Ali Sabir

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Government of the District of Columbia
Department of Public Works
Water and Sewer Utility Administration
Washington, D.C.

LEAD IN WATER STUDY

AUGUST 1990

WESTON MANAGERS DESIGNERS/CONSULTANTS® In Association with Delon Hampton and Associates

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LEAD IN WATER STUDY

August 1990

Prepared for:

Government of the District of Columbia
Department of Public Works
Water and Sewer Utility Administration
Washington, D.C.

Prepared by:

Roy F. Weston, P.E., P.C.
955 L'Enfant Plaza, S.W.
Washington, D.C.

in association with

Delon Hampton and Associates
12300 Twin Brook Parkway
Suite 380
Rockville, Maryland

WESTON
MANAGERS DESIGNERS/CONSULTANTS
955 L'ENFANT PLAZA, S.W.
6TH FLOOR
WASHINGTON, D.C 20024
(202) 646-6800

31 August 1990

Mr. William Garlow
Acting Chief, Design and Engineering Division
Water and Sewer Utility Administration
Department of Public Works
The District of Columbia
5000 Overlook Avenue, SW
Washington, DC 20032-5397

Subject: Lead in Water Study

Dear Mr. Garlow:

As per our agreement of March 1989 we submit herewith a final report on the Lead in Water Study for the District of Columbia.

In this study we have identified the probable sources of lead in the drinking water system of the District, the extent of the lead service lines in the District, alternatives for reducing the levels of lead at the customers' water faucets, and financial impacts on the district. A database management system for residential service lines has also been developed. A set of findings and recommendations is included in the report. Information presented in this report will form the basis for developing a lead in drinking water reduction strategy for the District.

We have appreciated the opportunity to work with you, your staff, and the other staff in the District.

Respectfully submitted,

ROY F. WESTON, P.E., P.C.

Arun K. Deb

Arun K. Deb, Ph.D., P.E.
Vice President

enclosures as stated

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TABLE OF CONTENTS

Section	Title	Page
	EXECUTIVE SUMMARY	1
	PROJECT OVERVIEW	4
1	INVESTIGATION OF WATER DISTRIBUTION SYSTEM RECORDS	1-1
	1.1 Introduction and Objectives of the Study	1-1
	1.2 Distribution System Data on Lead Service Lines	1-2
	1.2.1 Tap File	1-5
	1.2.2 Meter File	I-8
	1.2.3 Maintenance File	1-9
	1.2.4 Planning Commission Files	1-10
	1.2.5 Lead Service Replacement Program	1-11
	1.2.6 Meter Replacement Program	1-12
	1.2.7 Street Replacement Program	1-13
	1.2.8 Project Locator Data File	1-16
	1.2.9 Department of Consumer and Regulatory Affairs Permit Ledger	1-23
	1.3 Database QA/QC Program	1-25
	1.4 Use of Lead Material in Plumbing	1-26
	1.4.1 District of Columbia Plumbing Code	1-27
	1.4.1.1 Installation and Permit	1-27
	1.4.1.2 Existing Plumbing Systems	1-27
	1.4.1.3 Alteration and Repair	1-27
	1.4.1.4 Water Service Requirement	1-28
	1.4.1.5 Piping System Materials	1-28
	1.4.2 District of Columbia Plumbing Association and Plumbing Practices	1-28
	1.4.3 Distribution System Maintenance Personnel Interviews	1-32
	1.5 Lead Water Quality Data	1-33
	1.5.1 Department of Consumer and Regulatory Affairs Lead-in-Water Sampling Studies	1-33
	1.5.2 Review of Sampling Collection Protocols	1-35
	1.5.3 Relationships Between Sample Types	1-39
	1.5.4 Relationship of Lead Levels to Treatment Plant Parameters	1-40
	1.6 Service Connection Data	1-43
	1.7 Water Quality Sampling Data	1-43
	1.8 Conclusions and Recommendations	1-46

WESTON

TABLE OF CONTENTS
(continued)

Section	Title	Page
2	**METHODS OF REDUCING THE LEAD CONTENT IN DRINKING WATER**	2-1
	2.1 General Description of Existing System	2-1
	2.1.1 Description of Current Corrosion Control Practices	2-4
	2.1.2 Database of Water Quality Data	2-4
	2.1.3 Langlier Index of Treated Water	2-9
	2.2 Lead in the District's Drinking Water	2-10
	2.2.1 Sources of Lead	2-10
	2.2.1.1 Lead in Source Water	2-12
	2.2.1.2 Lead as a Corrosion By-Product	2-12
	2.2.2 Lead Corrosion Chemistry	2-15
	2.2.3 Existing Lead Levels	2-20
	2.2.3.1 Source Water	2-21
	2.2.3.2 Treatment Plant	2-21
	2.2.3.3 Distribution System	2-21
	2.2.3.4 Customer's Faucet	2-25
	2.2.4 Data Evaluation	2-25
	2.3 Investigation of Alternatives	2-32
	2.3.1 Centralized Treatment Alternatives	2-32
	2.3.2 Point-of-Use Devices	2-34
	2.3.3 Removal of Lead Material	2-34
	2.3.4 Plumbing Code Modifications and Enforcement	2-35
	2.3.5 Public Education	2-35
	2.3.6 Alternative Distribution Techniques	2-36
	2.4 Identification and Evaluation of Specific Alternatives	2-36
	2.4.1 Centralized Treatment Options	2-36
	2.4.1.1 Adjustment of pH and Alkalinity	2-37
	2.4.1.2 Calcium Carbonate Precipitation	2-37
	2.4.1.3 Orthophosphate Addition	2-39
	2.4.1.4 pH and DIC Control with Orthophosphate Addition	2-41
	2.4.2 Point-of-Use Devices	2-45
	2.4.2.1 Reverse Osmosis	2-45
	2.4.2.2 Granular Activated Carbon	2-48
	2.4.2.3 Distillation	2-48

TABLE OF CONTENTS
(continued)

Section	Title	Page
	2.4.3 Removal of Lead Material	2-48
	2.4.3.1 Lead Service Line Replacement (Partial)	2-48
	2.4.3.2 Lead Service Line Replacement (Total)	2-49
	2.4.3.3 Replacement of Lead Soldered Joints	2-49
	2.4.3.4 Replacement of Brass Faucets and Fixtures	2-54
	2.4.4 Plumbing Code Modifications and Enforcement	2-54
	2.4.5 Public Education	2-55
	2.4.6 Alternative Distribution Techniques	2-55
	2.4.6.1 Bottled Water	2-55
	2.4.6.2 Dual Water Distribution System	2-56
	2.5 Conclusions	2-56
	2.6 References	2-57
3	**INVESTIGATION OF GEOPHYSICAL AND REMOTE SENSING TECHNIQUES TO DETECT BURIED LEAD PIPES**	**3-1**
	3.1 Introduction	3-1
	3.1.1 Background	3-1
	3.1.2 Objectives	3-1
	3.1.3 Literature Search and Interviews	3-1
	3.2 Techniques Investigated	3-2
	3.2.1 Ground Penetrating Radar	3-2
	3.2.1.1 Theory	3-2
	3.2.1.2 General Applications	3-5
	3.2.1.3 Limitations	3-5
	3.2.2 Electrical Conductivity	3-5
	3.2.2.1 Theory	3-5
	3.2.2.2 General Applications	3-8
	3.2.2.3 Limitations	3-8
	3.2.3 Metal Detectors	3-8
	3.2.3.1 Theory	3-8
	3.2.3.2 General Applications	3-10
	3.2.3.3 Limitations	3-10
	3.2.4 Resistivity	3-15
	3.2.4.1 Theory	3-15
	3.2.4.2 General Applications	3-15
	3.2.4.3 Limitations	3-17

WESTON.

TABLE OF CONTENTS
(continued)

Section	Title	Page
	3.2.5 Magnetometer	3-17
	3.2.5.1 Theory	3-17
	3.2.5.2 General Applications	3-20
	3.2.5.3 Limitations	3-20
	3.2.6 Fiber-Optic Instruments	3-20
	3.2.6.1 Theory	3-20
	3.2.6.2 General Applications	3-20
	3.2.6.3 Limitations	3-22
	3.3 Conclusions and Recommendations	3-22
	3.3.1 Conclusions	3-22
	3.3.2 Recommendations	3-24
	3.4 References	3-24
4	**METHODOLOGY FOR IDENTIFYING LEAD SERVICE LINES**	**4-1**
	4.1 Introduction and Objectives	4-1
	4.2 Description of the Databases	4-1
	4.2.1 Tap File Database	4-1
	4.2.2 Water Quality Database	4-3
	4.3 Database Analysis	4-5
	4.3.1 Tap File Database	4-5
	4.3.2 Water Quality Database	4-24
	4.4 Service Line Excavation Summary	4-27
	4.5 Predictive Techniques	4-28
	4.5.1 Installation Date	4-32
	4.5.2 Proximity to Known Lead Service Lines	4-33
	4.5.3 Water Quality	4-35
	4.6 Geographic Breakdown of Lead Service Lines	4-40
	4.7 Procedure for Identifying Service Line Material	4-46
	4.8 Summary and Conclusions	4-48
5	**PRIORITIZED LEAD SERVICE REPLACEMENT PROGRAM**	**5-1**
	5.1 Introduction	5-1
	5.2 Methodology	5-2
	5.3 Conclusions and Recommendations	5-4
6	**EVALUATION OF FINANCIAL ALTERNATIVES**	**6-1**
	6.1 Introduction	6-1
	6.2 Financing of Water Service in the District	6-2

WESTON

TABLE OF CONTENTS
(continued)

Section	Title	Page
	6.2.1 Capital Improvements	6-2
	6.2.2 Federal Grants	6-3
	6.2.3 Financing Options	6-3
	6.3 Homeowner Financing Opportunities	6-4
	6.3.1 Costs for Service Line Replacement	6-9
	6.3.2 Replacing Service Lines on Private Property	6-19
	6.4 Recommendations	6-21
7	**WATER QUALITY SAMPLING**	**7-1**
	7.1 Introduction	7-1
	7.2 Purpose	7-1
	7.3 Description of the Detailed Sampling	7-2
	7.4 Description of the Full-Scale Sampling Program	7-4
	7.5 Results	7-8
	7.6 Quality Control	7-8
	7.7 Comparison to Previous Sampling Efforts	7-17
	7.8 Conclusions and Recommendations	7-17
8	**OPTIONS FOR REDUCING EXPOSURE TO LEAD IN DRINKING WATER**	**8-1**
9	**CONCLUSIONS AND RECOMMENDATIONS**	**9-1**

APPENDIX A -- INTERVIEWS OF DISTRIBUTION SYSTEM MAINTENANCE PERSONNEL

APPENDIX B -- MASTER PLUMBER INTERVIEWS

APPENDIX C -- WATER QUALITY DATA

APPENDIX D -- SUMMARY SPREADSHEET OF SERVICE LINE INSTALLATION

APPENDIX E -- LEAD SERVICE REPLACEMENT PROGRAM

APPENDIX F -- WATER SAMPLING INSTRUCTIONS

APPENDIX G -- WATER SAMPLING QUESTIONNAIRE

APPENDIX H -- TAP FILE DATABASE USER'S GUIDE

WESTON

LIST OF TABLES

Table No.	Title	Page
1	Summary of Water Quality Data for Known Service Lines	10
2	Effectiveness and Cost of Various Treatment Options	12
1-1	Distribution System and Water Quality Data Sources	1-3
1-2	Tap File dBASE IV Database Structure	1-6
1-3	Format of Project Locator Data File	1-17
1-4	Format of Account Number Versus Schedule Number Data File	1-22
1-5	Schedule of District of Columbia Approved Water Service Pipe Materials	1-29
1-6	Schedule of District of Columbia Approved Water Distribution Pipe Materials	1-30
1-7	Recommended Lead Monitoring Protocol -- Morning First Draw	1-37
1-8	Recommended Lead Monitoring Protocol -- Fixed First Draw	1-38
1-9	Summary of Service Line Data	1-44
1-10	Summary of New Construction Since 1984	1-45
1-11	Summary of Lead Concentrations for Data Sets 1 and 2	1-49
1-12	Summary of Lead Concentrations for Data Set 3	1-50
2-1	Locations of Lead in Plumbing and Distribution Systems	2-14
2-2	Complexation and Precipitation Reactions	2-17
2-3	Distribution System Lead Concentrations	2-24
2-4	Lead Levels in Homes Served by Lead Service Lines	2-33

LIST OF TABLES
(continued)

Table No.	Title	Page
2-5	Chemical Dosages and Costs for Lead Solubility Control	2-46
2-6	Effectiveness and Cost of Various Treatment Options	2-47
2-7	Cost Estimate for the Existing District of Columbia Lead Service Replacement Program	2-50
3-1	Approximate Conductivities of Different Materials	3-9
3-2	Summary of Discussions with Technical Representatives	3-13
4-1	Structure of the Tap File Database	4-2
4-2	Structure of the Water Quality Database	4-4
4-3	Priorities Among Data Sources	4-7
4-4	Summary of Service Line Installations	4-14
4-5	Summary of Known Lead Service Lines	4-22
4-6	Summary of Water Quality Data for Known Service Lines	4-26
4-7	Excavation Summary	4-29
4-8	Summary of Installation Date/Square Analysis	4-34
4-9	Results of Installation Date/Square Method Applied to Excavation Sites	4-36
4-10	Calibration of Installation Date/Square Method Using Excavation Sites	4-37
4-11	Comparison of Lead Levels with Service Line Material	4-39
4-12	Breakdown of Lead Service Line Replacements	4-41
4-13	Summary of Probable Lead Service Lines Using Equation 4.1	4-42

LIST OF TABLES
(continued)

Table No.	Title	Page
4-14	Breakdown of Probable Lead Service Lines Using the Installation Date/Square Method	4-43
4-15	Breakdown of Remaining Probable Lead Service Lines Using Installation Date and Ward	4-44
4-16	Distribution of Lead Service Lines	4-45
6-1	Summary of Types of Financing Mechanisms	6-5
6-2	Distribution of Household Incomes (1980) Below the Poverty Level (<$5,000)	6-10
6-3	Distribution of Household Incomes (1980) Above the Poverty Level (>$5,000)	6-11
6-4	Five-Year Lead Service Line Replacement Schedule for the Homeowner's Side (Year 1)	6-13
6-5	Five-Year Lead Service Line Replacement Schedule for the Homeowner's Side (Year 2)	6-14
6-6	Five-Year Lead Service Line Replacement Schedule for the Homeowner's Side (Year 3)	6-15
6-7	Five-Year Lead Service Line Replacement Schedule for the Homeowner's Side (Year 4)	6-16
6-8	Five-Year Lead Service Line Replacement Schedule for the Homeowner's Side (Year 5)	6-17
6-9	Summary of Total Costs to Replace Lead Service Connections	6-18
7-1	Detailed Sampling Results	7-3
7-2	Distribution of Homes in the Full-Scale Sampling Program	7-7
7-3	Laboratory Results for the 159 Full-Scale Sampling Homes	7-9
7-4	Summary of Data for Risk Category 1	7-13
7-5	Summary of Data for Risk Category 2	7-14
7-6	Summary of Data for Risk Category 3	7-15

WESTON.

LIST OF TABLES
(continued)

Table No.	Title	Page
7-7	Summary of Data for Risk Category 4	7-16
7-8	Laboratory Results for the QC Samples	7-18
7-9	Lead Concentrations for Previously Sampled Homes	7-19
7-10	Comparison of Results to Previous Sampling Efforts	7-20
8-1	Rating of Techniques to Reduce Lead in Drinking Water	8-2

WESTON.

LIST OF FIGURES

Figure No.	Title	Page
1	Schematic of Interaction of Various Databases	5
2	Distribution of Known Lead Service Lines for the District	7
3	Methodology for Identifying Service Line Material	9
1-1	Schematic of Interaction of Various Databases	1-4
1-2	Sample Meter Relocation Data Collection Form	1-14
1-3	Sample Street Replacement Program Data Form	1-15
1-4	Sample of DCRA Permit Ledger Data	1-24
1-5	Relationship Between Water Temperature and Lead Concentrations	1-42
1-6	Geographic Distribution of Sampling Data	1-48
2-1	Intake and Transmission System Diagram	2-2
2-2	Flow Diagram of the McMillan Treatment Plant	2-3
2-3	Monthly Average pH Values for the Dalecarlia Treatment Plant	2-5
2-4	Monthly Average Alkalinity Values for the Dalecarlia Treatment Plant	2-6
2-5	Monthly Average pH Values for Distribution System Sampling Points	2-7
2-6	Monthly Average Alkalinity Values for Distribution System Sampling Points	2-8
2-7	Variations in the Finished Water Langlier Index	2-11
2-8	Plot of Normalized Lead Concentration as a Function of Stagnation Time for Lead Pipes of Different Diameters	2-19

LIST OF FIGURES
(continued)

Figure No.	Title	Page
2-9	Raw Water Lead Concentrations	2-22
2-10	Treated Water Lead Concentrations	2-23
2-11	Variation in Calculated Lead Solubility	2-26
2-12	Measured Lead Concentration in District Water Mains as a Function of Equilibrium Lead Solubility of Finished Waters	2-28
2-13	Measured Lead Concentrations in First-Draw Samples Collected from Homes Served by Lead Service Lines as a Function of Equilibrium Lead Solubility	2-29
2-14	Measured Lead Concentrations in First-Draw Samples Collected from Homes Served by Nonlead Service Lines as a Function of Equilibrium Lead Solubility	2-30
2-15	Conceptual Decision Tree for the Selection of Treatment Options from Among pH, DIC, and Orthophosphate	2-38
2-16	Effect of Phosphate Concentration on Equilibrium Lead Solubility	2-40
2-17	Caldwell-Lawrence Diagram Depicting the Proposed DIC Removal Softening Treatment Process	2-42
2-18	Deffeyes Diagram Depicting Recarbonation of Softened Waters	2-44
3-1	Schematic Diagram of Ground Penetrating Radar Method	3-3
3-2	Ground Penetrating Radar Data over Trench with Buried Metal	3-4
3-3	Schematic Diagram of an Electrical Conductivity Instrument	3-6
3-4	Typical Electrical Conductivity Profile over a Metal Pipe	3-7

LIST OF FIGURES
(continued)

Figure No.	Title	Page
3-5	Schematic Diagram of a Simple Metal Detector	3-11
3-6	Metal Detector Data over Trench with Buried Drums	3-12
3-7	Schematic Diagram of a Resistivity Instrument	3-16
3-8	Schematic Diagram of a Magnetometer	3-18
3-9	Magnetometer Data over Trench with Buried Metal	3-19
3-10	Schematic Diagram of a Fiberscope	3-21
3-11	Inserting a Fiberscope into a Hydrant	3-23
4-1	Sample of Portion of Summary Spreadsheet of Service Line Installations	4-8
4-2	Distribution of Service Line Installations for the District	4-9
4-3	Distribution of Service Line Installations by Ward (Wards 1 Through 4)	4-10
4-4	Distribution of Service Line Installations by Ward (Wards 5 Through 8)	4-11
4-5	Distribution of Known Service Lines for the District	4-13
4-6	Ratio of Known Lead Service Lines to Known Service Lines for the District	4-15
4-7	Ratio of Known Lead Service Lines to Known Service Lines by Ward (Wards 1 Through 4)	4-16
4-8	Ratio of Known Lead Service Lines to Known Service Lines by Ward (Wards 5 Through 8)	4-17
4-9	Distribution of Known Lead Service Lines for the District	4-19
4-10	Distribution of Known Lead Service Lines by Ward (Wards 1 Through 4)	4-20

LIST OF FIGURES
(continued)

Figure No.	Title	Page
4-11	Distribution of Known Lead Service Lines by Ward (Wards 5 Through 8)	4-21
4-12	Ratio of Unknown Service Lines to Total Service Lines for the District	4-23
4-13	Example of Procedure for Calculating Installation Date/Square Lead Probabilities	4-25
4-14	Plot of Predicted Versus Actual Lead Probabilities	4-38
4-15	Methodology for Identifying Service Line Material	4-47
5-1	Methodology for Prioritizing the Lead Service Replacement Program	5-3
7-1	Schematic of Sampling Protocol	7-5

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Mr. William A. Garlow, Acting Chief, Design and Engineering Division, WASUA, Department of Public Works

Mr. R. Ali Sabir, Project Manager, Design and Engineering Division, WASUA, Department of Public Works

Mr. Kazys A. Vasaitis, Acting Chief, Bureau of Water Services, WASUA, Department of Public Works

Mr. James R. Collier, Chief, Water Hygiene Branch, Department of Consumer and Regulatory Affairs

Mr. Harry Ways, Chief, Washington Aqueduct Division, U.S. Army Corps of Engineers

Mr. Stanley Mithen, Design and Engineering Division, WASUA, Department of Public Works

Mr. Dolat Naik, Design and Engineering Division, WASUA, Department of Public Works

Mr. Curtis Cochrane, Bureau of Water Services, WASUA, Department of Public Works

Mr. George Papadopoulos, Bureau of Water Services, WASUA, Department of Public Works

Mr. George Thomas, III, Utility Controller, WASUA, Department of Public Works

Ms. Castina Kennedy, Chief, Bureau of Water Measurement and Billing, WASUA, Department of Public Works

Ms. Delores J. Andrews, Bureau of Water Measurement and Billing, WASUA, Department of Public Works

Ms. Geraldine Williams, Bureau of Water Measurement and Billing, WASUA, Department of Public Works

PROJECT PARTICIPANTS

Roy F. Weston, P.E., P.C.

Dr. Arun K. Deb, Ph.D., P.E., Project Director
Mr. William G. Richards, P.E., Project Consultant
Mr. Jack T. Urie, P.E., Project Manager
Mr. Frank M. Grablutz, P.E., Project Engineer
Ms. Azucena Cristaldo, Engineer
Ms. Barbara Bruenner, Engineer
Mr. Peter A. Ciotoli, AICP, Senior Policy Analyst
Mr. Sudipto Sarkar, Engineer
Ms. Lisa Harris, Policy Analyst
Ms. Sally Ann Sims, Technical Editor
Ms. Lisa Liberi, Secretarial Support

Delon Hampton and Associates

Mr. Effren Halili, Senior Engineer/Manager
Mr. David Nwabuisi, Project Engineer

Penn State University

Dr. M.M. Ghosh, Ph.D., Consultant
Mr. Christopher Cox, Consultant

EXECUTIVE SUMMARY

INTRODUCTION

It has been demonstrated by research that there are adverse health effects of high lead levels in humans. Lead toxicity can be especially detrimental to infants, children, and pregnant women. One route of intake of lead in the human body is through drinking water. The current U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) for lead is 50 micrograms per liter (ug/L) of drinking water. EPA is now in the process of revising the National Primary Drinking Water Regulations for lead in drinking water. Most of the lead enters into water from the District of Columbia- (District-) and homeowner-owned lead service lines and from lead solders and brass water faucets in house plumbing systems. Recent Federal legislation has banned the use of lead and lead-bearing material for all drinking water plumbing use.

After discovery of elevated lead levels in first flush water samples from some residences in Washington, D.C., the District retained Roy F. Weston, P.E., P.C., in March 1989 to conduct a study to determine the probable sources of lead in the drinking water system, the extent of lead service lines in the District, and alternatives for reducing the levels of lead at customers' water faucets.

PROJECT DESCRIPTION

The District maintains a record of more than 126,000 service line installations dating back to the beginning of this century. This information was converted from its paper format to a computerized database. This allowed for an analysis of the distribution of lead service lines by age and location throughout the District. The analysis showed that lead service line installations peaked during the late 1920s and early 1930s, then dropped off almost entirely. The use of lead service lines jumped again during the period of World War II when materials such as copper were in short supply.

In many cases, however, the service line material was not indicated in the records. Thus, a methodology was developed to predict whether a particular address possessed a lead service line based upon the location of the address and the year in which the service line was installed. Using this methodology there are approximately 28,000 actual and probable lead service lines remaining in the District.

The U.S. Army Corps of Engineers is responsible for providing treated drinking water to the District. The District maintains responsibility for distributing the water to homeowners. Water quality sampling in the distribution system for lead and other water quality parameters is performed regularly by the Corps of Engineers. Both the raw (untreated) water and the treated water contain very low levels of lead, typically less than 5 ug/L or 5 parts per billion. Specific water quality characteristics (chiefly pH, temperature, and alkalinity), as well as the age and condition of the service line, will govern whether lead will leach from the lead service line. An analysis of water quality data indicated that the water supply in the District is mildly corrosive.

Water quality samples also were taken from the kitchen faucets of more than 2,400 homes by the District and the consultant as a part of this study. The results of these analyses indicate that lead concentrations at the faucet are not always attributable to the presence of lead service lines. The factors contributing to high lead concentrations at the customer's faucet are:

- Lead leaching from brass faucets.
- Lead-based solders.
- District- and homeowner-owned lead service lines and connections.

The following steps are suggested to reduce the amount of lead ingested from water at the homeowner's faucet:

- Provide public education to consumers on simple ways to reduce lead intake through drinking water. These include using only the cold water faucet for cooking and drinking purposes, and flushing of water from the faucet prior to use.
- Continue to replace lead service lines throughout the District. The highest priority should be given to replacing those lead service lines that have been shown through water quality sampling to cause high lead levels at the faucet.
- Encourage homeowners to replace their portion of the lead service line.
- Modify the treatment process at the water treatment plants to reduce the corrosiveness of the water and thus reduce the amount of lead that leaches into the water from household plumbing systems.

FINDINGS

The following are the important findings in this study:

- The sources of lead in customers' water are brass faucets, lead-based solders, and District- and homeowner-owned lead service lines and connections.
- Potable water in the District is mildly corrosive.

- At present there are 8,271 Known Lead Service Lines and approximately 19,890 Probable Lead Service Lines in the District's water distribution system.

- Lead concentrations in water in the distribution system are typically less than 5 ug/L.

- Approximately 2,900 houses with Known Lead Service Lines or Probable Lead Service Lines have been identified to have lead concentrations of more than 20 ug/L.

RECOMMENDATIONS

The following recommendations are made:

- A public education program as outlined in the report should be developed to alert homeowners to the possible effects of lead ingestion in general, and to instruct them in specific ways to reduce their exposure. A comprehensive program addressing both lead paint and lead in drinking water would be more effective than approaching each issue individually.

- The District should continue to replace its portion of lead service lines, while encouraging homeowners to replace theirs as well.

- The replacement priority developed in this study should be followed, and the lead service lines at addresses in Replacement Categories 4 and 3 (a total of 2,898 service lines of high priority) should be replaced over a 2-year time frame at an estimated cost of $8,375,220.

- The District should conduct additional water sampling of water at the faucets in homes identified as having lead service lines to identify those lead service lines that are contributing to high lead levels at the faucet. This will provide a means to prioritize lead service line replacements after completing replacements of service lines in Replacement Categories 4 and 3.

- Additional sampling data and lead in blood data should be integrated into the database management system and used to revise the lead service line replacement priority developed in this study.

- Treatment processes at the water treatment plants should be modified to increase the pH of water above 8.0.

- The District should consider appropriate legislation requiring total lead service line replacement by homeowners as part of all real estate transfers.

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PROJECT OVERVIEW

INTRODUCTION

It has been demonstrated by research that there are adverse health effects of high lead levels in humans. Lead toxicity can be especially detrimental to infants, children, and pregnant women. One route of intake of lead in the human body is through drinking water. The current maximum contaminant level (MCL) for lead is 50 micrograms per liter (ug/L) of drinking water. The U.S. Environmental Protection Agency (EPA) is in the process of revising National Primary Drinking Water Regulations for lead in drinking water. Most of the lead enters into water from lead service lines and from lead solders and brass fixtures in house plumbing systems. Recent Federal legislation has banned the use of lead and lead-bearing material for all drinking water plumbing use.

The District of Columbia (District) has a considerable number of lead service lines. After discovery of elevated lead levels in first flush water samples from some residences in Washington, D.C., the Director of the District's Department of Public Works, John E. Touchstone, putting the city in the vanguard of cities addressing lead in water problems, directed Roy F. Weston, P.E., P.C., in March 1989 to conduct an extensive study to determine the probable sources of lead in the drinking water system, the extent of lead service lines in the District, and alternatives for reducing the levels of lead at the customers' taps.

DATABASE MANAGEMENT SYSTEM

The District does not have a complete record of the materials of service lines. In order to determine the extent of lead service lines, a database was compiled from several sources within the District containing information on service line material, date of installation, and water quality measurements by address. The database was set up on IBM-compatible personal computers using dBASE IV software. Data were obtained from the following data files and combined into a single database from which an estimate of the distribution of lead service lines was obtained:

- Tap File
- Meter File
- Maintenance File
- Planning Commission File
- Lead Service Replacement Program File
- Meter Relocation Program File
- Street Replacement Program File
- Project Locator Data File
- Permit Ledger Program File
- Corps of Engineers File

The Tap File, considered as the primary data for all water service lines in the District, was used in interaction with other data files. Figure 1 shows the schematic interaction of various data

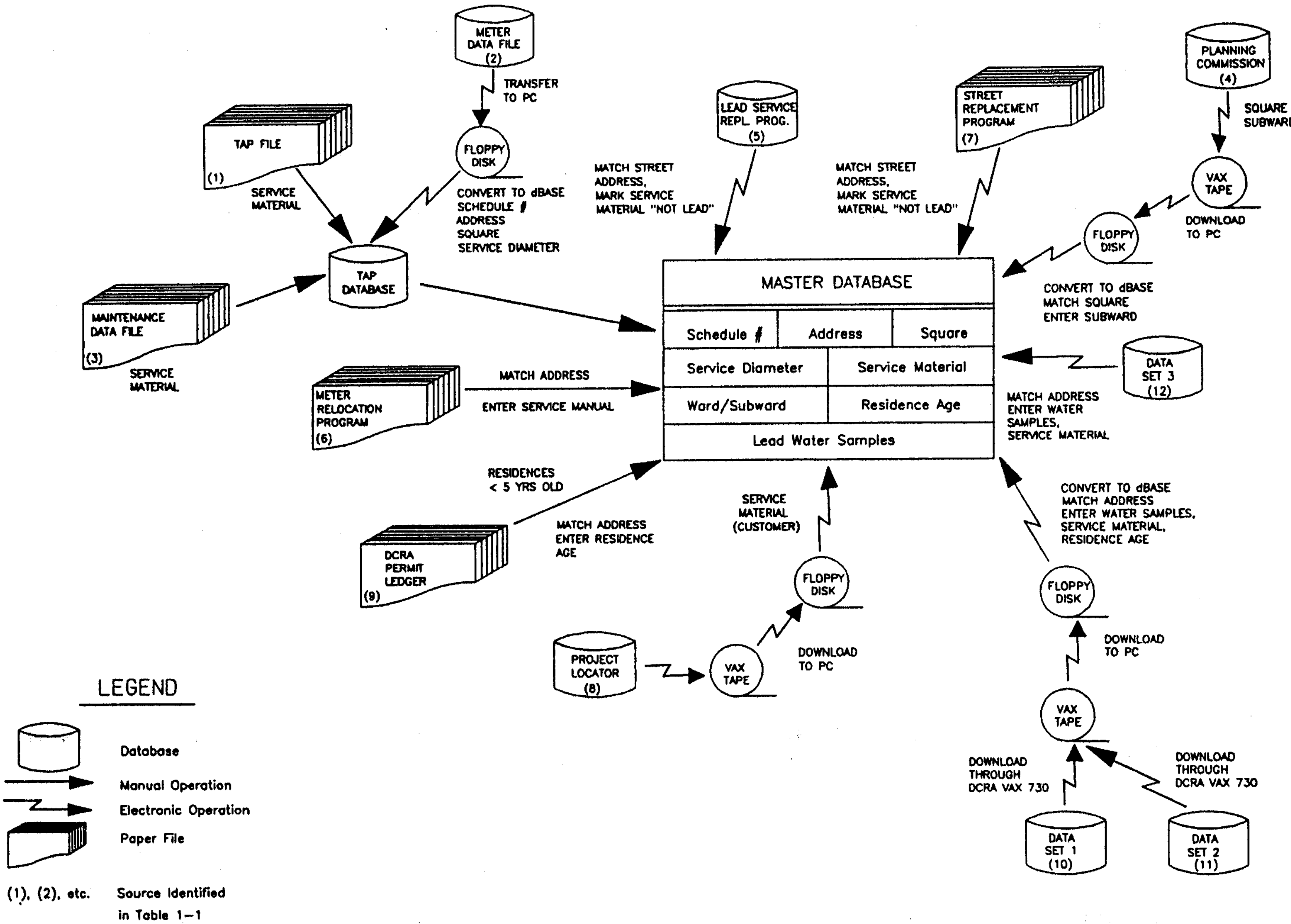


FIGURE 1 SCHEMATIC OF INTERACTION OF VARIOUS DATABASES

files with the Tap File. This database compiled records of 126,099 residential service lines in the District. Out of the 126,099 service lines, the service line material was identified for 81,356 connections, with known lead services lines for 8,987 service connections. This database was used to examine the history of lead service line installations in the District. The majority of early lead service line installations were done prior to 1911, and during the 1920s and early 1930s. Lead usage then dropped off to a fairly insignificant amount in the mid-1930s, then peaked again for about 5 years during World War II.

In order to gain information on the past practice of installation of lead service lines in the District, some members of the Association of Plumbing, Heating, and Cooling Contractors were interviewed. Their records did not indicate any significant installation of new lead service lines since late 1940s. Figure 2 shows the distribution of installation of known lead service lines in the District. This figure also confirms that there was no significant installation of lead service lines after 1946.

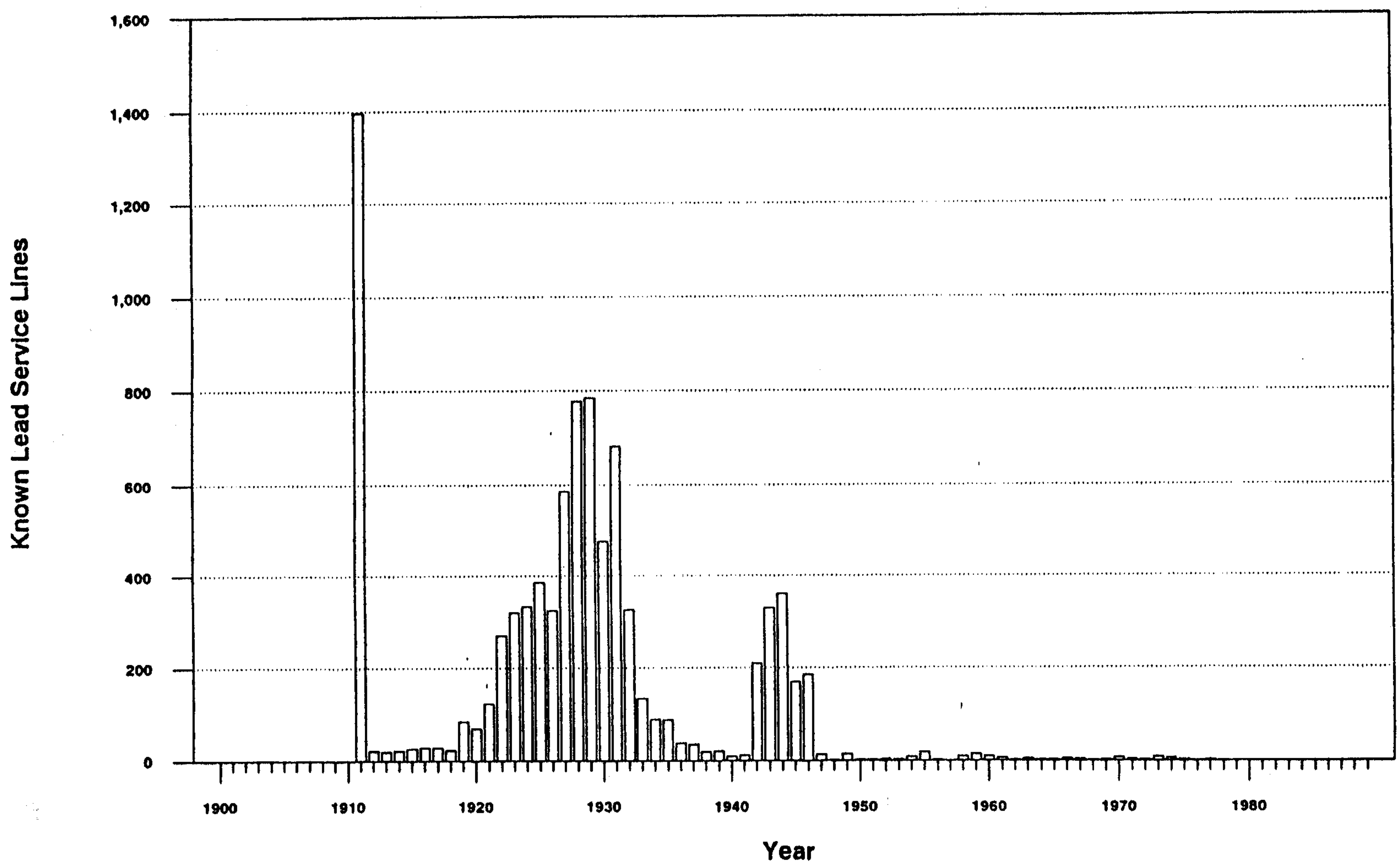
The final Tap File Database was shown to have a variety of uses within the District. Simple data retrieval and analysis programs were developed, and District personnel were trained in their use. Possible future uses of the database were outlined, with further development to occur once the specific uses of the database are determined.

METHODOLOGY FOR IDENTIFYING LEAD SERVICE LINES

There are 44,734 service lines in the District with no recorded line materials. In order to estimate the number of lead service lines among the unknown material service lines, a methodology was developed. The databases developed were used extensively in this methodology to determine the number and distribution of lead service lines in the District.

