in Drinking Water: A Benefit Analysis, 1986.

It should be noted that this is a comparison of two distinctive methods of reducing lead in drinking water. The EPA methodology is not well defined in that it does not specify how the lead levels would actually be reduced. All monetary values are estimates, and costs as well as benefits could change significantly once a reduction program is in place.

If Method 2 (Table 6-3) is used to determine monetized benefits in children, and this is combined with the estimate for benefits in adults, the maximum monetized benefit for the population affected by the proposed reduction program is estimated at $14 million annually.

6.6 BENEFIT-TO-COST RATIO

The annual $14 million in benefits occurs only after the complete removal of the lead services (both lines and connections). During the period of removal, benefits would be less by the fraction of services removed up to any point in time. Thus, the more accelerated a replacement program is, the earlier these benefits will be seen. Conversely, the ongoing replacement schedule (baseline conditions) will achieve the same benefits eventually, over a period estimated to occur in 55 years. Thus, an actual comparison of benefits to the costs of replacement must take into account both the period of time over which the replacement will occur and a comparison to the existing baseline conditions.

Figure 6-2 provides this comparison for the four time periods (10, 15, 20, and 25 years) of mandatory replacement described in Section 5. The annual costs have been estimated for future years assuming a 5 percent rate of inflation. Annual benefits are listed for the three replacement scenarios, increasing proportionately over the period of replacement until the full benefit of replacement is achieved in the last year of the program. Since the benefit of the mandatory accelerated program is the difference between that program and ongoing baseline conditions, the annual benefits of the baseline condition is then subtracted. This requires comparison of each replacement program to baseline over a period of 55 years after which the benefits of all alternatives are identical. Finally, the present worth of the differential benefits are determined using a discount rate of 10 percent. The total benefits range from $128 million for the 10-year accelerated replacement program to $66 million for the 25-year program. A year-by-year comparison of the annualized benefits for the entire 55-year baseline period for each of the four time periods of replacement are shown in Tables B-9 through B-12 in Appendix B.

The benefit-to-cost ratios are then presented for all four replacement time periods in Table 6-4. These benefit-to-cost ratios vary from 0.025 to 0.020 for programs carried out between 10 to 25 years. A benefit-to-cost ratio of 1.0 or higher is generally considered necessary to consider a program viable and worthy of implementation. These very low benefits relative to cost indicate that an accelerated mandatory lead service replacement program would cost exceedingly more than the benefits derived.

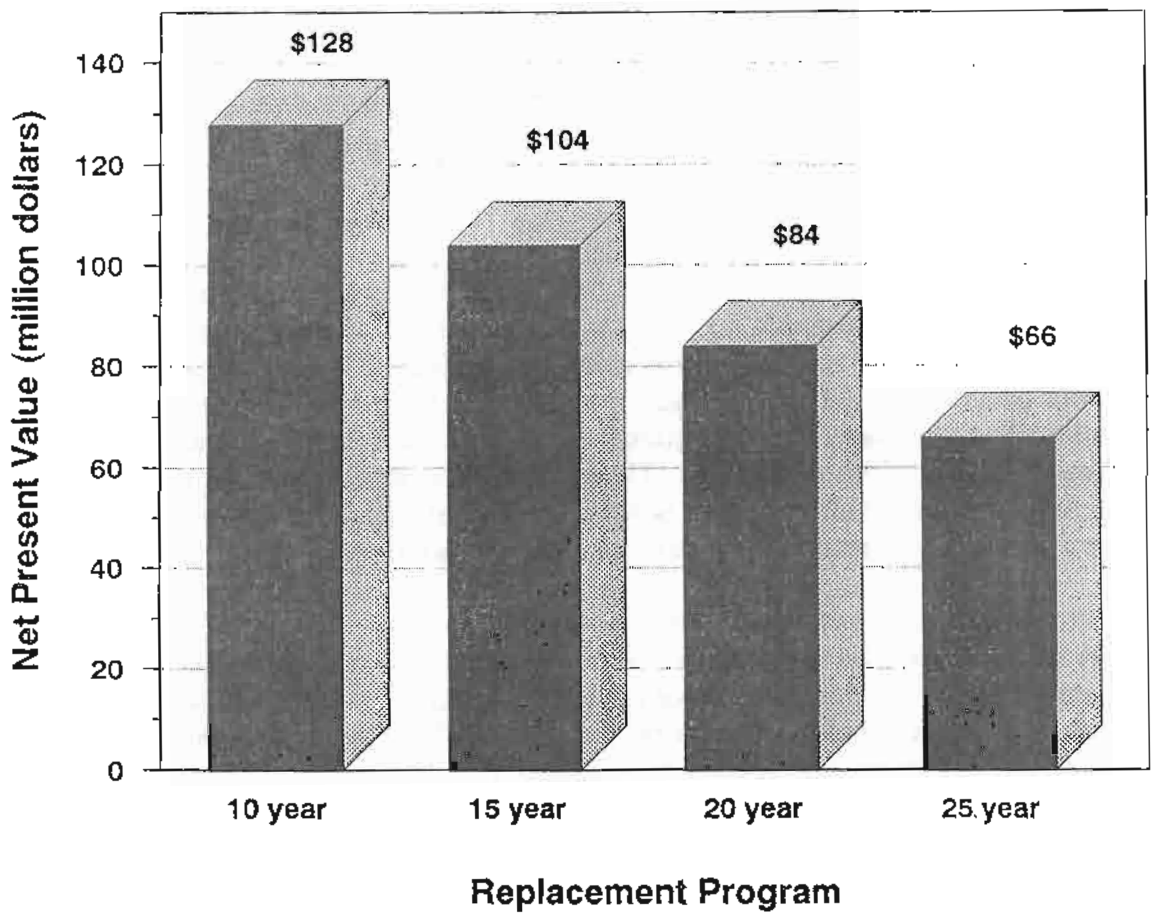


FIGURE 6-2 SUMMARY OF TOTAL BENEFITS

Table 6-4

Summary of Benefit-to-Cost Ratios

Replacement Program	Present Value Costs	Present Value Benefits	Benefit-to-Cost Ratio
10 Year	$5,114,000,000	$128,000,000	0.025
15 Year	$4,436,000,000	$104,000,000	0.023
20 Year	$3,860,000,000	$ 84,000,000	0.022
25 Year	$3,369,000,000	$ 66,000,000	0.020

All costs are shown in 1990 dollars.

Sensitivity Analysis

Four additional sets of calculations were performed to examine the sensitivity of the benefit-to-cost ratio for substantially different estimates of lead service lines and lead connections in the nation. The four additional cases considered are:

- Case 1 - double the number of lead service lines and adjust the number of lead connections accordingly.
- Case 2 - double the number of lead connections while leaving the number of lead service lines the same.
- Case 3 - halve the number of lead service lines while leaving the number of lead connections the same.
- Case 4 - halve the number of lead connections or reduce to the equivalent number of lead service lines for each replacement scenario.

The benefit-to-cost ratios for the four cases (for a 15-year program) are given in Table 6-5. It should be noted that substantial changes in the estimate of the number of lead service lines and lead connections nationwide do not significantly affect the conclusion that the benefit-to-cost ratios do not favor a mandatory lead service line replacement.

Table 6-5

Summary of Sensitivity Analysis

Sensitivity Case	Present Value Costs[1]	Present Value Benefits[1]	Sensitivity Benefit-to-Cost Ratio	Determined Benefit-to-Cost Ratio[2]
Case 1	$6,400,000,000	$208,000,000	0.033	0.023
Case 2	$5,800,000,000	$104,000,000	0.018	0.023
Case 3	$3,800,000,000	$ 52,000,000	0.014	0.023
Case 4	$3,900,000,000	$104,000,000	0.027	0.023

[1] All costs are shown in 1990 dollars for a 15-year replacement program.

[2] Taken from Table 6-4.

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APPENDIX A

LEAD SURVEY QUESTIONNAIRES

APPENDIX A.1

AWWA LIS QUESTIONNAIRE

Action! Requested

AMERICAN WATER WORKS ASSOCIATION LEAD INFORMATION SURVEY

The EPA has recently promulgated rules concerning lead in drinking water (53 FR 31516). Presently, EPA is seeking comments concerning the magnitude and cost of implementing a mandatory lead service line replacement program. Although the existing rule does not include lead service line replacement, EPA has considered making this a requisite and has specifically asked for our comments and data. The AWWA has informed EPA of the extensive effort and cost the rule may instigate, but we need hard data to quantify this!! This data will help us insure mandatory line replacement is not included in the rule. Therefore, we must act immediately to insure EPA realizes the potential adverse impacts of this regulation.

This survey is confidential. The data is for statistical and cost purposes only and your name will not be associated with your responses. Please note the return date below and keep in mind that a prompt response is necessary. The comment period is our opportunity to affect EPA's decision and possibly avert undue economic burdens in the future.

A. GENERAL

Utility Name: ______________________________
Contact Person: ______________________________
Address: ______________________________
City, State, Zip: ______________________________
Phone: ______________________________
Total Production (MG/yr): ______________________________
Total Population Served: ______________________________

B. LEAD SERVICE LINES

1. Are Lead Pipes or connections in the Distribution System? Yes__________ No__________
   a. Estimate number of lead service connections: ______________________________
   b. Estimate number of lead service lines in service: __________feet or __________miles
   c. Of this amount, estimate percent lead service lines owned by utility: __________ percent
   d. How is ownership determined?
      Ordinance __________ Building Code __________
      Informal Agreement __________ Contract __________
   e. Describe the typical lead service (i.e. utility owns the main and the service line up to and including meter. Private ownership begins after the meter, meters are at right-of-way line)
      Example: ______________________________
      ____
      ____

2. When lines are serviced, are lead pipes removed and replaced? Yes________ No________
   a. Is there a general policy to replace lead service lines? Yes________ No________
   b. Is the policy: mandated by ordinance? ________________
      volunteer? ________________
3. How many lead services are currently being replaced yearly? ________________
   a. At what cost? ________________ $/mi. or
      ________________ $/ft.
   b. Is replacement done: by contractor ________________
      in-house ________________
4. If replacement of lead service lines is mandated, estimate cost of compliance: ________________ $/service line
   ________________ $/foot

C. PUBLIC EDUCATION

Historical

A number of utilities have already shared their customers' reaction to the recent lead notice. Please take part in our data gathering effort by providing the following information:

1. method used for notification ________________
2. cost incurred to comply (direct and staff time) ________________
3. number of responses attributed to the notice ________________

If you were to summarize the customer questions/responses into three or four representative comments, what were the comments?

____
____
____
____
____
____

Future

1. Is there currently a continuing public information program concerning lead in effect: Yes________ No________.
2. Estimate cost to implement a public information program concerning lead (via television, radio, pamphlets, etc.) ________________ $.