The basic premise of this technique is that a house located near another house that has a lead service line is also likely to have a lead service line, provided that the service lines were installed at the same time. To analyze the records in the database, houses were considered to be in "proximity" if they were located in the same square. To ensure that these houses all had service lines installed at approximately the same time, the installation date for each was also considered.

The 81,356 records with known service line materials were examined to develop installation date/square combination lead probabilities. The resulting 24,892 combinations were then applied to the 44,734 records with unknown service lines. This was done by examining each of the addresses with an unknown service line, taking the installation date and square for this address, and searching the 24,892 installation date/square combinations for a match. The corresponding lead probability was then assigned to the address with the unknown service line.



Service line installations indicated for 1911
include years up to and including 1911.

FIGURE 2 DISTRIBUTION OF KNOWN LEAD SERVICE LINES FOR THE DISTRICT

An excavation program to excavate test pits at 120 addresses with unknown service line materials was conducted to have their service line material identified. The results of the excavation program were used to calibrate the installation date/square methodology for predicting service line material.

Using this methodology and extrapolation of ratios of known lead service lines with unknown service lines, an estimate of 28,161 possible lead service lines in the District was obtained.

PROCEDURE FOR IDENTIFYING SERVICE LINE MATERIAL

Having examined the various data sources available to the District, it is now possible to outline a procedure for identifying residential homes that have a high probability of possessing a lead service line. A flow diagram of this methodology is given in Figure 3.

WATER QUALITY

The water supply for the District comes from two water treatment plants: the Delcarlia treatment plant and the McMillan treatment plant. Both the plants are operated and maintained by the U.S. Army Corps of Engineers. Corrosion control is practiced at both treatment plants in the form of lime addition. Monthly average values of pH in the water in the distribution system vary from 7.6 during the summer to 8.0 during the spring. Calculated lead solubilities of the treated water of the District range from 0.14 to 0.36 mg/L. Lead solubility is generally high from August to December relative to that from January to July.

Most of the lead in the District's drinking water comes from lead service lines, lead solders, and brass fixtures at the tap. Lead service lines are the joint responsibility of the District and the homeowner. Concentrations of lead in water taken from home faucets are much higher than concentrations in the distribution system. Lead from the plumbing system leaches into water and tends to reach saturated solubility when it remains stagnant in the home plumbing systems between periods of use. However, lead levels found in water taken from home faucets are much lower than those predicted by solubility model analysis.

SAMPLING

The District conducted a preliminary sampling program to evaluate lead in drinking water in the District during 1986 and 1987. Three separate first flush samples (Samples A, B, and C) were collected. Sample A was taken as the first water out of the kitchen tap in the morning, representing lead contribution from lead solder and brass fixtures; Sample B was taken after running the water for 1 minute, representing lead contribution from service lines; and Sample C was taken after running the water for 15 minutes, representing lead contribution from street water mains. The results of known service line addresses have been segregated into known lead and known nonlead service addresses and are shown in Table 1. Averages of

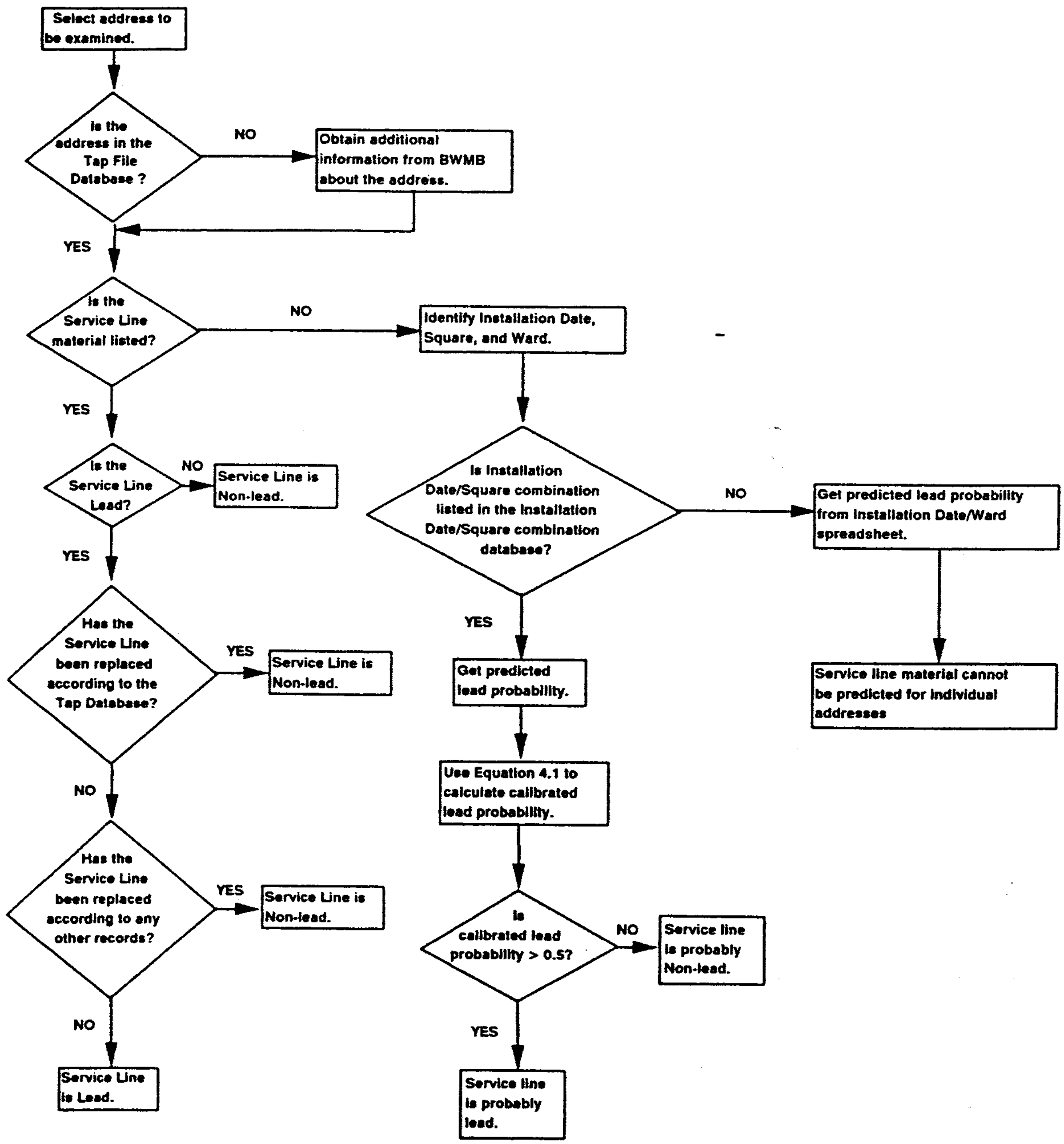


FIGURE 3 METHODOLOGY FOR IDENTIFYING SERVICE LINE MATERIAL

Table 1

Summary of Water Quality Data for Known Service Lines[1]

	Sample A		Sample B		Sample C	
	Known Lead	Known Nonlead	Known Lead	Known Nonlead	Known Lead	Known Nonlead
Avg[2]	20.00	10.75	19.56	8.21	2.00	1.61
Min	<2	<2	<2	<2	<2	<2
Max	390	558	134	308	53	47

[1]All results are in ug/L.
[2]Average values calculated using a value of 1 ug/L for all samples less than the detection limit of 2 ug/L.

Sample A and Sample B of known lead service line houses are significantly higher than the corresponding averages of nonlead service line houses. The average of Sample C is, however, in the same range in both lead service line and nonlead service line houses.

In this study, a separate sampling program was carried out to conduct sampling in 163 homes. Four samples were collected from each home early in the morning before any water was used. Samples were planned to represent lead contributions from faucets, from house plumbing solder, from lead service lines, and from distribution mains. To account for the age of the plumbing and service line material, homes were also assigned to four categories: new homes; homes 2 to 5 years of age; homes more than 5 years old with nonlead service lines; and homes more than 5 years old with lead service lines.

The results indicate that new home (age 0 to 2 years) plumbing systems are reasonably lead-free. Out of 14 homes, 3 homes showed high lead levels in the first sample, indicating the use of brass fixtures or lead solder. Samples from homes in age group 2 to 5 years showed high lead concentrations in the first flush samples, indicating lead contribution from brass fixtures or lead solder. Homes more than 5 years old with nonlead service lines showed lower lead concentrations in the first flush water samples than samples from homes with lead service lines.

ANALYSIS

It was desired to obtain a relationship between the calculated lead solubility and observed lead concentrations in homes served by lead service lines and homes served by nonlead service lines. A regression of the natural logarithms of the observed lead concentrations and corresponding equilibrium lead concentration values was developed. An analysis of 95-percent prediction of observed lead concentrations with equilibrium lead concentrations was performed, and 95-percent concentration levels were found to be about 36 percent of equilibrium lead concentration levels.

TREATMENT ALTERNATIVES

Adjustment of water chemistry at the treatment plant can potentially reduce lead equilibrium solubility of water.

Four treatment options were considered for lowering distribution system lead concentrations: (1) adjustment of pH and alkalinity to greater than 8.0 and 30 mg/L as $CaCO_3$, respectively; (2) precipitation of a protective $CaCO_3$ film; (3) orthophosphate addition alone; and (4) control of pH and alkalinity in conjunction with orthophosphate addition.

The aforementioned alternative treatment options were analyzed, and mean lead levels, 95-percent lead levels, and costs for various options are given in Table 2.

Table 2

Effectiveness and Cost of Various Treatment Options

Treatment Option	Mean Level Level (ug/L)	95% Lead Level (ug/L)	Capital Cost (millions of dollars)	Chemical Cost ($/MG)
1. pH and alk. control	10	55	---	1.00
2. Protective $CaCO_3$	10	55	---	1.00
3. Phosphate addn.	4	29	2	6.30
4. pH and alk. control	3	10	*	78.07

*Not available

As shown in Table 2, Options 1 and 2 can be achieved with minimum cost. However, using these options, it may not be possible to reduce the 95-percent lead level below 55 ug/L. Option 3 can reduce the 95-percent lead level below 29 ug/L. Option 4 will reduce the 95-percent lead level to 10 ug/L. However, sludge handling and disposal costs for this option will be particularly high. Due to anticipated variability of sludge management options, the capital cost for treatment options was not estimated.

FINANCING ALTERNATIVES

The cost of financing of replacement of the District's portion of lead service lines is expected to range between $70 and $80 million. The options available to the District are either to finance through its operating budget (within 20 years) or to finance as part of the District's Capital Improvement Program (within 5 years). An evaluation of the adequacy of the District's current water rate structure and user fee system need to be accomplished to determine the most cost-effective plan of action for the financing.

Financing for replacement of the homeowner's portion of lead service lines also was analyzed. The Community Development Block Grant Program is one potential source of homeowner financial assistance. The other option that was analyzed was a District-appropriated direct grant for low-income homeowners. This option will cost about $9 million to the District for grants to homeowners whose income places them below the poverty level. The District has the option of financing either through the District's Capital Improvement Program, or through its operations and maintenance budget. The determination of the precise financing mechanism to be used is a function of the degree to which the District wishes to or can afford to assist homeowners.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made about lead in drinking water in the District:

- A large amount of service line data is available to the District from a variety of sources. However, the data sources are scattered among a number of agencies and/or departments. Individual agencies/departments often are not aware of the information available from other sources.

- No proven technology is currently on the market that could be used to identify a lead service line without physical inspection.

- Lead concentrations in the raw water supply of the District and in water in the distribution system are typically <5 ug/L.

- High concentrations of lead in tap water may result from corrosion of lead in brass fixtures, lead-bearing solder, or the District- or homeowner-owned lead service lines.

- The presence of a lead service line did not always indicate elevated lead levels in water at the tap.

- There are approximately 28,000 lead service lines remaining in service in the District.

Based on these conclusions, a number of recommendations can be made to deal with the issue of lead in drinking water. Many of these recommendations are general in nature and should be acted on regardless of the content of the final EPA lead regulations. Those recommendations dealing with the District's specific actions to meet EPA guidelines may need to be modified depending on the final content of the regulations. The recommendations are as follows:

- The Tap File Database should be installed on a computer(s) and used by District personnel to assist in the Lead Service Replacement Program.

- Data from the Meter Relocation Program, Street Replacement Program, and Lead Service Replacement Program should be used to keep the Tap File Database current.

- A public education program should be instituted to teach customers how to reduce their exposure to lead in drinking water.

- Treatment processes at the water treatment plants should be modified to increase the pH of water above 8.0, and water quality samples should be taken at homes that had high lead levels (as identified by previous sampling studies) to determine the effectiveness of pH adjustment.

- If pH adjustment proves ineffective in reducing lead levels at the tap, orthophosphate addition at the water treatment plants to reduce the solubility of lead in water in the distribution system should be considered.

- Homeowners willing to participate in an ongoing water quality sampling program should be located. These homes would then be used for long-term monitoring to assess the effects of the different lead reduction strategies implemented at the water treatment plants, as well as for compliance monitoring for the EPA lead rule.

SECTION 1

INVESTIGATION OF WATER DISTRIBUTION SYSTEM RECORDS

1.1 INTRODUCTION AND OBJECTIVES OF THE STUDY

It has been demonstrated by research that there are adverse health effects of high lead levels in humans. Lead toxicity can be especially detrimental to infants, children, and pregnant women. One route of intake of lead in the human body is through drinking water. The current maximum contaminant level (MCL) for lead is 50 micrograms per liter (ug/L) of drinking water. In 1988, the U.S. Environmental Protection Agency (EPA) proposed a modification of Primary Drinking Water Regulations for lead. This draft modification has a two-part regulation consisting of an MCL of 5 ug/L for lead at the water distribution source and a requirement for water in the distribution system to have a pH of at least 8.0 and carbonate alkalinity of 30 mg/L or more. EPA is now in the process of finalizing National Primary Drinking Water Regulations for lead in drinking water. Most of the lead enters into water from lead service lines and from lead solders and brass fixtures in house plumbing systems. Recent Federal legislation has banned the use of lead and lead-bearing material for all drinking water plumbing use.

The District of Columbia (District) has a considerable number of lead service lines. After discovery of elevated lead levels in first flush water samples from some residences in Washington, D.C., the District contracted Roy F. Weston, P.E., P.C., in March 1989 to conduct this study. The main objectives of this study are to determine the probable sources of lead in the drinking water system, the extent of lead service lines in the District, and alternatives for reducing the levels of lead at the customers' faucets.

The remainder of this section describes the data collection and database development that served as the foundation of the study. Section 2 presents a discussion of the sources of lead in water in general, a detailed analysis of the lead chemistry of the District's water, and various methods of reducing consumers' lead intake through drinking water. Sections 3 and 4 focus on identifying lead service lines in the District. Section 3 describes state-of-the-art remote sensing equipment that was examined for its applicability in locating lead service lines. Section 4 presents the methodology that was used to estimate the number and location of lead service lines throughout the District. A prioritized lead service line replacement program is presented in Section 5, with the financial implications of such a program described in Section 6. The water quality sampling done as part of this study is described in Section 7. Section 8 presents three strategies for dealing with lead in drinking water. Finally, Section 9 lists several conclusions and recommendations drawn from the study.

The remainder of Section 1 is described as follows. Subsection 1.2, Distribution System Data on Lead Service Lines, lists the various sources of data that were combined to create a database from which an initial estimate of the distribution of lead service lines was obtained. Subsection 1.3, Database QA/QC Program, describes the rigorous program that was followed to minimize the number of transcription errors for the database. Subsection 1.4, Use of Lead Material in Plumbing, contains the results of the investigations into the plumbing codes and summarizes the interviews that were conducted with area plumbers and District employees. Subsection 1.5, Lead Water Quality Data, describes the work that was performed for the collection of water treatment plant data and the analysis of sampling program data. This subsection also contains the analysis of the sampling procedures and protocols that have been followed in the past by District agencies, as well as an analysis of the relationship of distribution system lead levels to the water treatment plant parameters. Subsection 1.6, Service Connection Data, presents the initial distribution of the lead service line data collected, and the distribution of the newer residences that could be at risk for lead solder leaching into the drinking water. Subsection 1.7, Water Quality Sampling Data, presents the distribution and statistics for all residences that have been sampled and tested for lead in drinking water.

1.2 DISTRIBUTION SYSTEM DATA ON LEAD SERVICE LINES

This subsection describes the various data files and sources of distribution system data that were investigated. The following data files were analyzed to obtain information regarding location of lead service lines in the District:

- Tap File
- Meter File
- Maintenance File
- Planning Commission File
- Lead Service Replacement Program File
- Meter Relocation Program File
- Street Replacement Program File
- Project Locator Data File
- Permit Ledger Program File
- Corps of Engineers File

Table 1-1 lists each data source, its location, the form in which the data were found, and the purpose for which the data were used. The Tap File, considered as the primary data file for all water service lines in the District, was used in interaction with other data files. Figure 1-1 shows the schematic interaction of various data files with the Tap File.

Table 1-1

Distribution System and Water Quality Data Sources

Source No.	Name	Source Location	Data Form	Purpose
1.	Tap File	Bureau of Water Measurement and Billing	Index Cards	Obtain Tap Information Starting Tap Numbers 67000 Through 188000
2.	Meter Data File	Information Systems	ASCII Files	Obtain Tap Information of First 67,000 Taps
3.	Maintenance Data File	Bureau of Water Measurement and Billing	Index Cards	Lead Service Line Determination
4.	Planning Commission Data File	D.C. Planning Commission	ASCII File	Match Wards to Square
5.	Lead Service Replacement Program Data File	Bureau of Water Measurement and Billing	dBase File	Obtain Additional Lead Service Line Information
6.	Meter Relocation Program Data	Bureau of Water Measurement and Billing	Paper	Obtain Additional Lead Service Line Information
7.	Street Replacement Program Data	Water and Sewer Utility Administration Office	Paper	Obtain Additional Lead Service Line Information
8.	Project Locator Data File	Information Systems	ASCII File	Obtain Additional Lead Service Line Information
9.	DCRA Permit Ledger Data	DCRA Permit Office	Paper	Obtain Housing Data Less Than 5 Years Old
10.	Data Set 1	DCRA	DecMate	Lead in Drinking Water Data
11.	Data Set 2	DCRA	DecMate	Lead in Drinking Water Data
12.	Data Set 3	DCRA	dBASE File	Lead in Drinking Water Data

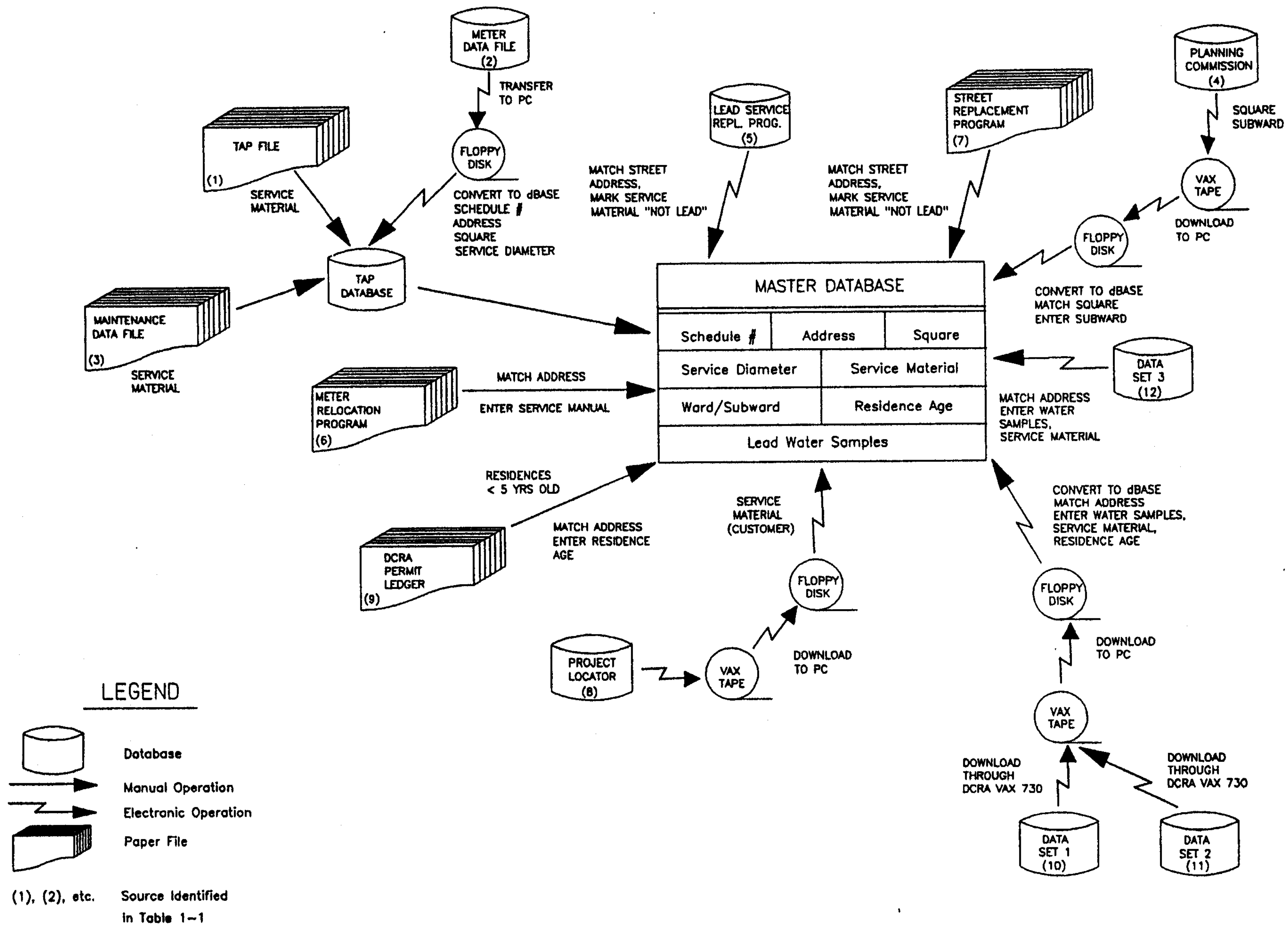


FIGURE 1-1 SCHEMATIC OF INTERACTION OF VARIOUS DATABASES

1.2.1 Tap File

The major source of information for lead service lines was the Tap File, which is a collection of index cards stored in the Bureau of Water Measurement and Billing (BWMB) offices at the Bryant Street Pumping Station. The database created from the Tap File records formed the base with which all of the other information sources were interacted.

This file contains cards that are submitted every time a water main is tapped for a new water service connection. All residential taps are recorded in this file, ordered by schedule number, which is a sequential, unique number assigned to every tap. Approximately 188,000 schedule numbers have been issued by the District.

The data collection effort began on 18 April 1989. Three data entry personnel obtained the information that was to be entered into the database from each index card. The tap cards typically contained the following information:

- Schedule number.
- Address.
- Square.
- Lot.
- Date of connection.
- Property owner and plumber names.
- Size of service line.
- Location of curb-cock.
- Location and size of main.

A database was set up on IBM-compatible personal computers using dBASE IV software. Table 1-2 shows the composition of the Tap File Database record.

Several data handling problems were encountered during the data entry effort:

- The first 67,000 tap records were no longer in the Tap File. According to BWMB employees, these records were taken from the file several years earlier and merged into the adjacent Maintenance File in an attempt to organize all of the data under one filing system. The Maintenance File (see Subsection 1.2.3) is organized alphabetically by street and by house number within a street as opposed to the Tap File's ascending schedule number order. The missing Tap File cards were, therefore, scattered throughout the much larger Maintenance File, effectively out of reach of the data entry staff. A database supplied by the Information Systems group of BWMB (see Subsection 1.2.2) supplied the schedule number, address, and square information for the missing tap records; the remaining information was gathered by the data entry staff through the Maintenance File, as described in Subsection 1.2.3.

Table 1-2

Tap File dBASE IV
Database Structure

Field Name	Field Width	Data from Tap File Card
SCHEDNUM	6	Schedule Number
DATE	4	Year of Tap
ADDNUM	5	House Number
STRADDR	50	Street Name
QUADRANT	2	Quadrant
PIPESIZE	5	Diameter of Service Line (in.)
PIPEMATL	1	Service Line Material
ABAN-REPL	1	Abandoned/Replacement Service Line
SQUARE	6	Square
WARD	2	Ward (not obtained from Tap File)
Lead Service Replacement Cost	8	Future use
Replacement Priority	3	Future use
Date of Replacement by the District	10	Future use
Date of Replacement by Owner	10	Future use

- The newest residential taps were also not recorded in the Tap File, but for a different reason. BWMB employees stated that the newer taps are recorded directly onto the computer. Therefore, all taps recorded since 1984 were not available for entry from the Tap File.

- A significant number of tap records either did not contain all of the needed information or had confusing information. The most persistent problem was when the original schedule number was crossed out and replaced with a different number. BWMB staff could not always explain the reason for the change. It was decided to let the original schedule number stand unless the index card was moved to the location in the Tap File that corresponded to the new number.

  Missing information included, at one time or another, any of the first nine fields listed in Table 1-2 except for the schedule number. Two of the most consistently missing pieces of information were the line material and square fields. Both fields are extremely important; the presence of the former field, especially if the service line is lead, provides confirmation of the service line and can provide some insight into the service line material for surrounding properties. The latter field is needed to determine in which of the eight wards the property is located.

- Although not unexpected, the condition of many of the index cards had deteriorated to the point where they were illegible. This had the combined effect of slowing the data entry effort and increasing the potential for typing errors. A QA program was designed to minimize the number of obvious errors in the data.

Tap File data entry was completed during the week of 12 June 1989. The database contained approximately 106,000 records, which represented all records available in the Tap File. Since the Tap File contained schedule numbers 67000 through 188000, so that the expected maximum number of records 121,000, this implies that only 12 percent of the original service lines have been abandoned (and the corresponding tap cards removed from the file). Subsection 1.3.1 contains a more thorough analysis of the database.

The Tap File Database was not complete at this point. Additional work was performed to obtain the data from the missing 67,000 tap records. In addition, each address in the file was assigned to its appropriate ward.

1.2.2 Meter File

As stated in the previous subsection, the Tap File did not contain the cards for the first 67,000 taps. Obtaining this information was imperative because these locations are the oldest in the District (pre-1915) and are the most likely to have had originally installed lead service lines. The BWMB Meter File contains information used for billing and customer service purposes. Upon reviewing this information, it was determined that the screen contained several useful fields. A meeting was scheduled with a system analyst from the Department of Public Works Office of Information Systems (OIS) group to determine whether the information could be obtained in a form suitable for entering into the Tap File Database.

It was discovered subsequently that the Meter File information consisted of selected fields from the master database that OIS maintains on its mainframe computer. The OIS analyst agreed to supply the data for all active residential addresses throughout the District on floppy disks. These data contained the following information for schedule numbers 000000 through 999999:

- Schedule number.
- House number.
- Street name.
- Quadrant.
- Square.

The missing Tap File information was addressed by creating a supplementary database for all records that had a schedule number less than 67000. Upon investigation of the records, it was discovered that the schedule number for several thousand records in the Meter File was 000000. Neither OIS nor BWMB personnel knew the reason for such an assignment. Several of these addresses were not found in the Maintenance File. It was assumed that these records were either inactive or abandoned service lines, and they were removed from the database.

This supplementary database was installed on the project computers at BWMB. Data entry personnel were instructed to look up each address in the Maintenance File and attempt to fill in the missing data. Subsection 1.2.3 describes the activities that comprised this effort.

It should be noted that only 20,400 of the first 67,000 taps were still active. This is not surprising, since most of these residences were located in the center of the District and as such were probably torn down and replaced by commercial or government buildings, or by open space (especially the Mall) or new roads.

The data present in the Meter File also contained schedule numbers greater than those found in the Tap File. It was initially decided to append this information to the Tap File Database to ensure that the most recent locations were included. However, this was not done because of four factors:

- Schedule numbers were not contiguous, as would be expected given the recent nature of the tap (post-1984). Many gaps appeared in the schedule numbers that caused concern over the reliability of the information.

- One piece of information that did not appear on the Meter File is the tap date. The date was not important for the first 67,000 schedule numbers because the taps occurred well before the introduction of materials other than lead. The tap date for the newest locations, however, becomes very important because of the potential of relatively new solder contributing to lead in the water of these households.

- Dates of construction were obtained for all residences built since 1984. It is expected that concentrations of lead in drinking water in newer homes may be high where lead solders were used in the house plumbing system. The data file is developed from the Department of Consumer and Regulatory Affair's Permit Ledger data and is discussed in Subsection 1.2.9.

- The Tap File database contained the schedule number, address, and square for all available single-family addresses. Data for the service line diameter and pipe material fields for the first 67,000 taps, as well as the ward location for all addresses, were still needed.

1.2.3 Maintenance File

All water system maintenance activities are recorded in a file called the Maintenance File. The Maintenance File is a very large collection of index cards and small paper records located next to the Tap File at the BWMB office. It contains the sum total of all known water system activity that has been performed at any address in the District. This file is much larger than the Tap File; BWMB personnel estimate that there are 500,000 pieces of paper in the Maintenance File. The file is separated into residential addresses and commercial (or nonresidential) addresses. The residential portion of the file is organized alphabetically by street name. Within the street name, records are organized by quadrant and, within the quadrant, by increasing house number. All work orders that pertain to a house number are arranged chronologically.

It was not originally intended to utilize the Maintenance File in reviewing the water distribution system records. The sheer size of the file is such that any attempts to obtain information on all addresses would be costly and time consuming. Furthermore, this file is the central repository of all information and is in constant use by BWMB personnel, service crews, meter replacement crews, and several other groups. Any extensive use of this file would severely disrupt the normal routine in the office.

The missing 67,000 tap records discussed in previous subsections required a limited investigation of the Maintenance File to be performed. In order to complete the data collection for the first 67,000 taps, the following data had to be obtained from the Maintenance File for each address in the supplementary Tap File Database:

- Date of tap installation.
- Service line material.
- Service line diameter.

The database was sorted to match the organization of the Maintenance File. Nevertheless, the volume of information available at any address that had to be sorted through greatly diminished productivity. To ensure that the effort was completed on time, the data entry staff were instructed to concentrate only on obtaining the service material for each address, which was the most important piece of information of the three. The staff were then free to look through all of the service orders for each address as well as the tap card, thus increasing the chances of obtaining a definite service line material indication.

Data entry on this file was completed on 30 June 1989. Quality assurance was performed on the supplemental database, and then it was appended to the main Tap File Database to produce the full 126,099-record Tap File Database.

1.2.4 <u>Planning Commission Files</u>

All data analyses for the project were performed on the basis of political wards. The District of Columbia is divided into eight wards, with each ward being further divided into five subwards. This initially presented a challenge, since the only geographical information that appeared in the Tap File was quadrants and squares. A District of Columbia Planning Commission map was obtained that showed the location of all squares and the boundaries of the eight wards in an attempt to determine whether an orderly relationship existed between squares and wards. It was immediately apparent that no such relationship existed; the approximately 7,900 squares often appeared at random in different areas of the District.

Before starting the square-versus-ward matching effort, additional inquiries were made to the Planning Commission staff. This led to the discovery of their mainframe database that, among other relationships, identified the ward location of every square. A Planning Commission programmer provided a floppy disk of this information in a form suitable for inclusion into the dBASE IV software.

The ward-versus-square database enabled staff members to quickly and easily fill in the ward field for any record in the Tap File Database, as long as the record contained the proper value in the square field. The merge was highly successful; over 90 percent of the records now had a ward location. Those records that did not get a ward had tap cards that did not have the square specified, which was fairly common in the older Tap File records.

The completion of this task marked the end of the database creation process. The Tap File Database now contained schedule number, address, tap size, square, and ward information for 126,099 records. Service line material information at this point, however, was limited to those rare occurrences where the plumber who installed the service line happened to note the material type somewhere on the index card. The objective of the remaining distribution system data collection tasks was to modify the database by ascertaining the presence or absence of lead service lines. The various data gathering efforts that the District initiated under past and ongoing programs were investigated, with the objective of detection of any additional lead service line information. The following programs were investigated:

- Lead Service Replacement Program
- Meter Relocation Program
- Street Replacement Program
- Project Locator Program

1.2.5 Lead Service Replacement Program

The first source of database modification information was provided by the District's Lead Service Replacement Program. The program, which has been in operation since June 1986, replaces District-owned, noncopper residential service lines (i.e., the portion of the service line that lies between the main and the curb shut-off valve).

The program operates as follows: a list of probable lead service line locations is maintained through a combination of addresses compiled by the Department of Consumer and Regulatory Affairs (DCRA) Water Hygiene Branch during its water testing program and by subsequent calls by concerned residents and other water consumers. Since the service line material has at this point been identified only by the homeowner, Lead Service Replacement Program personnel first attempt to identify the District side of the service line by checking the work order history in the BWMB Maintenance File. If no information to the contrary is found, the service line is assumed to be lead and is added to the list. The four dedicated Lead Service Replacement Program crews of the Bureau of Water Service (BWS) excavate the service line, replace it with copper, and note the customer's service line material. Whenever the customer's service line is not copper, notification is given to the customer describing the situation and urging him/her to replace it as soon as possible.

The Lead Service Replacement Program, which is headquartered at the Office of BWS, maintains a dBASE database of all addresses that had their service lines replaced since the program's inception. As of the third week of June 1989, when a floppy disk was obtained, the program's database contained 854 records. This ongoing program replaces 20 to 40 service lines per month depending on the weather. Close contact was maintained with program personnel throughout this study, and the main database was updated to ensure the most up-to-date assessment of lead service line distribution.

The Lead Service Replacement Program database contains the following fields of interest:

- House number.
- Street name.
- Quadrant.
- Material type replaced.
- Date.

The objective in using these data was to match each replaced service line with its corresponding entry in the Tap File Database and mark the service line material as being copper. It was desirable to perform this matching and marking function electronically; however, the lack of a simple, unique key field in the Lead Service Replacement Program database made this difficult. The only way to match the data was to attempt to search by a combination street name, house address, and quadrant. The potential for typographical errors in the street name and various inconsistent abbreviations (ST., ST, STREET) limits the success of such a search. The only alternative is to sort the databases the same way, print out the Lead Service Replacement Program database, and manually mark the addresses as having lead service lines and indicating that they have been replaced.

In the future, it is recommended that the Lead Service Replacement Program consider adding the schedule number and square to its database in order to facilitate the updating of the Tap File Database and to provide periodic feedback on the distribution of the remaining service lines. This latter point will ensure that all areas of the District are receiving equal attention from the program.

1.2.6 Meter Replacement Program

The second source of database information modification was provided by the District's Meter Relocation Program. The objectives of this program, which has been underway for approximately 10 years, are to move all water meters to the outside of the building and to standardize on one meter manufacturer. For the purposes of this study, the Meter Relocation Program differs from the Lead Service Replacement Program in several important ways:

- Service lines connected to the meter are not seen by the crews whenever the meter to be replaced is already outside of the building. In this case, the crew only digs deep enough to connect the new meter to the old risers (unless the risers are in poor condition in which case they are also replaced). The service line is not exposed and therefore its type cannot be ascertained.

- Each job is recorded on a paper meter replacement ticket, which is then filed in the BWMB Maintenance File. No computer records are maintained. Finding and recording all past meter replacement activity would have involved searching every address in the Maintenance File. Time, cost, and project scope constraints did not allow this search to be performed.

- Upon investigation of several Meter Relocation Program job tickets, it was discovered that the service line material type was rarely noted.

Since data on past meter relocation activity could not be obtained, it was decided to set up a mechanism that would obtain this information during all future activities. It was recommended to the Meter Relocation Program management to modify its program in the following two ways:

- Instruct all crews to excavate down to the service line so that they could determine the type of service line on both the customer and the District sides.

- Have the crews fill out a simple form (see Figure 1-2) and return it at the end of the day to a central location.

Program management has cooperatively implemented these recommendations. This has resulted in the collection of information on approximately 200 additional identified service lines to date. This information enabled further updating of the Tap File Database and provided valuable input for the statistical analyses.

1.2.7 <u>Street Replacement Program</u>

The third source of database information modification was identified at the first monthly project status meeting at the District's office in Blue Plains. This information, hereafter called the Street Replacement Program, is a result of the District's requirement that all noncopper service lines (as well as other utilities) be replaced whenever a street construction contract is awarded. All available street inspector logs (see Figure 1-3 for a sample) that identified the service line material were obtained.

As was found with the Meter Replacement Program information, the Street Replacement Program information is not computerized;

D.C LEAD STUDY

DATE: 05-26-89.

NAME OF CREW LEADER: L. HARTRIDGE

FULL ADDRESS OF WORK LOCATION	INDICATE TYPE OF PIPE MATERIAL OBSERVED IN THE APPROPRIATE SPACE BELOW							
	FROM BUILDING LINE TO METER				FROM THE METER TO WATER MAIN			
	IRON.	LEAD.	COPPER.	OTHER	IRON.	LEAD.	COPPER.	OTHER
~~1307 E ST. NE~~								
1307 G ST. NE				3/4 BRASS				3/4 BRASS
3935-MASSACHUSETTS AVE. NW (NF)			3/4 COPPER				3/4 COPPER	

FIGURE 1-2 SAMPLE METER RELOCATION DATA COLLECTION FORM

Contract No. 87-0029
Recap bid item #7
Replace 2" and smaller water services

Partial No.	Address			Length	Sq. No.	Lot NO.
3	1818	13th	st.	42.42	277	93 – Galv.
3	1820	"	"	45.09	"	92 – Galv.
3	1822	"	"	48.16	"	822 – Galv.
3	1824	"	"	53.74	"	846 – Galv.
3	1826	"	"	64.34	"	845 – Galv.
3	1828	"	"	62.32	"	95 – Galv.
3	1830	"	"	41.57	"	96 – Galv.
3	1832	"	"	41.09	"	74 – Galv.
3	1834	"	"	41.25	"	73 – Galv.
3	1836	"	"	52.75	"	844 – Galv.
3	1838	"	"	64.26	"	843 – Galv.
3	1840	"	"	64.26	"	842 – Galv.
3	1842	"	"	49.42	"	841 – Galv.
3	1844	"	"	50.42	"	840 – Lead.
3	1829	"	"	36.33	"	9 – Copper
Total#3= 759.42						
4	1800	"	"	47.45	"	800 – Galv.
4	1808	"	"	54.64	"	800 – Galv.
4	1810	"	"	58.14	"	77 – Galv.
4	1812	"	"	57.25	"	76 – Galv.
4	1814	"	"	47.42	"	75 – Galv.
4	1816	"	"	50.00	"	94 – Galv.
4	1825	"	"	59.64	"	813 – Lead
4	1817	"	"	47.40	"	808 – Galv.
4	1815	"	"	44.57	240	807 – Galv.
4	1813	"	"	60.92	"	806 – Galv.
4	1811	"	"	48.19	"	805 – Galv.
4	1809	"	"	41.10	"	804 – Galv.
4	1807	"	"	43.32	"	24 – Galv.
4	1805	"	"	43.74	"	23 – Galv.
4	1801	"	"	44.50	"	25 – Galv.
4	1500	"	"	30.92	241	74 – Lead
Total #4 = 779.50						
5	1504	"	"	50.99	"	842 – Lead
5	1506	"	"	49.83	"	88 – Lead
5	1508	"	"	50.08	"	87 – Lead
5	1510	"	"	51.82	"	86 – Lead
5	1512	"	"	51.24	"	85 – Galv.
5	1514	"	"	50.32	"	84 – Galv.
5	1700	"	"	32.07	"	819 – Galv.
5	1711	"	"	29.33	240	102 – Galv.
5	1714	"	"	48.89	241	108 – Tie in/in Basem
5	1716	"	"	51.68	"	107 – Galv.
5	1718	"	"	34.43	"	99 – Galv.
5	1722	"	"	50.42		– Lead
5	1736	"	"	52.50		– Lead
5	1740	"	"	33.25		– Lead.
Total #5 = 636.85						

FIGURE 1-3 SAMPLE STREET REPLACEMENT PROGRAM DATA FORM

moreover, the information is not centrally located. The data were obtained by contacting the inspectors, who then pulled their logs from their personal files. The inspectors were found to be highly organized and extremely knowledgeable.

Since each group of addresses represents a replaced street, almost all of the records to be changed are located on one street and, therefore, will appear together in the Tap File Database. The database was sorted to allow rapid entry of this information. For each address found, the original service line material was marked to match that indicated on the Street Replacement Sheet, and the service line was marked as having been replaced.

1.2.8 Project Locator Data File

The fourth source of database information modification was identified at the 6 July 1989 project progress meeting and presentation. These data, hereafter called the Project Locator Data File, is the end product of an extensive study performed in 1983 to 1984 by the Office of Engineering Services for the BWMB. Project Locator was a house-to-house survey, the objective of which was to improve the quality and accuracy of water billing.

The Project Locator records were located at the OIS office. All of the information was copied to magnetic tapes readable by WESTON's VAX mainframe computer system. Table 1-3 shows the format of each record in the Project Locator Data File.

As can be seen in Table 1-3, the Project Locator Data File uses the 11-digit customer account number as the key (unique) field. The Tap Data File keys on the tap schedule number. Therefore, a second run was requested on the main database from which the Meter File (see Subsection 1.2.2) was obtained in order to build another database that related the customer's account number to the schedule number. The format of this temporary file appears in Table 1-4.

Several steps were required to move the desired data from the Project Locator Data File to the Tap File Database. The first step taken was to strip unnecessary data from Project Locator Data File. After loading the magnetic tapes onto the WESTON mainframe computer, a simple program was written to extract the following information from each record:

- Account number.
- Riser pipe type.
- Service pipe type.

The second step taken was to load the magnetic tape containing the account number versus schedule number onto the mainframe. The third step taken was to download both files from the mainframe to the PC for subsequent loading into the same database program used for the Tap File Database. Once the two files were loaded into dBASE, the temporary account number versus schedule number database was merged with the Project Locator Database.

Table 1-3

Format of Project Locator Data File

DATE: 08/01/83 PAGE: 1 of 5

FILE ID: PLMAST FILE NAME: PROJECT LOCATOR MASTER FTYPE#: 910

RECORD SIZE: 632 FILE TYPE: XD CREATED BY:
DATA LOC: PLDATA,1

I/O TO JOBS: P/L REPORTS UPDATED BY: PL;PLORDR

DESCRIPTION:

This is the master file record layout for the Project Locator System.
The V/I# Column signifies the source of the data element:
P=Program Generated, BLANK=Water Revenue, R=Real Property F=Field Survey

Fld No.	Field Name	Mask	V/ I#	Fld Desc	Fld Len	Fld Mod	Positions From	Positions To
1	SURVEY SHEET NUMBER	CK DIGIT	P	N	7		1	7
2	ACCOUNT NUMBER			X	11		8	18
3	SERVICE ADDRESS			X	41		19	59
	House/Building number			N	4		19	22
	House Number Suffix			X	1		23	23
	Street Name			X	18		24	41
	Street type			X	2		42	43
	Quadrant			X	2		44	45
	Apartment Number			X	5		46	50
	Zip code			N	9		51	59
4	SPECIAL INST CODE	TLU		X	1		60	60
5	SPECIAL INSTRUCTIONS			X	30		61	90
6	METER MANUFACTURER 1			X	2		91	92
7	METER MANUFACTURER 2		F	X	2		93	94
8	METER SIZE			N	3		95	97
9	METER ID NUMBER 1			X	9		98	106
10	METER ID NUMBER 2		F	X	9		107	115

Table 1-3
(continued)

DATE: 08/01/83 PAGE: 2 of 5

FILE ID: PLMAST FILE NAME: PROJECT LOCATOR MASTER FTYPE#: 910

RECORD SIZE: 632 FILE TYPE: XD CREATED BY:
DATA LOC: PLDATA,1

I/O TO JOBS: P/L REPORTS UPDATED BY: PL;PLORDR

DESCRIPTION:

This is the master file record layout for the Project Locator System.
The V/I# Column signifies the source of the data element:
P=Program Generated, BLANK=Water Revenue, R=Real Property, F=Field

Fld No.	Field Name	Mask	V/ I#	Fld Desc	Fld Len	Fld Mod	Positions From	Positions To
11	METER LOCATION			X	60		116	175
12	CURB COCK LOCATION			X	50		176	225
13	RISER MATERIAL		F	X	1		226	226
14	PIPE TYPE		F	X	1		227	227
15	# OF METER REGISTERS			N	1		228	228
16	METER DIAL UNITS		F	N	15		229	243
	lowest dial unit 1		F	N	4		229	232
	lowest dial unit 2		F	N	4		233	236
	lowest dial unit 3		F	N	4		237	240
	number of dials 1		F	N	1		241	241
	number of dials 2		F	N	1		242	242
	number of dials 3		F	N	1		243	243
17	ACCOUNT TYPE			N	1		244	244
18	PROPERTY USE		R	N	2		245	246
19	BUILDING NAME		F	X	25		247	271
20	NUMBER OF UNITS			N	5		272	276

Table 1-3
(continued)

DATE: 08/01/83 PAGE: 3 of 5

FILE ID: PLMAST FILE NAME: PROJECT LOCATOR MASTER FTYPE#: 910

RECORD SIZE: 632 FILE TYPE: XD CREATED BY:
DATA LOC: PLDATA,1

I/O TO JOBS: P/L REPORTS UPDATED BY: PL;PLORDR

DESCRIPTION:

This is the master file record layout for the Project Locator System.
The V/I# Column signifies the source of the data element:
P=Program Generated, BLANK=Water Revenue, R=Real Property, F=Field

Fld No.	Field Name	Mask	V/ I#	Fld Desc	Fld Len	Fld Mod	Positions From	To
21	FIELD AUDITORS INITS 1		F	X	3		277	279
22	FIELD AUDITORS INITS 2		F	X	3		280	282
23	CONNECTION SIZE			N	3		283	285
24	SET (RESET) DATE			N	6		286	291
25	PIPE DATE		F	N	6		292	297
26	TEST DATE		F	N	6		298	303
27	TEST RESULTS			N	3		304	306
28	METER REMOVAL DATE			N	6		307	312
29	METER AUDITORS INITIALS		F	X	3		313	315
30	SQUARE		R	N	4		316	319
31	SQUARE SUFFIX		R	X	4		320	323
32	LOT		R	N	4		324	327
33	OFFICE AUDITORS INITS		F	X	3		328	330
34	DATE FORM ISSUED		P	N	6		331	336
35	DATE OFFICE UPDATE		P	N	6		337	342
36	DATE MD UPDATE		P	N	6		343	348
37	AGENT CODE	TLU		X	4		349	352

Table 1-3
(continued)

DATE: 08/01/83 PAGE: 4 of 5

FILE ID: PLMAST FILE NAME: PROJECT LOCATOR MASTER FTYPE#: 910

RECORD SIZE: 632 FILE TYPE: XD CREATED BY:
DATA LOC: PLDATA,1

I/O TO JOBS: P/L REPORTS UPDATED BY: PL;PLORDR

DESCRIPTION:

This is the master file record layout for the Project Locator System.
The V/I# Column signifies the source of the data element:
P=Program Generated, BLANK=Water Revenue, R=Real Property, F=Field

Fld No.	Field Name	Mask	V/ I#	Fld Desc	Fld Len	Fld Mod	Positions From	Positions To
38	POLICE STREET CODE		PF	N	4		353	356
39	ROUTE			N	4		357	360
40	TALLY			N	3		361	363
41	LICENSED BUSINESS CODE		R	N	3		364	366
42	ADDRESS RANGE		F	X	20		367	386
43	NEW ACCOUNT		F	X	1		387	387
44	HELD ACCOUNTS	1,2,3	F	X	1		388	388
45	HELD REASON		F	X	25		389	413
46	RANK		P	N	4		414	417
47	ALTERNATE ADDRESS		P	X	40		418	457
48	FILLER		P	X	8		458	465
49	REAR FLAG		P	X	1		466	466
50	CORNER FLAG		P	X	1		467	467
51	FILLER		P	N	1		468	468
52	ISSUE COUNT		P	N	1		469	469
53	ERROR FLAG		P	X	1		470	470

Table 1-3
(continued)

DATE: 08/01/83 PAGE: 5 of 5

FILE ID: PLMAST FILE NAME: PROJECT LOCATOR MASTER FTYPE#: 910

RECORD SIZE: 632 FILE TYPE: XD CREATED BY:
DATA LOC: PLDATA,1

I/O TO JOBS: P/L REPORTS UPDATED BY: PL;PLORDR

DESCRIPTION:

This is the master file record layout for the Project Locator System.
The V/I# Column signifies the source of the data element:
P=Program Generated, BLANK=Water Revenue, R=Real Property, F=Field

Fld No.	Field Name	Mask	V/ I#	Fld Desc	Fld Len	Fld Mod	Positions From	Positions To
54	STATE FLAG		P	X	1		471	471
55	RESERVATION FLAG		P	X	1		472	472
56	FILLER		P	X	160		473	632

Table 1-4

Format of Account Number Versus Schedule Number Data File

Field Name	Columns
Account Number	1-11
House Number	12-15
Street Name	16-40
Lot	41-44
Square	45-48
Schedule Number	49-54

The final step in the procedure was to merge the service line material information from the Project Locator Database onto the Tap File Database by matching the schedule numbers in the two databases. To accommodate the service line material information, a new field was created in the Tap File Database entitled "Customer Service." This addition was necessitated by the fact that the service line material entry in the Project Locator effort is what the Project Locator personnel viewed for those residences that had inside water meters and is, therefore, a direct observation of the customer's side of the service line only. The information collected to date has represented direct observation of the District's side of the service line. It was decided to segregate the two pieces of service line material information to avoid making unsubstantiated inferences on the material type of any portion of a residential service line.

1.2.9 Department of Consumer and Regulatory Affairs Permit Ledger

The objective of the final data collection activity was to examine new construction data in order to identify the population that is potentially exposed to drinking water actively leaching lead solder. It was learned that the Department of Consumer and Regulatory Affairs (DCRA) Permit Office was responsible for maintaining the records for all construction permits.

The following information was gathered from a visit to the Permit Office: (1) the information was contained in a bound ledger; (2) the ledger could not be removed from the building; and (3) photocopying was not available. Due to the importance of this information and the lack of another source of the same data, it was decided to transcribe the data by hand for later entry into the computer as the New Construction Database. A sample of this transcription appears in Figure 1-4. The following information was obtained from the ledger for all new construction of single-family dwellings since 1 January 1984:

- House number.
- Street name.
- Quadrant.
- Square.
- Permit date.

The first three pieces of information were used in the project to identify locations for water sampling needed to identify the contribution of brass fixtures and lead solder to lead levels in drinking water. The square information enables the location to be tied into one of the eight wards in the District to provide the distribution of new construction. The permit date provides a reasonable estimate of the service line's age. While the permit date does not coincide with the actual service activation date, it does provide a relative age of the service line compared with other new construction.

NEW CONSTRUCTION: APRIL 1984

Permit No.	Address/Quadrant	Square	Date	Remarks
13300662	4459 Salem Lane, NW	1364	4-3-84	SFD
13300663	4465 Salem Lane, NW	1364	4-3-84	SFD
13300664	4477 Salem Lane, NW	1364	4-3-84	SFD
13300665	4471 Salem Lane, NW	1364	4-3-84	SFD
13300666	4489 Salem Lane, NW	1364	4-3-84	SFD
13300667	4483 Salem Lane, NW	1364	4-3-84	SFD
13300722	2715 M. Street, NW	1214	4-6-84	
13300728	2620 Bowen Road, SE	5869	4-6-84	
13300795	3645 Alabama Ave., SE	5671	4-11-84	Townhouse
13300796	3647 Alabama Ave., SE	5671	4-11-84	Townhouse
13300796	3649 Alabama Ave., SE	5671	4-11-84	Townhouse
13300796	3651 Alabama Ave., SE	5671	4-11-84	Townhouse
13300799	3627 36th Place, SE	5671	4-11-84	Townhouse
13300800	3625 36th Place, SE	5671	4-11-84	Townhouse
13300801	3623 36th Place, SE	5671	4-11-84	Townhouse
13300802	3621 36th Place, SE	5671	4-11-84	Townhouse
13300803	3619 36th Place, SE	5671	4-11-84	Townhouse
13300804	3617 36th Place, SE	5671	4-11-84	Townhouse
13300805	3615 36th Place, SE	5671	4-11-84	Townhouse
13300806	3613 36th Place, SE	5671	4-11-84	Townhouse
13300807	3611 36th Place, SE	5671	4-11-84	Townhouse
13300808	3609 36th Place, SE	5671	4-11-84	Townhouse
13300809	3607 36th Place, SE	5671	4-11-84	Townhouse
13300810	3605 36th Place, SE	5671	4-11-84	Townhouse
13300811	3603 36th Place, SE	5671	4-11-84	Townhouse
13300812	3601 36th Place, SE	5671	4-11-84	Townhouse
13300944	317 Mass. Ave., NE	1749	4-23-84	

FIGURE 1-4 SAMPLE OF DCRA PERMIT LEDGER DATA

This information was used in the effort to determine the contribution of brass fixtures and lead solder to lead concentrations in drinking water. The New Construction Database was sorted into two categories: (1) those addresses that are less than 2 years old, and (2) those addresses that are 2 to 5 years old. Houses that are in the first category should have no lead solder because of the recent ban on using lead solder in potable water service lines. Houses that appear in the second category are considered to be at risk for leaching of lead solder into drinking water. Further discussion on the distribution of these data appears in Subsection 1.6.3.

1.3 DATABASE QA/QC PROGRAM

A rigorous QA/QC program was created and followed for the database that was created from the Tap File index cards. A combination of manual and electronic checking enabled every record to be checked for missing information and keypunch errors.

The keypunch errors were corrected, and, when possible, missing information was filled in by consulting similar records or the knowledge of the project staff members.

The objectives of the QA/QC program are to ensure the following:

- To confirm that data that appear on each card in the Tap File is entered into a corresponding record in the Tap File Database.
- To check the database for keypunch errors. The QA/QC was performed on all the tap records with schedule numbers greater than 67,000. The QA/QC for the data entry task was performed in two stages. One of the staff members was assigned this task and designated as database QA/QC coordinator. The methodology is described in the following paragraphs.

Stage I -- Data Scanning

Each time the Tap File Database was backed up, the QA/QC coordinator would scan the data. The frequency of such data scanning was every 3 to 4 working days. The QA/QC coordinator would scan the data entered since the previous backup for each machine. Normally, the QA/QC coordinator would browse through the data and correct any apparent typing errors on the screen (e.g., "Nwe Jersey Ave." would be corrected to "New Jersey Ave."). Moreover, the data would be constantly indexed and sorted to locate any blank entries.

For each blank entry the QA/QC coordinator would check for an "X" in the UNSURE field. If an "X" were present, the blanks were filled in most cases with the probable entry by checking the fields of adjacent entries (e.g., if the SCHEDNUM field had the following entries: 92372, blank, 92374, the blank would be replaced with a 92373, the most logical entry).

In addition to the preceding tasks, the QA/QC coordinator would periodically print out portions of the database and methodically check for any blank or improper entries and also compare that portion of the database with the corresponding tap records. If an improper/illogical entry was noticed, the QA/QC coordinator would immediately rectify the mistake. Approximately 8 to 10 percent of the entire database was randomly sampled and checked by this method.

By carrying out the procedure described in Stage I, a random and quick QA/QC of the database would be accomplished. However, since there were approximately 10,000 records entered every week, it could have been possible to overlook some typing errors. To overcome this problem, the Stage II of the QA/QC program was undertaken.

Stage II -- Electronic Checking

The second stage was designed for an extensive QA/QC process by which the entire database was checked. To carry out this step, utility programs were compiled in the dBASE environment. The programs were designed to check for the validity of an entry for each field in every record for the entire database. Whenever a nonstandard entry or an invalid value was encountered, the program would direct the record in question to the printer. The QA/QC coordinator would then scrutinize the hard copy of the printout and make the necessary correction on the hard copy and in the database. The rigorous project QA/QC program enabled the development of an extremely accurate database. However, no database of this size is without errors. Even with 99 percent accuracy, a 126,099-record database will contain more than 1,200 errors. Furthermore, certain types of errors cannot be recognized as such. For example, if the square is supposed to be 1012 and the data entry staff accidentally entered 1013, this error will not be noticed if there is a square 1013.

1.4 USE OF LEAD MATERIAL IN PLUMBING

A second potential source of lead in drinking water involves the leaching of lead solder from the various plumbing connections within the residence. Older plumbing solders contain up to 50 percent lead, while newer "no-lead" solders have reduced lead to no more than 0.2 percent. Although the District of Columbia has banned the use of lead solder in potable water systems since 1987, it is still available on the market for use in heating and wastewater conveyance systems. Consequently, the local use of lead materials in plumbing was investigated by assessing the current District of Columbia Plumbing Code, conducting interviews of licensed plumbers, and interviewing experienced BWMB management and supervisory personnel.

1.4.1 District of Columbia Plumbing Code

The District of Columbia Plumbing Code sets standards for all plumbing work performed by registered plumbers as well as for materials used in design, installation, repair, and replacement of plumbing fixtures intended to receive and discharge water. This subsection focuses on those code provisions that pertain to potable water systems. These provisions described are for installation and permitting for plumbing work, existing plumbing systems, alteration and repair, water service line requirements, and piping system materials.

1.4.1.1 Installation and Permit

This section of the plumbing code provides that all work must be done by a registered master plumber under a duly issued permit. Furthermore, any person granted a license to practice as a master plumber shall post a bond before engaging in this trade.

Every application for a permit to connect with the District's water system, to install service lines attached thereto, or to repair a service line outside the building line must state upon the application form the number and address of the building, premises, or establishment; the square lot or sublot number; the number of stories and the frontage measurement; the purpose for which the water is to be used; and the time at which the tap will be required to be made by the Department of Public Works. The application form required for the connection is the index card that is subsequently inserted by the BWMB into its Tap File. The form, which must be signed by the owner of the building that is to receive the service connection, authorizes the plumber to notify the proper authorities to tap into the water supply system. The only exception to the permit requirement is for repairs involving only the working part of a faucet or valve, the clearance of stoppages, or the replacement of defective faucets, provided that no changes are made in piping to existing fixtures.

1.4.1.2 Existing Plumbing Systems

The code's provision for existing plumbing systems addresses the service requirements for existing buildings. It states that if the authorized occupancies in an existing building do not change, the existing plumbing system may continue to be used unless a change is required by this code or by regulations of other departments of the government of the District of Columbia that affect the health, safety, and welfare of the public.

1.4.1.3 Alteration and Repair

The alteration and repair code provision requires that repairs made to any part of the plumbing system conform as nearly as may be practicable to the regulations for new work of like character. This provision also states that if cumulative additions, alterations, or repairs to an existing water system through timed or phased work exceeds 50 percent of the total length of the service line in the building's system, the entire system must comply with the codes.

This provision of the code has a direct impact on the potential sources of lead in water distribution systems. The extensive rehabilitation of old buildings throughout the city surely results in more than 50 percent water service line replacement. Therefore, assuming that the code was obeyed, the rehabilitated structure would not contain any lead service lines. Furthermore, if the work is less than 2 years old, the solder should be lead-free.

These rehabilitated structures could not be identified from any of the available records. A second consideration arising from this provision of the code involves those buildings that receive less than 50 percent water service line replacement. In these cases it is possible that only the easily accessible lines have been replaced.

1.4.1.4 Water Service Requirement

General water service regulations require that every building, including separate business establishments having an outside entrance, have an independent water connection with a public or private water main. Also, it is required that installation of every water service line be at a right angle to the lot line common to the property and the public way under which the main lies.

The exceptions to the independent and separate service requirement occur when a building is located in an interior lot behind another building such that service line cannot be established directly from the main or line cannot be installed via an adjacent alley, courtyard, or driveway. In these cases, the code allows the extension of the water service line from the front building to the rear building. This arrangement is then considered to be one service line.

1.4.1.5 Piping System Materials

The District of Columbia Plumbing Code has adopted a modified version of the Building Officials and Code Administration (BOCA) schedules for water service line and water distribution line. Tables 1-5 and 1-6 show the approved water service line materials and water distribution line materials, respectively.

1.4.2 District of Columbia Plumbing Association and Plumbing Practices

The District of Columbia Metropolitan Area has a functional plumbing association, which is based in Washington, D.C. The association is known as Metropolitan Washington Association of Plumbing, Heating, and Cooling Contractors (MWAPHCC). It is a local chapter of the National Association of Plumbing, Heating, and Cooling Contractors. This association, which has been in operation

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Table 1-5

Schedule of District of Columbia Approved Water Service Pipe Materials

Material	Standard
- Acrylonitrile butadiene styrene (ABS) plastic pipe	ASTM D1527 ASTMD2282
- Brass pipe	ASTM B43
- Cast iron (ductile iron) water pipe	ASTM A377; AWWA C151
- Copper or copper alloy pipe	ASTM B42; ASTM B302
- Copper or copper alloy tubing (Type K & L)	ASTM B75; ASTM B88 ASTM B251
- Polyvinyl chloride (PVC) plastic pipe	ASTM D2846; ASTM F441;ASTM F442
- Polybutylene (PB) plastic pipe tubing	ASTM D2662; ASTM D2666 ASTM D3309
- Polyethylene (PE) plastic pipe	ASTM D2239
- Polyethylene (PE) plastic pipe	ASTM D2737
- Polyvinyl chloride (PVC) plastic pipe	ASTM D1785; ASTM D2441; ASTM D2672

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Table 1-6

Schedule of District of Columbia Approved Water Distribution Pipe Materials

Material	Standard
- Brass pipe	ASTM B43
- Copper or copper alloy pipe	ASTM B42; ASTM B32
- Copper or copper alloy tubing	ASTM B75; B88;ASTM B251
- Polyvinyl chloride (PVC)	ASTM D2846;ASTM F441; ASTM F442
- Galvanized steel pipe	ASTM A53; ASTM A120
- Polybutylene (PB) plastic pipe	ASTM D3309

since the 1890s, is the oldest trade association in the country. Although membership is open to all eligible master plumbers, the existing association comprises only 10 to 15 percent of all the master plumbers in the Washington, D.C., Metropolitan Area.

Several registered master plumbers in the District of Columbia Metropolitan Area were contacted to obtain an understanding of current plumbing practices and how and when they have changed over the years. After making telephone contact, a questionnaire was sent to the plumbers who were willing to participate to determine whether they served the District and to set up a meeting to interview them on plumbing practices.

Response to the questionnaire was poor. Only 4 plumbing firms responded out of the 20 questionnaires that were mailed. In an attempt to obtain greater cooperation, MWAPHCC was contacted for help. The President of the Association, Mr. James Wimmel, provided excellent cooperation by distributing the questionnaires directly to 30 of the members at the Association's monthly meeting. Ten plumbers returned their questionnaires; five of whom agreed to be interviewed.

Appendix A contains the five interviews. The small number of interviews makes it difficult to draw any conclusions as to the overall state of current plumbing practices. Some of the more consistent remarks are presented as follows:

- There was no indication of installation of any new lead service lines since the mid-1940s by those plumbers whose service involved installation or replacement. Some repair work involving lead service lines took the form of either sectional or complete replacement of the existing service lines. Current water service lines are made of copper, brass, cast iron, or some alloys.

- The common use of lead service lines years ago was based on the fact that lead service lines were easy to work with, and the pipe came in rolled lengths and required very few couplings for most installations. Furthermore, lead pipe was less expensive than the other competitive materials.

- With respect to the use of lead solder, it was discovered that whereas the use of the pure lead solder and solder made of alloy of lead and other materials has been discontinued and banned for use in drinking water applications, they are still on the market and can be used in other areas such as drainage, sewer, and vents.

- Inspection of plumbing supply centers and responses from master plumbers confirmed that there are no more lead lines available in the market. The following three categories of lead solder are on the market and in use by plumbers:

- Alloy of 50 percent tin and 50 percent lead used for drainage and sewer service lines.
- Alloy of 95 percent tin and 5 percent antimony (nonlead).
- Alloy of 95 percent tin, 4.5 percent copper, and 0.5 percent silver; the only one approved for water service lines (nonlead).

The two areas of concern with regard to plumbing practices and lead in drinking water are lead service line repairs and the potential for continued application of lead solder in potable water distribution systems. Interviews with the plumbers revealed that, while the know-how needed to work with lead service lines is disappearing, it is still possible that an existing private lead service line can be repaired rather than replaced. These repairs involve cutting the defective section and fitting and soldering a copper sleeve. This practice, while not illegal, can introduce lead into the drinking water due to the disturbance of the protective coating inside the pipe and the possible presence of lead filings generated by the cutting action. The plumbers say that they encourage homeowners to replace all lead service lines in the house. However, economic issues are often the deciding factor, and the owner may choose the less expensive method.

As previously stated, lead solder is still available for use on nonpotable distribution systems. Its use for drinking water lines is illegal. Enforcement of this ban is difficult. Lead solder is much less expensive than no-lead solder, and its fluxing characteristics and ease of use are superior. These two advantages make lead solder attractive to homeowners and plumbers who are either ignorant of the potential hazards or do not have a master plumber license to lose.

1.4.3 Distribution System Maintenance Personnel Interviews

Eight service line crew supervisors were interviewed in an attempt to understand past and current practices on service line replacement and to obtain additional, first-hand information on lead service line distribution throughout the District. Each supervisor was interviewed separately; interviews were brief, lasting only 10 to 15 minutes, to avoid interfering with their work. Appendix B contains all of the interviews. Summary results are presented in this subsection.

Questionnaires that rely on personal experience and recollection tend to produce inconsistent results, especially when the sample size (in this case, eight) is small. It is not possible to use the information obtained by the questionnaires to assign service line distribution probabilities or any related statistical inferences. However, this was never the objective of this effort. Instead, the questionnaires can be used to get an idea of service line maintenance practices and to obtain empirical information on service line material types.

The eight supervisors interviewed were highly experienced. All but 1 supervisor had more than 10 years of experience; 4 had more than 20 years of experience. None of the supervisors had ever installed a lead service line, and they have been replacing lead service lines for the last 3 to 4 years. Responses on service line material varied somewhat. There was some consensus that lead service lines are more prevalent in the northwest quadrant, although three supervisors thought that the distribution was approximately equal throughout the District.

The opinion of BWS, and the initial results from the tap records, indicates that lead service lines tend to appear most often in the northwest quadrant. The crews attempt to determine the service line material before arriving at the site either by checking the maintenance file or by calling the dispatcher (who then checks the maintenance file). The supervisors stated that they occasionally get an indication of the service line material, and that on those occasions when lead is expected, they actually unearth lead "most of the time." The supervisors also noted that the material of the customer side of the service line (i.e., from the curb stop to the meter) is rarely different from the District side (from the curb stop to the main), although several supervisors thought that the service lines differed about half the time. Information gathered from the Meter Replacement Program crews indicate that both sides of the service line are the same material nearly all the time.

1.5 LEAD WATER QUALITY DATA

Water quality data were gathered from several sources. DCRA provided data on lead in drinking water that it had collected during several sampling efforts. These data provided insight into the lead concentrations in water at the tap. The U.S. Army Corps of Engineers provided water quality data for both water treatment plants and several sampling points located throughout the distribution system.

The following subsections describe the efforts in collecting and organizing these data. Preliminary analyses were performed on the data, which are also described and the results presented. These data are used to develop recommended strategies for reducing the exposure to lead in drinking water and for developing predictive techniques for identifying lead service lines.

1.5.1 Department of Consumer and Regulatory Affairs Lead-in-Water Sampling Studies

Three distinct lead-in-water sampling efforts conducted by the District in 1986 and 1987 were analyzed. The results of this sampling were collected into three databases. For the purposes of this study, the three databases will be identified as Data Set 1, Data Set 2, and Data Set 3. Because of differences among the three sampling efforts, each will be described separately. The following paragraphs contain a brief summary of each sampling effort, followed by a discussion of the associated database. A detailed discussion of the sampling protocols is given in Subsection 1.5.2. A brief analysis of the data is given in Subsections 1.5.3 and 1.5.4.

Data Set 1 was collected from 156 buildings along Sherrier Place, N.W. Two types of samples were collected: midday and first flush. A 1-liter midday sample was collected by District personnel working door to door. The sample was generally collected at the kitchen faucet, although it was reported that some samples were collected at outside spigots. Three separate first flush samples labeled A, B, and C were collected. These three first flush samples were collected by the homeowner in expandable "cubitainers" provided and labeled by the District. Sample A was to be taken as the first water out of the tap in the morning; Sample B after running the water for 1 minute; and Sample C after running the water for 15 minutes. The three cubitainers were then placed outside the front door of the residence where they were collected by District staff.

The samples were analyzed for lead with a detection limit of 2 ug/L. The results of the sampling were entered into a DecMate personal computer. The data were transferred from the DecMate to an IBM personal computer compatible format via DCRA's Vax 11/730 mainframe computer. This data file was then modified and loaded into a dBASE IV database file.

Several issues had to be resolved after examining this database. First, lead values that were less than the detection limit of 2 ug/L were entered as "less than 2." For the purposes of analysis, a standard convention of assigning a value halfway between zero and the detection limit is generally accepted. Therefore, all values less than 2 in the database were changed to a value of 1.0. Second, two records having the same address (5100 Sherrier Place) were identified. However, as the sample IDs were different for the two records, both records were retained for analysis. Finally, three pairs of records having the same sample ID, either first flush or midday, were located. One of the records, however, had an address of "0 Sherrier Place." It was decided that this record was in error, and it was deleted. The remaining two pairs of records were corrected by deleting the sample ID and associated result from one record of the pair, making sure that at least one sample remained at each address.

Data Set 2 was collected after Data Set 1. Midday and/or first flush samples were collected from 757 addresses. Sampling procedures, analysis, and data entry were identical to that for the Sherrier Place Study.

These data were entered into dBASE IV in the same manner as Data Set 1. Close examination of the data resulted in two minor updates of the database. First lead values less than the detection limit were entered as "less than 2." These values were replaced with values of 1.0 as in Data Set 1. Next, 10 pairs of records were identified that were exact duplicates. This was corrected by deleting one record of each pair.

Both Data Set 1 and Data Set 2 were included in a report issued by the Water Hygiene Branch (WHB) of DCRA. Data Set 3 consisted of lead-in-water data from sampling performed after the completion of this report. Data Set 3 consisted of two first flush samples collected by the homeowner and sent directly to a laboratory for analysis. Since the sampling protocol for Data Set 3 required discarding the first 1 cup of water from the first flush sample, the results are expected to be different from Data Sets 1 and 2. The laboratory analyzed 1,330 first flush samples.

This last database was received in dBASE IV format. Examination of the data showed several issues needing attention. First, there were 12 records that contained no data; these were deleted. Next, four pairs of records were identified that were identical, except for insignificant differences (e.g., different spellings of last names, different phone numbers, etc). One record of each pair was deleted to solve this problem. Next, 29 pairs of records were identified that had identical sample IDs, but different addresses or different values of lead concentrations. Since there were differences, it was decided to retain both records of the pair in the database.

1.5.2 Review of Sampling Collection Protocols

As described in Subsection 1.5.1, several sets of water samples were collected and analyzed for lead. In some cases samples were collected by DCRA personnel, and in other cases the samples were collected by the homeowners. The method of collecting the samples varied with the type of sample taken (e.g., first flush A, B, or C, or midday).

In all cases samples were collected in cubitainers and preserved with acid. The midday samples collected on 6 November 1986 (Data Set 1) were collected by WHB personnel from 83 homes on Sherrier Place. WHB personnel were instructed to take samples from the kitchen if possible, but the cold water tap was not specifically mentioned. WHB personnel were instructed to run water for 2 minutes prior to sampling if water had been run during the day. If water had not been used, water was allowed to run for 15 minutes before sampling.

If permission to sample from inside a residence was denied, but a sample from the outdoor spigot was granted, then the water was allowed to run for 10 minutes prior to sampling. WHB personnel were instructed to record the name of the person collecting the water sample, and the time and location of the sample.

The first flush samples collected on 8 November 1986 (Data Set 1) from 136 residences on Sherrier Place were collected by individual homeowners. The homeowners were instructed to sample from a cold water tap first thing in the morning before using any water, but were not instructed to sample from the kitchen. Homeowners were instructed not to sample if toilets had been flushed within 6 hours of the sampling time. The first sample, marked A, was collected immediately after turning on the faucet. The sample marked B was collected after the water was run for 1 minute, and the sample marked C was collected after the water had run for an additional 15 minutes (presumably 16 minutes total). No instructions were given for recording the name of the person collecting the sample, or time or location of sample collection.

For comparison, draft guidance from EPA specifies that samples should be taken from the cold water kitchen tap in single-family homes (U.S. EPA, 1988, "Lead Monitoring Protocol for Drinking Water System," 13 April 1988). It should be noted that this guidance did not exist at the time that the District performed the sampling. A series of four samples are recommended for "Morning First Draw" samples as shown in Table 1-7.

After the samples are collected, the water also should be tested for pH, alkalinity, and residual chlorine. In addition, one sample should be taken from the treatment plant and analyzed for pH, lead, and alkalinity (total and phenolphthalein). The water is then shut off and all plumbing in the house is not used for one-half hour. Then, the one-half hour samples are taken for comparison with the first draw samples as shown in Table 1-8. This "Fixed First Draw" sample is being considered as an alternative to the "Morning First Draw."

Both protocols used to collect water samples in the District in 1986 had some potential problems that could affect the concentration of lead in the sample:

- Instructions to WHB personnel did not specifically request samples from the cold water tap. Samples taken from the hot water tap could result in higher lead concentrations than from a sample taken from the cold water tap.

- Relying upon homeowners to take first flush samples introduces a whole range of potential sampling errors. Some problems related to this were discovered, such as sampling from another residence and not allowing water to flush between samples.

- Homeowners were not instructed to sample from the kitchen, where most water ingested would come from. This could introduce inconsistencies in sample results.

- Homeowners were not instructed to record time or location of sample, or other relevant observations.

The aforementioned criticisms describe potential problems that could affect sampling results. It is not evident from the data

Table 1-7

Recommended Lead Monitoring Protocol
Morning First Draw*

Sample No.	Description	Purpose
1	250 ml taken immediately upon opening the tap without wasting water, then shut off the tap.	Contribution of faucet assembly to lead levels.
2	750 ml taken immediately after Sample No. 1, without wasting any water between Sample No. 1 and Sample No. 2.	Contribution of household plumbing (solder) to lead levels.
3	250 ml sample collected after the water turns cold, or some other indication that the water is representative of the service line.	Contribution of service line to lead levels.
4	250 ml sample taken after water has run for about 3 additional minutes after Sample No. 3, or has otherwise been determined to be representative of water in the main.	Contribution of distribution system to lead levels.

*Samples should be taken after water has been standing overnight for at least 8 hours.

Source: U.S. EPA, Lead Monitoring Protocol for Drinking Water Systems, 13 April 1988.

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Table 1-8

Recommended Lead Monitoring Protocol
Fixed First Draw

Sample No.	Description	Purpose
1	250 ml taken immediately upon opening the tap, without wasting any water, then shut off the water.	Contribution of faucet assembly to lead levels.
2	750 ml taken immediately after Sample No. 1, without wasting any water between Sample No. 1 and Sample No. 2.	Contribution of household plumbing (solder) to lead levels.
3	250 ml sample taken after the water turns cold, or any other indication that the water is representative of the service line.	Contribution of service line to lead levels.

Source: U.S. EPA, Lead Monitoring Protocol for Drinking Water Systems, 13 April 1988.