Return to AWWA by:

Don't throw away this form and our chance to head off costly programs that may have limited benefits!

APPENDIX A.2

PROJECT QUESTIONNAIRE

APPENDIX A.2

PROJECT LEAD SURVEY QUESTIONNAIRE

1. Total population served: ____________________

2. Total number of service lines: ____________________

3. How old is the system? ____________________
   How old are the oldest mains in service? ____________________

4. Location of mains with respect to street right-of-way:
   Centered ____________________
   Fixed offset from center ____________________
   Near the curb ____________________

5. Average length of service line from:
   Main to curbstop ____________________ feet
   Curbstop to meter ____________________ feet

6. Lengths based on data from:
   Older, urban section? ____________________
   Newer suburban area? ____________________

7. Describe ownership to typical service line:
   Main to curbstop service line owned by: ____________________
   Curbstop to meter service line owned by: ____________________
   Meter owned by: ____________________

8. Do system files indicate the presence of:
   Lead service lines (Main to curbstop): ____________________
   Lead service lines (Curbstop to meter): ____________________
   Lead connections: ____________________
   Goosenecks: ____________________

9. If YES, estimate total length and/or quantity of lead piping:
   Main to curbstop service lines: ____________________ feet
   Curbstop to meter service lines: ____________________ feet
   Connections: ____________________ units
   Goosenecks: ____________________ units

10. If YES, what is the basis for the estimate? ____________________

11. Are there other data sources to estimate the quantity or location of lead services? __________ (list potential data sources) __________

    If the service lines are metered, would you use meter readers to visually inspect the type of pipe? __________

12. What action is taken when lead services are encountered? __________
    Is there a replacement program? __________
    Customer notification? __________

13. Has water sampling been performed in response to concerns over lead in water? __________

14. Do you have any data on standing lead levels measured at the tap both before and after you've replaced a portion of a lead service line? __________
    ____

15. If YES, what kind of treatment do you provide? __________
    Lime addition: __________
    Corrosion control: __________

16. What are the typical replacement costs? __________
    $/service line: __________
    $/foot: __________

17. If a mandatory replacement program were implemented, how would you locate lead service lines? __________

APPENDIX B

ECONOMIC COST ANALYSIS

Table B-1

10 - YEAR PROGRAM ANNUALIZED COSTS

YEAR	SCENARIO I ANNUAL COST	SCENARIO II ANNUAL COST	SCENARIO III ANNUAL COST	TOTAL ANNUAL COST	TOTAL ANNUAL COST ADJUSTED FOR BASELINE	TOTAL ADJ COST IN 1990 DOLLARS
1991	$62,712,732	$24,342,741	$400,370,384	$487,425,858	$434,254,536	$394,776,851
1992	$112,822,466	$334,025,665	$396,986,572	$843,834,704	$788,004,816	$651,243,650
1993	$100,792,461	$337,638,633	$416,835,901	$855,266,994	$796,645,612	$598,531,639
1994	$105,832,084	$354,520,565	$437,677,696	$898,030,344	$836,477,893	$571,325,656
1995	$111,123,688	$372,246,593	$459,561,580	$942,931,861	$878,301,787	$545,356,308
1996	$116,679,872	$390,858,923	$482,539,659	$990,078,454	$922,216,877	$520,567,385
1997	$122,513,866	$410,401,869	$506,666,642	$1,039,582,377	$968,327,721	$496,905,231
1998	$128,639,559	$430,921,962	$531,999,974	$1,091,561,496	$1,016,744,107	$474,318,630
1999	$135,071,537	$452,468,060	$558,599,973	$1,146,139,571	$1,067,581,312	$452,758,692
2000	$141,825,114	$475,091,463	$586,529,972	$1,203,446,549	$1,120,960,378	$432,178,751

Note: Assumes an inflation rate of 5% and a discount rate of 10%.

Table B-2

15 - YEAR PROGRAM ANNUALIZED COSTS

YEAR	SCENARIO I ANNUAL COST	SCENARIO II ANNUAL COST	SCENARIO III ANNUAL COST	TOTAL ANNUAL COST	TOTAL ANNUAL COST ADJUSTED FOR BASELINE	TOTAL ADJ COST IN 1990 DOLLARS
1991	$62,712,732	$24,342,741	$274,342,901	$361,398,375	$308,227,053	$280,206,412
1992	$78,539,317	$219,182,593	$264,657,715	$562,379,624	$506,549,736	$418,636,146
1993	$64,795,153	$217,053,407	$277,890,600	$559,739,161	$501,117,778	$376,497,204
1994	$68,034,911	$227,906,077	$291,785,130	$587,726,119	$526,173,667	$359,383,695
1995	$71,436,656	$239,301,381	$306,374,387	$617,112,425	$552,482,351	$343,048,072
1996	$75,008,489	$251,266,450	$321,693,106	$647,968,046	$580,106,468	$327,454,978
1997	$78,758,914	$263,829,773	$337,777,762	$680,366,448	$609,111,792	$312,570,661
1998	$82,696,859	$277,021,262	$354,666,650	$714,384,771	$639,567,381	$298,362,904
1999	$86,831,702	$290,872,325	$372,399,982	$750,104,009	$671,545,750	$284,800,953
2000	$91,173,287	$305,415,941	$391,019,981	$787,609,210	$705,123,038	$271,855,455
2001	$95,731,952	$320,686,738	$410,570,980	$826,989,670	$740,379,190	$259,498,389
2002	$100,518,549	$336,721,075	$431,099,529	$868,339,153	$777,398,149	$247,703,008
2003	$105,544,477	$353,557,128	$452,654,506	$911,756,111	$816,268,057	$236,443,780
2004	$110,821,701	$371,234,985	$475,287,231	$957,343,917	$857,081,460	$225,696,336
2005	$116,362,786	$389,796,734	$499,051,593	$1,005,211,113	$899,935,533	$215,437,411
						$4,457,595,404

Note: Assumes an inflation rate of 5% and a discount rate of 10%.

Table B-3

20 – YEAR PROGRAM ANNUALIZED COSTS

YEAR	SCENARIO I ANNUAL COST	SCENARIO II ANNUAL COST	SCENARIO III ANNUAL COST	TOTAL ANNUAL COST	TOTAL ANNUAL COST ADJUSTED FOR BASELINE	TOTAL ADJ COST IN 1990 DOLLARS
1991	$62,712,732	$24,342,741	$211,329,159	$298,384,633	$245,213,311	$222,921,192
1992	$62,299,930	$164,783,243	$198,493,286	$425,576,459	$369,746,571	$305,575,678
1993	$47,743,797	$159,934,089	$208,417,950	$416,095,837	$357,474,455	$268,575,849
1994	$50,130,987	$167,930,794	$218,838,848	$436,900,629	$375,348,177	$256,367,856
1995	$52,637,536	$176,327,334	$229,780,790	$458,745,660	$394,115,586	$244,714,771
1996	$55,269,413	$185,143,700	$241,269,830	$481,682,943	$413,821,366	$233,591,373
1997	$58,032,884	$194,400,885	$253,333,321	$505,767,090	$434,512,434	$222,973,583
1998	$60,934,528	$204,120,930	$265,999,987	$531,055,445	$456,238,055	$212,838,420
1999	$63,981,254	$214,326,976	$279,299,987	$557,608,217	$479,049,958	$203,163,946
2000	$67,180,317	$225,043,325	$293,264,986	$585,488,628	$503,002,456	$193,929,222
2001	$70,539,333	$236,295,491	$307,928,235	$614,763,059	$528,152,579	$185,114,257
2002	$74,066,300	$248,110,266	$323,324,647	$645,501,212	$554,560,208	$176,699,973
2003	$77,769,615	$260,515,779	$339,490,879	$677,776,273	$582,288,218	$168,668,156
2004	$81,658,095	$273,541,568	$356,465,423	$711,665,086	$611,402,629	$161,001,421
2005	$85,741,000	$287,218,646	$374,288,694	$747,248,341	$641,972,761	$153,683,175
2006	$90,028,050	$301,579,579	$393,003,129	$784,610,758	$674,071,399	$146,697,576
2007	$94,529,453	$316,658,557	$412,653,286	$823,841,296	$707,774,969	$140,029,504
2008	$99,255,925	$332,491,485	$433,285,950	$865,033,360	$743,163,717	$133,664,527
2009	$104,218,721	$349,116,060	$454,950,247	$908,285,028	$780,321,903	$127,588,867
2010	$109,429,658	$366,571,863	$477,697,760	$953,699,280	$819,337,998	$121,789,373
						$3,879,588,717

Note: Assumes an inflation rate of 5% and a discount rate of 10%.

Table B–4

25 – YEAR PROGRAM ANNUALIZED COSTS

YEAR	SCENARIO I ANNUAL COST	SCENARIO II ANNUAL COST	SCENARIO III ANNUAL COST	TOTAL ANNUAL COST	TOTAL ANNUAL COST ADJUSTED FOR BASELINE	TOTAL ADJ COST IN 1990 DOLLARS
1991	$62,712,732	$24,342,741	$173,520,915	$260,576,388	$207,405,066	$188,550,060
1992	$52,826,954	$133,050,289	$158,794,629	$344,671,871	$288,841,984	$238,712,383
1993	$37,797,173	$126,614,487	$166,734,360	$331,146,020	$272,524,638	$204,751,794
1994	$39,687,031	$132,945,212	$175,071,078	$347,703,321	$286,150,870	$195,444,895
1995	$41,671,383	$139,592,472	$183,824,632	$365,088,487	$300,458,414	$186,561,036
1996	$43,754,952	$146,572,096	$193,015,864	$383,342,912	$315,481,334	$178,080,989
1997	$45,942,700	$153,900,701	$202,666,657	$402,510,057	$331,255,401	$169,986,398
1998	$48,239,835	$161,595,736	$212,799,990	$422,635,560	$347,818,171	$162,259,744
1999	$50,651,826	$169,675,523	$223,439,989	$443,767,338	$365,209,080	$154,884,301
2000	$53,184,418	$178,159,299	$234,611,989	$465,955,705	$383,469,534	$147,844,105
2001	$55,843,639	$187,067,264	$246,342,588	$489,253,490	$402,643,010	$141,123,919
2002	$58,635,821	$196,420,627	$258,659,718	$513,716,165	$422,775,161	$134,709,195
2003	$61,567,612	$206,241,658	$271,592,703	$539,401,973	$443,913,919	$128,586,050
2004	$64,645,992	$216,553,741	$285,172,339	$566,372,072	$466,109,615	$122,741,230
2005	$67,878,292	$227,381,428	$299,430,956	$594,690,676	$489,415,096	$117,162,083
2006	$71,272,206	$238,750,500	$314,402,503	$624,425,209	$513,885,850	$111,836,533
2007	$74,835,817	$250,688,025	$330,122,628	$655,646,470	$539,580,143	$106,753,055
2008	$78,577,607	$263,222,426	$346,628,760	$688,428,793	$566,559,150	$101,900,643
2009	$82,506,488	$276,383,547	$363,960,198	$722,850,233	$594,887,107	$97,268,796
2010	$86,631,812	$290,202,725	$382,158,208	$758,992,745	$624,631,463	$92,847,487
2011	$90,963,403	$304,712,861	$401,266,118	$796,942,382	$655,863,036	$88,627,147
2012	$95,511,573	$319,948,504	$421,329,424	$836,789,501	$688,656,188	$84,598,640
2013	$100,287,152	$335,945,929	$442,395,895	$878,628,976	$723,088,997	$80,753,247
2014	$105,301,509	$352,743,225	$464,515,690	$922,560,425	$759,243,447	$77,082,645
2015	$110,566,585	$370,380,387	$487,741,475	$968,688,446	$797,205,619	$73,578,888
						$3,386,645,262

Note: Assumes an inflation rate of 5% and a discount rate of 10%.