181C/S1

that any of these problems actually occurred. In addition, standard QA/QC samples were collected and analyzed (e.g., duplicates, spikes, replicates) and did not indicate any problems with laboratory procedures. In addition, the large differences between EPA protocols for "Morning First Draw" and "Fixed First Draw," which EPA considers to be roughly equivalent, underscore the point that sampling for lead in drinking water is an imprecise science at best. The sampling protocols used by DCRA fall within the EPA guidelines.

1.5.3 Relationships Between Sample Types

The sampling programs described in Subsection 1.5.1 collected two basic sample types: midday and first flush. The midday sample was a single 1-liter sample. The first flush sample consisted of a set of three distinct 1-liter samples. The two types of samples were collected in different fashions (as described in Subsection 1.5.2), and to examine lead levels in different areas of concern. This subsection describes the expected purpose of each sample type.

The midday sample was meant by DCRA to represent the water intake a consumer would typically be expected to ingest. As described in Subsection 1.5.2, the water was allowed to run for 2 minutes if water had been in use throughout the day, and for 15 minutes if no water had been used previously.

The sampling procedure for the set of three first flush samples is described in detail in Subsection 1.5.2. Sample A would represent the effect of lead leaching into the water from the interior plumbing system. Sample B would be likely to contain water from the service line, and thus give an indication of the amount of lead contributed by the service line. Finally, Sample C would consist of water from the distribution system. It was expected that Sample C would have a low lead concentration. It was also expected that a Sample C would be equivalent to a midday sample.

The set of first flush samples provide the District with a good understanding of both the lead concentrations in drinking water, as well as a general indication of where the lead is originating. Sample A represents what is probably the highest lead concentration a consumer would be exposed to in drinking water from the tap. This sample corresponds to the at-the-tap sampling proposed by EPA in the most recently proposed lead regulations. Sample B should show the contribution of the service line to lead levels at the tap. Finally, Sample C, representing water in the distribution system having minimal contact with the service line and interior home plumbing, will provide a baseline against which Samples A and B can be compared.

It is important to note, however, that due to differences in interior plumbing arrangements, Sample B may not always represent water from the service line. The only way to verify that the sample was from the service line is to inspect the interior plumbing, calculate the volume of water held there, and then flush this amount from the tap prior to sampling. Since this was not possible in all cases, the sampling protocol called for a 1-minute flush prior to sampling, which in most cases will result in a service line sample.

The midday sample represents distribution system water, which is expected to have low lead concentrations. It is not indicative of the worst-case situation that results from lead leaching into the water from household plumbing systems (including lead service lines). It does, however, show localized differences in lead levels within the distribution system.

1.5.4 Relationship of Lead Levels to Treatment Plant Parameters

Water quality data were obtained in dBASE format from the U.S. Army Corps of Engineers (COE) for both the Dalecarlia and McMillan water treatment plants. The data also included sampling results for 10 sampling points located throughout the distribution system. Data available included values for alkalinity, pH, hardness, temperature, and lead concentrations from October 1984 through May 1989. Water quality data prior to October 1984 were obtained in paper format, but were not included in this analysis. A more detailed analysis of water quality is presented in Section 2.

The first parameter considered was lead concentration. The proposed lead regulations call for quarterly sampling from each point of entry to the distribution system for water systems serving more than 3,300 people. A system is considered to be in noncompliance if the Maximum Contaminant Level (MCL) of 5 ug/L is exceeded in any one sample. An examination of the water quality data from the District's two water treatment plants shows that the lead concentration exceeded the proposed MCL in two samples taken since October 1984. The two occurrences are as follows:

Location	Date	Lead Concentration (ug/L)
McMillan WTP	5/3/85	12.3
McMillan WTP	6/3/85	13.4

The next water quality parameter evaluated was pH. The proposed lead regulations will require water systems serving more than 3,300 people to take and analyze 20 water samples per quarter to determine compliance with certain "no-action" levels. Water systems that exceed these "no-action" levels will be required to reduce the corrosiveness of their water through treatment. The "no-action" level for pH calls for no more than 5 percent of the samples to have a pH less than 8.0. These samples are to be taken from the cold water kitchen tap of homes considered to be at high risk for lead or copper problems, including:

- Residences at the ends of the distribution system (i.e., dead-ends or areas of low or no flow); and either

- Residences that have lead solder that is less than 5 years old in their plumbing systems, or

- Residences with lead service line connections and or lead interior plumbing.

The pH data from the 10 sampling points in the distribution system were examined for compliance with the "no-action" level for pH. Out of a total of 5,214 samples in the database, 3,410 had a pH of less than 8.0. Although these samples were not taken in accordance with the proposed sampling protocol (i.e., at the kitchen tap of a worst-case residence), they do indicate that the District would likely be in noncompliance with this "no-action" level if the proposed sampling protocol were followed.

Next, lead concentrations at the 10 distribution system sampling points were compared to lead concentrations at the 2 treatment plants. This was done to determine the amount of lead contributed by the distribution system and sampling point plumbing system. The database was first sorted by sample location and date. Then, the average value of lead concentration for a given date for the 10 sampling points was compared to the average for the same date for the 2 treatment plants. The comparison shows that lead levels in the distribution system are almost always greater than or equal to lead levels in water leaving the treatment plant.

Next, an attempt was made to relate water temperature to lead levels in the distribution system. Lead solubility increases with temperature, and seasonal variations in lead levels in drinking water have been reported in other cities. Monthly average water temperatures were calculated using data from October 1984 to April 1989. Finally, monthly average lead concentrations were calculated using the data from the 10 distribution sampling points.

The resulting averages were plotted as shown in Figure 1-5. This graph shows that there is apparently no increase in lead levels in the distribution system associated with increasing water temperatures.

The final water quality parameter examined was alkalinity. Although the most recently proposed lead regulations do not include a "no-action" level for alkalinity, EPA did consider using alkalinity as a "no-action" trigger, and the final rule may include such a provision. The "no-action" alkalinity level considered by EPA called for the water system to reduce the corrosiveness of its water if total alkalinity in 95 percent or more samples was not 30 mg/L or higher. The sampling procedure would be identical to that for the pH "no-action" level.

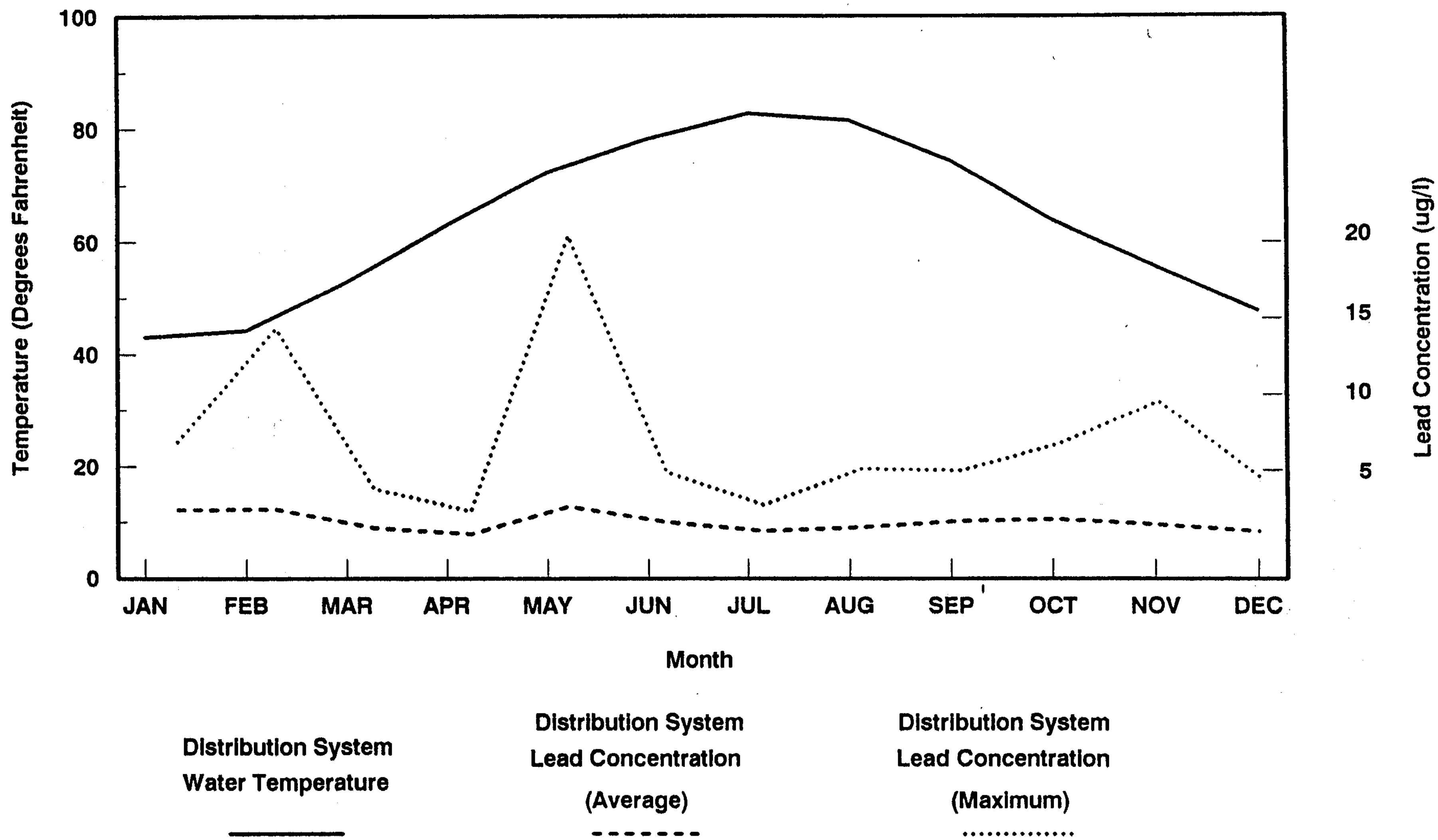

FIGURE 1-5 RELATIONSHIP BETWEEN WATER TEMPERATURE AND LEAD CONCENTRATIONS

only 9 had an alkalinity less than 30 mg/L. Although these samples were not taken in accordance with the proposed sampling protocol (i.e, at the kitchen tap of worst-case residences), it is apparent that the District would be in compliance with a "no-action" level for alkalinity, since the alkalinity in the distribution system is almost always greater than 30 mg/L.

1.6 SERVICE LINE DATA

This subsection contains a summary of data extracted from the Tap Data File and input into the database. As described in Subsection 1.2.1, a total number of 126,099 records was input into the database.

The lead service line data summarized in Table 1-9 comprise a list of the number of records per ward with positive indication of lead service lines based on information in the Tap File, the Meter Replacement Program, the Street Replacement Program, the Lead Service Replacement Program, or the Project Locator File.

Analysis of these data from the point of view of the date that service was installed revealed a few very important facts:

Alkalinity data were examined for the 10 distribution system sampling points. Out of a total of 5,214 samples in the database,

- Before the year 1950, the total existing number of records is 95,583. Of these 95,583 records, 8,844 records have a positive indication of lead service line material. Of the remaining 86,739 records, 49,420 are not lead, 37,319 are unknown.
- After the year 1950, 140 records were found to have positive indication of lead service line material.
- The most recent indication of an installation of a lead service line was 1977.

As described in Subsection 1.2.9 and given the impact that new construction might have in potentially exposing the population to actively leaching lead solder, new construction data were collected from the Planning Commission Files on construction permits starting in 1984. Table 1-10 is a summary of new construction data per ward, including the number of buildings by age group between 0 to 5 years old.

1.7 WATER QUALITY SAMPLING DATA

The data from the three sampling efforts was input into dBASE IV as described in Subsection 1.5.1. Because Data Set 1 and Data Set 2 were included in a single report, they were combined into a

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Table 1-9

Summary of Service Line Data

Ward	Number of Records with Recorded Lead Service Lines	Total Number of Records
1	644	11,088
2	545	14,657
3	1,997	17,997
4	1,990	19,518
5	1,174	18,370
6	1,186	17,854
7	854	15,004
8	430	5,549
Subtotal	8,820	120,037
Ward Unknown	167	6,062
Total	8,987	126,099

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Table 1-10

Summary of New Construction Since 1984

Ward	Number of Buildings: 0 to 2 Years of Age	2 to 5 Years of Age	Total
1	30	38	68
2	132	279	411
3	319	301	620
4	122	69	191
5	85	156	241
6	117	34	151
7	38	73	111
8	13	39	52
*	9	26	35
Total	865	1,015	1,880

*35 records did not include a ward designation.

single database and analyzed together. Data Set 3 was analyzed separately. All analyses were performed after the changes were made to the database as described in Subsection 1.5.1.

The first step in the analysis was to sort the data into wards. Neither database, however, originally contained a value for ward. A two-step process was necessary to assign a ward to each record. First, each record was updated to include its appropriate square by linking the database, by address, to a second database containing addresses and squares. Second, each record was then updated to include its appropriate ward by linking the database, now by square, to a second database containing squares and wards.

Unfortunately, it was not possible to assign a ward to each record. This was mainly because the database containing address and square did not contain every address, and certain records did not match. In addition there were other minor inconsistencies in the addresses (spelling errors, abbreviations, unusual addresses, etc.) that could not be corrected easily.

A breakdown of the water quality sampling data by ward is shown in Figure 1-6. By far the largest number of samples was taken in Ward 3 (66.3 percent of Data Sets 1 and 2, and 44.9 percent of Data Set 3). Ward 8 had a total of only 20 samples out of both databases, compared to the total of 1,652 samples for Ward 3.

Finally, the minimum, maximum, and average lead concentrations were calculated for each sample type (midday and first flush) by ward. These results are summarized in Table 1-11 (Data Sets 1 and 2) and in Table 1-12 (Data Set 3).

1.8 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from the investigation of the District's records:

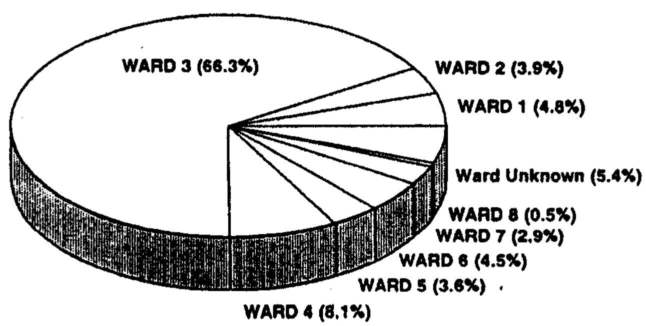
- A large amount of data is available to the District from a variety of sources. However, the data sources are scattered among a number of agencies and/or departments. Individual agencies/departments often are not aware of the information available from other sources.

- The District's Tap File, which contains information about service line installations, is incomplete and/or outdated in some cases.

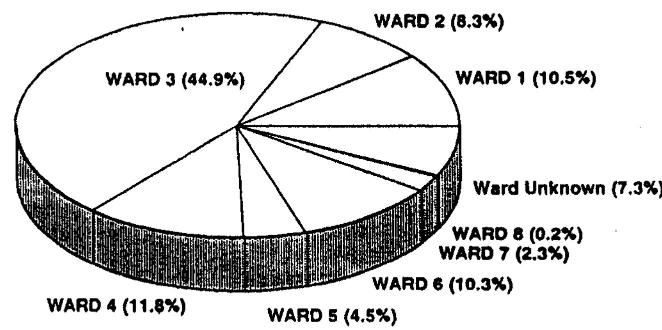
The following recommendations are made:

- The Tap File Database should be installed on a computer(s) and used by District personnel to assist in the Lead Service Replacement Program. The Tap File Database User's Guide presented in Appendix H can be used to familiarize personnel with the database.

- Data from the Meter Relocation Program, Street Replacement Program, and Lead Service Replacement Program should be used to keep the Tap File Database current.



DATA SETS 1 and 2



DATA SET 3

FIGURE 1-6 GEOGRAPHIC DISTRIBUTION OF SAMPLING DATA

Table 1-11

Summary of Lead Concentrations for Data Sets 1 and 2

WARD	NUMBER OF SAMPLES		MIDDAY SAMPLE			SAMPLE A			SAMPLE B			SAMPLE C		
	MIDDAY	FIRST FLUSH	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX
1	45	0	1	6.09	115	--	--	--	--	--	--	--	--	--
2	34	6	1	3.26	9	2	14	39	1	6	21	2	8	27
3	555	132	1	6.66	131	1	16	91	1	18	141	9	1	78
4	76	0	1	6.09	84	--	--	--	--	--	--	--	--	--
5	33	1	1	14.94	309	1	1	1	1	1	1	4	4	4
6	42	0	1	3.88	23	--	--	--	--	--	--	--	--	--
7	27	0	1	6.52	45	--	--	--	--	--	--	--	--	--
8	5	0	1	1	1	--	--	--	--	--	--	--	--	--
Not designated	50	2	1	8.16	217	1	3.50	6	1	2	3	1	11.50	22
District Total	867	141	1	6.68	309	1	15.96	91	1	17.5	141	1	9.28	78

Notes: 1) All values given in ug/L.
2) Values less than the detection limit of 2 ug/L are listed as 1 ug/L.

Table 1-12

Summary of Lead Concentrations for Data Set 3

WARD	NUMBER OF SAMPLES		MIDDAY SAMPLE			SAMPLE A			SAMPLE B			SAMPLE C		
	MIDDAY	FIRST FLUSH	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX
1	0	140	---	---	---	1	10.86	124	1	7.88	116	1	1	1
2	0	110	---	---	---	1	18.61	389	1	10.83	324	1	1	1
3	0	597	---	---	---	1	13.08	399	1	11.70	308	1	1.08	47
4	0	157	---	---	---	1	15.36	278	1	14.57	292	1	1	1
5	0	60	---	---	---	1	23.92	558	1	13.42	152	1	1	1
6	0	137	---	---	---	1	10.09	106	1	9.07	117	1	1	1
7	0	30	---	---	---	1	6.53	28	1	5.53	25	1	1	1
8	0	2	---	---	---	3	4.50	6	2	3.50	5	1	1	1
Not Designated	0	97	---	---	---	1	12.76	210	1	13.56	357	1	1	1
District Total	0	1,330	---	---	---	1	13.57	558	1	11.35	357	1	1.04	47

Notes: 1) All values given in ug/L.
2) Values less than the detection limit of 2 ug/L are listed as 1 ug/L.
3) No Midday samples were collected as part of Data Set 3.

SECTION 2

METHODS OF REDUCING THE LEAD CONTENT IN DRINKING WATER

2.1 GENERAL DESCRIPTION OF EXISTING SYSTEM

The Washington Aqueduct Division (WAD) of the U.S. Army Engineer District, Baltimore, provides the water supply for more than 1 million residents of the District of Columbia (District) and northern Virginia, and to the Federal government. The mission of WAD is the collection, purification, and pumping of an adequate supply of potable water for the District of Columbia, Arlington County, and parts of Fairfax County. Water distribution in these areas is the responsibility of the local governments.

The water treatment system of WAD consists of two intakes from the Potomac River, two conventional treatment plants, and associated raw and finished water transmission lines and water storage facilities. A diagram of the intake and transmission system is shown in Figure 2-1.

Water from the Potomac River at the Great Falls dam and intake and the Little Falls dam and intake is pumped to the Dalecarlia Reservoir. Raw water from the Dalecarlia Reservoir is treated at the Dalecarlia treatment plant. The nominal capacity of the Dalecarlia treatment plant is 164 million gallons per day (mgd) average flow rate and 246 mgd peak flow rate. The average annual flow through the plant for Fiscal Year 1989 was 121 mgd.

Treatment consists of activated carbon addition, aluminum sulfate addition, coagulation, flocculation, settling, prechlorination, filtration (rapid sand and mixed media), hydrofluosilicic acid addition, post-chlorination, and lime addition for corrosion control. The capability for powdered activated carbon addition prior to filtration exists. Treated water is pumped from the Dalecarlia treatment plant to five service area pressure zones.

The McMillan treatment plant receives water from Dalecarlia Reservoir. Fluoride and alum are added to the raw water at Dalecarlia Reservoir before it flows by gravity to Georgetown Reservoir. The provision for addition of chlorine and activated carbon also exists. Georgetown Reservoir acts as a sedimentation basin for the water before it arrives at McMillan Reservoir. The McMillan plant was completely replaced and brought on-line in 1985. The treatment train at the McMillan plant is similar to the Dalecarlia treatment plant. A flow diagram of the McMillan treatment plant is shown in Figure 2-2. The capacity of the McMillan treatment plant is 100 mgd average and 150 mgd peak flow rate. The average annual flow rate for Fiscal Year 1989 was 60 mgd.

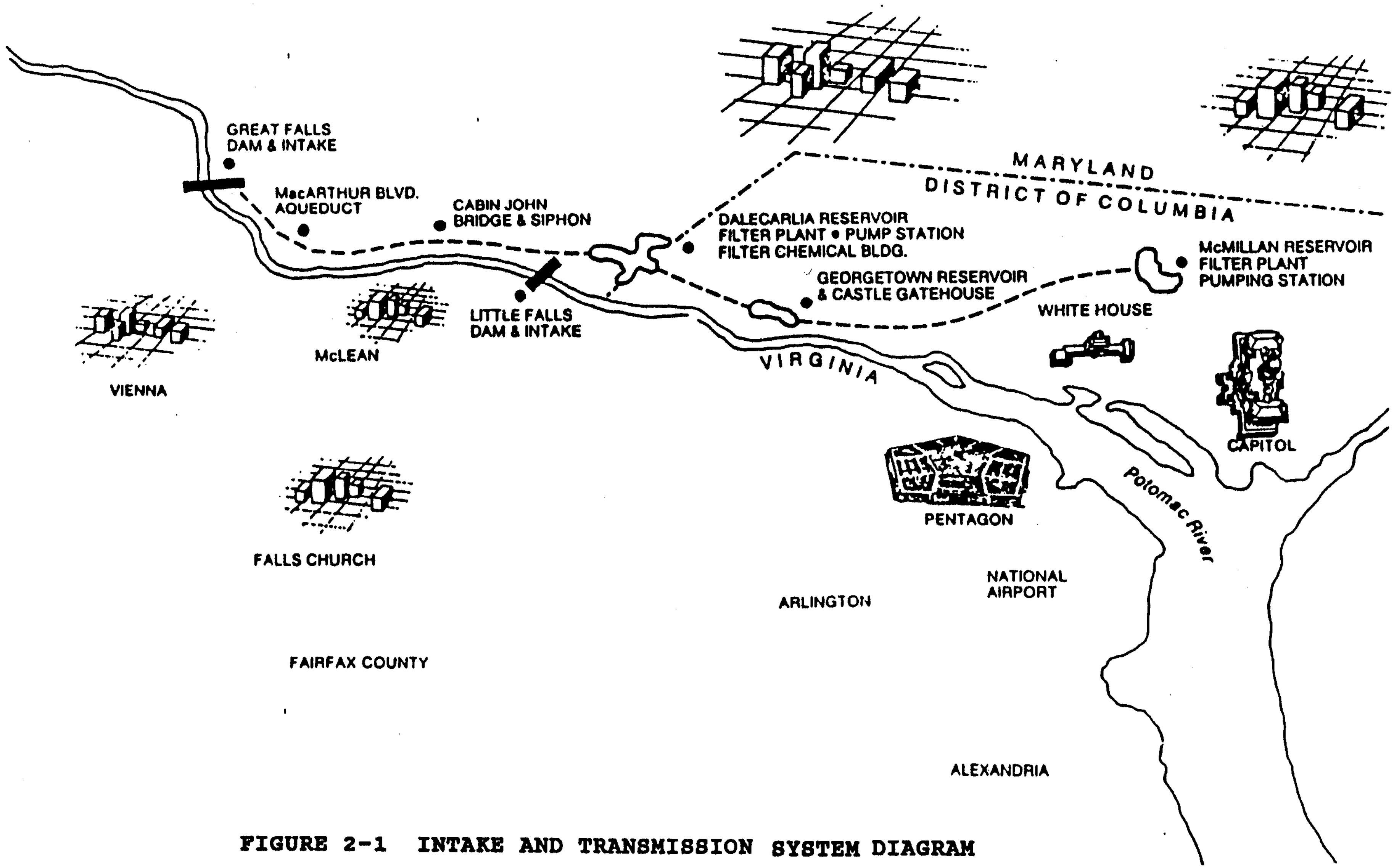


FIGURE 2-1 INTAKE AND TRANSMISSION SYSTEM DIAGRAM

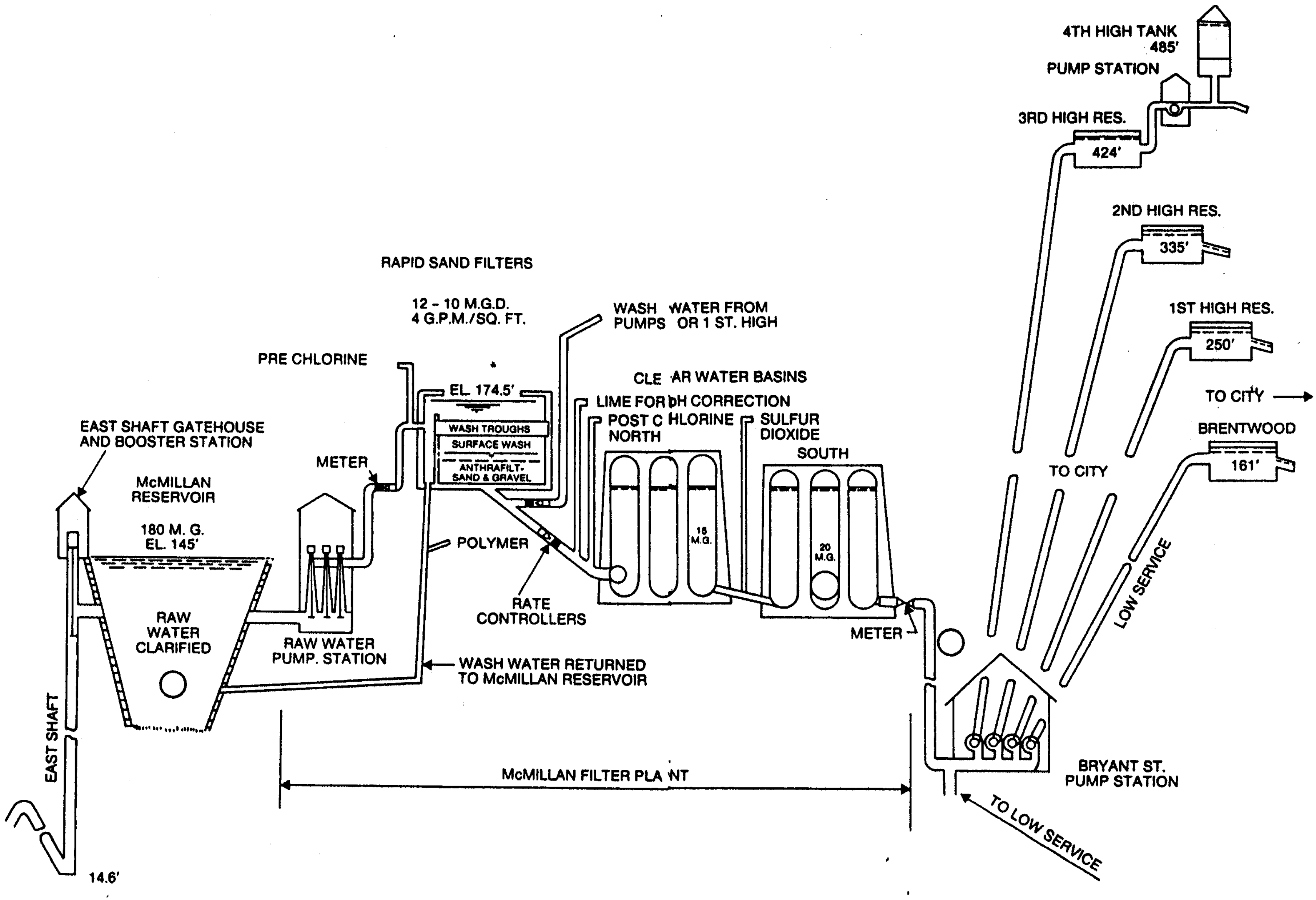


FIGURE 2-2 FLOW DIAGRAM OF THE MCMILLAN TREATMENT PLANT

2.1.1 Description of Current Corrosion Control Practices

Corrosion control is practiced at both treatment plants in the form of lime addition (calcium hydroxide). Lime addition has been used for many years at both treatment plants. Lime addition reduces corrosivity of plant-treated water by raising the pH and increasing the alkalinity. The dosage of lime applied to the filtered water is determined by the pH and turbidity of the water. The target pH level of between 8.0 and 8.5 is used as a guide. The amount of lime added to the filtered water is sometimes limited by the turbidity limit of 1 NTU since addition of lime also increases the turbidity of the finished water. Lime dosage is limited by turbidity mainly in the summer months. The monthly average lime dosage ranges from 39 to 109 pounds per million gallons at the Dalecarlia treatment plant and 32 to 62 pounds per million gallons at the McMillan treatment plant.

2.1.2 Database of Water Quality Data

A large quantity of water quality data is available for the District's water supply system. The Corps of Engineers collects raw water quality data, treated water quality data, and water quality data from sampling points located throughout the distribution system. These data provide the foundation on which the analysis of lead in the drinking water system is based.

Raw water samples collected and analyzed on a monthly basis for a variety of parameters were examined. The raw water data were examined to investigate lead levels in the water prior to treatment. Raw water quality data for the period 1984 through 1988 are presented in Appendix C.

Monthly water quality data after treatment at the two water treatment plants also were examined. The water quality parameters that were of particular interest were pH, alkalinity, calcium, temperature, total solids, hardness, and lead. These parameters were used in all water quality analyses presented in subsequent subsections of this report. Monthly average values of pH and alkalinity since 1985 for the Dalecarlia plant are shown in Figures 2-3 and 2-4. Treated water quality data for each of the treatment plants for the period 1984 through 1988 are presented in Appendix C.

The Corps of Engineers also collects water samples from 75 to 80 sampling points located throughout the distribution system. Of these, nine are used to sample for metals, including lead. The sites are sampled in pairs, with one pair being sampled once per month for a period of 3 months before samplers move to the next pair. These data represent water quality typical of that reaching a customer's service line. Monthly average values of pH and alkalinity of distribution system water since 1985 are shown in Figures 2-5 and 2-6.

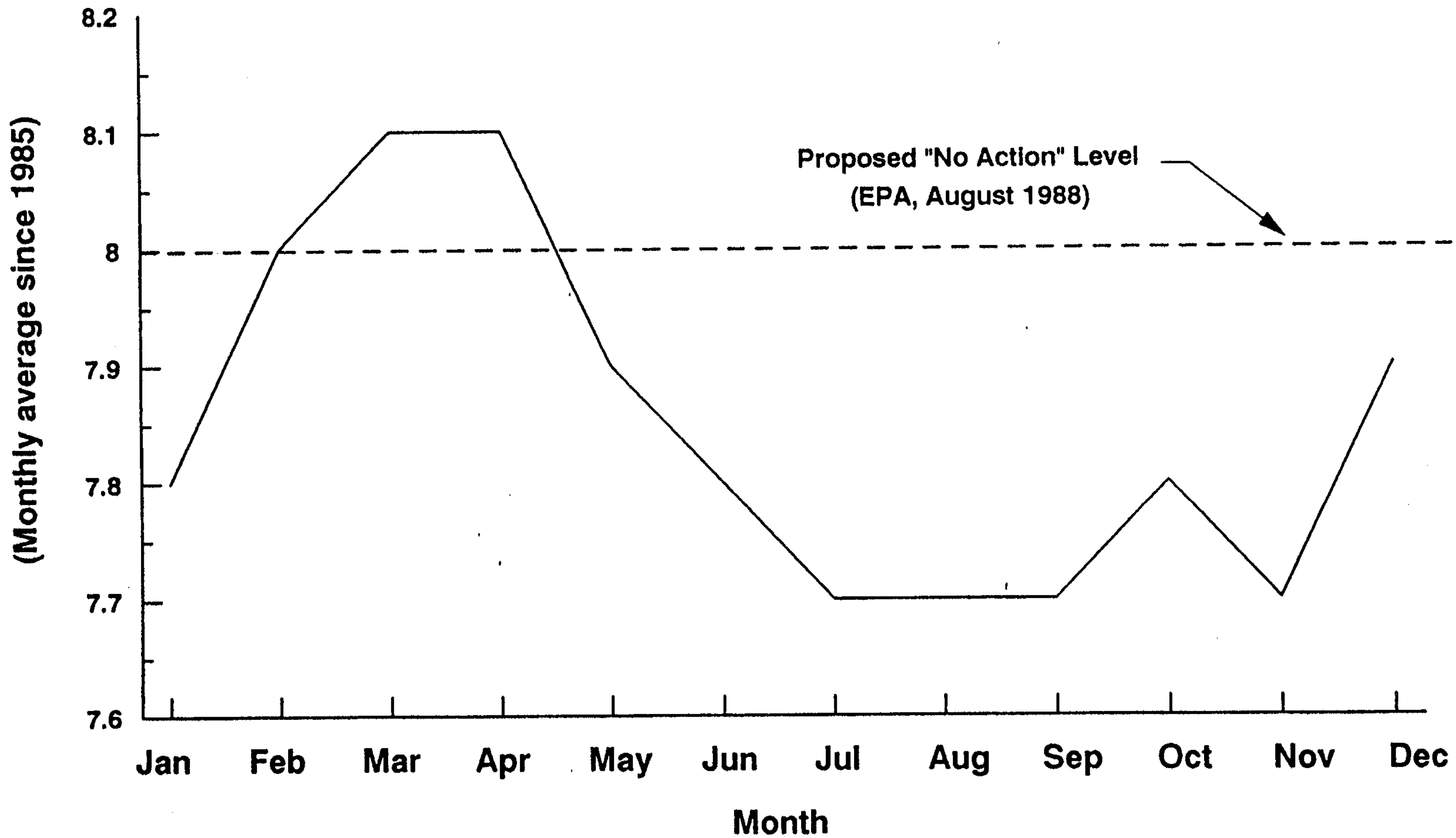


FIGURE 2-3 MONTHLY AVERAGE pH VALUES FOR THE DALECARLIA TREATMENT PLANT

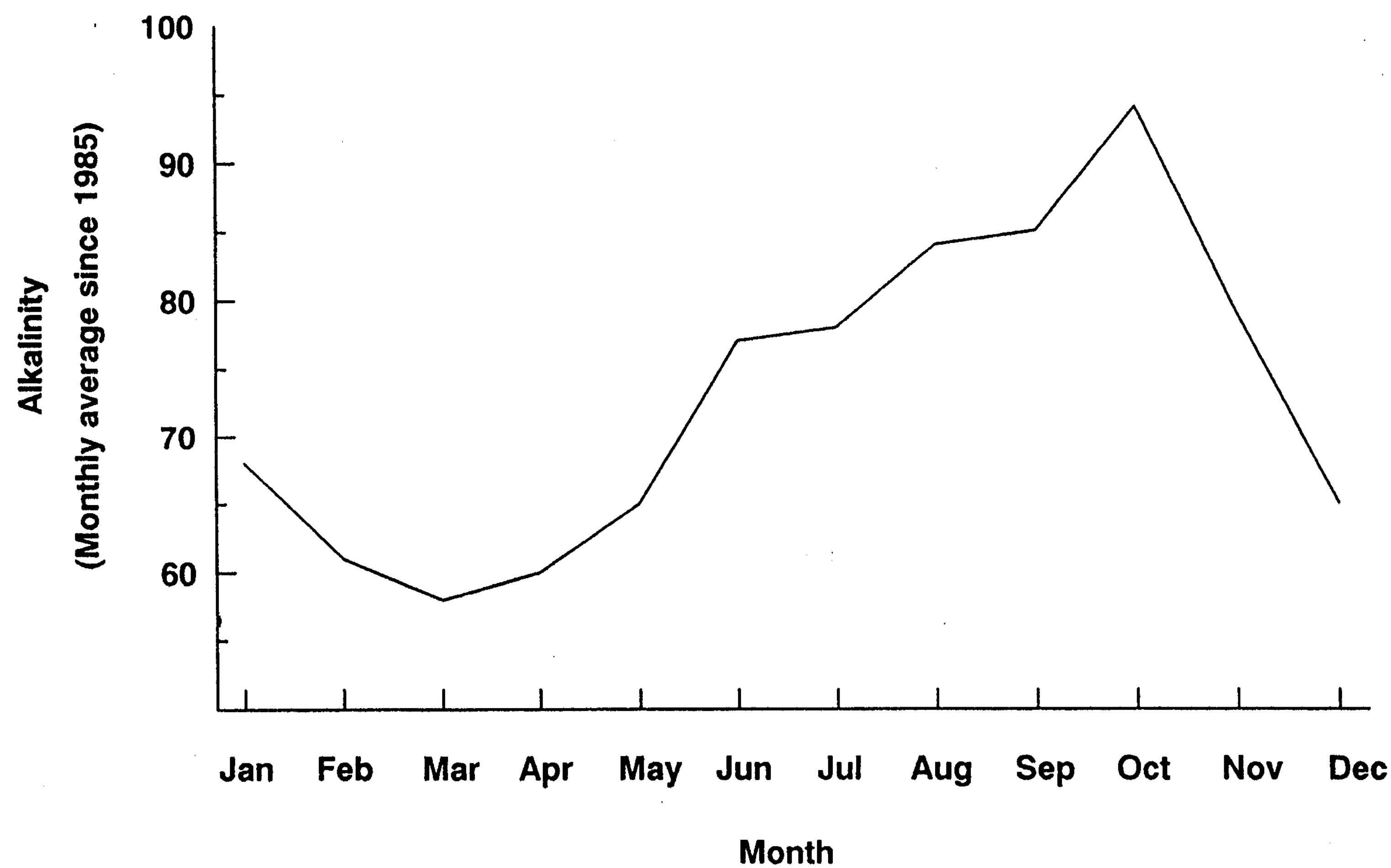


FIGURE 2-4 MONTHLY AVERAGE ALKALINITY VALUES FOR THE DALECARLIA TREATMENT PLANT

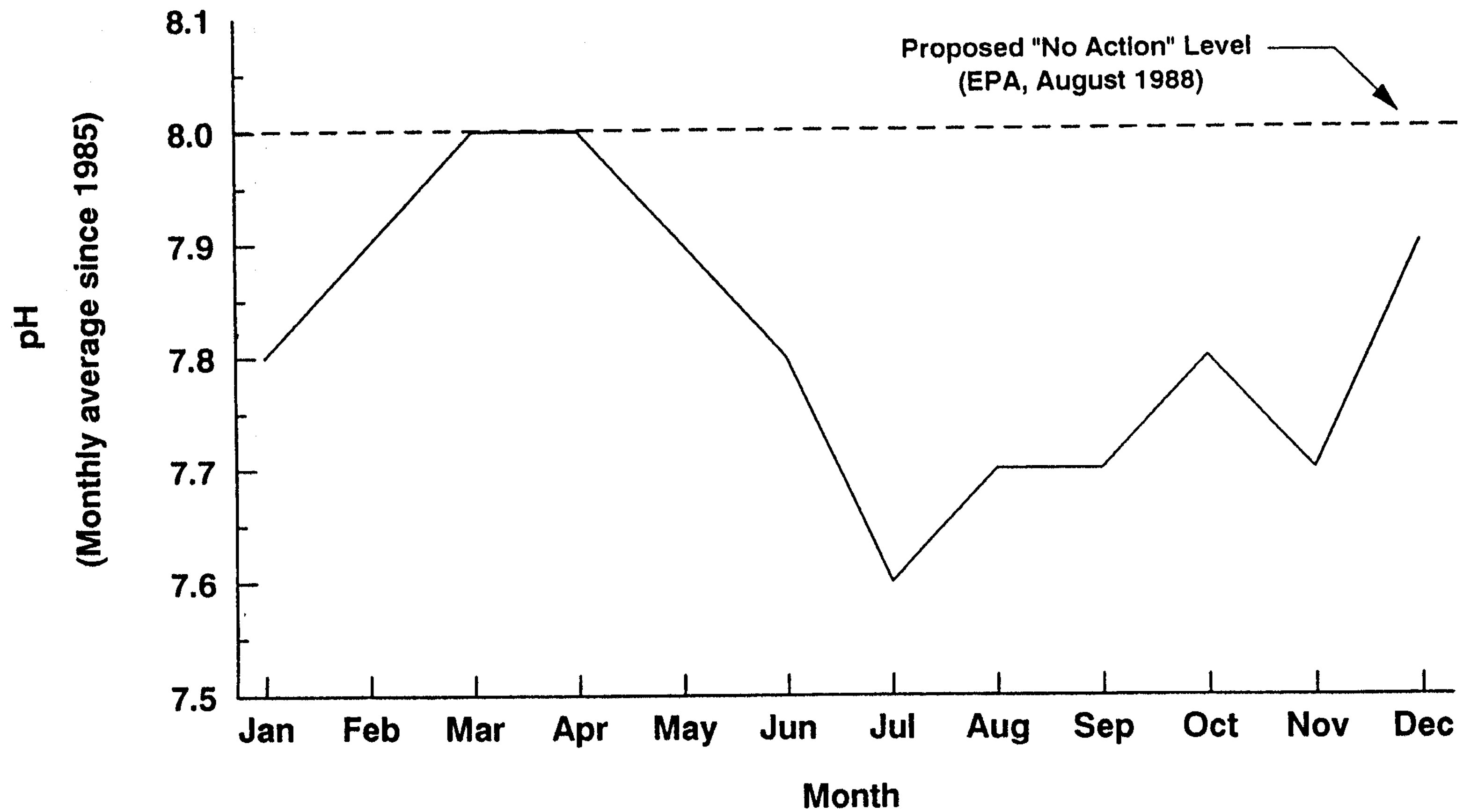


FIGURE 2-5 MONTHLY AVERAGE pH VALUES FOR DISTRIBUTION SYSTEM SAMPLING POINTS

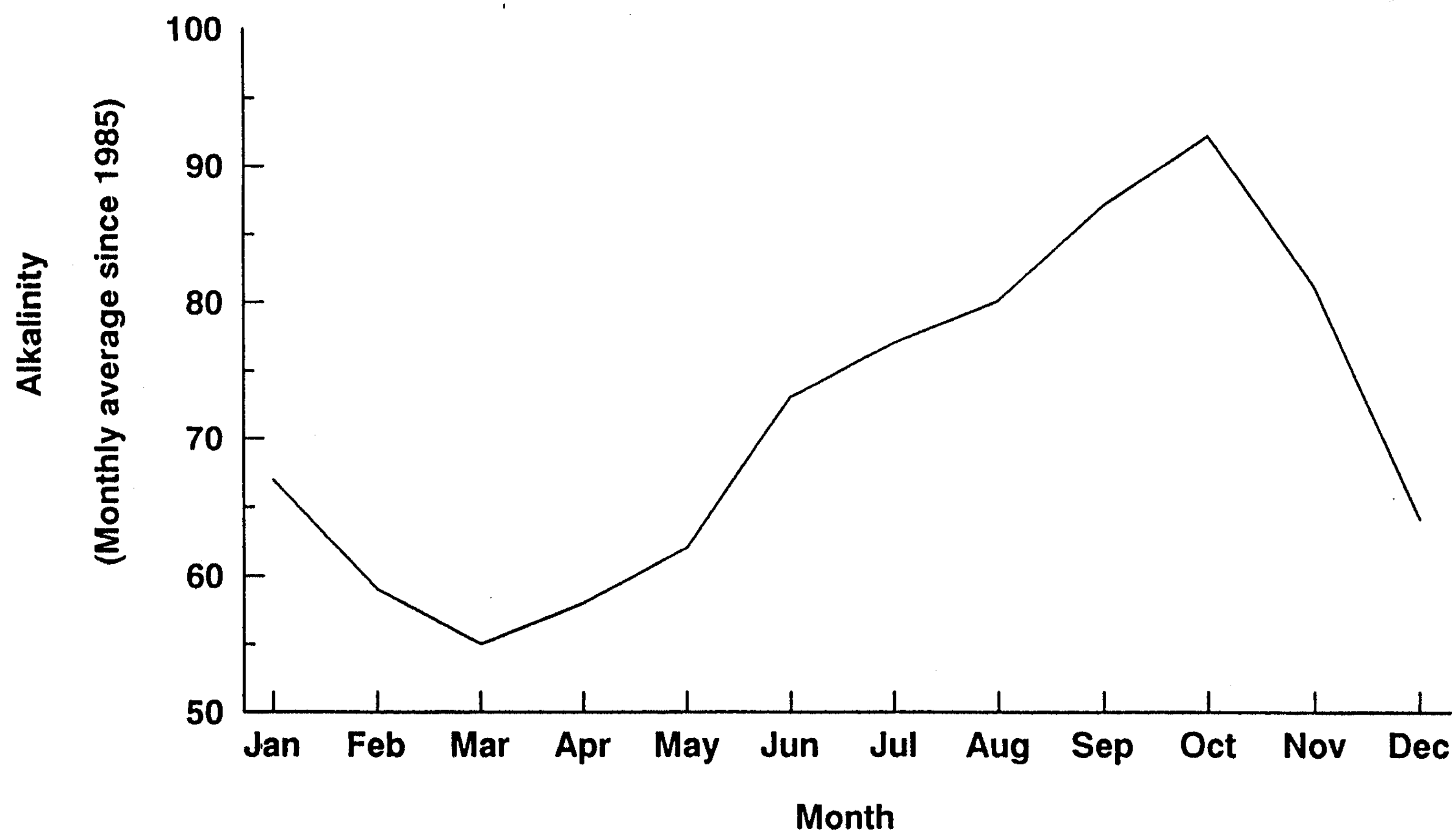


FIGURE 2-6 MONTHLY AVERAGE ALKALINITY VALUES FOR DISTRIBUTION SYSTEM SAMPLING POINTS

2.1.3 Langlier Index of Treated Water

One of the major sources of lead in drinking water is the corrosion of lead service lines and other lead-bearing materials in both the water distribution system and individual home plumbing systems. The Langlier Saturation Index (LSI) is an important indicator of whether such corrosion is taking place. This subsection briefly describes the LSI and how it is calculated and then presents the LSI calculated from water quality data for both the Dalecarlia and McMillan water treatment plants.

The LSI is a measure of the tendency of water to "lay down" or precipitate a protective coating of calcium carbonate ($CaCO_3$) in the interior service line wall. It is important to note that the LSI is not a measurement of the corrosiveness of water. It is simply an indication of the tendency of water to deposit a $CaCO_3$ layer. A thin layer of $CaCO_3$ is desirable as it keeps the water from contacting the service line and reduces the chance for corrosion. However, excessive deposits of $CaCO_3$ can reduce the carrying capacity of the service line.

EPA requires water system managers to calculate and report the LSI of their treated water. The basic procedure for calculating LSI has been in use since the early 1940s (Schock, 1984). The LSI is based on the effect of pH on the solubility of $CaCO_3$. The pH at which water is saturated with $CaCO_3$ is known as the pH of saturation or pH_s. At pH_s water will neither deposit nor dissolve a protective layer of $CaCO_3$. The LSI is defined as (EPA, 1984):

$$LSI = pH - pH_s$$

To calculate the LSI, the following information is needed:

- Total alkalinity as $CaCO_3$ (mg/L).
- Calcium as $CaCO_3$ (mg/L).
- Total dissolved solids (mg/L).
- pH.
- Temperature.

The pH_s can be calculated from these data using the following equation:

$$pH_s = A + B - \log(\text{calcium}) - \log(\text{total alkalinity})$$

Where: A = A constant based on temperature.
B = A constant based on total dissolved solids.

The calculated LSI can then be interpreted as follows:

- LSI > 0: Water is supersaturated and tends to precipitate a layer of $CaCO_3$.

- LSI = 0: Water is saturated (in equilibrium) with $CaCO_3$; a scale layer of $CaCO_3$ is neither precipitated nor dissolved.

- LSI < 0: Water is undersaturated and tends to dissolve $CaCO_3$.

Attempts have been made in the last several years to refine the calculation of LSI based on advances in the solubility chemistry of calcium carbonate and in solution chemistry. Schock (1984) described adjustments made to constants A and B that produce LSI figures more consistent with current aqueous chemical theory. He cautions, however, that it remains to be seen whether even these updated LSI calculations will provide any tangible improvements in the reliability of predicting calcium carbonate deposition.

Monthly water quality records from the Dalecarlia and McMillan water treatment plants were examined for the period 1984 through 1988. A LSI was calculated for each month using two different methods. The first method used the classic equations followed by EPA. These equations follow the typical water industry technique for calculating LSI. The second method used the corrections presented by Schock and produced slightly different values for LSI. The calculated LSI values are presented in Figure 2-7 for both methods.

2.2 LEAD IN THE DISTRICT'S DRINKING WATER

Lead is found in drinking water as a result of either naturally occurring lead in raw water sources or as a by-product of corrosion of plumbing materials. Source water lead levels are typically low, and the techniques for removal are well established. Controlling the corrosion of plumbing materials is more complicated, as there are many factors that affect the corrosion rate. This subsection describes the various ways in which lead enters the drinking water system and presents lead levels currently found in the District.

2.2.1 Sources of Lead

There are two potential sources of the lead found in any drinking water system. Lead may be present in the water source (i.e., the raw water), or may enter the water as a result of corrosion of plumbing materials containing lead. Raw water sources typically have low levels of lead. Of greater concern is lead entering the water as a result of corrosion within the water distribution system and of household plumbing materials. The following subsections describe the sources from which lead may enter the drinking water. Subsection 2.2.2 describes lead corrosion chemistry in more detail.

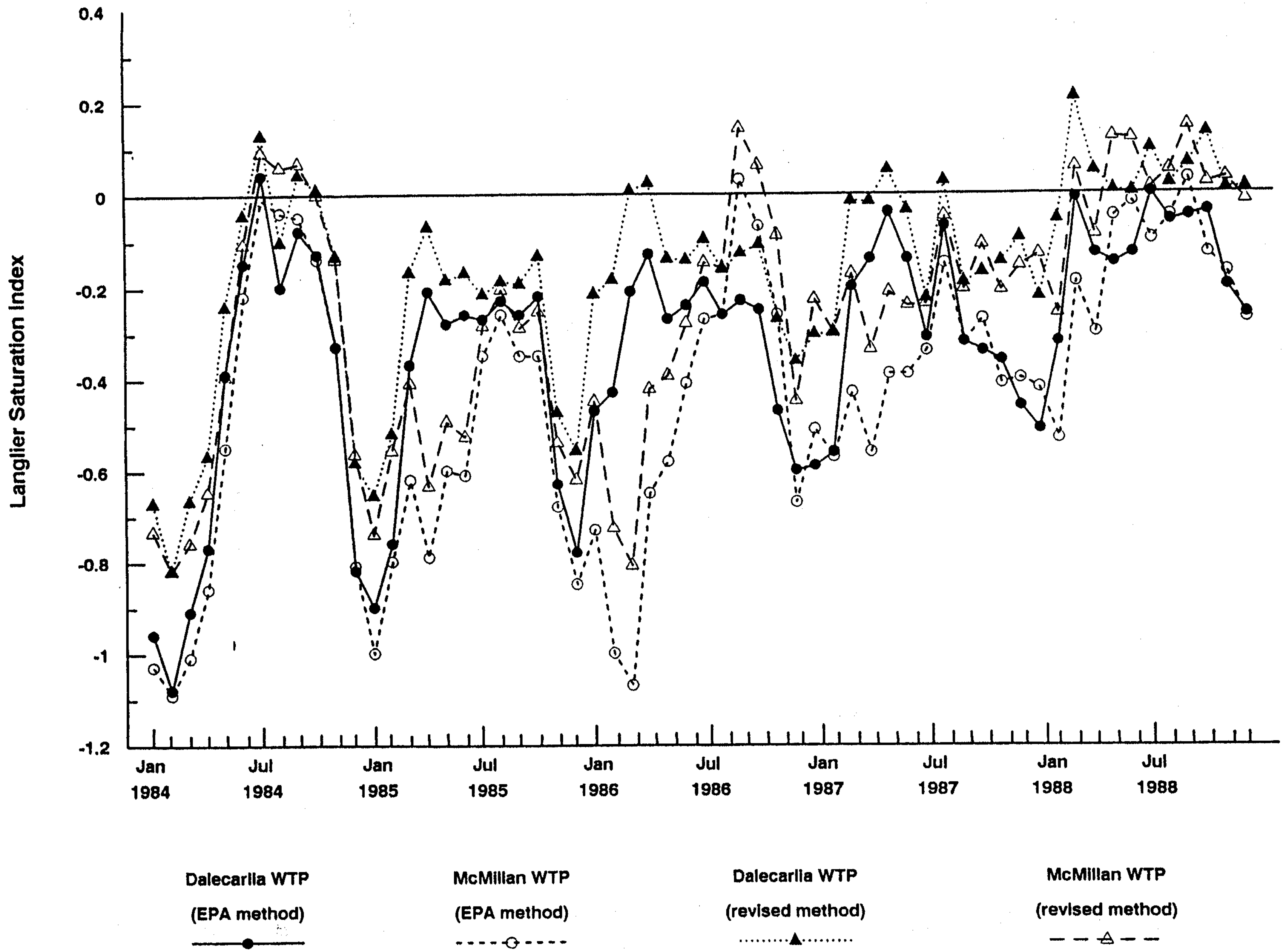


FIGURE 2-7 VARIATIONS IN THE FINISHED WATER LANGLIER INDEX

2.2.1.1 Lead in Source Water

Groundwater used as a drinking water source generally has very low lead concentrations (EPA, 1988). A 1967 study of 1,000 randomly chosen groundwater supplies (The National Inorganics and Radionuclides Survey or NIRS) found that approximately 5 percent of the samples taken exceeded 0.005 mg/L of lead. Due to the sampling procedure used, however, it was believed that lead may also have been present in the samples as the result of corrosion.

Therefore, EPA resampled the sources in the NIRS that showed positive results for lead, and found very few sources in which the lead level was above 0.005 mg/L. Based on these data, EPA has estimated that approximately 900 groundwater suppliers may have water leaving the treatment plant with lead levels greater than 0.005 mg/L (EPA, 1988). This represents approximately 1 percent of the community and nontransient, noncommunity water systems in the country.

Surface water typically contains higher levels of lead than do groundwaters. A significant portion of this lead exists in the form of suspended solids. The lead comes from naturally acquired lead in soils, atmospheric deposition, and industrial and municipal discharges to surface waters. However, water entering the distribution system from these sources generally has a much lower lead level than the raw water because of the effects of treatment, particularly coagulation and sedimentation.

EPA currently estimates that approximately 99 percent of the 219 million people in the country served by public water supplies (both surface and groundwater) are exposed to distribution water lead levels between 0 and 0.005 mg/L, and that the remainder are exposed to distribution water lead levels greater than 0.005 mg/L (EPA, 1988).

2.2.1.2 Lead as a Corrosion By-Product

Lead and lead-bearing materials are used in a variety of locations within both the water distribution system and in individual home plumbing systems. The word plumbing, in fact, derives from plumbum, the Latin word for lead. Although lead service lines within the distribution system are rare, EPA estimates that there are approximately 4.4 million lead service lines in use in the United States (EPA, 1988). In addition to lead service lines, lead is present in a variety of materials used within both distribution systems and home plumbing systems.

Lead materials have been used in plumbing applications for centuries because of the low cost, ease of use, durability, and availability of lead. Most water systems, including the District's, stopped using lead service lines in the late 1940s, although some cities were still installing lead service lines into the 1980s. The review of water distribution system records identified 1977 as the last year in which a lead service line was installed in the District. Recent Federal legislation has banned the use of lead and lead-bearing material for all plumbing use.

In general, lead and lead-bearing materials have been used for a variety of purposes within both distribution systems and individual home plumbing systems. However, in the District there are no significant sources of lead in the distribution system, excluding service connections to water mains. This is supported by the low lead concentrations measured in distribution system water. A list of typical locations where lead or lead-bearing materials may be found is given in Table 2-1. Lead may leach or dissolve into the drinking water from any of these locations, regardless of the age of the material. However, older materials will contribute lead at a slower rate. Descriptions of each of these potential sources, along with a method of alleviating the lead leaching problem, follow.

Jute/Lead Joint Packing -- A combination of jute and lead was commonly used at the junction of two or more cast iron water mains. Jute was tightly packed into the joint between the two pipes. Molten lead was then poured over the joint to mechanically join the pipe segments. However, since the lead theoretically never comes in contact with the water there should be no leaching of lead.

Galvanized Iron Service Line Connection -- It was a common practice in the District to use a short (2- to 4-foot) section of lead pipe to connect a galvanized iron service line to the distribution main. Galvanized iron pipe has a relatively short service life, and many galvanized iron service lines have been replaced. Galvanized iron pipe is no longer approved for use in new service line installations.

Lead Service Lines -- Lead pipe was commonly used to connect the water main in the street with the customer's home. The District stopped allowing the installation of lead service lines during the 1940s. Lead leaching from lead service lines may or may not affect the levels of lead at the consumer's tap. In many instances an insoluble lead carbonate film will have developed on the inside of the service line, thus preventing lead from entering the drinking water. Under other water quality conditions this film may not form, and water standing in the service line for extended periods, e.g., overnight, may have relatively high lead levels. The options for eliminating lead exposure from this source include removal of the lead service line, flushing of water from pipes before use, and/or treating the water to reduce its corrosive qualities.

Lead Pipes -- Some older homes may have lead pipes as part of the interior plumbing system. These pipes would have to be replaced to reduce the amount of lead in the drinking water. Lead pipes are easily identified; however, the cost of such rehabilitation can be expensive.

WESTON

Table 2-1

Locations of Lead in Plumbing and Distribution Systems

Location	Source
Distribution system	Jute/lead joint packing Galvanized iron service line connection
Household plumbing	Lead service lines Lead pipes Lead solder Brass fixtures Brass service lines

Lead Solder -- The most common household plumbing systems consist of copper pipe joined by a lead-based solder. Numerous studies have shown that lead will leach from this solder into the drinking water, especially when the soldering was done poorly and an excess of solder is present on the pipe interior. A good plumber may actually put more solder into the joints (rather than simply on the outer surface), thereby increasing exposure to lead. After a period of time (typically considered as approximately 5 years), the lead leaching rate from soldered joints is reduced to a relatively low level. Methods of avoiding lead due to solder joints include reconnecting all pipes with lead-free solder (defined as containing less than 0.2 percent lead) and the flushing of pipes prior to use for drinking or cooking. Lead-free solder is required for all new and remodeling projects.

Brass Fixtures -- The use of brass plumbing fixtures is almost universal. Brass generally contains 3 to 8 percent lead and is still allowed to contain this amount of lead under the 1986 Safe Drinking Water Act lead ban. A study by the American Water Works Service Company (Lee, Becker, and Collins, 1989) found that as much as one-third of the lead in a 1-liter, first-draw sample of water standing overnight in a kitchen tap is contributed from the brass faucet. Flushing the water from the tap prior to use or replacing the brass fixture with a lead-free substitute are options for reducing exposure to lead from this route.

Brass Service Lines -- There are a small number of brass service lines in use in the District. As with brass fixtures, a brass service line contains a small percentage of lead that may leach into the drinking water. The installation of brass pipe for a service line is uncommon, but brass pipe is still an approved material for service line installations.

2.2.2 Lead Corrosion Chemistry

The corrosion of lead plumbing materials is a complex phenomenon. Many of the chemical factors contributing to plumbosolvency have only recently been identified. There is a current need for data relating changes in lead concentration in the distribution system to specific measures for reducing corrosion for various types of water. Prediction of lead levels is hindered further by the fact that data from actual distribution systems seldom agree with those predicted by theory and controlled experiments. Despite these limitations, a sound chemical framework is essential in understanding lead corrosion and in evaluating potential remediation measures. Recent studies of corrosion of plumbing materials suggest that the chemical characteristics necessary to reduce corrosion from solder are different than those needed to reduce corrosion from brass faucets (Schock and Neff, 1988).

Solubility Control

Equilibrium thermodynamics predicts that lead carbonate (cerussite, $PbCO_3$) and basic lead carbonate (hydrocerussite, $Pb_3(OH)_2(CO_3)_2$) will be the predominant solid phases of lead at pH, Eh, and dissolved inorganic carbon (DIC) levels encountered in typical drinking waters. Generally, $PbCO_3$ is predominant in the 6 to 8 pH range, with $Pb_3(OH)_2(CO_3)_2$ the controlling phase at higher pHs. However, x-ray diffraction analysis of distribution pipe coatings seems to indicate that $Pb_3(OH)_2(CO_3)_2$ is the controlling phase regardless of pH (Schock and Gardels, 1983).

Factors Influencing Lead Solubility

Since $Pb_3(OH)_2(CO_3)_2$ appears to be the controlling solid phase in the distribution system, pH and DIC levels of the finished water will affect the leaching of lead from plumbing materials. DIC and pH also may affect solubility through complexation. The precipitation and complexation reactions controlling lead solubility, along with their stability constants, are given in Table 2-2.

EPA experiments (Schock and Gardels, 1983) have determined that a minimum lead solubility of 0.05 mg/L can be obtained at a pH of 9.5 to 10 and a DIC of 30 mg/L as $CaCO_3$. Thus, waters of high pH and low akalinity are nonaggressive to lead plumbing, and control of these variables provides a possible method of reducing lead corrosion. This work also demonstrates that calculations based on the stability constants listed in Table 2-2 provide an effective model for predicting equilibrium lead solubility as a function of DIC and pH.

Orthophosphate can combine with lead to form precipitates less soluble than those formed by carbonate. Thus, adding orthophosphate to finished waters prior to distribution may provide another method of reducing plumbosolvency. Calculations based on the formation of hydroxypyromorphite ($Pb_5(PO_4)_3OH$) indicate that lead solubilities as low as 0.003 mg/L can be achieved using 5 mg/L of orthophosphate to treat water containing 5 mg/L DIC as $CaCO_3$ at a pH of 7.5 to 8 (Schock, 1989). In a survey conducted by the American Water Works Service Company (Lee, Becker, and Collins, 1989) of 96 water companies and districts, the average lead concentration at 11 utilities that employed orthophosphate addition was 0.004 mg/L, the lowest of any of the survey groups. Thus, orthophosphate addition appears to be a promising technology for controlling lead in distribution systems. One drawback to orthophosphate addition, however, is that it may elevate the phosphate levels in the wastewater.

Limitations of Solubility Calculations

Solubility calculations usually agree well with measured lead concentrations in experimental pipe loop systems. However, lead

Table 2-2

Complexation and Precipitation Reactions

	Reaction	Log K	Reference
	Complexation		
1.	$Pb^{2+} + H_2O = PbOH^+ + H^+$	-7.23	(Schock and Gardels, 1983)
2.	$Pb^{2+} + 2H_2O = Pb(OH)_2 + 2H^+$	-16.9	(Schock and Gardels, 1983)
3.	$Pb^{2+} + 3H_2O = Pb(OH)_3^- + 3H^+$	-28.1	(Schock and Gardels, 1983)
4.	$Pb^{2+} + 4H_2O = Pb(OH)_4^{2-} + 4H^+$	-39.7	(Schock and Gardels, 1983)
5.	$Pb^{2+} + CO_3^{2-} = PbCO_2$	7.1	(Schock and Gardels, 1983)
6.	$Pb^{2+} + 2CO_3^{2-} = Pb(CO_3)_2^{2-}$	10.3	(Schock and Gardels, 1983)
	Precipitation		
7.	$3Pb^{2+} + 2CO_3^{2-} + 2H_2O = Pb_3(CO_3)_2(OH)_2 + 2H^+$	18.0	(Schock and Gardels, 1983)
8.	$5Pb^2 + H_2O + 3PO_4^{2-} = Pb_5(PO_4)_3OH + H^+$	62.8	(Hogfeldt, 1982)

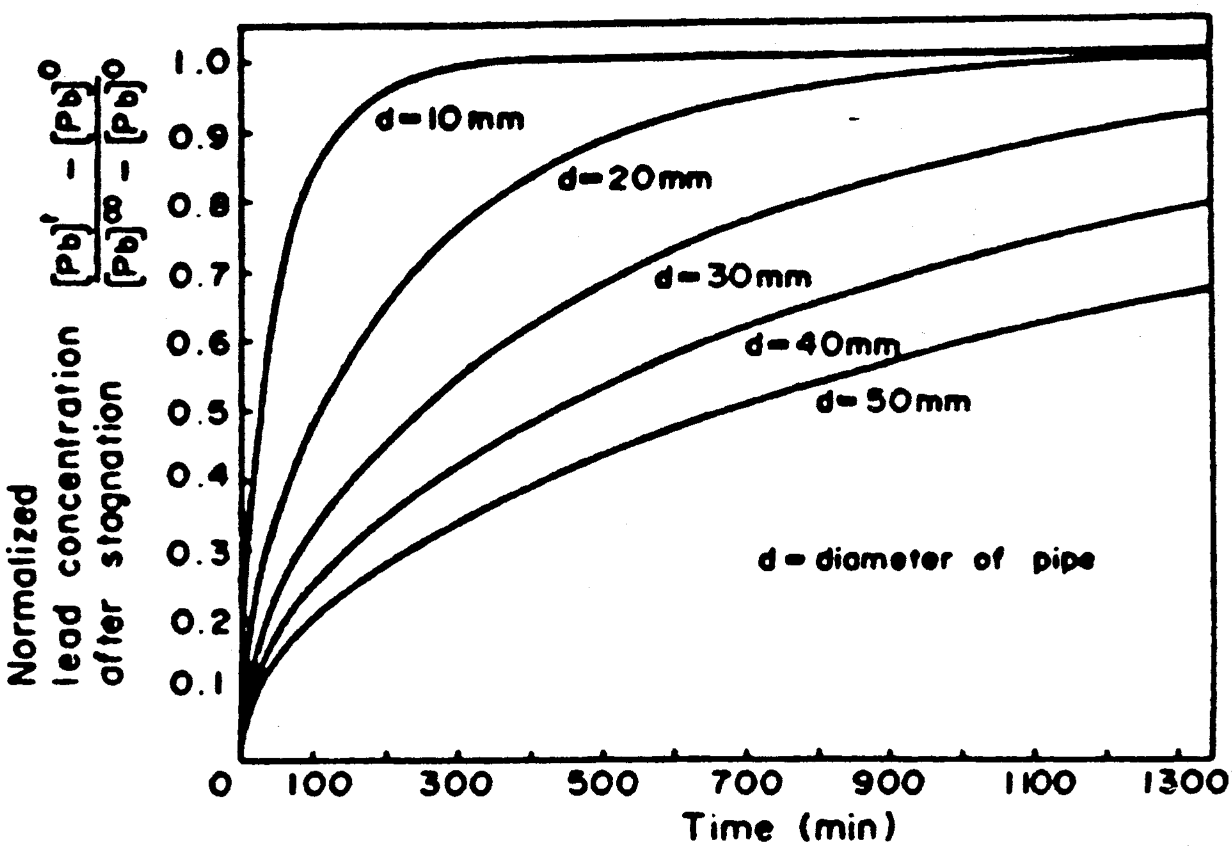
levels measured in actual distribution systems are generally much lower than those predicted by solubility models. For instance, in the aforementioned survey (Lee, Becker, and Collins, 1989), the most corrosive waters (pH < 7.0) had an average lead concentration of only 0.019 mg/L, with only 16 percent of all samples having concentrations higher than 0.020 mg/L. Solubility calculations for these waters would predict lead levels up to 1 mg/L. Factors that may contribute to the discrepancy between model calculations and field data include dilution, inhibition by diffusion, occurrence of unidentified lead compounds of low solubility, protective coatings on interior pipe surfaces, and nonequilibrium sampling conditions (slow kinetics of dissolution) (Schock, 1989). Therefore, although lead solubility calculations provide a basis for determining the tendency of a water type to leach lead, these calculations predict lead levels that are typically much greater than observed lead concentrations in actual distribution systems.

Diffusion Effects

As mentioned previously, diffusion limitation is one factor that may cause the observed lead concentration to be less than that predicted by equilibrium calculations. Since the water will often remain stagnant in service lines and in home plumbing between periods of use, the effect of this factor is of particular interest. Kuch and Wagner (1983) developed a radial diffusion model to predict the approach to equilibrium lead concentration as a function of stagnation time. The results predicted by the model for various diameters are presented in Figure 2-8. For a typical 3/4-in.-diameter (20-mm) service line, the model predicts that the lead concentration will approach 80 to 90 percent of the equilibrium lead concentration for a typical overnight stagnation time of 6 to 10 hours. Thus, lead concentrations in first-draw samples can approach equilibrium concentrations after standing overnight in home plumbing. Diffusion from the interior surface of the pipe does not appear to limit the rate of lead leaching for small diameter pipes.

Deposition of Protective Coatings

Many solid phases that limit lead solubility also act as a physical barrier between the water and plumbing materials. For example, $Pb_3(OH)_2(CO_3)_2$ and $Pb_5(PO_4)_3OH$ meet this description. Waters that are supersaturated with $CaCO_3$ may precipitate protective coatings in the distribution system and provide an effective barrier against corrosion. However, as will be described, conditions promoting $CaCO_3$ precipitation also increase lead solubility. Care must be taken to ensure that the water is properly conditioned to provide an effective coating and to avoid excess scaling.



Source: Kuch and Wagner, 1983.

FIGURE 2-8 PLOT OF NORMALIZED LEAD CONCENTRATION AS A FUNCTION OF STAGNATION TIME FOR LEAD PIPES OF DIFFERENT DIAMETERS

Silicate and polyphosphate addition also are believed to provide protective coatings under certain circumstances. However, the solid phases resulting from such precipitants have not been identified. Thus, the conditions favorable to the production of protective coatings can be predicted only after extensive experimentation with the water and distribution system of interest.

2.2.3 Existing Lead Levels

The District has access to lead in water data for all parts of its water system. The Army Corps of Engineers has data on raw water from the Potomac River, on treated water leaving the Dalecarlia and McMillan treatment plants, and from several sampling points located throughout the distribution system. In addition, the Department of Consumer and Regulatory Affairs (DCRA) has collected data on lead levels at the customers' taps from more than 2,200 homes throughout the District. This subsection describes the data available from these sources and presents the lead levels typically found in the District's drinking water.

EPA first promulgated a Maximum Contaminant Level (MCL) for lead in 1975 as part of the interim drinking water regulations. The MCL was set at 50 ug/L (50 parts per billion) and is still in effect today. In November 1985, EPA began the process of revising the standards for both lead and copper by proposing Maximum Contaminant Level Goals (MCLGs) for each of them. The MCLG for lead was set at 20 ug/L at that time.

In August 1988, EPA proposed new standards for both lead and copper. These standards set the MCLG for lead at 0.0 mg/L. [The MCLG is a nonenforceable level at which "no known or anticipated adverse effects on the health of persons occur and which allows an adequate margin of safety" (EPA, 1988)]. The proposed MCL for lead, measured at the entry points to the distribution system, was set at 5 ug/L.

In addition, EPA also proposed a set of no-action levels for lead and copper. Compliance with these no-action levels was to be measured at the customer's faucet. The four no-action levels were defined as follows:

- 1 -- Average lead level $\leq$ 0.010 mg/L (10 ug/L).
- 2 -- No more than 5 percent of samples > 1.3 mg/L (copper).
- 3 -- No more than 5 percent of samples have pH < 8.
- 4 -- Lead level $\leq$ 0.020 mg/L (20 ug/L) in 95 percent of samples.

The sampling program required to monitor for compliance with these no-action levels varies according to the size of the system. In all cases, however, the samples were to be collected in homes considered to be "worst case." If any one of the first three no-action levels is exceeded, the water system must install or improve its corrosion control capabilities. If no-action level 1 or 4 is exceeded, the water system must conduct a public education program.

The lead and copper rules proposed in August 1988 generated a great deal of comment, both from environmental groups and the water industry. EPA is not expected to produce the final regulations for lead and copper until the end of 1990.

2.2.3.1 Source Water

The Corps of Engineers reports raw water lead levels on a monthly basis. Examination of these data for the years 1984 through 1988 shows a maximum lead level of 0.0095 mg/L occurred in November 1986, while levels of 0.0 (i.e., nondetectable) were found on two occasions. The average lead content in the raw water over this time period was 0.0015 mg/L. This compares favorably with the current lead MCL of 0.05 mg/L and with the anticipated proposed MCL for water entering the distribution system of 0.005 mg/L. A complete breakdown of lead levels in raw water for these years is shown in Figure 2-9.

2.2.3.2 Treatment Plant

The Corps of Engineers reports treated water lead levels on a monthly basis for each water treatment plant (WTP). Examination of these data for the years 1984 through 1988 shows a maximum lead concentration of 0.0019 mg/L at the Dalecarlia WTP, and a maximum of 0.0134 mg/L at the McMillan WTP. The average lead concentrations were 0.0005 mg/L and 0.0009 mg/L at the Dalecarlia WTP and McMillan WTP, respectively.

Lead concentrations at the Dalecarlia WTP were consistently below both the current and proposed MCLs for lead in treated water. However, in May and June 1985 the lead levels in the treated water at the McMillan WTP exceeded the anticipated proposed MCL for lead in treated water of 0.005 mg/L. A summary of lead levels in the water from both treatment plants from 1984 through 1988 is presented in Figure 2-10.

2.2.3.3 Distribution System

The Corps of Engineers reports lead concentrations in water from sampling points located throughout the District. These data, available for the years 1984 through 1988, are presented in Table 2-3.

Examination of the data shows that the current MCL for lead of 0.05 mg/L (50 ug/L) (which is for water leaving the treatment plant) has not been exceeded at any of the sites. However, the anticipated lead rules are expected to set much lower allowable lead levels.