Table B-5

10 – YEAR PROGRAM ANNUALIZED COSTS (including salvage value)

YEAR	SCENARIO I ANNUAL COST	SCENARIO II ANNUAL COST	SCENARIO III ANNUAL COST	TOTAL ANNUAL COST	TOTAL ANNUAL COST ADJUSTED FOR BASELINE	TOTAL ADJ COST IN 1990 DOLLARS
1991	$62,712,732	$24,342,741	$399,528,869	$486,584,342	$433,413,021	$394,011,837
1992	$112,129,263	$331,910,134	$396,102,981	$840,142,378	$784,312,490	$648,192,141
1993	$100,064,597	$335,417,325	$415,908,130	$851,390,052	$792,768,670	$595,618,835
1994	$105,067,827	$352,188,192	$436,703,536	$893,959,555	$832,407,104	$568,545,252
1995	$110,321,218	$369,797,601	$458,538,713	$938,657,533	$874,027,459	$542,702,286
1996	$115,837,279	$388,287,481	$481,465,649	$985,590,409	$917,728,832	$518,034,000
1997	$121,629,143	$407,701,855	$505,538,931	$1,034,869,930	$963,615,273	$494,487,000
1998	$127,710,600	$428,086,948	$530,815,878	$1,086,613,426	$1,011,796,037	$472,010,318
1999	$134,096,130	$449,491,295	$557,356,672	$1,140,944,097	$1,062,385,839	$450,555,304
2000	$140,800,937	$471,965,860	$585,224,505	$1,197,991,302	$1,115,505,131	$430,075,517
						$5,114,232,492

Note: Assumes an inflation rate of 5% and a discount rate of 10%.

Table B-6

15 - YEAR PROGRAM ANNUALIZED COSTS (including salvage value)

YEAR	SCENARIO I ANNUAL COST	SCENARIO II ANNUAL COST	SCENARIO III ANNUAL COST	TOTAL ANNUAL COST	TOTAL ANNUAL COST ADJUSTED FOR BASELINE	TOTAL ADJ COST IN 1990 DOLLARS
1991	$62,712,732	$24,342,741	$273,781,891	$360,837,364	$307,666,043	$279,696,402
1992	$78,093,686	$217,822,609	$264,068,654	$559,984,948	$504,155,060	$416,657,075
1993	$64,327,241	$215,625,423	$277,272,086	$557,224,751	$498,603,369	$374,608,091
1994	$67,543,603	$226,406,695	$291,135,691	$585,085,988	$523,533,537	$357,580,450
1995	$70,920,783	$237,727,029	$305,692,475	$614,340,288	$549,710,214	$341,326,793
1996	$74,466,822	$249,613,381	$320,977,099	$645,057,302	$577,195,725	$325,811,939
1997	$78,190,164	$262,094,050	$337,025,954	$677,310,167	$606,055,511	$311,002,306
1998	$82,099,672	$275,198,752	$353,877,252	$711,175,676	$636,358,287	$296,865,837
1999	$86,204,655	$288,958,690	$371,571,114	$746,734,460	$668,176,201	$283,371,935
2000	$90,514,888	$303,406,624	$390,149,670	$784,071,183	$701,585,011	$270,491,393
2001	$95,040,632	$318,576,956	$409,657,154	$823,274,742	$736,664,261	$258,196,330
2002	$99,792,664	$334,505,803	$430,140,011	$864,438,479	$773,497,475	$246,460,133
2003	$104,782,297	$351,231,094	$451,647,012	$907,660,403	$812,172,348	$235,257,399
2004	$110,021,412	$368,792,648	$474,229,362	$953,043,423	$852,780,966	$224,563,881
2005	$115,522,483	$387,232,281	$497,940,831	$1,000,695,594	$895,420,014	$214,356,432
						$4,436,246,397

Note: Assumes an inflation rate of 5% and a discount rate of 10%.

Table B-7

20 – YEAR PROGRAM ANNUALIZED COSTS (including salvage value)

YEAR	SCENARIO I ANNUAL COST	SCENARIO II ANNUAL COST	SCENARIO III ANNUAL COST	TOTAL ANNUAL COST	TOTAL ANNUAL COST ADJUSTED FOR BASELINE	TOTAL ADJ COST IN 1990 DOLLARS
1991	$62,712,732	$24,342,741	$210,908,402	$297,963,875	$244,792,554	$222,538,685
1992	$61,971,570	$163,781,149	$198,051,490	$423,804,210	$367,974,322	$304,111,010
1993	$47,399,020	$158,881,891	$207,954,065	$414,234,976	$355,613,593	$267,177,756
1994	$49,768,971	$166,825,985	$218,351,768	$434,946,724	$373,394,273	$255,033,313
1995	$52,257,419	$175,167,285	$229,269,357	$456,694,060	$392,063,987	$243,440,889
1996	$54,870,290	$183,925,649	$240,732,824	$479,528,764	$411,667,186	$232,375,394
1997	$57,613,805	$193,121,931	$252,769,466	$503,505,202	$432,250,545	$221,812,876
1998	$60,494,495	$202,778,028	$265,407,939	$528,680,462	$453,863,073	$211,730,473
1999	$63,519,220	$212,916,929	$278,678,336	$555,114,485	$476,556,226	$202,106,361
2000	$66,695,181	$223,562,776	$292,612,253	$582,870,209	$500,384,037	$192,919,708
2001	$70,029,940	$234,740,915	$307,242,865	$612,013,720	$525,403,239	$184,150,630
2002	$73,531,437	$246,477,960	$322,605,008	$642,614,406	$551,673,401	$175,780,147
2003	$77,208,009	$258,801,858	$338,735,259	$674,745,126	$579,257,071	$167,790,140
2004	$81,068,409	$271,741,951	$355,672,022	$708,482,382	$608,219,925	$160,163,316
2005	$85,121,829	$285,329,049	$373,455,623	$743,906,501	$638,630,921	$152,883,165
2006	$89,377,921	$299,595,501	$392,128,404	$781,101,826	$670,562,467	$145,933,930
2007	$93,846,817	$314,575,276	$411,734,824	$820,156,918	$704,090,591	$139,300,570
2008	$98,539,158	$330,304,040	$432,321,565	$861,164,763	$739,295,120	$132,968,726
2009	$103,466,116	$346,819,242	$453,937,644	$904,223,002	$776,259,876	$126,924,693
2010	$108,639,421	$364,160,204	$476,634,526	$949,434,152	$815,072,870	$121,155,388
						$3,860,297,170

Note: Assumes an inflation rate of 5% and a discount rate of 10%.

Table B-8

25 – YEAR PROGRAM ANNUALIZED COSTS (including salvage value)

YEAR	SCENARIO I ANNUAL COST	SCENARIO II ANNUAL COST	SCENARIO III ANNUAL COST	TOTAL ANNUAL COST	TOTAL ANNUAL COST ADJUSTED FOR BASELINE	TOTAL ADJ COST IN 1990 DOLLARS
1991	$62,712,732	$24,342,741	$173,184,308	$260,239,782	$207,068,460	$188,244,055
1992	$52,567,003	$132,256,964	$158,441,192	$343,265,160	$287,435,272	$237,549,811
1993	$37,524,224	$125,781,497	$166,363,252	$329,668,973	$271,047,591	$203,642,067
1994	$39,400,435	$132,070,572	$174,681,414	$346,152,421	$284,599,970	$194,385,609
1995	$41,370,457	$138,674,100	$183,415,485	$363,460,043	$298,829,969	$185,549,900
1996	$43,438,980	$145,607,805	$192,586,259	$381,633,045	$313,771,467	$177,115,813
1997	$45,610,929	$152,888,196	$202,215,572	$400,714,697	$329,460,040	$169,065,094
1998	$47,891,475	$160,532,606	$212,326,351	$420,750,432	$345,933,042	$161,380,317
1999	$50,286,049	$168,559,236	$222,942,669	$441,787,953	$363,229,695	$154,044,848
2000	$52,800,351	$176,987,198	$234,089,802	$463,877,351	$381,391,179	$147,042,810
2001	$55,440,369	$185,836,557	$245,794,292	$487,071,219	$400,460,738	$140,359,046
2002	$58,212,387	$195,128,385	$258,084,007	$511,424,779	$420,483,775	$133,979,089
2003	$61,123,007	$204,884,805	$270,988,207	$536,996,018	$441,507,964	$127,889,131
2004	$64,179,157	$215,129,045	$284,537,617	$563,845,819	$463,583,362	$122,075,988
2005	$67,388,115	$225,885,497	$298,764,498	$592,038,110	$486,762,530	$116,527,080
2006	$70,757,521	$237,179,772	$313,702,723	$621,640,016	$511,100,657	$111,230,394
2007	$74,295,397	$249,038,761	$329,387,859	$652,722,017	$536,655,690	$106,174,467
2008	$78,010,167	$261,490,699	$345,857,252	$685,358,117	$563,488,474	$101,348,355
2009	$81,910,675	$274,565,233	$363,150,115	$719,626,023	$591,662,898	$96,741,612
2010	$86,006,209	$288,293,495	$381,307,621	$755,607,325	$621,246,043	$92,344,266
2011	$90,306,519	$302,708,170	$400,373,002	$793,387,691	$652,308,345	$88,146,799
2012	$94,821,845	$317,843,578	$420,391,652	$833,057,075	$684,923,762	$84,140,126
2013	$99,562,937	$333,735,757	$441,411,234	$874,709,929	$719,169,950	$80,315,575
2014	$104,541,084	$350,422,545	$463,481,796	$918,445,425	$755,128,448	$76,664,867
2015	$109,768,138	$367,943,672	$486,655,886	$964,367,697	$792,884,870	$73,180,101
						$3,369,137,220

Note: Assumes an inflation rate of 5% and a discount rate of 10%.