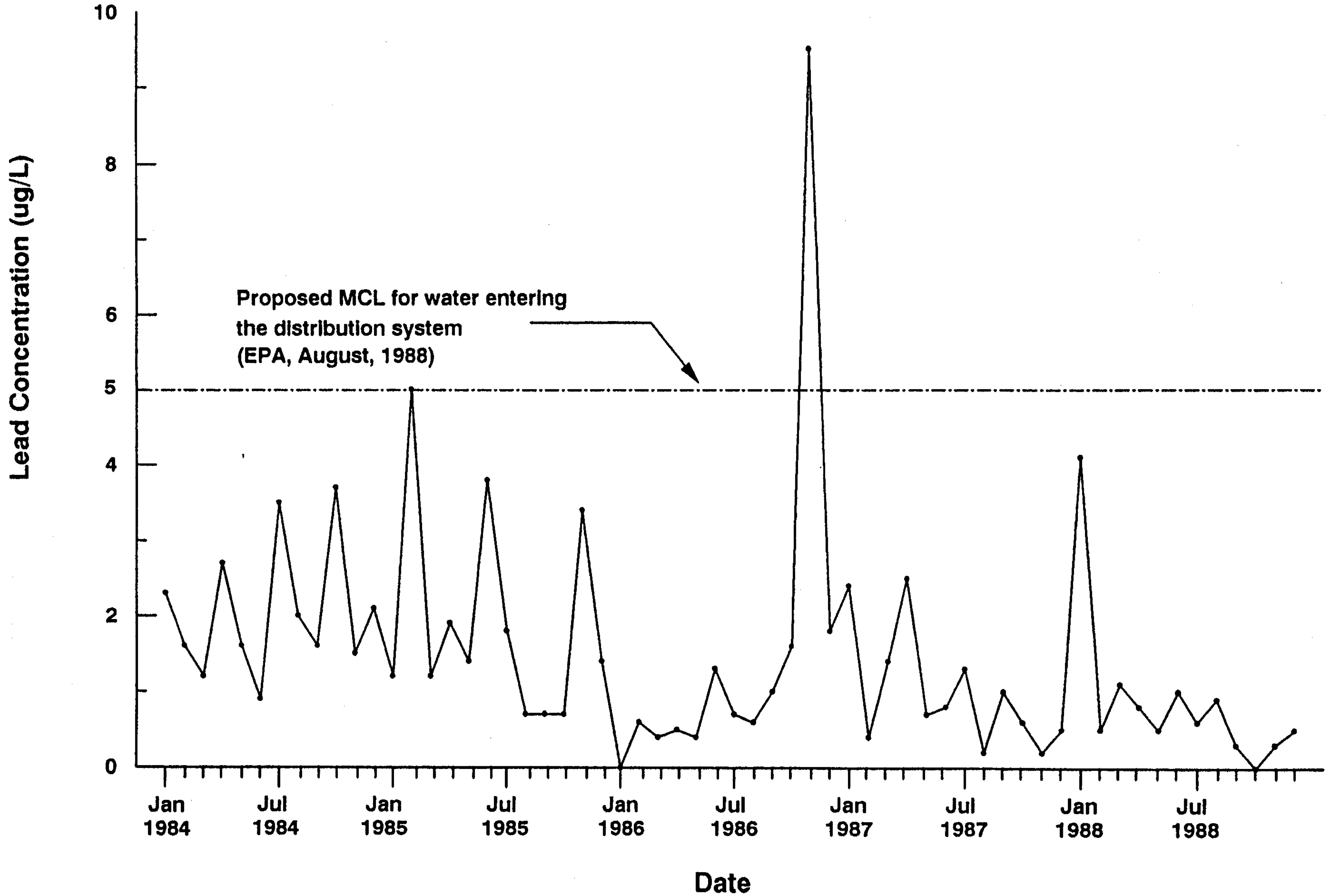


FIGURE 2-9 RAW WATER LEAD CONCENTRATIONS

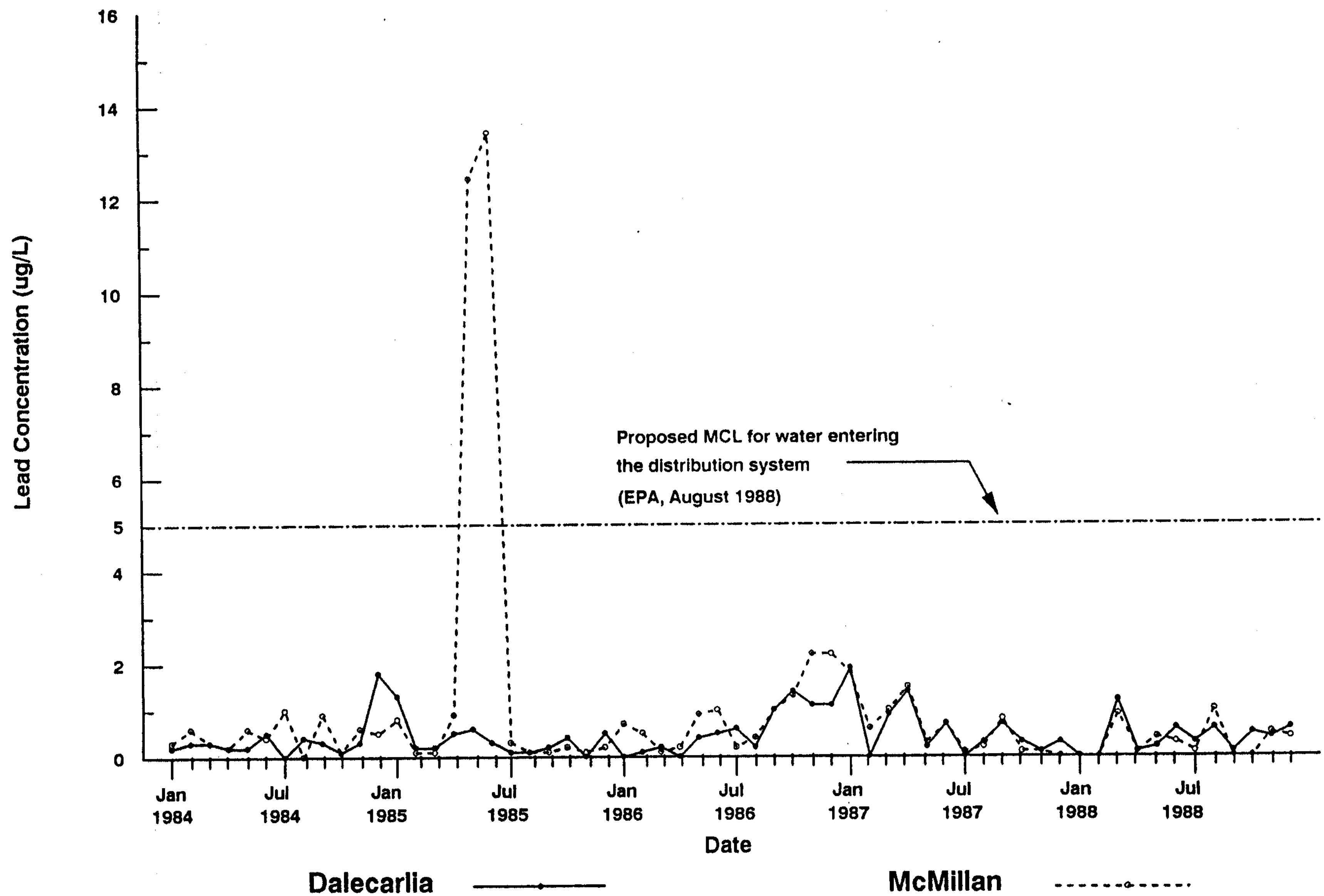


FIGURE 2-10 TREATED WATER LEAD CONCENTRATIONS

Table 2-3

Distribution System Lead Concentrations

LOCATION c-10		LOCATION c-14		LOCATION c-22		LOCATION c-29		LOCATION c-42		LOCATION c-49		LOCATION c-54		LOCATION c-7		LOCATION c-9	
DATE	LEAD VALUE	DATE	LEAD VALUE	DATE	LEAD VALUE	DATE	LEAD VALUE	DATE	LEAD VALUE	DATE	LEAD VALUE	DATE	LEAD VALUE	DATE	LEAD VALUE	DATE	LEAD VALUE
08/05/85	2.3	10/03/84	6.8	04/09/85	0.5	01/03/85	4.8	08/02/85	0.1	04/10/85	1.0	04/09/86	0.2	01/04/85	0.7	10/04/84	0.2
09/09/85	3.2	11/09/84	0.5	07/02/85	2.3	02/14/85	5.9	09/06/85	2.3	05/01/85	2.3	05/02/86	0.3	02/08/85	1.5	11/06/84	2.3
07/03/86	0.2	12/12/84	0.6	04/08/86	0.2	03/07/85	3.9	07/07/86	0.2	06/06/85	1.0	06/03/86	0.6	01/13/86	0.8	12/10/84	0.9
08/04/86	0.6	11/08/85	0.7	05/01/86	1.3	05/02/85	2.7	08/04/86	3.3	07/08/85	2.3	04/07/87	2.3	02/05/86	0.9	10/03/85	0.8
09/09/86	2.0	12/04/85	0.4	04/07/87	1.8	06/04/85	5.0	09/10/86	3.0	04/12/88	0.7	05/20/87	1.9	03/05/86	0.5	11/07/85	0.8
07/06/87	1.5	10/08/86	5.7	06/02/87	2.6	01/16/86	1.8	07/06/87	0.8	05/17/88	20.0	06/02/87	1.1	01/07/87	1.8	12/04/85	0.5
08/04/87	1.8	11/10/86	1.4	04/12/88	0.5	02/04/86	1.7	08/05/87	0.9	06/01/88	1.4	04/04/89	0.9	02/04/87	14.1	10/07/86	3.0
09/10/87	5.1	10/16/87	0.5	05/17/88	0.5	03/04/86	1.3	09/09/87	2.1					03/06/87	1.0	11/10/86	1.7
07/01/88	2.9	11/25/87	1.4	06/01/88	1.4	01/07/87	3.7	07/01/88	0.4					01/22/88	6.9	12/01/86	1.8
08/01/88	5.2	12/14/87	0.5	04/04/89	0.8	02/05/87	0.8	08/01/88	1.3					02/08/88	0.6	10/13/87	1.5
09/01/88	1.3	10/03/88	0.4			03/03/87	0.3	09/02/88	0.4					03/07/88	1.0	11/24/87	0.2
		11/02/88	0.2			01/19/88	4.8							01/04/89	0.6	12/14/87	0.8
		12/05/88	0.5			02/09/88	0.8							02/01/89	1.3	10/03/88	0.4
						03/08/88	1.7							03/01/89	3.5	11/01/88	0.3
						01/10/89	2.3									12/05/88	4.7
						02/02/89	2.5										
						03/02/89	2.0										
AVG =	2.37	AVG =	1.51	AVG =	1.19	AVG =	2.71	AVG =	1.35	AVG =	4.10	AVG =	1.04	AVG =	2.51	AVG =	1.33
MIN =	0.2	MIN =	0.2	MIN =	0.2	MIN =	0.3	MIN =	0.1	MIN =	0.7	MIN =	0.2	MIN =	0.5	MIN =	0.2
MAX =	5.2	MAX =	6.8	MAX =	2.6	MAX =	5.9	MAX =	3.3	MAX =	20.0	MAX =	2.3	MAX =	14.1	MAX =	4.7

All lead values given in ug/L.

Location Index

c-10 Connecticut Ave. and Fessenden St., NW
c-14 13th and K Sts, NW
c-22 18th St and Rhode Island Ave., NE
c-29 Minnesota Ave. and Hayes St, NE
c-42 4th and E Sts, SW
c-49 1500 Pennsylvania Ave, SE
c-54 8th and E STs, SE
c-7 1227 Monroe St, NW
c-9 1301 East Capitol St, NE

2.2.3.4 Customer's Faucet

The District has conducted three water sampling studies to collect data on lead levels in water at the customer's faucet. Data Sets 1 and 2 consisted of information on midday and first flush samples from 941 homes, while Data Set 3 contained information on first flush sample results from 1,330 homes. These sampling efforts were described in detail in Section 1. The results of these sampling efforts are described in the following subsections.

Four basic types of samples were collected during the sampling efforts, although not all homes had all four samples collected. The midday sample was taken during the day with the water in contact with home plumbing for a short duration. The A, B, and C samples were first flush samples taken after allowing the water to stand overnight for a minimum of 8 hours. Sample A was the first 1 liter of water drawn from the kitchen faucet. Sample B was meant to be a sample of water standing in the service line overnight. Finally, Sample C was meant to be a sample of water from the distribution system.

2.2.4 Data Evaluation

The monthly data for finished water quality and lead concentrations in the distribution system for the Dalecarlia and McMillan WTPs, for the period 1984 through 1988, are analyzed in this subsection. Prior to analysis, the quality of the treatment plant data was assessed by performing an ion charge balance for each monthly water analysis. A charge balance error of <10 percent was considered acceptable. All monthly data sets met this criterion, with the majority being within 5 percent. Likewise, a hardness balance also was within acceptable limits.

Lead Solubility

The solubility of lead, assuming equilibrium with $Pb_3(OH)_2(CO_3)_2$, was calculated for each month based on the average water quality measured in each month. All calculations were made at 25°C and at an ionic strength effect of 0.01 M. To calculate the total soluble lead, the concentration of Pb^{2+} was first calculated from the pH and alkalinity assuming equilibrium with $Pb_3(OH)_2(CO_3)_2$ alone (Equation 7 in Table 2-2). Next, the concentrations of soluble lead complexes were computed from pH, alkalinity, and Pb^{2+} concentration based on the reactions and stability constants listed in Table 2-2. Finally, concentrations of all soluble lead complexes and Pb^{2+} were added to obtain the total lead solubility.

The calculated solubilities of treated waters from each of the two treatment plants are shown in Figure 2-11. Calculated lead solubilities range from 0.14 to 0.34 mg/L. The calculated lead

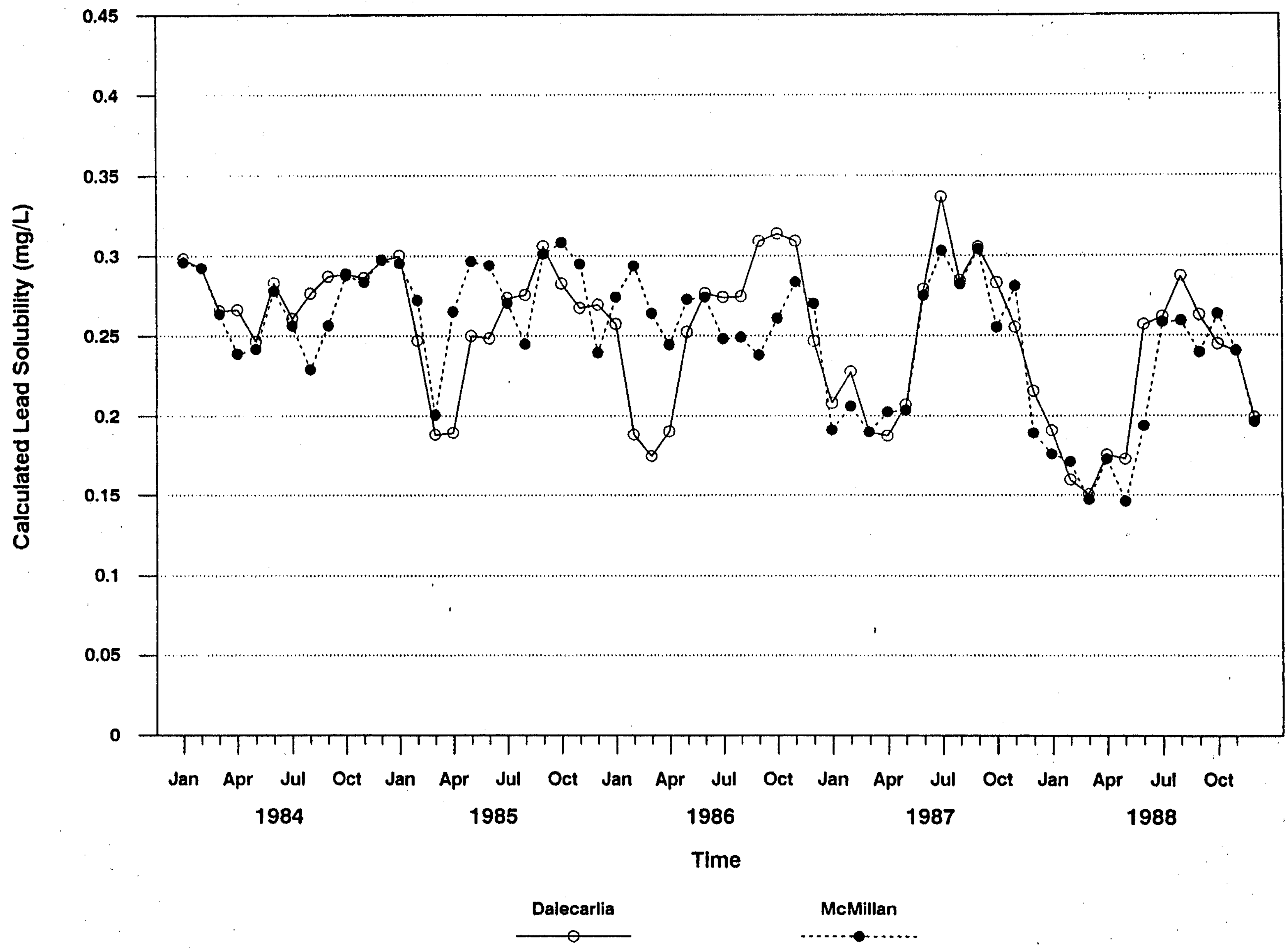


FIGURE 2-11 VARIATION IN CALCULATED LEAD SOLUBILITY

solubilities of the finished waters from the two plants are quite similar. There also is an apparent seasonal trend to the solubility calculations; lead solubility is high from August to December relative to that from January to July. It appears these variations are related to seasonal changes in the raw water quality.

As shown in Figure 2-11, the calculated lead solubility invariably exceeded the current 0.050 mg/L for lead. However, when the predicted solubilities are compared with observed lead concentrations in the District's distribution mains (Figure 2-12), first-draw samples in homes served by lead service lines (Figure 2-13), and first-draw samples in homes served by nonlead service lines (Figure 2-14), relatively few violations of the current MCL are observed. The new no-action limit proposed by EPA is 0.010 mg/L measured at the customer's tap. Comparisons between predicted and observed lead concentrations in the District's water mains and in first-draw samples collected from customers' taps can aid in evaluating various strategies for meeting the new no-action limit.

In Figure 2-12, the measured lead concentrations in the District's distribution mains are plotted against predicted lead solubilities for the period 1984 through 1988. Measured lead concentrations are very low during this period. There were no violations of the current 0.050 mg/L MCL measured during this period; and only 2 of the 105 samples would have been in violation of the proposed no-action limit. It can be concluded that there is little potential for leaching of lead from the District's mains.

It was desired to obtain a relationship between the calculated equilibrium lead solubility and observed lead concentration in homes served by lead service lines. Preliminary analysis of the Data Set 3 database indicated that the distribution of observed lead concentrations is lognormal. Thus, the natural logarithms of the observed lead concentrations were plotted against the equilibrium values as shown in Figure 2-13. The relationship between predicted and observed lead concentrations is as follows:

$$\ln Pb_{obs} = 0.00663\ Pb_{eq} + 0.9442 \qquad (1)$$

This relationship was found to be statistically significant ($r = 0.273$, $p < 0.001$). However, it is unsuitable for predicting actual lead concentrations because of the variation in observed concentration for a given equilibrium value. The 95-percent prediction limit also was plotted as shown in Figure 2-13. The point at which the 95-percent prediction limit crosses the no-action limit could serve as a target value for equilibrium lead solubility. If the chemistry of the water could be adjusted so that the equilibrium lead solubility was below this target value, 95 percent of all observed lead concentrations should be below the no-action limit. Unfortunately, the statistical 95-percent prediction limit (labeled "A" in Figure 2-13) did not cross the

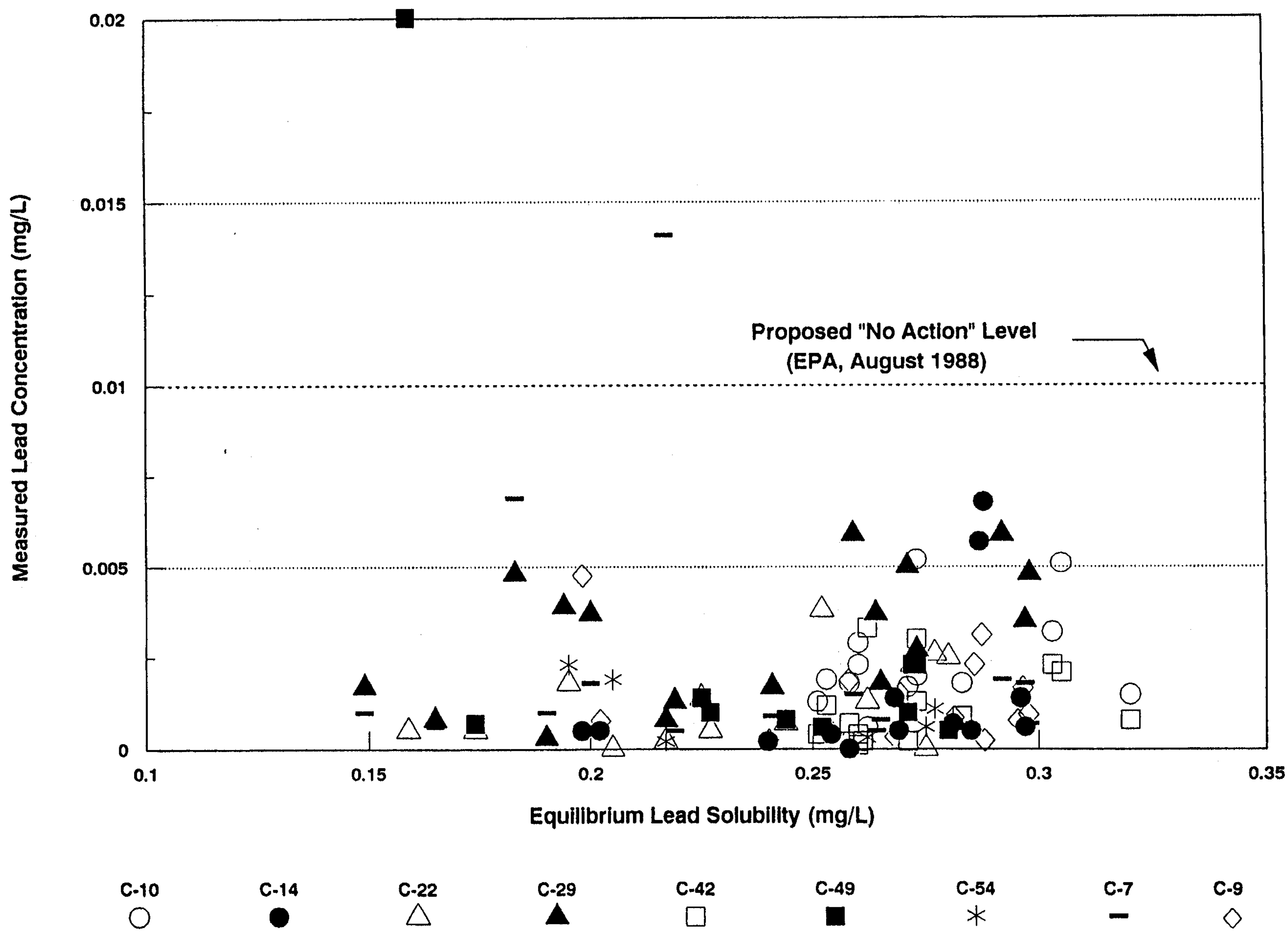
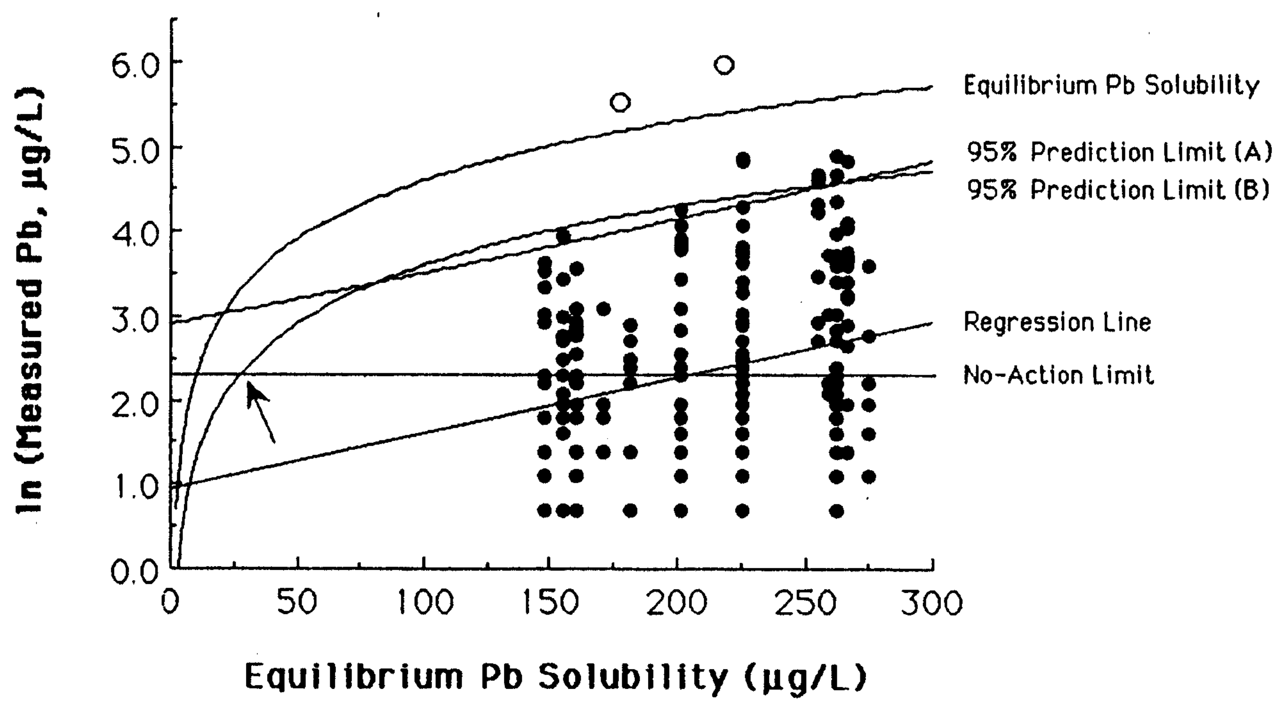
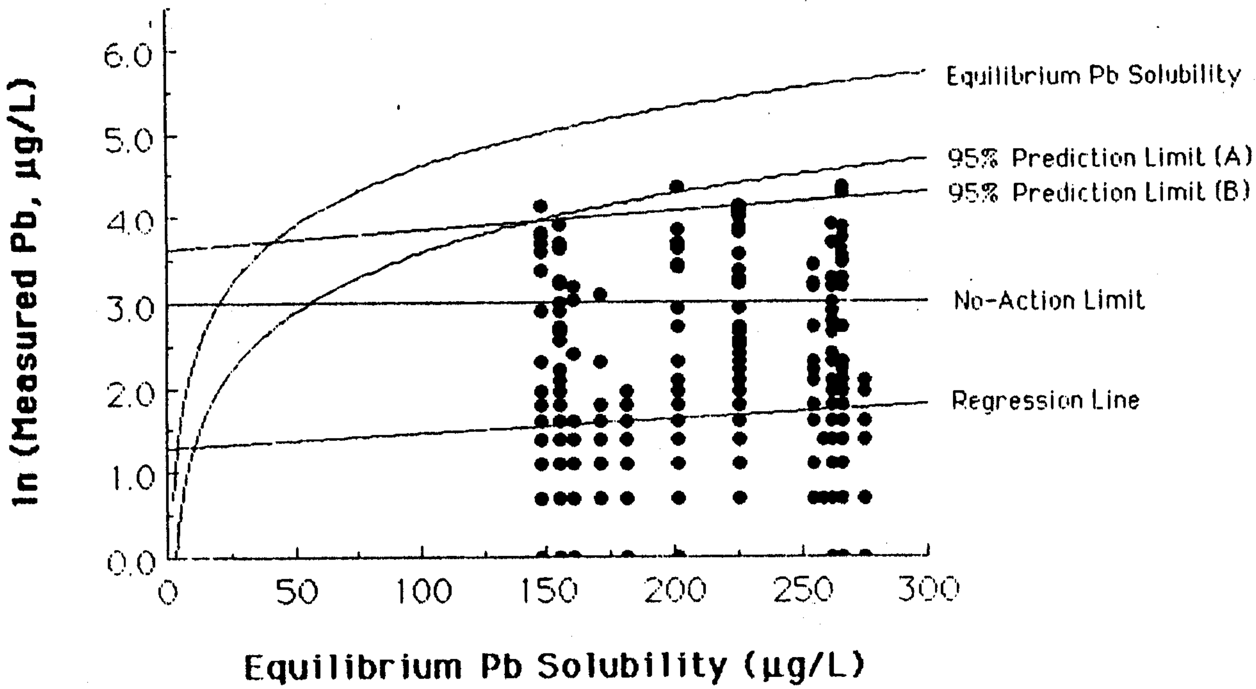


FIGURE 2-12 MEASURED LEAD CONCENTRATION IN DISTRICT WATER MAINS AS A FUNCTION OF EQUILIBRIUM LEAD SOLUBILITY OF FINISHED WATERS



95% Prediction Limits: A) Statistically Derived, B) Equation (2) Text. Data from Data Set 3 Database.

FIGURE 2-13 MEASURED LEAD CONCENTRATIONS IN FIRST-DRAW SAMPLES COLLECTED FROM HOMES SERVED BY LEAD SERVICE LINES AS A FUNCTION OF EQUILIBRIUM LEAD SOLUBILITY



Data from Data Set 3 Database

FIGURE 2-14 MEASURED LEAD CONCENTRATIONS IN FIRST-DRAW SAMPLES COLLECTED FROM HOMES SERVED BY NONLEAD SERVICE LINES AS A FUNCTION OF EQUILIBRIUM LEAD SOLUBILITY

no-action concentration limit, probably because of a lack of data for low values of equilibrium lead concentrations. It can be seen in Figure 2-13 that the statistical 95-percent prediction limit parallels the equilibrium lead solubility curve over the range of equilibrium lead solubility for which data are available. Since there is a relationship between the equilibrium and observed lead concentrations, we have assumed that the observed lead concentrations will parallel the equilibrium lead solubility over the entire concentration range. With this assumption we have derived an expression for the 95-percent prediction line that we believe will reflect more accurately the observed lead concentration over the entire range of equilibrium lead solubilities:

$$Pb_{obs95\%} = 0.36\ Pb_{eq} \qquad (2)$$

This line is plotted in Figure 2-13 (labeled "B") and agrees with the statistically derived 95-percent prediction limit over the range of equilibrium lead solubility for which data are available. Thus, in order for 95 percent of all observed lead concentrations to be below the no-action limit of 0.01 mg/L, we can project from Equation 2 that the equilibrium lead solubility must be near 0.03 mg/L. Since data are not available at low equilibrium lead solubilities, it is impossible to determine precisely the maximum value of equilibrium lead solubility resulting in lead concentrations below 0.01 mg/L. A reasonable range for this value of equilibrium lead solubility is 0.01 to 0.05 mg/L. It may be possible to achieve equilibrium lead solubilities as low as 0.01 mg/L; in practice, however, a more reasonable goal is 0.03 to 0.05 mg/L. The aforementioned analysis indicates that this equilibrium lead solubility may be sufficient to meet the no-action limit; however, without data for low values of solubility, it is impossible to say for certain.

The two data points in Figure 2-13 that are indicated by open circles are above the equilibrium lead solubility calculated for these waters. These high lead concentrations could be related to particulate lead-containing corrosion products sloughing from the interior surface of the pipe (Schock, 1989). These data points were not included in the regression analysis.

A similar analysis was performed for nonlead service lines. The natural logarithms of lead concentrations reported in the Data Set 3 database file for homes served by nonlead service lines are plotted against equilibrium lead solubility in Figure 2-14. Several data points with lead concentrations greater than 0.10 mg/L were not included in this plot because they were believed to be related to particulate corrosion products. In general, the lead concentrations in homes served by nonlead service lines are lower than those in homes served by lead service lines. Nevertheless, it can be seen that the measured lead concentration is higher than the no-action limit for several of the samples collected. The lead observed in these samples may have leached from lead solder joints, brass plumbing fixtures, or lead plumbing in the home. Figure 2-14 illustrates that measured lead concentrations in first-draw samples are likely to exceed the no-action limit even if lead service lines are replaced. The relationship between predicted and observed lead concentrations is as follows:

$$\ln Pb_{obs} = 0.001729\ Pb_{eq} + 1.279 \qquad (3)$$

A regression line was fit through the data in Figure 2-14 and was found to be statistically significant. However, the lower value of the slope of this regression line (compared to the slope of the regression line for lead service lines shown in Figure 2-13) suggests that the effect of changes in equilibrium lead solubility of the water is less for nonlead service lines than for lead service lines. We have assumed that since the lead levels are lower in homes served by nonlead service lines, satisfactory lead levels in these homes will be achieved by reduction of lead below the no-action limit in homes that are served by lead lines.

Data Sets 1 and 2 were used to verify Equations 1 and 2. Of the 941 records in this database, 72 were identified as being served by lead service lines. Of these 72 files, midday samples were collected for 68 of them and first-flush A, B, and C samples were collected for 13. The data were collected during November 1986. The average equilibrium lead solubility for this month was 0.293 mg/L. Thus, a mean lead level of 0.018 mg/L would be predicted by Equation 1, while Equation 2 would predict that 95 percent of all samples will be less than 0.105 mg/L. The measured lead levels in Data Sets 1 and 2 for homes served by lead service lines are summarized in Table 2-4. In general, the predictions given by Equations 1 and 2 agree fairly well with the data, with the exception of Sample B, which represents water in contact with the service line.

2.3 INVESTIGATION OF ALTERNATIVES

There is a variety of alternatives available for reducing customers' exposure to lead in drinking water. This subsection briefly summarizes the approach involved in each of these alternatives.

2.3.1 Centralized Treatment Alternatives

One category of alternatives for reducing lead in drinking water is to add or modify the water treatment plants. Centralized treatment for lead removal is based on the principles of corrosion control rather than removal of lead at the treatment plant since the levels of lead in the source water are very low. Corrosion control techniques can be categorized as barrier methods. Barrier methods involve placement of a protective coating on the interior surface of the pipe to prevent or reduce dissolution of lead from plumbing materials. Protective coatings can be calcium carbonate, silicates, or lead orthophosphates. Solubility-based methods involve

Table 2-4

Lead Levels* in Homes Served by Lead Service Lines

Sample Type	N (number of (samples)	Measured Mean	Predicted Mean	Measured 95% Level	Predicted 95% Level	Range
Midday	68	0.013	.018	0.046	0.105	0.001 - 0.108
A	13	0.021	.018	0.064	0.105	0.001 - 0.065
B	13	0.032	.018	0.121	0.105	0.001 - 0.125
C	13	0.013	.018	0.048	0.105	0.001 - 0.058

*All units in mg/L.

modification of the water chemistry to reduce the solubility of lead in the water distribution system. Several recent papers have appeared on the subject of reducing the corrosivity of drinking water (Schock, 1989; Neff et al., 1987; Schock and Neff, 1988; Lee et al., 1989; and Gardels and Sorg, 1988).

Centralized treatment options are attractive because centralized treatment facilities exist that could be modified to reduce corrosivity of water to a greater extent than is currently practiced. Four centralized treatment options are described in detail in Subsection 2.4.1.

2.3.2 Point-of-Use Devices

Point-of-use devices are water treatment units placed in the homes of water users. Point-of-use devices are designed and sized to reliably produce potable quality water for drinking and cooking. All other water uses including bathing, washing, lawn watering, and toilet flushing are not affected by the levels of lead found in the Washington, D.C., drinking water system. Therefore, most point-of-use devices are sized to produce enough water for drinking and cooking uses, approximately 5 to 8 gallons per day.

Point-of-use devices using a variety of treatment processes are available. These include mechanical filtration/granular activated carbon, distillation, and reverse osmosis units. A detailed description of these units is included in Subsection 2.4.2.

2.3.3 Removal of Lead Material

A major source of lead in drinking water is the corrosion of lead from lead-bearing materials within distribution systems and home plumbing systems. By removing these materials and replacing them with lead-free materials, this source of lead would be eliminated.

In the most recently proposed lead regulations, EPA considered requiring the replacement of lead service lines where it was shown that the service line was contributing measurable amounts of lead to water at the tap. This option, however, has uncertainties about the effectiveness of partial service line removal resulting from legal and financial questions over replacement responsibility. EPA's August 1988 proposed lead regulations have no provision for removal of any lead-bearing materials currently found in water systems or home plumbing systems.

The District has an ongoing program to replace the District's portion of a lead service line. At the same time, the homeowner is notified and encouraged to replace the remaining portion of the service line. This program has resulted in the partial replacement of many lead service lines over the last several years.

Replacement of other lead-bearing materials such as solder, flux, and brass fixtures is beyond the control of the water system managers. Newly enacted plumbing codes (see Subsection 2.3.4) should prevent the use of such materials in the future. Also, lead solder and flux is typically considered to no longer contribute significantly to lead in drinking water after a period of approximately 5 years.

2.3.4 Plumbing Code Modifications and Enforcement

As previously described, a major source of lead in drinking water is the corrosion of lead from lead-bearing pipe, fittings, solder, and flux. There are two basic methods for eliminating this source of lead: prevent corrosion by modifying water quality or eliminate corrosion by removing the lead-bearing materials. Modifications to the plumbing code, while they cannot undo what has been done in the past, can reduce future exposures to lead by requiring the use of lead-free pipe, fittings, solder, and flux.

The Safe Drinking Water Act (SDWA) amendments of 1986 require the use of lead-free pipes, fittings, solder, and flux in the installation or repair of public water systems and individual home plumbing systems. Solder and flux are considered lead-free when they contain no more than 0.2 percent lead. Pipes and fittings (including fixtures) are considered lead-free when they contain no more than 8.0 percent lead. The District has enacted its own version of such a lead ban legislation.

The effectiveness of such a lead ban is dependent on the degree to which the ban is enforced. For example, lead solder will still be available under the ban. Its use, however, is meant to be restricted to applications other than in drinking water installations. Lead-free solder is generally more difficult to work with, and homeowners and even plumbers may be tempted to use lead solder in its place.

2.3.5 Public Education

A relatively simple yet effective method of reducing customers' exposure to lead in drinking water is to conduct a public education program. Public education is a requirement under the most recently proposed lead regulations for water systems failing to meet certain no-action levels. In addition, the SDWA amendments of 1986 required all water system managers to notify the public about lead in drinking water, regardless of whether the system was in compliance with existing lead standards.

The most recently proposed lead regulations are quite specific regarding what must be included in a public education program. The basic purpose of such a program is to inform the public on the sources of lead in their drinking water, describe potential health effects of lead exposure, describe what the water system can and is doing to reduce lead concentrations, and to give advice as to how homeowners could minimize their own exposure to lead in drinking water.

2.3.6 Alternative Distribution Techniques

Lead in water becomes a health issue only when the water is ingested through drinking or food preparation. For this reason it may be possible to eliminate lead intake from drinking water by providing alternate sources of water for drinking and cooking. Two possibilities are an expanded use of bottled water and the implementation of some form of alternative water distribution system.

The use of bottled water has increased in recent years. As consumers have become more concerned with the quality of their drinking water (from a health standpoint, and preferences concerning taste and odor), they have become willing to pay the additional cost for bottled water. The costs associated with bottled water use are high; however, and the socioeconomic impacts must be addressed before bottled water use could be advocated as a means of reducing lead exposure from drinking water.

A major portion of lead in drinking water originates in the customers' plumbing systems. Exposure to this lead could be eliminated by providing customers with direct access to water in the distribution system mains. This could be accomplished by setting up common distribution points where the customer could obtain water for drinking and cooking, or by installing new services that connect directly to a separate fixture in the house to be used only for cooking and drinking.

2.4 IDENTIFICATION AND EVALUATION OF SPECIFIC ALTERNATIVES

2.4.1 Centralized Treatment Options

Adjustment of water chemistry at the treatment plant can potentially reduce the formation of lead-containing corrosion by-products in the distribution system. Four treatment options were considered for lowering distribution system lead concentrations: (1) adjustment of pH and alkalinity to greater than 8.0 and 30 mg/L as $CaCO_3$, respectively; (2) precipitation of a protective $CaCO_3$ film; (3) orthophosphate addition alone; and (4) control of pH and DIC in conjunction with orthophosphate addition. Selection of the appropriate technology depends upon the final format of EPA's lead regulations. Also, pilot studies would be necessary to verify the effectiveness of the chosen technique.

The first option, adjustment of pH and alkalinity, was considered in the August 1988 EPA proposed lead regulations as a corrosion control technology to be implemented in response to a violation of lead standards at the customer's faucet. Precipitation of calcium carbonate films has long been considered an effective method of corrosion control. The third and fourth treatment methods are suggested by the decision tree diagram for lead control strategies shown in Figure 2-15 (Schock, 1989). Polyphosphate and silica additives were not considered because currently there is no scientific basis for predicting their effectiveness for a given water type. Extensive experimentation would be required to determine the feasibility of these options.

2.4.1.1 Adjustment of pH and Alkalinity

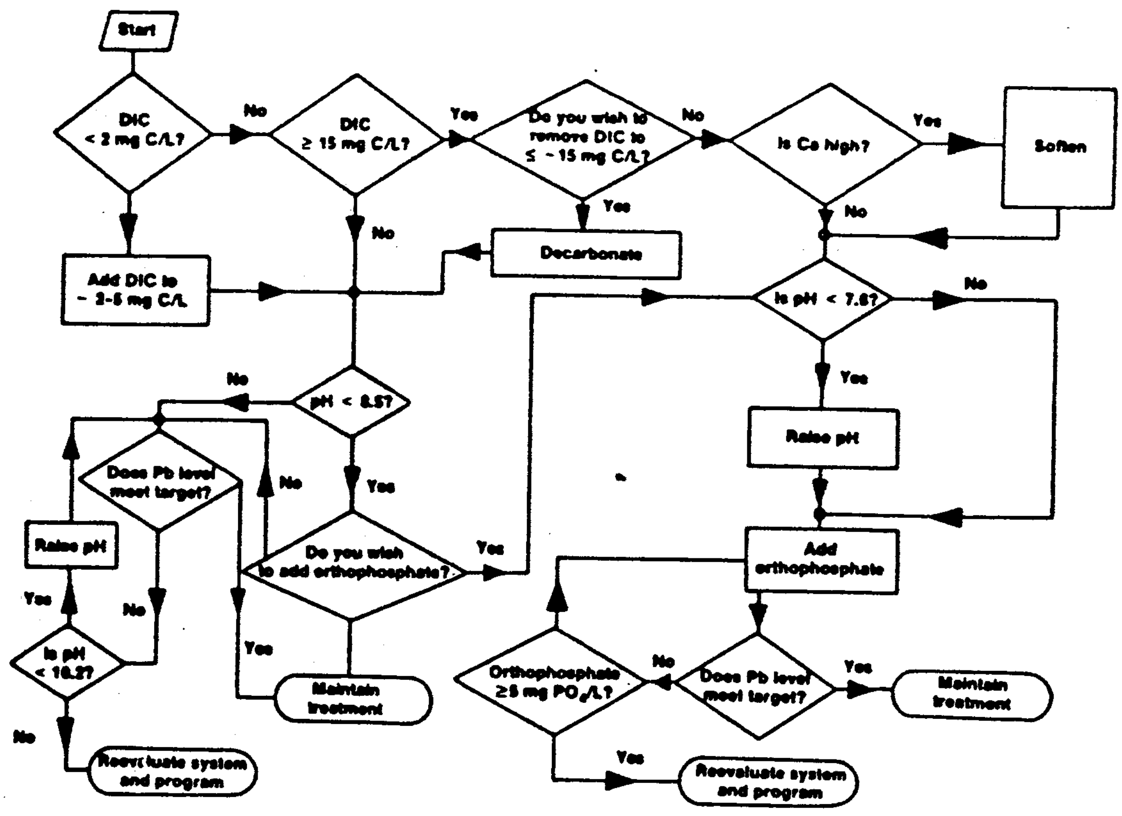
Corrosion control by adjustment of pH and alkalinity was practiced by 42 percent of the utilities responding to the 1987 AWWA Lead Information Survey (Frey, 1989). The average lead concentration was below the 0.01 mg/L no-action limit for 48 percent of the utilities practicing this technology. The City of Boston was successful in reducing mean lead concentrations in the distribution system below the current 0.05 mg/L MCL by addition of NaOH (Karalekas, Ryan, and Taylor, 1983). Water of pH greater than 8.0 had the lowest lead levels among homes with copper plumbing in a survey conducted by the American Water Works Service Company (Lee, Becker, and Collins, 1989). Mean lead levels for samples of pH greater than 8.0 were 0.005 mg/L, with only 4 percent of these samples exceeding 0.020 mg/L. It can be concluded that adjustment of pH and alkalinity is a commonly practiced corrosion control technology. Water of pH greater than 8.0 appears to be less corrosive than water of lower pH.

The performance of this treatment option can best be predicted by considering historical data from the Washington, D.C., distribution system. The technology considered in the 1988 EPA proposed lead regulations consisted of increasing the pH above 8.0 and increasing alkalinity above 30 mg/L as $CaCO_3$. The monthly composite analysis of treated water from the Dalecarlia and McMillan WTPs indicates that alkalinity is greater than 30 mg/L as $CaCO_3$ for all samples, and that pH is greater than 8.0 for some samples. Therefore, the water currently being produced by the Dalecarlia and McMillan WTPs occasionally meets the proposed treatment criteria being considered by EPA. Thus, EPA's recommended treatment may not significantly improve the lead levels measured at the tap. Based on a projected equilibrium lead solubility of 0.150 mg/L and Equations 1 and 2, mean lead levels from homes served by lead service lines can be expected to be between 0.005 and 0.010 mg/L, while 95 percent of all samples will be below 0.055 mg/L.

There should be no need for capital expenditure for this treatment option since lime addition is currently practiced at both treatment plants. The cost for additional lime would be less than $1/MG.

2.4.1.2 Calcium Carbonate Precipitation

Calcium carbonate precipitation on internal pipe surfaces has long been considered an effective means to prevent corrosion. The stabilization of water by adjustment of the LSI has been practiced for more than 60 years. Therefore, it must be considered as a



Source: Schock, 1989.

FIGURE 2-15 CONCEPTUAL DECISION TREE FOR THE SELECTION OF TREATMENT OPTIONS FROM AMONG pH, DIC, AND ORTHOPHOSPHATE feasible and practical option for reducing the corrosiveness of water.

The performance of this treatment technology is contingent on the ability of the $CaCO_3$ coating to provide a complete, continuous, and stable physical barrier between the internal pipe surface and the water. Despite the long-standing use of this corrosion control strategy, there is little evidence demonstrating the existence of these films in actual distribution systems (Schock, 1989). Lead service lines in the District that have been excavated to date show no evidence of these films. Assuming that formation of these films is possible, solubility of lead could be increased during the period of initial deposition of these coatings because of the higher DIC levels required to precipitate $CaCo_3$. It would also seem to be extremely difficult to achieve a uniform coating throughout the distribution system. Controlling the dosage of conditioning chemicals to keep pace with changing water quality also could prove challenging. For these reasons, this treatment option is not expected to provide significant reduction in lead levels in the distribution system, other than what would be achieved by reducing the solubility through increasing pH. Thus, the performance and cost of this treatment option are comparable to the first treatment option.

2.4.1.3 Orthophosphate Addition

Of the utilities responding to the aforementioned AWWA lead survey, 26 percent used some type of corrosion inhibitor (Schock and Gardels, 1983), such as orthophosphate. The American Water Works Service Company survey indicated that samples from homes served by utilities that add orthophosphate as a corrosion inhibitor had mean lead levels of 0.004 mg/L, with only 1 percent of all samples exceeding 0.02 mg/L (Schock, 1989). Thus, it can be surmised that orthophosphate addition is a well-established and effective method of reducing lead levels in distribution systems. One drawback to orthophosphate addition, however, is that the addition of phosphates to drinking water may cause other environmental problems in the Potomac River. This is because the water sent through the distribution system as drinking water eventually returns (after treatment) to the Potomac River as wastewater. Higher phosphate levels in this wastewater would result in increased nutrient loads in the river.

The effect of orthophosphate addition on calculated lead solubility was determined by use of the water quality model MINEQL (Westall, Zachary, and Morel, 1976). MINEQL is a chemical equilibrium model that solves a set of mass action equations describing a chemical system under the constraint of mass balance for each chemical component. The values of stability constants listed in Table 2-2 were used in lieu of the default values supplied by MINEQL.

The effect of orthophosphate addition on lead solubility for typical finished waters is shown in Figure 2-16. The calculation of DIC = 2.0 mM is representative of orthophosphate addition to

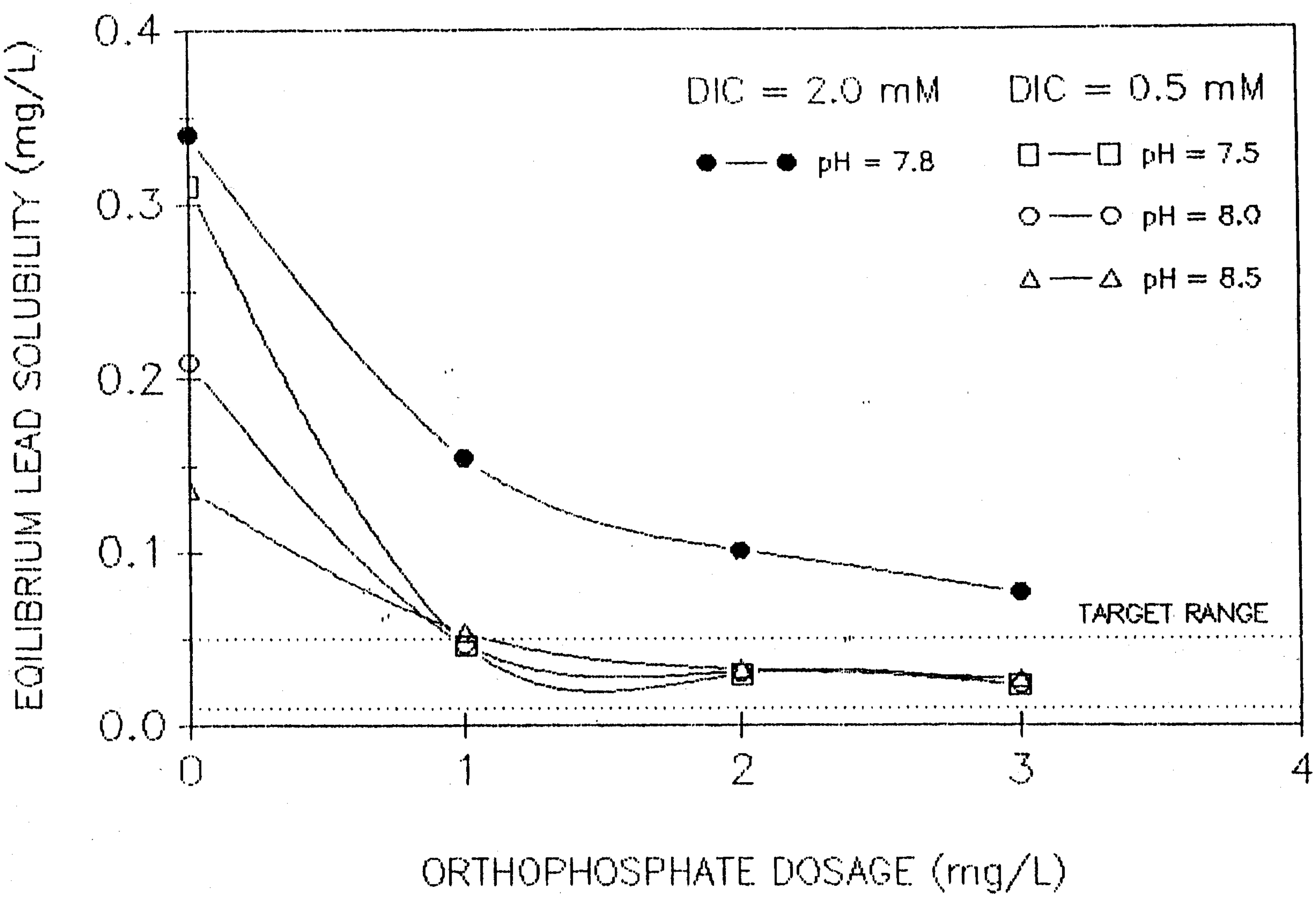


FIGURE 2-16 EFFECT OF PHOSPHATE CONCENTRATION ON EQUILIBRIUM LEAD SOLUBILITY

finished water produced at the present time. A significant decrease in lead solubility can be achieved through addition of orthophosphate, without otherwise altering the water chemistry. Figure 2-16 indicates that addition of 2 mg/L orthophosphate is capable of reducing equilibrium lead solubility to approximately 0.08 mg/L. This corresponds to a predicted mean level of 0.004 mg/L, and a prediction that 95 percent of all samples will be below 0.029 mg/L.

A phosphate feed system and possibly some mixing equipment and instrumentation would have to be added to each treatment plant to implement this technology. It is estimated that these improvements will cost less than $1 million per plant. Orthophosphate addition will cost approximately $6.30/MG, assuming addition of phosphoric acid.

2.4.1.4 pH and DIC Control with Orthophosphate Addition

MINEQL calculations indicate that lead complexation by carbonate prevents phosphate from lowering the lead solubility to levels below the expected EPA no-action levels. Thus, to make phosphate addition more effective it is necessary to remove DIC from the water. Lime softening, air stripping, and ion exchange are treatment processes applicable to DIC removal. For evaluating the feasibility and cost of lead solubility control by DIC removal, lime softening was chosen as the treatment process. Lime softening has the additional advantage of removing Ca^{2+} and Mg^{2+} from the water, which can potentially bind with the phosphate, thus leaving it unavailable for control of lead solubility. Both softening and orthophosphate addition are well-established treatment processes. It should be noted, however, that soft waters have been statistically linked to increased rates of heart disease and should be considered in more detail if serious consideration is given to this option.

Analysis of this treatment option is based on raw water quality data for the Potomac River in August 1988. The potential for lead solubility is relatively high for this water. Water quality goals of 30 mg/L Ca, 10 mg/L Mg, 0.5 mM DIC, and pH of 7.5 to 8.5 were selected. Since the primary objective of the softening process is to lower the DIC, it may not be necessary to remove Ca and Mg to such low levels. Thus, the softening scheme presented below may not be the most cost-effective scheme possible; however, it does allow preliminary investigation into the feasibility and cost of lead solubility reduction by pH and DIC control with orthophosphate addition.

The first step in the treatment process is addition of lime and soda ash and the resulting precipitation process. This is represented schematically in the Caldwell-Lawrence diagram (Loewenthal and Marias, 1976) shown in Figure 2-17. Point 1 in Figure 2-17 represents the raw Potomac River water from August 1988 equilibrated with $CaCO_3$.

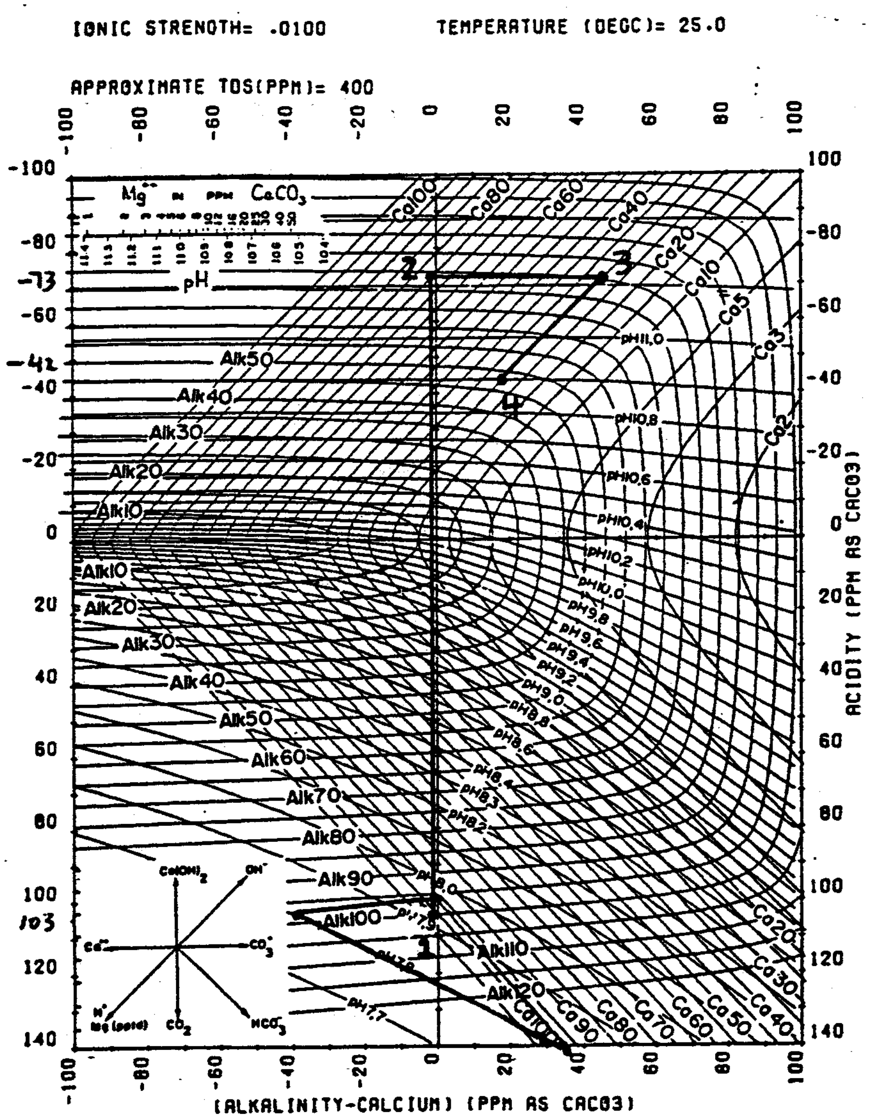


FIGURE 2-17 CALDWELL-LAWRENCE DIAGRAM DEPICTING THE PROPOSED DIC REMOVAL SOFTENING TREATMENT PROCESS

The path from points 1 to 2 represents addition of lime, while the path from points 2 to 3 represents soda ash addition. Point 4 represents the water after precipitation.

Prior to filtration, the water must be neutralized and recarbonated. Point A on the Deffeyes diagram (Deffeyes, 1965) (see Figure 2-18) represents the softened water prior to recarbonation. While the low DIC (0.1 mM) of this water is desirable for reduction of lead solubility, the DIC is too low to provide buffering capacity. The pH of a water of such low buffering capacity could easily drop below 7.0, resulting in high lead solubilities. Thus, it is necessary to raise the DIC level of the water to 0.3 to 0.5 mM to provide buffering capacity at the pipe surface. Recarbonation by CO_2 addition is represented by the path from A to B in Figure 2-18. H_2SO_4 is then added (path B to C) until an approximate pH of 8 is obtained.

Finally, orthophosphate can be added to produce a water of low equilibrium lead solubility. Figure 2-16 indicates that an equilibrium lead solubility of less than 0.030 mg/L can be obtained at an orthophosphate dosage of 2 mg/L in the pH range of 7.5 to 8.5 for waters containing 0.5 mM DIC. The final DIC, pH, and orthophosphate levels must be optimized to minimize lead concentrations measured in first-draw samples collected at customer taps.

By reducing the equilibrium lead solubility to the range of 0.03 to 0.05 mg/L, the average lead concentrations measured in first-draw samples should be well below the no-action limit. In addition, the number of samples that exceed the no-action limit should be reduced to a few percent. However, it must be stressed that it is impossible to predict accurately the response of measured lead concentration for low values of equilibrium lead solubility without data taken in the low solubility range.

Furthermore, water with an equilibrium lead solubility below 0.01 mg/L could still contain greater than 0.01 mg/L lead because of sloughing of particulate, lead-containing corrosion products from interior plumbing surfaces. Therefore, it would be difficult, if not impossible, to produce water for which 100 percent of all first-draw samples contain less than the no-action limit of 0.01 mg/L.

Since water softening sludges are more dense and are produced in higher volumes than turbidity removal sludges, this treatment scheme would require extensive upgrading of the existing water treatment plants. Several additional unit processes would have to be added to each plant, in addition to facilities for handling and disposing of sludges.

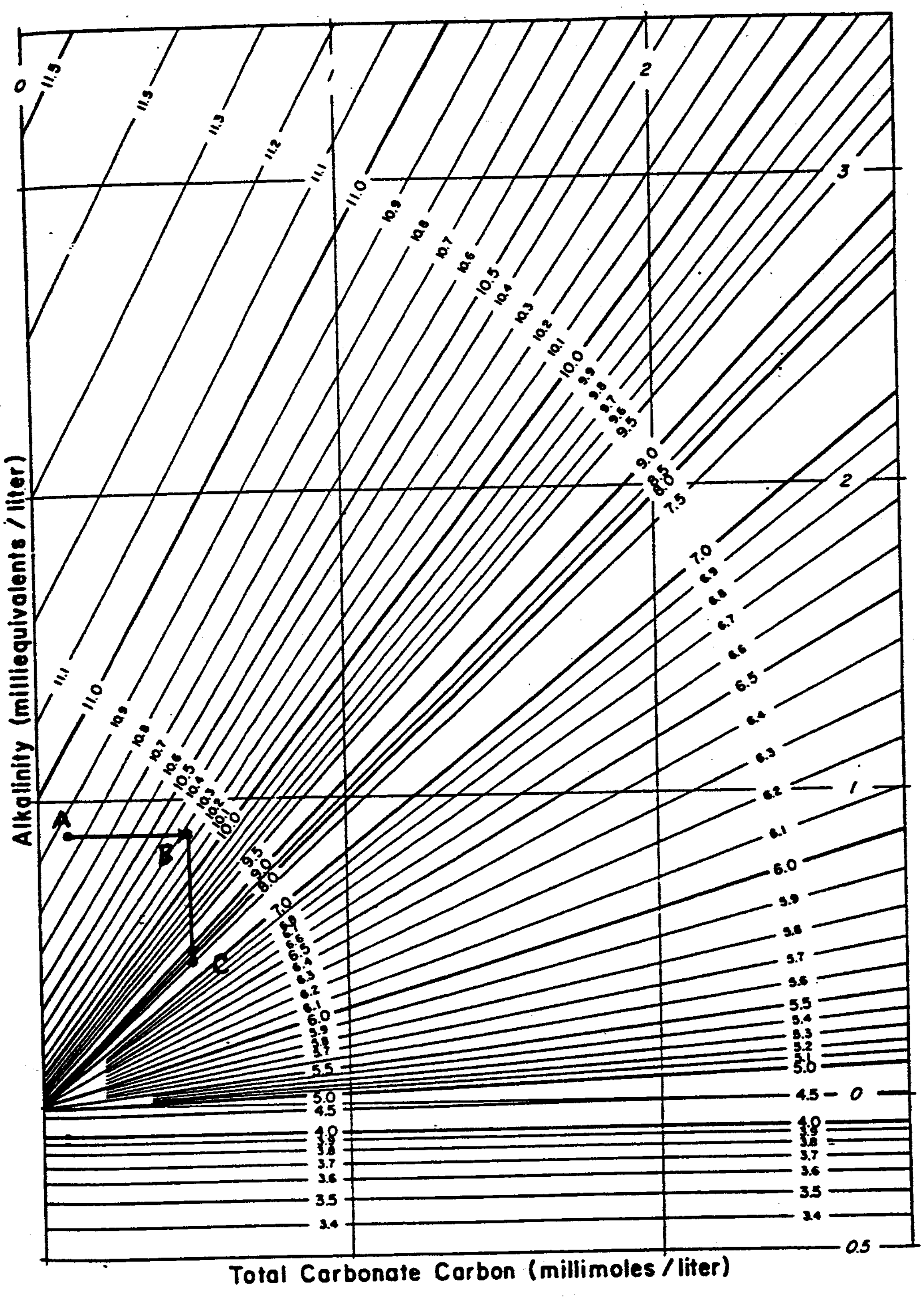


FIGURE 2-18 DEFFEYES DIAGRAM DEPICTING RECARBONATION OF SOFTENED WATERS

It should be noted that sludge handling and disposal costs would be particularly high. Cost notwithstanding, sludge disposal is a particularly severe problem for both the Corps of Engineers and the District of Columbia, Department of Public Works. The additional sludge generated by this option limits the feasibility and practicality of this treatment option.

The chemical dosages and approximate costs for treating the water, assuming the August 1988 raw water quality and the proposed treatment scheme, are summarized in Table 2-5. Labor, energy, and sludge disposal costs will be more expensive than present costs because of the added complexity of the treatment process and the greater mass of sludge. Table 2-6 summarizes effectiveness and costs of various treatment options. The cost of sludge disposal may be very high and depends on various available options. The capital cost for the last treatment option has not been estimated because of uncertainties concerning the sludge disposal options available.

2.4.2 Point-of-Use Devices

As described in Subsection 2.3.2, point-of-use devices represent an alternative method of removing lead from drinking water. The capability of certain point-of-use devices to remove lead from drinking water has been established by independent testing agencies. As with any water treatment unit, point-of-use devices must be maintained. Responsibility for maintenance must rest with the homeowner or user. In some cases, lack of maintenance can cause the quality of drinking water to become worse than the water entering the treatment unit. The issue of maintenance is a serious one that affects all point-of-use devices.

2.4.2.1 Reverse Osmosis

Reverse osmosis is a well-established and reliable method for removing dissolved materials from water. Reverse osmosis (RO) treatment units are available for installation and use in domestic residences. Typical units have a capacity to treat between 2 and 8 gallons of water per day. This is sufficient for the cooking and drinking water needs of an average household.

The cost of an RO unit is approximately $800 installed, with maintenance costs of $50 per year for replacement of pre- and post-filters and RO modules. In addition, there are energy costs associated with the operation of the unit. RO is a technically feasible, reliable alternative for removing lead from drinking water. The cost is relatively high, however; and the need for continuous maintenance has both water quality and legal implications that the District should explore before more serious consideration can be given to this alternative.

Table 2-5

Chemical Dosages and Costs for Lead Solubility Control

Chemical	Dosage (lb/1,000 G)	Unit Cost ($/ton) (Ref. 14)	Treatment Cost ($/MG)
CaO (90%)	0.913	45.00	20.54
Na_2CO_3 (58%)	0.737	93.00	34.25
CO_2	0.183	120.00	10.98
H_2SO_4 (98%)	0.125	96.00	6.00
H_3PO_4	0.020	630.00	6.30
		Total	$78.07

The effectiveness and cost of the various treatment options are summarized in Table 2-6.

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Table 2-6

Effectiveness and Cost of Various Treatment Options

Treatment Option	Mean Lead Level (mg/L)	95% Lead Level (mg/L)	Capital Cost (millions of dollars)	Chemical Cost ($/MG)
pH and alk. control	0.01	0.055	---	1.00
L.I. adjustment	0.01	0.055	---	1.00
Phosphate addn.	0.004	0.029	2	6.30
pH & DIC control with phosphate addn.	0.003	0.010	*	78.07

*Not available.

2.4.2.2 Granular Activated Carbon

Water treatment units using granular activated carbon (GAC) to remove impurities from drinking water are available for home use. GAC is widely used for the removal of organic compounds from water but has not generally been thought to be capable of removing lead from water. Recent evidence suggests that some removal of lead by GAC is possible under certain pH ranges (National Sanitation Foundation, 1989). Some point-of-use devices have been rated as being capable of removing lead from water while the majority are not. The factors allowing one unit to remove lead while other units cannot are not known. The use of GAC to remove lead is not well-accepted or well-established among sanitary engineers. Therefore, the performance of GAC in removing lead from water is uncertain. The cost of GAC point-of-use devices ranges from $105 to $325 without installation. Maintenance costs range from $25 to $70 per year for replacement of filter cartridges. Maintenance of GAC units is particularly important since organics adsorbed to the carbon particles provide an ideal nutrient source for bacteria. Bacteria levels will increase over time in water treated by GAC filters as more nutrients and bacteria accumulate on the carbon. Although bacteria alone may not cause health problems, the possibility of pathogenic microorganisms increases as the number of bacteria increases. As with all point-of-use devices, maintenance requirements have significant water quality and legal implications that must explored by the District before further consideration can be given to this option.

2.4.2.3 Distillation

Distillation is capable of treating water to a very high degree of purity. However, the resulting water is highly corrosive and has a flat taste compared to natural water. Distillation units are available for home use that range in cost from $500 for nonpressurized units to $1,200 for pressurized units capable of pumping distilled water to different floors of a house. Operation costs are high for distillation units.

2.4.3 Removal of Lead Material

Water is exposed to lead-bearing materials in several locations once it leaves the distribution main and enters the customer's service line. As described in previous subsections, the corrosion of these materials may result in increased lead levels in drinking water. Removal of these materials would effectively eliminate this source of lead.

2.4.3.1 Lead Service Line Replacement (Partial)

In the District's water system, as in most water systems throughout the country, ownership/control of the service line is shared between the water system and the homeowner. The District is currently replacing its portion of the service line when it is found to be lead. At the same time the District notifies the homeowner that a lead service line is present and suggests that the homeowner replace the remaining portion.

As part of the most recently proposed lead regulations (August 1987), EPA considered making service line replacement mandatory where it was shown to contribute to high lead levels at the tap.

Partial replacement of a lead service line does not necessarily result in lower lead levels at the tap. At this time no data are available that relate partial lead service line replacement to lead levels at the tap. EPA is likely to make lead service line replacement a part of the final lead rule.

The current cost of replacing the District's portion of a lead service line has been estimated at $2,890 per service. This cost includes all labor charges (direct labor and administrative labor, plus employee benefits); equipment costs (using the purchase cost of equipment and the expected life); and the cost of supplies. A detailed calculation of this replacement cost is given in Table 2-7. This represents actual cost incurred by the District in replacing lead service lines in the District during 1989.

2.4.3.2 Lead Service Line Replacement (Total)

In cases where the lead service line has been shown to contribute to high lead levels at the tap, consideration should be given to the complete removal of the service line. Since it is impractical to test each location for the contribution of the lead service line to total lead concentrations, it is likely that a replacement program would have to include all lead service lines in the District.

While the District's portion of a service line is fairly standard, the homeowner's portion can vary greatly in length and depth. This makes estimating the cost of a total service line replacement difficult. Replacement of the District's portion of a lead service line has been estimated at $2,890, including $600 for street replacement. Based on the actual cost incurred by the District, a rough approximation of total service line replacement cost can be made assuming that replacing the homeowner's portion is about equal to the cost of replacing the District's portion, excluding the cost of street replacement. Thus, the cost of a total service line replacement for each house is estimated at $5,180 [$2,890 + ($2,890 - $600)].

2.4.3.3 Replacement of Lead Soldered Joints

The most common household plumbing system consists of copper pipes joined by solder. Until recently, this solder consisted of an alloy containing up to 50 percent lead. Recent studies (Lee, Becker, and Collins, 1989) have shown that a large portion of the lead at the tap is contributed by corrosion of lead solder joints. Removal of such joints from the plumbing system would reduce overall lead levels in the water.

Table 2-7

Cost Estimate for the Existing District of Columbia Lead Service Replacement Program

Total Annual Program Costs (375 replacements)

ITEM	COST
Labor	$696,344
Equipment	$109,680
Supplies	$277,875
TOTAL	**$1,083,899**

Cost per service line = $2,890

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Table 2-7
(continued)

DIRECT LABOR COSTS

Labor Category	Quantity	Salary Grade	Salary ($/hr)	% of Time on Program	Cost
General Foreman	1	SW15	$23.18	20%	$9,272
Foreman	3	SW10	$18.92	100%	$113,520
Crew Chief	3	RW10	$15.22	100%	$91,320
Crew 1	3	8	$13.76	100%	$82,560
Crew 2	7	6	$10.93	100%	$153,020
Backhoe Operator	1.5	RW10	$15.22	100%	$45,660
Truck Driver	1.5	RW7	$13.05	100%	$39,150
TOTAL					$534,502

ADMINISTRATIVE LABOR COSTS

Labor Category	Quantity	Salary Grade	Salary ($/hr)	% of Time on Program	Cost
Data Management	1		$12.50	20%	$5,000
Deputy Chief	1		$19.00	10%	$3,800
Chief	1		$25.00	10%	$5,000
TOTAL					$13,800

TOTAL LABOR COSTS

Item	Cost
Direct	$534,502
Administrative	$13,800
Subtotal	$548,302
Fringe Benefits (27%)	$148,042
TOTAL	$696,344

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Table 2-7
(continued)

EQUIPMENT COST

Equipment	Quantity	% Used	Purchase Cost	Life (yrs)	Total Cost ($/yr)
Crew Cab	3	100%	$14,000	6	$7,000
Compressor	3	100%	$11,000	6	$5,500
Backhoe	1.5	100%	$38,000	6	$9,500
Dump Truck	1.5	100%	$45,000	6	$11,250
Pickup Truck	3	100%	$11,000	6	$5,500
(foreman)				6	
Pickup Truck	1	20%	$11,000	6	$367
(general foreman)				6	
Pickup Truck	1	10%	$11,000	6	$183
(deputy chief)				6	
Pickup Truck	1	10%	$11,000	6	$183
(chief)				6	
Power Mole Machine	1	10%	$5,000	6	$83
Portable Pumps	4	100%	$600	6	$400
Pavement Breakers	6	100%	$600	6	$600
Tampers	4	100%	$840	6	$560
Pneumatic Tools	3	100%	$1,400	6	$700
Generators	4	100%	$800	6	$533
Radio	3	100%	$1,000	10	$300
Tap Machine	3	100%	$1,400	10	$420
SUBTOTAL					$43,080
Uniforms					$2,850
Maintenance Cost ($/yr)					$63,750
TOTAL					$109,680

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Table 2-7
(continued)

SUPPLY COST

ITEM	COST PER SERVICE	TOTAL * ANNUAL COST
One length of copper pipe	$100	$37,500
1" corporation cock	$16	$6,000
1" curbcock	$13	$4,875
1" bend	$12	$4,500
Street Replacement	$600	$225,000
		$0
TOTAL	$741	$277,875

* Based on the total number of services replaced in a given year.

Soldered joints will not contribute lead at the same rate. Studies have shown that typically after 5 years a soldered joint will no longer contribute significant levels of lead. Also, a neatly soldered joint should, theoretically, contribute less lead than a sloppy joint using excessive amounts of solder. Finally, joints soldered within the last 2 years should be lead-free because of the enactment of the lead ban in 1988.

Regardless of the number of joints that would need replacement, replacing all lead soldered joints within the District would be a monumental task and beyond the control of the District. Encouraging homeowners to undertake such a rehabilitation of their plumbing systems could be done as part of a public education program (see Subsection 2.4.5). The danger inherent in this is that homeowners may mistakenly use leaded solders to make the repairs, thus aggravating the situation they were trying to remedy. Therefore, although technically feasible, this option appears to be impractical.

2.4.3.4 Replacement of Brass Faucets and Fixtures

Fixtures containing brass are almost universal in interior home plumbing applications. Recent studies (Lee, Becker, and Collins, 1989) have shown that the lead contained in these brass fixtures can contribute up to one-third of the lead found in a 1-liter, first-flush sample.

The District has no control over the types of fixtures individuals choose to install. They can, however, through a public education program, encourage homeowners with brass fixtures to replace them with newer fixtures having a lower lead content.

2.4.4 Plumbing Code Modifications and Enforcement

While replacement of all existing lead pipe and solder in the District is impractical, it is possible to ensure that all new installations (and repairs of existing systems) use only lead-free materials. The first step in such a plan has already been taken with the passage of the District's lead ban in 1988. Simply having such a lead ban is insufficient. Active enforcement is needed to make the program effective in reducing exposures to lead.

Enforcement must be directed at professional plumbers, as there can be little direct control over a homeowner making his/her own repairs. It must be remembered that lead solder is still on the market; only its use in drinking water supply systems has been banned. Building inspectors must be aware of the difference between lead and lead-free solder.

The cost of enforcement is negligible. There should be little extra effort required to ensure that a building's plumbing system has been installed using lead-free materials, assuming that the work is inspected at all. For homeowners doing their own repairs (i.e., without a permit), the only "enforcement" possible is to stress to the public the importance of working with lead-free material.

2.4.5 Public Education

The implementation of a public education program to teach consumers about the sources of lead in drinking water and methods of reducing their exposure to the lead can be an effective method of reducing exposure. Over the last several years the Federal government has passed legislation requiring water system personnel to conduct public information campaigns and, under certain circumstances, public education programs. Such programs cannot be considered as complete solutions to the problem of lead in drinking water. Rather, they should be combined with other measures as part of an overall lead reduction program.