Table B-9

10 - YEAR PROGRAM ANNUALIZED BENEFITS

YEAR	SCENARIO I CUMULATIVE BENEFIT	SCENARIO II CUMULATIVE BENEFIT	SCENARIO III CUMULATIVE BENEFIT	TOTAL CUMULATIVE BENEFIT	BASELINE BENEFITS	DIFFERENTIAL BENEFITS	DIFFERENTIAL BENEFITS IN 1990 DOLLARS
1991	$0	$0	$373,905	$373,905	$267,273	$106,632	$96,938
1992	$318,010	$960,768	$785,201	$2,063,978	$561,273	$1,502,705	$1,241,905
1993	$667,821	$2,017,612	$1,236,691	$3,922,124	$884,005	$3,038,119	$2,282,584
1994	$1,051,818	$3,177,739	$1,731,367	$5,960,924	$1,237,606	$4,723,317	$3,226,089
1995	$1,472,545	$4,448,834	$2,272,419	$8,193,799	$1,624,358	$6,569,440	$4,079,105
1996	$1,932,716	$5,839,095	$2,863,248	$10,635,059	$2,046,692	$8,588,367	$4,847,909
1997	$2,435,222	$7,357,259	$3,507,479	$13,299,960	$2,507,197	$10,792,763	$5,538,394
1998	$2,983,147	$9,012,642	$4,208,975	$16,204,764	$3,008,637	$13,196,128	$6,156,091
1999	$3,579,776	$10,815,171	$4,971,852	$19,366,799	$3,553,952	$15,812,847	$6,706,191
2000	$4,228,610	$12,775,421	$5,800,494	$22,804,525	$4,146,277	$18,658,248	$7,193,562
2001	$4,440,041	$13,414,192	$6,090,518	$23,944,751	$4,788,950	$19,155,801	$6,713,991
2002	$4,662,043	$14,084,901	$6,395,044	$25,141,989	$5,485,525	$19,656,464	$6,263,155
2003	$4,895,145	$14,789,146	$6,714,797	$26,399,088	$6,239,784	$20,159,304	$5,839,432
2004	$5,139,902	$15,528,604	$7,050,536	$27,719,042	$7,055,756	$20,663,286	$5,441,289
2005	$5,396,898	$16,305,034	$7,403,063	$29,104,995	$7,937,726	$21,167,269	$5,067,276
2006	$5,666,742	$17,120,285	$7,773,216	$30,560,244	$8,890,253	$21,669,991	$4,716,021
2007	$5,950,080	$17,976,300	$8,161,877	$32,088,256	$9,918,188	$22,170,068	$4,386,230
2008	$6,247,584	$18,875,115	$8,569,971	$33,692,669	$11,026,692	$22,665,978	$4,076,675
2009	$6,559,963	$19,818,870	$8,998,470	$35,377,303	$12,221,250	$23,156,053	$3,786,200
2010	$6,887,961	$20,809,814	$9,448,393	$37,146,168	$13,507,697	$23,638,470	$3,513,708
2011	$7,232,359	$21,850,305	$9,920,813	$39,003,476	$14,892,236	$24,111,240	$3,258,166
2012	$7,593,977	$22,942,820	$10,416,853	$40,953,650	$16,381,460	$24,572,190	$3,018,595
2013	$7,973,676	$24,089,961	$10,937,696	$43,001,333	$17,982,375	$25,018,957	$2,794,071
2014	$8,372,359	$25,294,459	$11,484,581	$45,151,399	$19,702,429	$25,448,970	$2,583,722
2015	$8,790,977	$26,559,182	$12,058,810	$47,408,969	$21,549,531	$25,859,438	$2,386,723
2016	$9,230,526	$27,887,141	$12,661,750	$49,779,418	$23,532,088	$26,247,329	$2,202,294
2017	$9,692,053	$29,281,498	$13,294,838	$52,268,389	$25,659,027	$26,609,361	$2,029,700
2018	$10,176,655	$30,745,573	$13,959,580	$54,881,808	$27,939,829	$26,941,978	$1,868,247
2019	$10,685,488	$32,282,851	$14,657,559	$57,625,898	$30,384,565	$27,241,334	$1,717,278
2020	$11,219,762	$33,896,994	$15,390,437	$60,507,193	$33,003,924	$27,503,270	$1,576,173
2021	$11,780,751	$35,591,844	$16,159,959	$63,532,553	$35,809,257	$27,723,296	$1,444,347
2022	$12,369,788	$37,371,436	$16,967,957	$66,709,181	$38,812,614	$27,896,566	$1,321,249
2023	$12,988,277	$39,240,008	$17,816,354	$70,044,640	$42,026,784	$28,017,856	$1,206,358
2024	$13,637,691	$41,202,008	$18,707,172	$73,546,872	$45,465,339	$28,081,533	$1,099,182
2025	$14,319,576	$43,262,109	$19,642,531	$77,224,215	$49,142,682	$28,081,533	$999,256
2026	$15,035,555	$45,425,214	$20,624,657	$81,085,426	$53,074,097	$28,011,329	$906,144
2027	$15,787,332	$47,696,475	$21,655,890	$85,139,697	$57,275,796	$27,863,901	$819,431
2028	$16,576,699	$50,081,298	$22,738,685	$89,396,682	$61,764,980	$27,631,702	$738,730

Table B-9 (cont'd)

10 – YEAR PROGRAM ANNUALIZED BENEFITS

YEAR	SCENARIO I CUMULATIVE BENEFIT	SCENARIO II CUMULATIVE BENEFIT	SCENARIO III CUMULATIVE BENEFIT	TOTAL CUMULATIVE BENEFIT	BASELINE BENEFITS	DIFFERENTIAL BENEFITS	DIFFERENTIAL BENEFITS IN 1990 DOLLARS
2029	$17,405,534	$52,585,363	$23,875,619	$93,866,516	$66,559,893	$27,306,623	$663,672
2030	$18,275,811	$55,214,631	$25,069,400	$98,559,842	$71,679,885	$26,879,957	$593,911
2031	$19,189,601	$57,975,363	$26,322,870	$103,487,834	$77,145,476	$26,342,358	$529,120
2032	$20,149,081	$60,874,131	$27,639,013	$108,662,226	$82,978,427	$25,683,799	$468,993
2033	$21,156,535	$63,917,838	$29,020,964	$114,095,337	$89,201,809	$24,893,528	$413,239
2034	$22,214,362	$67,113,730	$30,472,012	$119,800,104	$95,840,083	$23,960,021	$361,584
2035	$23,325,080	$70,469,416	$31,995,613	$125,790,109	$102,919,180	$22,870,929	$313,771
2036	$24,491,334	$73,992,887	$33,595,393	$132,079,615	$110,466,587	$21,613,028	$269,558
2037	$25,715,901	$77,692,531	$35,275,163	$138,683,595	$118,511,436	$20,172,159	$228,716
2038	$27,001,696	$81,577,158	$37,038,921	$145,617,775	$127,084,604	$18,533,171	$191,030
2039	$28,351,781	$85,656,016	$38,890,867	$152,898,664	$136,218,810	$16,679,854	$156,297
2040	$29,769,370	$89,938,817	$40,835,411	$160,543,597	$145,948,725	$14,594,872	$124,327
2041	$31,257,838	$94,435,757	$42,877,181	$168,570,777	$156,311,084	$12,259,693	$94,941
2042	$32,820,730	$99,157,545	$45,021,040	$176,999,316	$167,344,808	$9,654,508	$67,969
2043	$34,461,767	$104,115,422	$47,272,092	$185,849,281	$179,091,126	$6,758,156	$43,253
2044	$36,184,855	$109,321,194	$49,635,697	$195,141,746	$191,593,714	$3,548,032	$20,643
2045	$37,994,098	$114,787,253	$52,117,482	$204,898,833	$204,898,833	$0	$0
							$127,683,435

Note: Assumes an inflation rate of 5% and a discount rate of 10%.

Table B-10

15 – YEAR PROGRAM ANNUALIZED BENEFITS

YEAR	SCENARIO I CUMULATIVE BENEFIT	SCENARIO II CUMULATIVE BENEFIT	SCENARIO III CUMULATIVE BENEFIT	TOTAL CUMULATIVE BENEFIT	BASELINE BENEFITS	DIFFERENTIAL BENEFITS	DIFFERENTIAL BENEFITS IN 1990 DOLLARS
1991	$0	$0	$249,270	$249,270	$267,273	($18,003)	($16,366)
1992	$204,435	$617,636	$523,467	$1,345,538	$561,273	$784,266	$648,153
1993	$429,314	$1,297,036	$824,461	$2,550,810	$884,005	$1,666,806	$1,252,296
1994	$676,169	$2,042,832	$1,154,245	$3,873,245	$1,237,606	$2,635,639	$1,800,177
1995	$946,636	$2,859,965	$1,514,946	$5,321,547	$1,624,358	$3,697,189	$2,295,663
1996	$1,242,460	$3,753,704	$1,908,832	$6,904,996	$2,046,692	$4,858,304	$2,742,386
1997	$1,565,500	$4,729,667	$2,338,319	$8,633,486	$2,507,197	$6,126,289	$3,143,755
1998	$1,917,737	$5,793,842	$2,805,983	$10,517,562	$3,008,637	$7,508,926	$3,502,969
1999	$2,301,285	$6,952,610	$3,314,568	$12,568,462	$3,553,952	$9,014,510	$3,823,032
2000	$2,718,392	$8,212,770	$3,866,996	$14,798,159	$4,146,277	$10,651,881	$4,106,761
2001	$3,171,458	$9,581,565	$4,466,380	$17,219,403	$4,788,950	$12,430,453	$4,356,798
2002	$3,663,034	$11,066,708	$5,116,036	$19,845,777	$5,485,525	$14,360,253	$4,575,619
2003	$4,195,839	$12,676,411	$5,819,490	$22,691,740	$6,239,784	$16,451,956	$4,765,546
2004	$4,772,767	$14,419,418	$6,580,501	$25,772,685	$7,055,756	$18,716,929	$4,928,752
2005	$5,396,898	$16,305,034	$7,403,063	$29,104,995	$7,937,726	$21,167,269	$5,067,276
2006	$5,666,742	$17,120,285	$7,773,216	$30,560,244	$8,890,253	$21,669,991	$4,716,021
2007	$5,950,080	$17,976,300	$8,161,877	$32,088,256	$9,918,188	$22,170,068	$4,386,230
2008	$6,247,584	$18,875,115	$8,569,971	$33,692,669	$11,026,692	$22,665,978	$4,076,675
2009	$6,559,963	$19,818,870	$8,998,470	$35,377,303	$12,221,250	$23,156,053	$3,786,200
2010	$6,887,961	$20,809,814	$9,448,393	$37,146,168	$13,507,697	$23,638,470	$3,513,708
2011	$7,232,359	$21,850,305	$9,920,813	$39,003,476	$14,892,236	$24,111,240	$3,258,166
2012	$7,593,977	$22,942,820	$10,416,853	$40,953,650	$16,381,460	$24,572,190	$3,018,595
2013	$7,973,676	$24,089,961	$10,937,696	$43,001,333	$17,982,375	$25,018,957	$2,794,071
2014	$8,372,359	$25,294,459	$11,484,581	$45,151,399	$19,702,429	$25,448,970	$2,583,722
2015	$8,790,977	$26,559,182	$12,058,810	$47,408,969	$21,549,531	$25,859,438	$2,386,723
2016	$9,230,526	$27,887,141	$12,661,750	$49,779,418	$23,532,088	$26,247,329	$2,202,294
2017	$9,692,053	$29,281,498	$13,294,838	$52,268,389	$25,659,027	$26,609,361	$2,029,700
2018	$10,176,655	$30,745,573	$13,959,580	$54,881,808	$27,939,829	$26,941,978	$1,868,247
2019	$10,685,488	$32,282,851	$14,657,559	$57,625,898	$30,384,565	$27,241,334	$1,717,278
2020	$11,219,762	$33,896,994	$15,390,437	$60,507,193	$33,003,924	$27,503,270	$1,576,173
2021	$11,780,751	$35,591,844	$16,159,959	$63,532,553	$35,809,257	$27,723,296	$1,444,347
2022	$12,369,788	$37,371,436	$16,967,957	$66,709,181	$38,812,614	$27,896,566	$1,321,249
2023	$12,988,277	$39,240,008	$17,816,354	$70,044,640	$42,026,784	$28,017,856	$1,206,358
2024	$13,637,691	$41,202,008	$18,707,172	$73,546,872	$45,465,339	$28,081,533	$1,099,182
2025	$14,319,576	$43,262,109	$19,642,531	$77,224,215	$49,142,682	$28,081,533	$999,256
2026	$15,035,555	$45,425,214	$20,624,657	$81,085,426	$53,074,097	$28,011,329	$906,144
2027	$15,787,332	$47,696,475	$21,655,890	$85,139,697	$57,275,796	$27,863,901	$819,431
2028	$16,576,699	$50,081,298	$22,738,685	$89,396,682	$61,764,980	$27,631,702	$738,730

Table B-10 (cont'd)

15 - YEAR PROGRAM ANNUALIZED BENEFITS

YEAR	SCENARIO I CUMULATIVE BENEFIT	SCENARIO II CUMULATIVE BENEFIT	SCENARIO III CUMULATIVE BENEFIT	TOTAL CUMULATIVE BENEFIT	BASELINE BENEFITS	DIFFERENTIAL BENEFITS	DIFFERENTIAL BENEFITS IN 1990 DOLLARS
2029	$17,405,534	$52,585,363	$23,875,619	$93,866,516	$66,559,893	$27,306,623	$663,672
2030	$18,275,811	$55,214,631	$25,069,400	$98,559,842	$71,679,885	$26,879,957	$593,911
2031	$19,189,601	$57,975,363	$26,322,870	$103,487,834	$77,145,476	$26,342,358	$529,120
2032	$20,149,081	$60,874,131	$27,639,013	$108,662,226	$82,978,427	$25,683,799	$468,993
2033	$21,156,535	$63,917,838	$29,020,964	$114,095,337	$89,201,809	$24,893,528	$413,239
2034	$22,214,362	$67,113,730	$30,472,012	$119,800,104	$95,840,083	$23,960,021	$361,584
2035	$23,325,080	$70,469,416	$31,995,613	$125,790,109	$102,919,180	$22,870,929	$313,771
2036	$24,491,334	$73,992,887	$33,595,393	$132,079,615	$110,466,587	$21,613,028	$269,558
2037	$25,715,901	$77,692,531	$35,275,163	$138,683,595	$118,511,436	$20,172,159	$228,716
2038	$27,001,696	$81,577,158	$37,038,921	$145,617,775	$127,084,604	$18,533,171	$191,030
2039	$28,351,781	$85,656,016	$38,890,867	$152,898,664	$136,218,810	$16,679,854	$156,297
2040	$29,769,370	$89,938,817	$40,835,411	$160,543,597	$145,948,725	$14,594,872	$124,327
2041	$31,257,838	$94,435,757	$42,877,181	$168,570,777	$156,311,084	$12,259,693	$94,941
2042	$32,820,730	$99,157,545	$45,021,040	$176,999,316	$167,344,808	$9,654,508	$67,969
2043	$34,461,767	$104,115,422	$47,272,092	$185,849,281	$179,091,126	$6,758,156	$43,253
2044	$36,184,855	$109,321,194	$49,635,697	$195,141,746	$191,593,714	$3,548,032	$20,643
2045	$37,994,098	$114,787,253	$52,117,482	$204,898,833	$204,898,833	$0	$0
							$103,982,341

Note: Assumes an inflation rate of 5% and a discount rate of 10%.

Table B-11

20 - YEAR PROGRAM ANNUALIZED BENEFITS

YEAR	SCENARIO I CUMULATIVE BENEFIT	SCENARIO II CUMULATIVE BENEFIT	SCENARIO III CUMULATIVE BENEFIT	TOTAL CUMULATIVE BENEFIT	BASELINE BENEFITS	DIFFERENTIAL BENEFITS	DIFFERENTIAL BENEFITS IN 1990 DOLLARS
1991	$0	$0	$186,953	$186,953	$267,273	($80,320)	($73,018)
1992	$150,636	$455,100	$392,600	$998,337	$561,273	$437,064	$361,210
1993	$316,336	$955,711	$618,345	$1,890,392	$884,005	$1,006,388	$756,114
1994	$498,230	$1,505,245	$865,684	$2,869,158	$1,237,606	$1,631,551	$1,114,372
1995	$697,521	$2,107,342	$1,136,210	$3,941,073	$1,624,358	$2,316,715	$1,438,498
1996	$915,497	$2,765,887	$1,431,624	$5,113,008	$2,046,692	$3,066,316	$1,730,856
1997	$1,153,526	$3,485,017	$1,753,740	$6,392,283	$2,507,197	$3,885,086	$1,993,663
1998	$1,413,069	$4,269,146	$2,104,488	$7,786,703	$3,008,637	$4,778,067	$2,229,003
1999	$1,695,683	$5,122,976	$2,485,926	$9,304,585	$3,553,952	$5,750,633	$2,438,830
2000	$2,003,026	$6,051,515	$2,900,247	$10,954,788	$4,146,277	$6,808,511	$2,624,976
2001	$2,336,864	$7,060,101	$3,349,785	$12,746,750	$4,788,950	$7,957,799	$2,789,160
2002	$2,699,078	$8,154,416	$3,837,027	$14,690,521	$5,485,525	$9,204,996	$2,932,995
2003	$3,091,671	$9,340,513	$4,364,618	$16,796,802	$6,239,784	$10,557,017	$3,057,992
2004	$3,516,775	$10,624,834	$4,935,375	$19,076,985	$7,055,756	$12,021,229	$3,165,565
2005	$3,976,661	$12,014,235	$5,552,297	$21,543,194	$7,937,726	$13,605,468	$3,257,041
2006	$4,473,744	$13,516,015	$6,218,573	$24,208,332	$8,890,253	$15,318,079	$3,333,660
2007	$5,010,593	$15,137,937	$6,937,596	$27,086,126	$9,918,188	$17,167,937	$3,396,585
2008	$5,589,943	$16,888,260	$7,712,974	$30,191,178	$11,026,692	$19,164,486	$3,446,901
2009	$6,214,702	$18,775,772	$8,548,546	$33,539,020	$12,221,250	$21,317,770	$3,485,626
2010	$6,887,961	$20,809,814	$9,448,393	$37,146,168	$13,507,697	$23,638,470	$3,513,708
2011	$7,232,359	$21,850,305	$9,920,813	$39,003,476	$14,892,236	$24,111,240	$3,258,166
2012	$7,593,977	$22,942,820	$10,416,853	$40,953,650	$16,381,460	$24,572,190	$3,018,595
2013	$7,973,676	$24,089,961	$10,937,696	$43,001,333	$17,982,375	$25,018,957	$2,794,071
2014	$8,372,359	$25,294,459	$11,484,581	$45,151,399	$19,702,429	$25,448,970	$2,583,722
2015	$8,790,977	$26,559,182	$12,058,810	$47,408,969	$21,549,531	$25,859,438	$2,386,723
2016	$9,230,526	$27,887,141	$12,661,750	$49,779,418	$23,532,088	$26,247,329	$2,202,294
2017	$9,692,053	$29,281,498	$13,294,838	$52,268,389	$25,659,027	$26,609,361	$2,029,700
2018	$10,176,655	$30,745,573	$13,959,580	$54,881,808	$27,939,829	$26,941,978	$1,868,247
2019	$10,685,488	$32,282,851	$14,657,559	$57,625,898	$30,384,565	$27,241,334	$1,717,278
2020	$11,219,762	$33,896,994	$15,390,437	$60,507,193	$33,003,924	$27,503,270	$1,576,173
2021	$11,780,751	$35,591,844	$16,159,959	$63,532,553	$35,809,257	$27,723,296	$1,444,347
2022	$12,369,788	$37,371,436	$16,967,957	$66,709,181	$38,812,614	$27,896,566	$1,321,249
2023	$12,988,277	$39,240,008	$17,816,354	$70,044,640	$42,026,784	$28,017,856	$1,206,358
2024	$13,637,691	$41,202,008	$18,707,172	$73,546,872	$45,465,339	$28,081,533	$1,099,182
2025	$14,319,576	$43,262,109	$19,642,531	$77,224,215	$49,142,682	$28,081,533	$999,256
2026	$15,035,555	$45,425,214	$20,624,657	$81,085,426	$53,074,097	$28,011,329	$906,144
2027	$15,787,332	$47,696,475	$21,655,890	$85,139,697	$57,275,796	$27,863,901	$819,431
2028	$16,576,699	$50,081,298	$22,738,685	$89,396,682	$61,764,980	$27,631,702	$738,730

Table B-11 (cont'd)

20 - YEAR PROGRAM ANNUALIZED BENEFITS

YEAR	SCENARIO I CUMULATIVE BENEFIT	SCENARIO II CUMULATIVE BENEFIT	SCENARIO III CUMULATIVE BENEFIT	TOTAL CUMULATIVE BENEFIT	BASELINE BENEFITS	DIFFERENTIAL BENEFITS	DIFFERENTIAL BENEFITS IN 1990 DOLLARS
2029	$17,405,534	$52,585,363	$23,875,619	$93,866,516	$66,559,893	$27,306,623	$663,672
2030	$18,275,811	$55,214,631	$25,069,400	$98,559,842	$71,679,885	$26,879,957	$593,911
2031	$19,189,601	$57,975,363	$26,322,870	$103,487,834	$77,145,476	$26,342,358	$529,120
2032	$20,149,081	$60,874,131	$27,639,013	$108,662,226	$82,978,427	$25,683,799	$468,993
2033	$21,156,535	$63,917,838	$29,020,964	$114,095,337	$89,201,809	$24,893,528	$413,239
2034	$22,214,362	$67,113,730	$30,472,012	$119,800,104	$95,840,083	$23,960,021	$361,584
2035	$23,325,080	$70,469,416	$31,995,613	$125,790,109	$102,919,180	$22,870,929	$313,771
2036	$24,491,334	$73,992,887	$33,595,393	$132,079,615	$110,466,587	$21,613,028	$269,558
2037	$25,715,901	$77,692,531	$35,275,163	$138,683,595	$118,511,436	$20,172,159	$228,716
2038	$27,001,696	$81,577,158	$37,038,921	$145,617,775	$127,084,604	$18,533,171	$191,030
2039	$28,351,781	$85,656,016	$38,890,867	$152,898,664	$136,218,810	$16,679,854	$156,297
2040	$29,769,370	$89,938,817	$40,835,411	$160,543,597	$145,948,725	$14,594,872	$124,327
2041	$31,257,838	$94,435,757	$42,877,181	$168,570,777	$156,311,084	$12,259,693	$94,941
2042	$32,820,730	$99,157,545	$45,021,040	$176,999,316	$167,344,808	$9,654,508	$67,969
2043	$34,461,767	$104,115,422	$47,272,092	$185,849,281	$179,091,126	$6,758,156	$43,253
2044	$36,184,855	$109,321,194	$49,635,697	$195,141,746	$191,593,714	$3,548,032	$20,643
2045	$37,994,098	$114,787,253	$52,117,482	$204,898,833	$204,898,833	$0	$0
							$83,504,425

Note: Assumes an inflation rate of 5% and a discount rate of 10%.

Table B-12

25 - YEAR PROGRAM ANNUALIZED BENEFITS

YEAR	SCENARIO I CUMULATIVE BENEFIT	SCENARIO II CUMULATIVE BENEFIT	SCENARIO III CUMULATIVE BENEFIT	TOTAL CUMULATIVE BENEFIT	BASELINE BENEFITS	DIFFERENTIAL BENEFITS	DIFFERENTIAL BENEFITS IN 1990 DOLLARS
1991	$0	$0	$149,562	$149,562	$267,273	($117,711)	($107,010)
1992	$119,254	$360,288	$314,080	$793,622	$561,273	$232,349	$192,024
1993	$250,433	$756,604	$494,676	$1,501,714	$884,005	$617,709	$464,094
1994	$394,432	$1,191,652	$692,547	$2,278,631	$1,237,606	$1,041,024	$711,034
1995	$552,204	$1,668,313	$908,968	$3,129,485	$1,624,358	$1,505,127	$934,565
1996	$724,768	$2,189,660	$1,145,299	$4,059,728	$2,046,692	$2,013,037	$1,136,307
1997	$913,208	$2,758,972	$1,402,992	$5,075,172	$2,507,197	$2,567,975	$1,317,777
1998	$1,118,680	$3,379,741	$1,683,590	$6,182,011	$3,008,637	$3,173,374	$1,480,403
1999	$1,342,416	$4,055,689	$1,988,741	$7,386,846	$3,553,952	$3,832,894	$1,625,521
2000	$1,585,729	$4,790,783	$2,320,198	$8,696,709	$4,146,277	$4,550,432	$1,754,388
2001	$1,850,017	$5,589,246	$2,679,828	$10,119,092	$4,788,950	$5,330,141	$1,868,182
2002	$2,136,770	$6,455,580	$3,069,621	$11,661,971	$5,485,525	$6,176,446	$1,968,006
2003	$2,447,573	$7,394,573	$3,491,694	$13,333,840	$6,239,784	$7,094,055	$2,054,895
2004	$2,784,114	$8,411,327	$3,948,300	$15,143,741	$7,055,756	$8,087,985	$2,129,819
2005	$3,148,190	$9,511,270	$4,441,838	$17,101,298	$7,937,726	$9,163,572	$2,193,686
2006	$3,541,714	$10,700,178	$4,974,859	$19,216,751	$8,890,253	$10,326,498	$2,247,347
2007	$3,966,720	$11,984,200	$5,550,077	$21,500,996	$9,918,188	$11,582,808	$2,291,597
2008	$4,425,372	$13,369,873	$6,170,379	$23,965,624	$11,026,692	$12,938,932	$2,327,181
2009	$4,919,972	$14,864,153	$6,838,837	$26,622,962	$12,221,250	$14,401,712	$2,354,795
2010	$5,452,969	$16,474,436	$7,558,715	$29,486,120	$13,507,697	$15,978,422	$2,375,091
2011	$6,026,966	$18,208,587	$8,333,483	$32,569,036	$14,892,236	$17,676,799	$2,388,676
2012	$6,644,730	$20,074,967	$9,166,831	$35,886,528	$16,381,460	$19,505,068	$2,396,119
2013	$7,309,203	$22,082,464	$10,062,680	$39,454,347	$17,982,375	$21,471,972	$2,397,950
2014	$8,023,511	$24,240,523	$11,025,198	$43,289,232	$19,702,429	$23,586,803	$2,394,664
2015	$8,790,977	$26,559,182	$12,058,810	$47,408,969	$21,549,531	$25,859,438	$2,386,723
2016	$9,230,526	$27,887,141	$12,661,750	$49,779,418	$23,532,088	$26,247,329	$2,202,294
2017	$9,692,053	$29,281,498	$13,294,838	$52,268,389	$25,659,027	$26,609,361	$2,029,700
2018	$10,176,655	$30,745,573	$13,959,580	$54,881,808	$27,939,829	$26,941,978	$1,868,247
2019	$10,685,488	$32,282,851	$14,657,559	$57,625,898	$30,384,565	$27,241,334	$1,717,278
2020	$11,219,762	$33,896,994	$15,390,437	$60,507,193	$33,003,924	$27,503,270	$1,576,173
2021	$11,780,751	$35,591,844	$16,159,959	$63,532,553	$35,809,257	$27,723,296	$1,444,347
2022	$12,369,788	$37,371,436	$16,967,957	$66,709,181	$38,812,614	$27,896,566	$1,321,249
2023	$12,988,277	$39,240,008	$17,816,354	$70,044,640	$42,026,784	$28,017,856	$1,206,358
2024	$13,637,691	$41,202,008	$18,707,172	$73,546,872	$45,465,339	$28,081,533	$1,099,182
2025	$14,319,576	$43,262,109	$19,642,531	$77,224,215	$49,142,682	$28,081,533	$999,256
2026	$15,035,555	$45,425,214	$20,624,657	$81,085,426	$53,074,097	$28,011,329	$906,144
2027	$15,787,332	$47,696,475	$21,655,890	$85,139,697	$57,275,796	$27,863,901	$819,431
2028	$16,576,699	$50,081,298	$22,738,685	$89,396,682	$61,764,980	$27,631,702	$738,730

Table B-12 (cont'd)

25 - YEAR PROGRAM ANNUALIZED BENEFITS

YEAR	SCENARIO I CUMULATIVE BENEFIT	SCENARIO II CUMULATIVE BENEFIT	SCENARIO III CUMULATIVE BENEFIT	TOTAL CUMULATIVE BENEFIT	BASELINE BENEFITS	DIFFERENTIAL BENEFITS	DIFFERENTIAL BENEFITS IN 1990 DOLLARS
2029	$17,405,534	$52,585,363	$23,875,619	$93,866,516	$66,559,893	$27,306,623	$663,672
2030	$18,275,811	$55,214,631	$25,069,400	$98,559,842	$71,679,885	$26,879,957	$593,911
2031	$19,189,601	$57,975,363	$26,322,870	$103,487,834	$77,145,476	$26,342,358	$529,120
2032	$20,149,081	$60,874,131	$27,639,013	$108,662,226	$82,978,427	$25,683,799	$468,993
2033	$21,156,535	$63,917,838	$29,020,964	$114,095,337	$89,201,809	$24,893,528	$413,239
2034	$22,214,362	$67,113,730	$30,472,012	$119,800,104	$95,840,083	$23,960,021	$361,584
2035	$23,325,080	$70,469,416	$31,995,613	$125,790,109	$102,919,180	$22,870,929	$313,771
2036	$24,491,334	$73,992,887	$33,595,393	$132,079,615	$110,466,587	$21,613,028	$269,558
2037	$25,715,901	$77,692,531	$35,275,163	$138,683,595	$118,511,436	$20,172,159	$228,716
2038	$27,001,696	$81,577,158	$37,038,921	$145,617,775	$127,084,604	$18,533,171	$191,030
2039	$28,351,781	$85,656,016	$38,890,867	$152,898,664	$136,218,810	$16,679,854	$156,297
2040	$29,769,370	$89,938,817	$40,835,411	$160,543,597	$145,948,725	$14,594,872	$124,327
2041	$31,257,838	$94,435,757	$42,877,181	$168,570,777	$156,311,084	$12,259,693	$94,941
2042	$32,820,730	$99,157,545	$45,021,040	$176,999,316	$167,344,808	$9,654,508	$67,969
2043	$34,461,767	$104,115,422	$47,272,092	$185,849,281	$179,091,126	$6,758,156	$43,253
2044	$36,184,855	$109,321,194	$49,635,697	$195,141,746	$191,593,714	$3,548,032	$20,643
2045	$37,994,098	$114,787,253	$52,117,482	$204,898,833	$204,898,833	$0	$0
							$65,753,246

Note: Assumes an inflation rate of 5% and a discount rate of 10%.

Water Industry Technical Action Fund

American Water Works Association

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Minimizing Peak Lead Concentrations After Partial Lead Service Replacements

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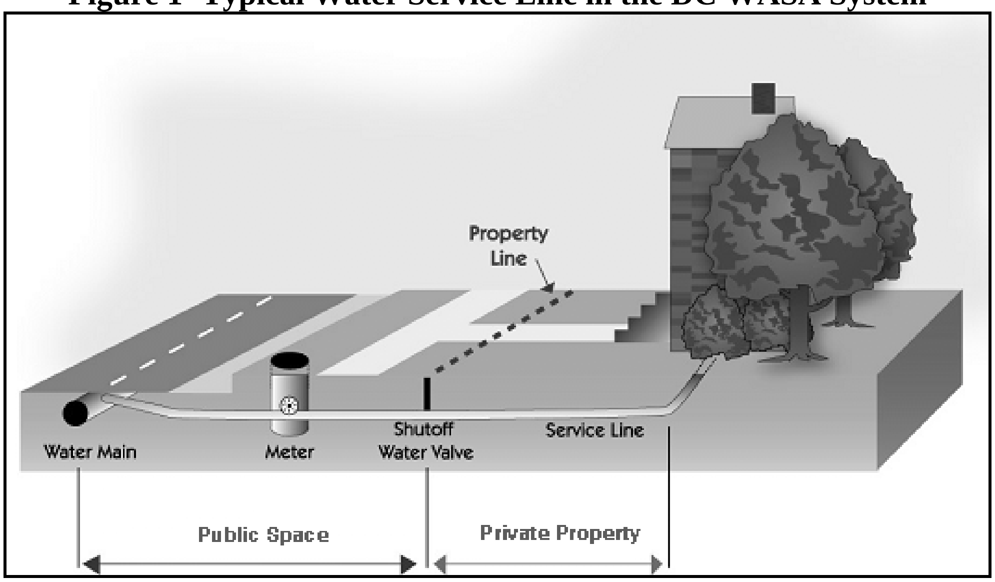
The District of Columbia Water and Sewer Authority (DC WASA) has approximately 130,000 service connections of which approximately 23,000 are reportedly lead service lines. Since 2002, lead sampling and testing conducted as part of the Lead and Copper Rule (LCR) has shown that more than 10% of the residences sampled exceeded the Lead Action Level of 15 ppb. As a result, DC WASA must replace 7% of the lead water service lines in the system every year that the system is not in compliance with the Lead Action Level. The following summarizes DC WASA's lead service replacement program and the steps that were undertaken to minimize lead levels to consumers taps after partial lead service line replacements.

The configuration of a typical DC WASA water service line is shown in Figure 1. The water service line extends from a corporation stop on the water main to the building it serves, and includes a meter located in a small vault in public space and a shut-off valve (curb stop) at the property line.

Figure 1- Typical Water Service Line in the DC WASA System



As shown in Figure 1, a typical water service line includes a public space portion and private property portion. For lead service line replacements, the LCR requires that DC WASA replace the public space portion and offer the property owner to replace the portion of the lead service line on private property at cost. If the property owner elects not to have the portion of the lead service line replaced, and DC WASA replaces all of the lead piping in public space, this is considered a partial lead service replacement. The LCR requires that follow-up sampling be performed for partial lead service replacements.

The sequence of construction for lead service replacement in the DC WASA system is as follows:

- A test pit is performed to field verify the service line material type. Test pits that reveal non-lead service lines are backfilled and the area is restored to pre-existing conditions.
- The area around the corporation stop connection to the water main, meter and property line is excavated to provide access for removal and replacement of the lead piping.
- Lead service lines are replaced with copper piping by either open cut or trenchless methods, i.e. snaking or moling.
- The existing corporation stop, meter box, meter setter and shut-off valve (curb stop) are removed and replaced within public space.
- If the property owner authorizes and pays to replace the portion on private property, the DC WASA contractor replaces the lead service line from the property line to the first fitting inside the building including the installation of a shut-off valve and a pressure reducing valve.
- The new water service line is flushed and put back into service.
- The excavations around the new water service line are backfilled and the area is restored to pre-existing conditions.

As required by the LCR, prior to a partial replacement, DC WASA notifies the resident that a temporary increase in lead levels may be experienced, and to flush the service line before cooking or drinking. In addition to this notification, DC WASA included notifications at least 48 hours before construction as a door hanger and within the sampling kit that was distributed for collecting post replacement lead samples. Sampling kits are delivered to the customer the day a partial replacement is made. The LCR requires that DC WASA sample and test at the customer's tap within 72 hours and report the results of the analysis to the property owner and residents within three business days of receiving the results.

Upon review of partial replacement sampling results, it was identified that some of the customers had very high lead levels (>1000 ppb). The high lead levels may have been a result of insufficient flushing to remove lead particles that are derived from the installation process; or the disturbance/exposure of the "cut" joint where the existing lead service line is "cut" and connected to the new copper piping. Over the past two years DC WASA has developed a "service line profile" procedure to determine the lead concentration of lead along the entire length of the service line. Although profile sampling undertaken by DC WASA of previous partial lead service line replacements indicated that overall lead levels were reduced after replacement (Giani, Edwards et al 2004), in April 2004 the DC Department of Health (DOH) advised DC WASA to conducted further testing to determine the duration of the temporary high lead levels and establish construction practices that would result in lower lead levels following partial replacement.

Subsequently, the following sampling protocol was by developed DC WASA in coordination with the US Environmental Protection Agency (US EPA) and DOH:

- Coordinate with the homeowner to obtain consecutive samples from the kitchen sink after no water usage for at least 6 hours.
- Based upon plug flow through the interior plumbing system and water service, sample at predetermined intervals to obtain: three samples from the internal plumbing; three samples from the water service line; three samples of water from the main passing through the water service; one sample after a three minute flush; and one sample after a ten minute flush.
- The aerator / screen on the kitchen sink outlet was removed prior to performing the sampling.
- Analyze the samples for total lead.

The objective was to sample at multiple addresses before and after a partial lead service replacement to determine: 1) the duration of the temporary high lead levels; and 2) to evaluate various pipe cutting techniques. Three methods of cutting the existing service lines were used: hacksaw, tube cutter, and pipe lathe.

Sampling was conducted before the partial lead service replacement, immediately after cutting and flushing, and regularly for a period of fourteen days after the service lines had been replaced. Sampling was performed by DC WASA staff in cooperation with the homeowner.

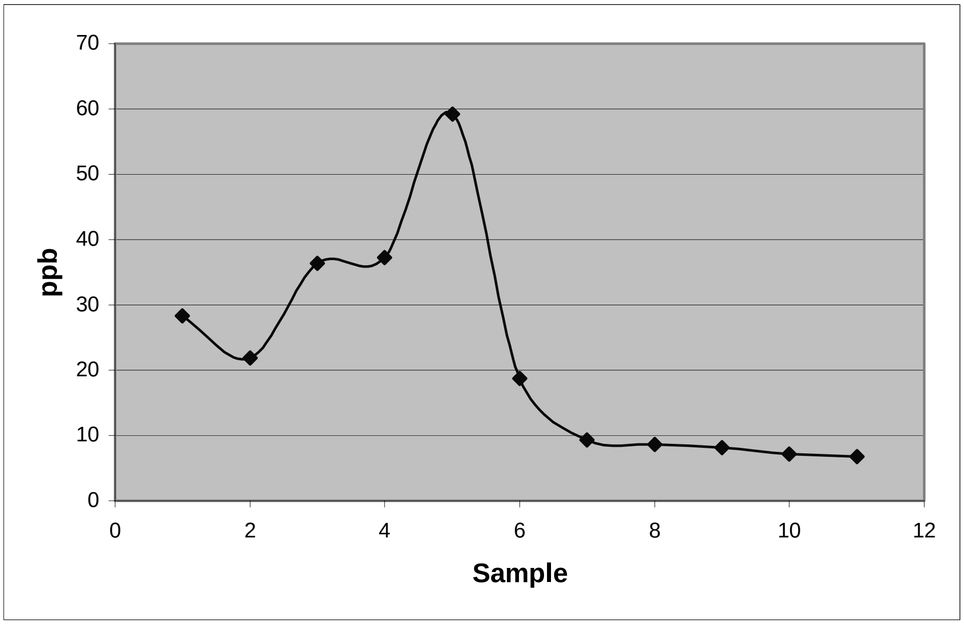
Seven addresses were sampled as part of this program and the breakdown of cutting methods used for the partial replacements were: four addresses with a hacksaw; two addresses with a pipe lathe; and one address with a pipe cutter.

The seven addresses that were selected for this program had very similar building plumbing and water service line configurations. Sampling was performed at the following intervals:

1) 1st liter of water;
2) 2nd liter of water;
3) 4th liter of water;
4) 6th liter of water;
5) 8th liter of water;
6) 11th liter of water;
7) 14th liter of water;
8) 18th liter of water;
9) 22nd liter of water;
10) 3 minute flush; and
11) 10 minute flush.

Eighteen pre partial service replacement sampling profiles at the seven addresses were conducted. The average pre partial lead service line replacement sampling results are shown in Figure 2. In summary the average results are consistently above the Lead Action Level for the samples within the internal plumbing (Samples 1, 2 and 3) and lead water service (Samples 4, 5 and 6). The sample results from the water in the water main passing thru the lead service (Samples 7, 8, 9, 10 and 11) were all below the Lead Action Level.

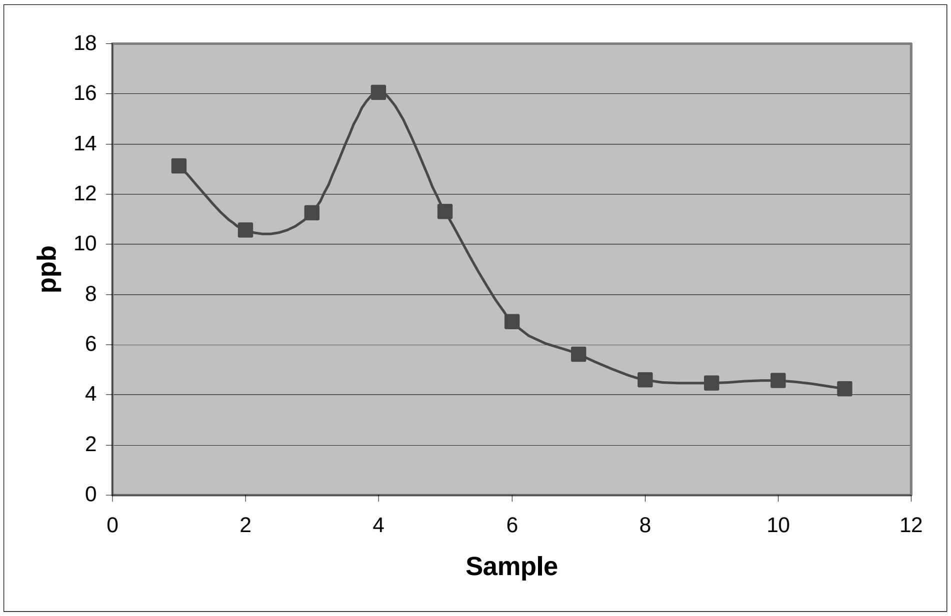
Figure 2 – Pre Partial Replacement Sampling Results



After the pre partial replacement sampling was performed, the DC WASA contractor replaced the lead service line in public space with copper pipe using the cutting methods specified herein. As a result, for each of these addresses, approximately 15 feet of lead service piping remained from the property line to the building face. Immediately following construction, the water service was flushed and the post partial replacement sampling was performed. Forty-five post partial replacement sampling profiles at the seven addresses were performed.

The average post partial lead service line replacement sampling results are shown in Figure 3. In summary the results are consistently below the Lead Action Level for all the samples within the internal plumbing (Samples 1, 2 and 3), copper service line (Samples 5 and 6) and the water from the water main passing thru the lead service Samples 7, 8, 9, 10 and 11). The average results for the water in contact with the partial lead service (Sample 4) were above the Lead Action Level.

Figure 3 – Post Partial Replacement Sampling Results



In comparing the results from the day immediately following construction to each of the sampling dates for fourteen days after construction there were no significant changes in the lead levels observed.

A total of 687 sample results were used to develop 63 profiles, which were included in the analysis. The following two very high 2nd liter sample results from the same address were excluded from the analysis:

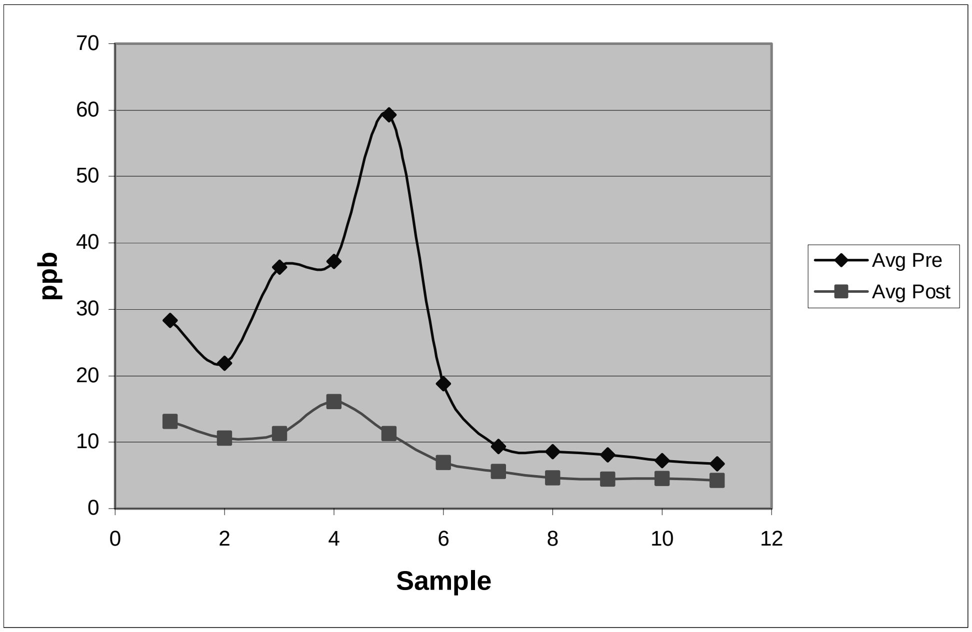
- 15,888 ppb pre partial replacement (all other results were <350ppb); and
- 854 ppb post partial replacement (all other results were <70ppb).

These two very high 2nd liter results may have been from particulate lead dislodged when the aerator was removed and were deleted from the analysis.

Ultimately, the sampling results are a clear indication that flushing immediately following a partial lead service replacement reduces lead levels that may have been a result of construction. The sampling also showed that the disturbance/exposure of the end of the existing lead service line where it is "cut" and connected to new copper piping does not significantly increase lead levels in the delivered water.

Overall, the average results of the pre and post partial replacement sampling performed are shown in Figure 4.

Figure 4 – Pre & Post Partial Replacement Sampling Results



The following flushing requirements were implemented immediately following the replacement of a lead service:

- the contractor flushes the service at an external hose bib of the connected building for at least fifteen (15) minutes; or
- if unable to perform the flushing from the external hose bib, inform the customer of the need for appropriate flushing (generally 15 minutes from a faucet).

Upon analysis of the different cutting methods, there was very little difference in the final lead levels based on the manner in which the pipe was cut. The following summarizes the results of the different types of pipe cutters used:

- Pipe Lathe Pre to Post Sampling Results dropped 71% (see Figure 5)
- Hacksaw Pre and Post Sampling Results dropped 65% (see Figure 6)
- Pipe Cutter Pre and Post Sampling Results dropped 62% (see Figure 7)

Figure 5 – Pre & Post Partial Replacement Sampling Results – Pipe Lathe

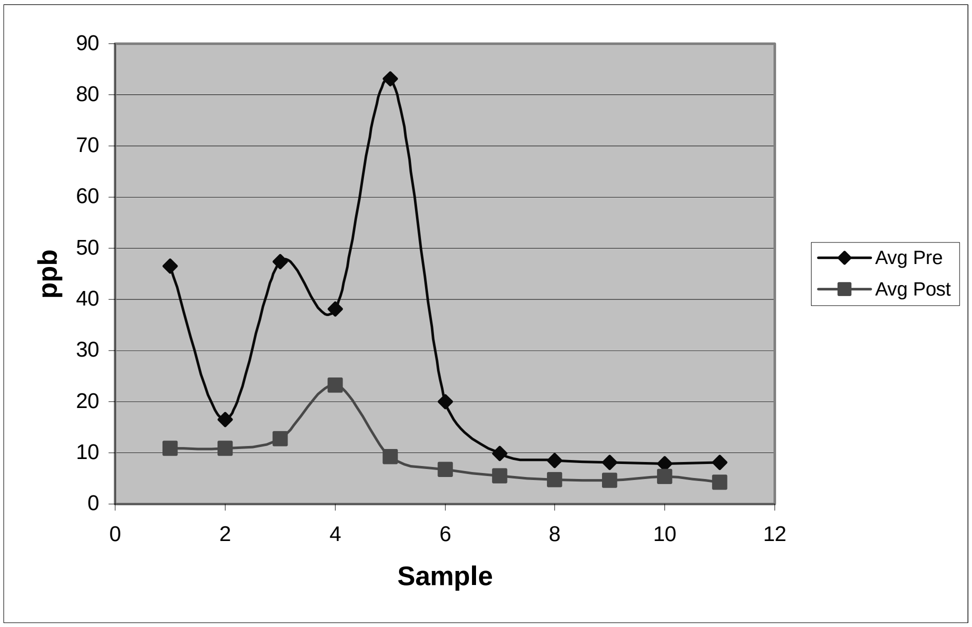


Figure 6 – Pre & Post Partial Replacement Sampling Results – Hacksaw

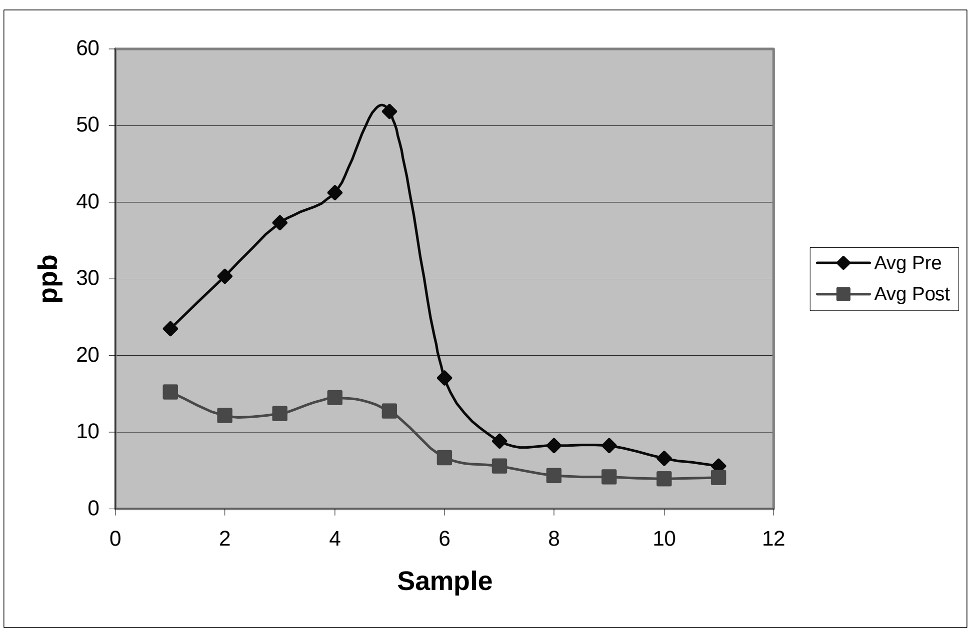
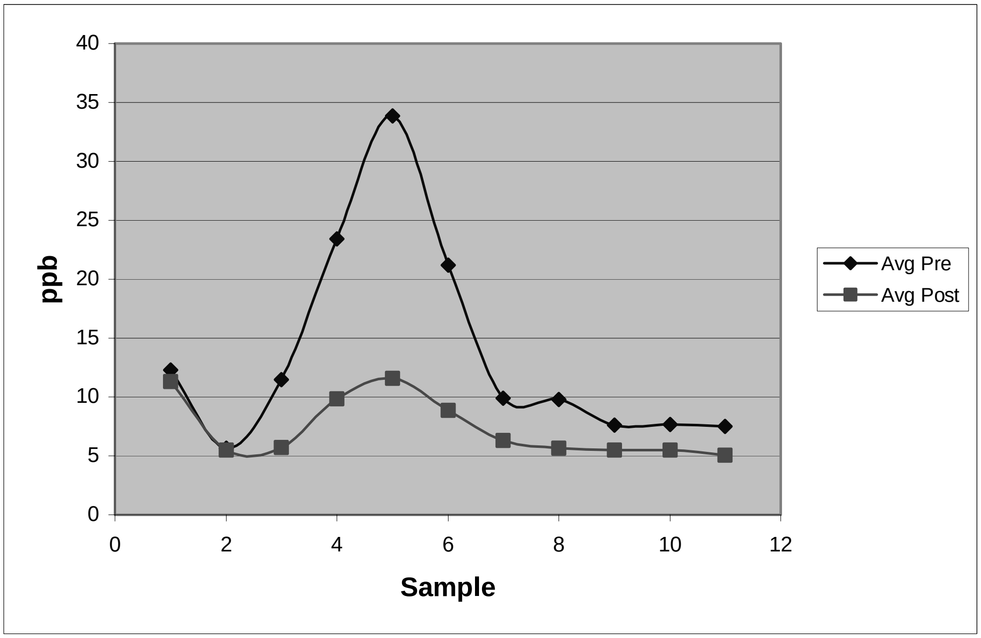


Figure 7 – Pre & Post Partial Replacement Sampling Results – Pipe Cutter



Conclusion

For each cutting method the average results were reduced significantly, which is a clear indication that any of the cutting methods for a partial lead service replacement are effective. However, flushing immediately following a partial lead service replacement may be the most important factor in reducing lead levels immediately following partial replacement.