The effectiveness of a public education program to reduce customers' exposure to lead in drinking water is difficult to measure. The methods of reducing lead exposure outlined in such programs are simply suggestions. Homeowner initiative is needed to carry out the suggestions and make them successful.

The cost of developing and implementing a successful public education program would vary depending on the scope of the program and the target audience.

2.4.6 Alternative Distribution Techniques

As described in Subsection 2.3.6, lead exposure from drinking water could be reduced by altering the way in which customers receive their water for cooking and drinking. The following subsections detail two ways in which this could be accomplished: bottled water and dual water distribution.

2.4.6.1 Bottled Water

The major source of lead in the District's water is from the corrosion of lead-bearing materials. Providing water to customers that has never been in contact with these lead-bearing materials would eliminate the exposure to lead in water. One way to accomplish this is through the use of bottled water for cooking and drinking.

Many customers already use bottled water for reasons of taste. However, bottled water is not inexpensive, and many customers would balk at suggestions that they must purchase it. In addition, there also would be many customers who could not afford the bottled water even if they did wish to purchase it.

Bottled water currently has a retail cost of approximately $0.70 per gallon. Assuming a per capita consumption of 2 gallons per day for cooking and drinking, a typical family of four could expect to pay an additional $2,044 per year for its water, if the water were purchased retail. The District could choose to have the consumer bear the entire cost of the water, or could enact programs to help pay all of part of the cost. One option would be for the District to subsidize the use of bottled water through a reduction in water rates. A second option would be for the District to bottle its own water and provide it free of charge to customers. In either case, a careful analysis would be required to determine the cost effectiveness of such a plan.

In summary, although the use of bottled water is attractive in that it basically eliminates a major source of lead in drinking water, it would appear that this solution is impractical from an economic perspective.

2.4.6.2 Dual Water Distribution System

Another option to provide customers with water that has been isolated from any possible contact with lead-bearing materials is the concept of a dual water distribution system. This concept is based on the fact that lead levels in the water distribution system are quite low. By providing water for cooking and drinking that never comes in contact with lead in service lines, solder joints, brass faucets, etc., exposure to lead in water will be minimized.

This could be accomplished in one of two ways. The first is to simply install a new tap for each affected customer, and install a new service line. Once inside the house, a new pipe would be installed directly to a separate fixture at the kitchen sink. This new plumbing work would, of course, be lead-free. The customer would then be instructed to use only this new installation for all cooking and drinking purposes.

The second method would be to install a common distribution point in each neighborhood or block. This faucet would tap directly into a distribution main. Customers who are found to have high lead levels at the tap could collect a supply of water for cooking and drinking from this tap, while continuing to use their regular supply for all other purposes.

While each of these methods would effectively eliminate exposure to lead in drinking water from corrosion, each has significant problems. Installing new service lines and fixtures in all houses with high lead levels would be costly and impractical. The common distribution point concept has serious potential to create public health problems, as well as requiring customers to undergo dramatic changes in water use habits.

2.5 CONCLUSIONS

The following conclusions can be made about lead in drinking water in the District:

- The raw water supply of the District contains low concentrations of lead, typically <5 ug/L.

- Lead concentrations in water in the distribution system are typically <5 ug/L.

- High concentrations of lead in tap water, more than 500 ug/L in one case, can be found in some homes in the District.

- High concentrations of lead in tap water may result from corrosion of lead in brass faucets, lead-bearing solder, or lead service lines.

- The presence of a lead service line does not necessarily result in elevated lead levels in water at the tap.

- The current cost to replace the District's portion of a single lead service line is approximately $2,900.

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SECTION 3

INVESTIGATION OF GEOPHYSICAL AND REMOTE SENSING TECHNIQUES TO DETECT BURIED LEAD PIPES

3.1 INTRODUCTION

3.1.1 Background

One of the objectives of this study is to determine the extent of lead service lines in the District. When possible, the type of service line can be determined from existing data files. However, in many cases the information in the data files will not be sufficient, and physical methods will be required to ascertain the presence of buried lead pipes. Because the service lines are buried and on private property, these lines cannot be directly examined without direct access to the customers' premises, or by excavation. Therefore, the use of remote sensing techniques would be of substantial benefit to acquire this information.

To fulfill one of the requirements of this study, an investigation of available techniques that could be used to locate and identify buried lead pipes was conducted.

3.1.2 Objectives

The major objectives of this task are to research available geophysical methods and remote sensing techniques to determine whether any of them would be effective in locating and identifying buried lead pipes, and to issue a report summarizing the results and recommendations including the expected accuracy of the methods.

The following geophysical methods were researched: ground penetrating radar, electrical conductivity, metal detectors, resistivity, and magnetometer. The use of fiber-optic instruments as remote sensing equipment was also analyzed. Subsection 3.2 presents discussions of each of the techniques covering the theory of operation, general applications of the technique in other fields, and the possible limitations of the method for this project. Subsection 3.3 is a summary of the findings of the literature review and the interviews, followed by the conclusions and recommendations.

3.1.3 Literature Search and Interviews

In order to accomplish the objectives of this task, a computer literature search was conducted using electronic information search facilities. The search listed the available published sources of similar field applications as well as state-of-the-art research on the subject.

Many telephone consultations were also conducted with different experts in the field such as geophysical instrument manufacturers, university laboratories, and independent research facilities. Our own field staff also were interviewed to inquire about currently used techniques for locating buried materials. These conversations were especially valuable in that they provided a great deal of information from hands-on experience necessary to complement the literature sources.

The thorough review of the existing literature substantiates the summary of conclusions and recommendations in Subsection 3.3.

3.2 TECHNIQUES INVESTIGATED

3.2.1 Ground Penetrating Radar

3.2.1.1 Theory

Ground penetrating radar is a surface interface radar that transmits an electromagnetic pulse into the subsurface. The electromagnetic pulse travels through the subsurface until it encounters a soil interface or an object with a different dielectric constant (Telford, 1984). The dielectric constant is a measure of the ability of a material to polarize an electric field.

This contrast in dielectric constant causes part of the transmitted pulse to be reflected back to the surface. Variations in dielectric constants occur at soil/rock interfaces, rock/air interfaces, voids, buried pipelines, manmade objects, etc. For example, digging a trench and filling it again can create a difference between the dielectric properties of the disturbed earth and those of the undisturbed material, and it will be sensed by the radar. Figure 3-1 is a schematic diagram showing the various components of a ground penetrating radar system.

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 dielectric properties of the media through which the pulse travels. The reflected energy is received by the antenna and is then transmitted to a microprocessor in the control unit. There the reflected electromagnetic pulse is processed and transmitted to an oscilloscope and a graphic recorder. The graphic recorder produces a hard copy of the electromagnetic energy's response to the subsurface profile that can be subsequently analyzed. As an example, Figure 3-2 shows the cross section resulting from a radar measurement across a traverse that produces the images of three buried 55-gallon drums.

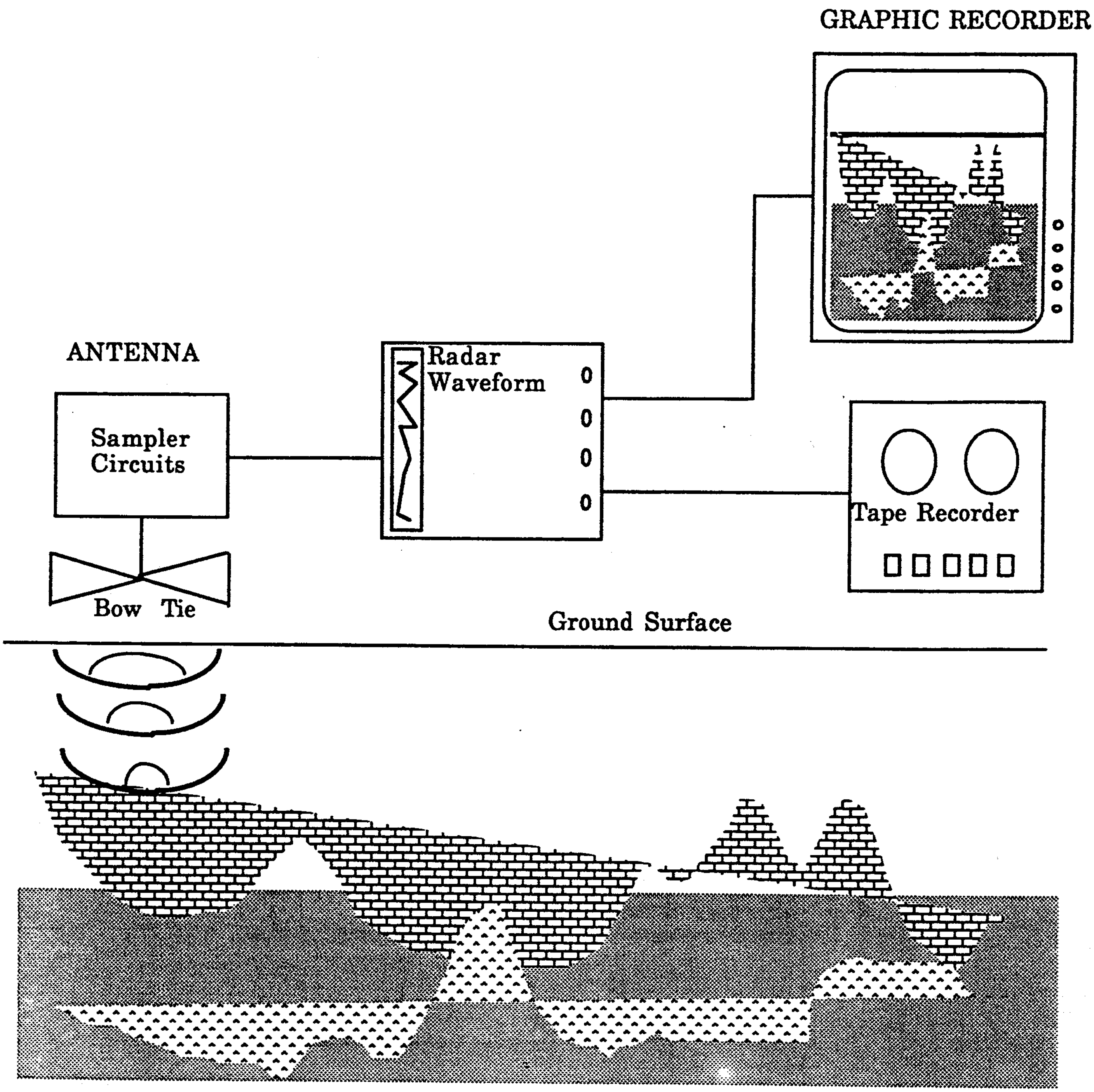

FIGURE 3-1 SCHEMATIC DIAGRAM OF GROUND PENETRATING RADAR METHOD

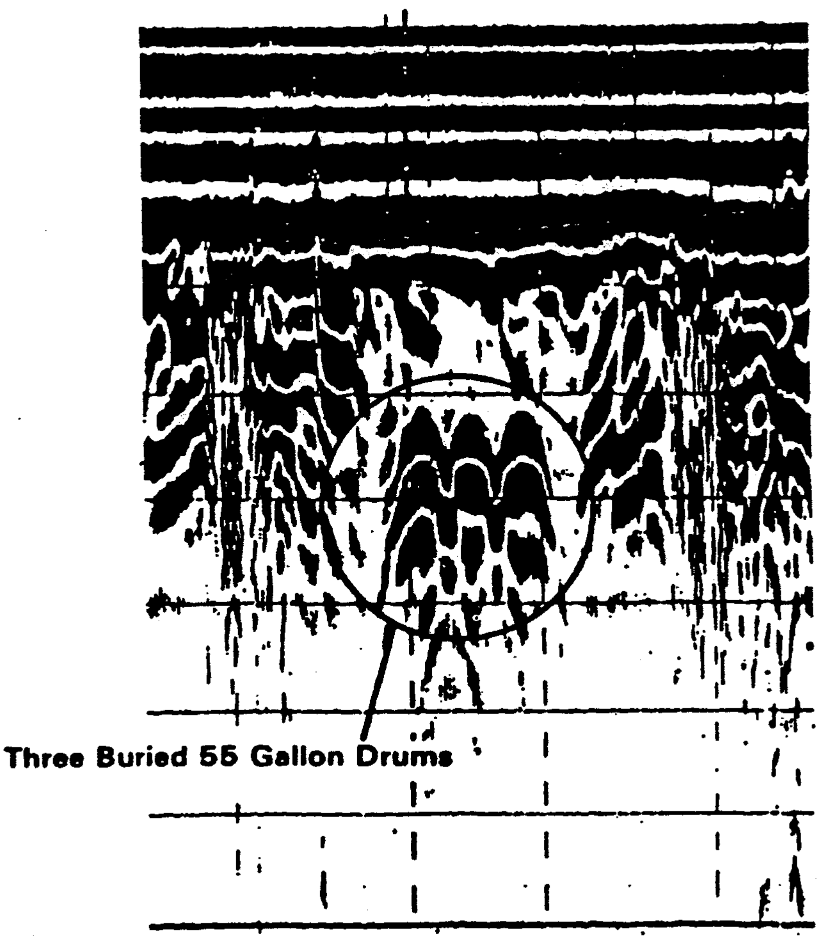

FIGURE 3-2 GROUND PENETRATING RADAR DATA OVER TRENCH WITH BURIED METAL

3.2.1.2 General Applications

Ground penetrating radar is typically used to map geohydrologic features, to locate boundaries of buried trenches, and to locate buried metallic objects.

3.2.1.3 Limitations

This method can be used to determine the location of a metal object buried in a dielectric (insulating) medium by the change in dielectric properties, i.e., transition from a dielectric (soil) to a conductor (lead pipe), but the radar cannot be used to obtain information about the conductor because by definition it has no dielectric constant (the charges are free to move) (Evans, 1982). Therefore, if this method were used to locate a lead service line, analysis of the hard copy of the profile would display a continuous profile of the pipe, which would confirm its location, but the same experiment performed with a copper pipe would exhibit no significant difference in the profile because the radar does not penetrate conductors.

The depth of radar penetration is very site-specific. This depth is reduced if water encountered in the profile has high electrical conductivity, or if there are sufficiently high concentrations of fine-grained materials (e.g., silts or clays) present. For example, high concentrations of salts tend to defeat the radar pulse, and penetration may not exceed 3 feet (WESTON, 1987).

Electromagnetic measurements in general are affected by "cultural features" such as fences, buildings, vehicles, storage tanks, power lines, railroad tracks, scrap metal, etc., which considerably diminish the reliability of the instruments.

3.2.2 Electrical Conductivity

3.2.2.1 Theory

The principal operation of the electrical conductivity method is shown in Figure 3-3. The instrumentation consists of a transmitter coil that radiates an electromagnetic field, which induces current loops in the earth which act as a conductor. These current loops in turn generate a secondary electromagnetic field that is proportional to the current flowing in the loop. Part of the secondary magnetic field of each loop is intercepted by the receiver and produces an output voltage that is related to subsurface conductivity. Subsurface conductivity varies according to Archie's Law, which states that the conductivity of a material is directly proportional to the conductivity of water and the square of the porosity of the material (e.g., soil/rock type, percent of saturation, etc.) (Keller et al., 1982). Figure 3-4 illustrates a typical electrical conductivity profile over a metal pipe.

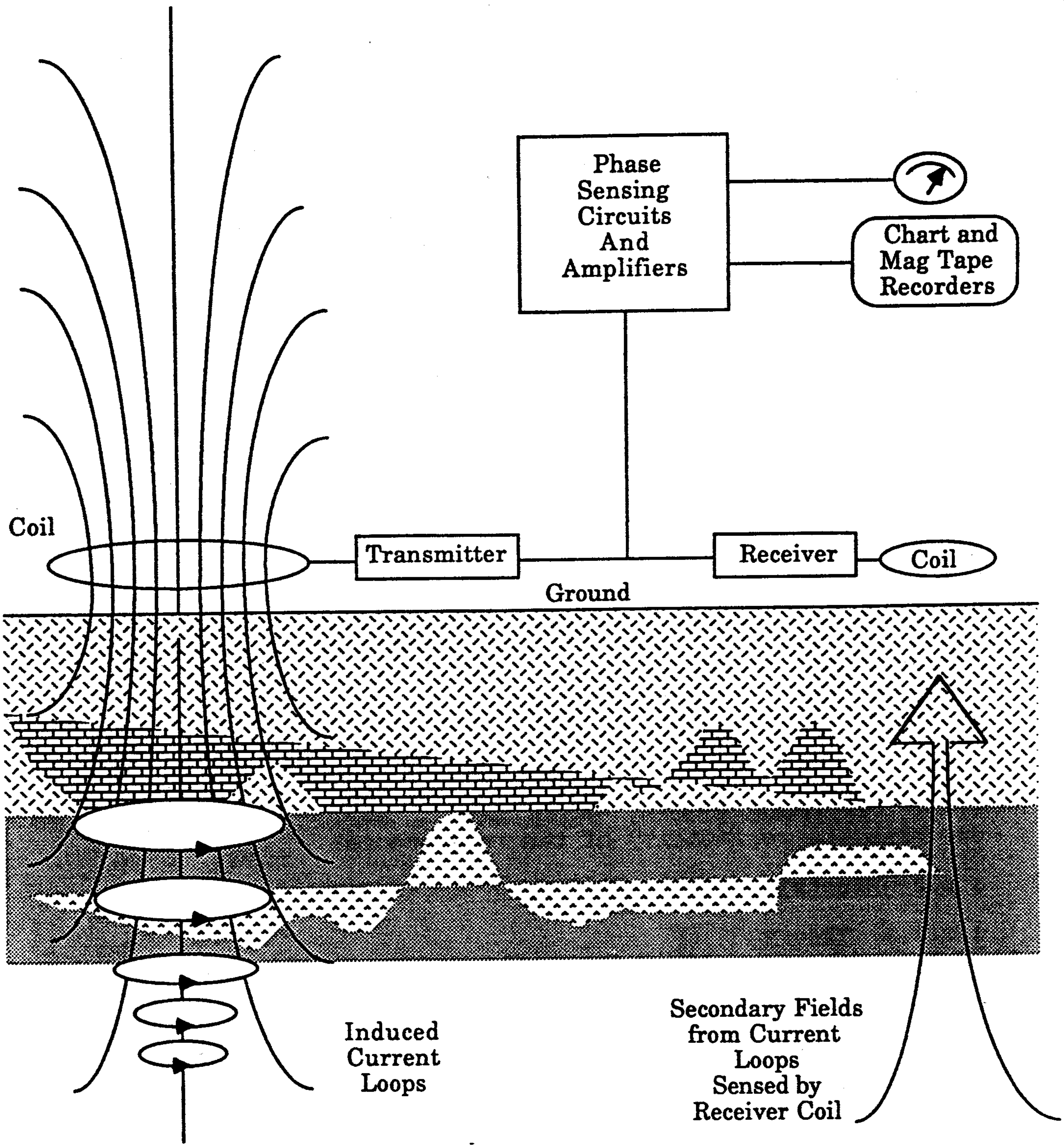

FIGURE 3-3 SCHEMATIC DIAGRAM OF AN ELECTRICAL CONDUCTIVITY INSTRUMENT

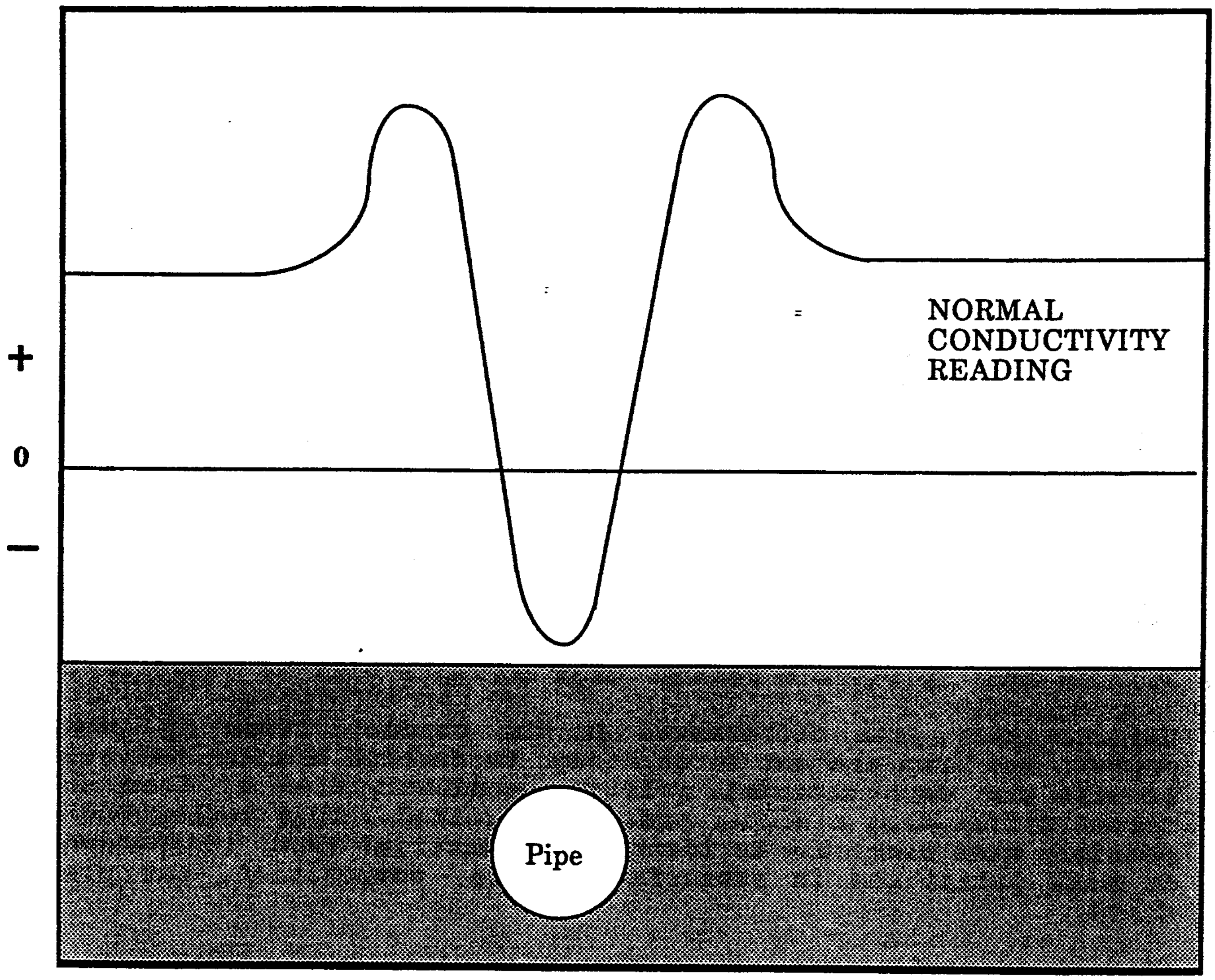

FIGURE 3-4 TYPICAL ELECTRICAL CONDUCTIVITY PROFILE OVER A METAL PIPE

3.2.2.2 General Applications

Electrical conductivity instruments may be calibrated to read the true subsurface conductivity within a uniform earth; however, subsurface conditions are rarely uniform. In a layered earth where each layer has a different conductivity, the reading will depend on the thickness and depth of the layers, and the specific conductivities of each layer. The resulting conductivity measurement is a complex function of all these conditions. An accurate solution requires knowledge of the layer thicknesses, depth, and relative conductivities.

This method is well suited for acquiring information on lateral changes in electrical conductivities in the subsurface (called profiling) and vertical changes in subsurface conditions (called sounding). Electrical conductivity is used primarily to identify areas of anomalous electrical conductivities, to find lateral and vertical variations of electrical conductivity in the subsurface, to locate buried materials, and to determine the presence of plumes and the distribution of contaminants in groundwater (Evans, 1982).

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.

3.2.2.3 Limitations

Since metals are of much higher conductance with respect to air, water, and soils (see Table 3-1), any subsurface metallic object will be readily visible because high currents will be generated.

Unfortunately, the differences in the conductivities of lead, copper, and iron are not large enough to furnish a characteristic profile for each material. If the conductivities of lead and copper differed by a higher order of magnitude, this method would possibly have been able to identify the material type, independent of site variations in subsurface strata, composition, and pipe depth.

Electrical conductivity measurements are negatively affected by cultural features that are typical of residential areas, such as fences, buildings, vehicles, storage tanks, power lines, railroad tracks, scrap metal, antennas, etc. These cultural features mask the small differences in conductivity between copper and lead.

3.2.3 Metal Detectors

3.2.3.1 Theory

The transmitter of a metal detector creates an alternating magnetic field around the transmitter coil. The primary field will induce eddy currents in a metal target within range of the instrument

Table 3-1

Approximate Conductivities of Different Materials*

Material	Conductivity (mmho/m)
Air	0
Fresh water	0.1
Seawater	4,000
Clay	1,000
Marble	<10
Copper	5.8×10^{10}
Iron	1×10^{9}
Lead	5×10^{9}

*Adapted from Telford et al., 1984.

(Telford, 1984). These eddy currents in turn produce a secondary field that interacts with the primary field to upset the existing balance. The result is an output on a meter and/or an audio signal. Figure 3-5 shows the operation of a simple metal detector.

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

3.2.3.2 General Applications

Figure 3-6 shows profiles taken with a metal detector at a rural site at which drums were suspected of being buried (Tyagi, 1983). Metal detectors respond to the electrical conductivity of metal targets and are commonly used for locating buried drums. They can detect both ferrous metals, such as iron and steel, and nonferrous metals, such as lead, aluminum, and copper.

3.2.3.3 Limitations

Among the various types of metal detectors, the detector used for locating buried drums may also be used for locating utilities; however, in general, they have been found to be insensitive to buried objects of small cross-sectional size. Special effort went into finding the latest available technology in metal detectors. Table 3-2 summarizes WESTON's discussions with leading manufacturers of metal detectors.

Cintex of America has metal detectors that measure the permeability of materials. This allows differentiation of materials, because measurements close to zero are obtained for PVC pipes, medium responses for lead and copper, and high responses for ferrous materials.

The Cintex technical representative, Mr. Daniels, commented that in our specific application, copper should show a slightly higher permeability response than lead; however, variabilities in the surrounding medium (e.g., depth, composition, and additional cultural features) might add to the problem of differentiation. For instance, the electrical response to a copper pipe buried 6 feet deep could be identical to that of a 3-foot-deep lead pipe. Differentiation between lead and copper with some degree of accuracy could be ascertained up to a maximum depth of 12 inches. The representative of Garret Electronics, Inc., Mr. Jack Lowry, also believes that it is possible to discriminate between lead and copper buried less than 12 inches deep with 70 to 75 percent reliability.

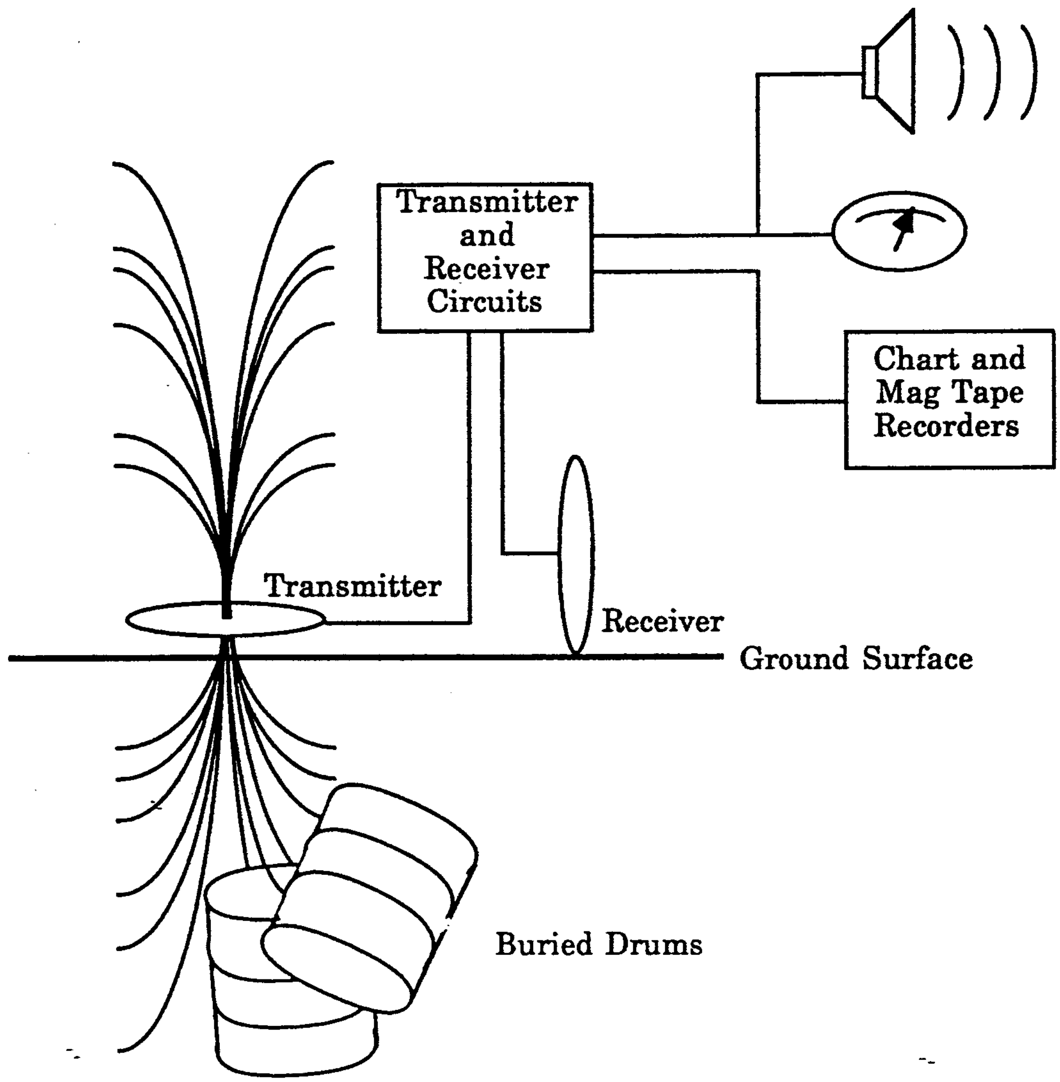

FIGURE 3-5 SCHEMATIC DIAGRAM OF A SIMPLE METAL DETECTOR

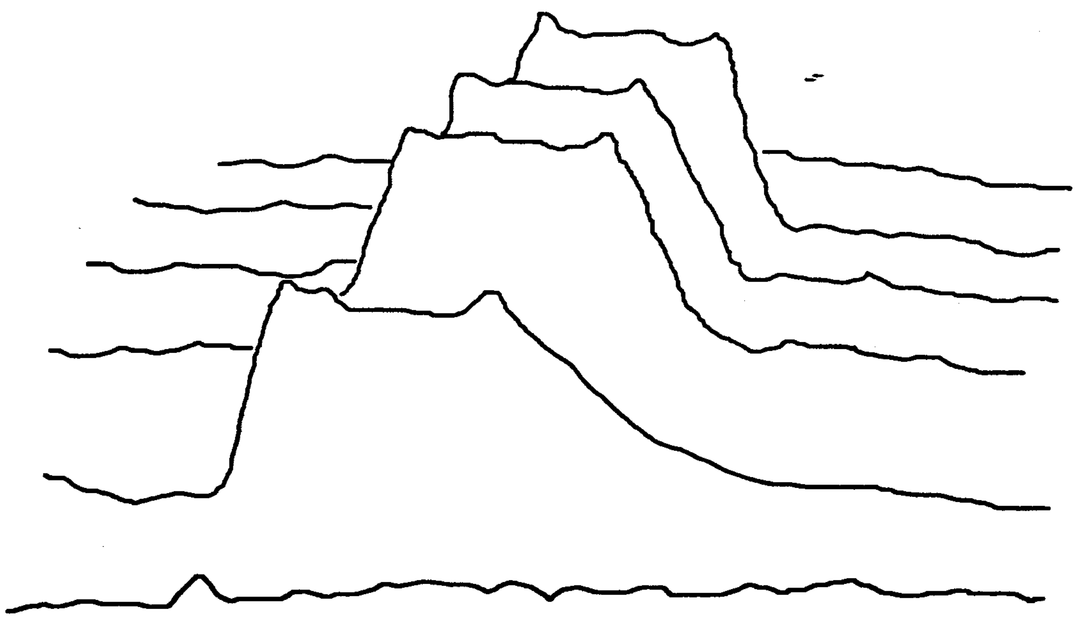

FIGURE 3-6 METAL DETECTOR DATA OVER TRENCH WITH BURIED DRUMS

Table 3-2

Summary of Discussions with Technical Representatives

Manufacturer	Instruments Manufactured and Capabilities
Applied Electronics Corp.	Manufactures heavy-duty industrial equipment, aperture-type only; for food, drug, and lumber industries for detecting ferrous and nonferrous metals only.
Cintex of America	Manufactures hand-held, portable metal detectors for differentiating metals from nonmetals, and within the metals for differentiating ferrous from nonferrous. The metal detectors work on a phase dispersion system compared to the permeability of air. Nonferrous metals have a permeability coefficient less than 1, very small range. In comparison, ferrous metals have permeability coefficients of 1 to 1,000, wide range, i.e., ferrite. Nonmetals have permeability coefficients of 0. The difference in ranges provides the ability to discriminate metals from nonmetals and ferrous from nonferrous. However, the permeability range of nonferrous metals is too small to adequately discriminate between types of nonferrous metals. Permeabilities of lead and copper are too similar to distinguish.
Garret Electronics, Inc.	Manufactures several types of portable metal detectors, and has been in the industry for many years. These metal detectors operate on the same principle as those described for Cintex of America. The representative is not familiar with any metal detection system that in general will discriminate between nonferrous metals with any degree of confidence. However, he did note that it "may be possible to discriminate between lead and copper buried less than 12 in. deep with 70 to 75 percent reliability."
Stearns Magnetics, Inc.	Manufactures primarily industrial aperture-type metal detectors for food, drug, wood, and plastics industries. The representative does not believe metal detection will work for our specific application, he suggested calling White Electronic, Inc.
White Electronic, Inc.	Designs, manufactures, and distributes pipe and cable locator systems and metal detection systems for private and government use. Top of the line systems include: PCL-400 pipe and cable locator, and EAGLE 2 SL metal detector. In our particular case, copper will give a slightly higher response than lead; however, variabilities in the surrounding medium, i.e., depth, composition, and additional cultural features, compound the problem of differentiation. The representative also believes it is possible to discriminate between lead and copper with some degree of accuracy, but only to a depth of 12 in.
Lock International, Inc.	Manufactures industrial metal detectors. The representative believes that this system will not solve our problem of differentiating lead and copper.
Barkley Dexter, Inc.	Manufactures industrial metal detectors. Representative believes we may get some response with the permeability detector, and, depending on depth, we may be able to differentiate lead from copper, but not with much reliability for depths greater than 12 in.

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Table 3-2
(continued)

Manufacturer	Instruments Manufactured and Capabilities
Gisco, Inc.	Is not aware of any remote sensing method commercially available that is able to differentiate lead from other types of nonferrous metals.
Sandia National Lab	The Electromagnetic and Optical Testing Group was not aware of any instrumentation or research specifically related to the proposed application of distinguishing between lead and copper in a soil medium.
Los Alamos National Lab	Some independent facilities are doing research, but Los Alamos is not aware of any progress. References recommended: Proceedings IEEE July 1979, special issue on EM Theory to Geophysical Exploration. Ohio State University. Microwave Association, Inc.
University of Arizona	Electrical Engineering Department. Dr. James Wait is involved in research on "Electromagnetic Theory in Dissipated Media," which will eventually lead to metal-specific metal detectors. As of now, he has no knowledge of any metal detectors available on the market able to locate specific metals.

Based on the survey conducted in this study of more than 20 manufacturers of metal detectors, plus many independent contractors that are currently using these instruments, the permeabilities of lead and copper are too similar to distinguish between the metal types with any degree of certainty at the present state of the art. Additional research and more powerful detectors may result in metal detectors in the future that can differentiate lead and copper pipe, if manufacturers believe there is a market for such devices. A few manufacturers have offered to set up a pilot study to test their equipment for our purposes.

3.2.4 Resistivity

3.2.4.1 Theory

Application of the resistivity method requires that an electrical current be injected into the ground by a pair of surface electrodes (Keller et al., 1982). The current flow within the subsurface produces an electric field with lines of equal potential, perpendicular to the lines of current. The potential field is measured by a voltmeter at the surface by a second pair of electrodes. A schematic of such a configuration is shown in Figure 3-7. The subsurface resistivity is calculated from the electrode separation, the applied current, and measured voltage.

The method provides data similar to that obtained using the electrical conductivity method. It measures the electrical resistivity (or inverse conductivity) of the subsurface or geohydrologic section which includes soil, rock, and ground water. Similarly, the electrical resistivity of the subsurface varies according to subsurface composition (e.g., soil/rock type, percent saturation, etc.). Interpretation of these measurements provides information on layering and depths of subsurface horizons as well as lateral changes.

3.2.4.2 General Applications

In general, most soil and rock minerals are electrical insulators (high resistivity), and, as a result, the flow of current is conducted primarily through the moisture-filled pore spaces. Therefore, the resistivity of soils and rocks is predominantly controlled by the amount of pore water, the porosity, and permeability of the system (SOILTEST, Inc., 1982).

In most applications, the presence, quantity, and quality of groundwater are the dominating factors influencing the resistivity value. As such, the method is primarily used to evaluate contaminant plumes at hazardous waste sites, and to assess lateral and vertical changes in natural geohydrologic settings of uniformly layered geological conditions, where the results will indicate the

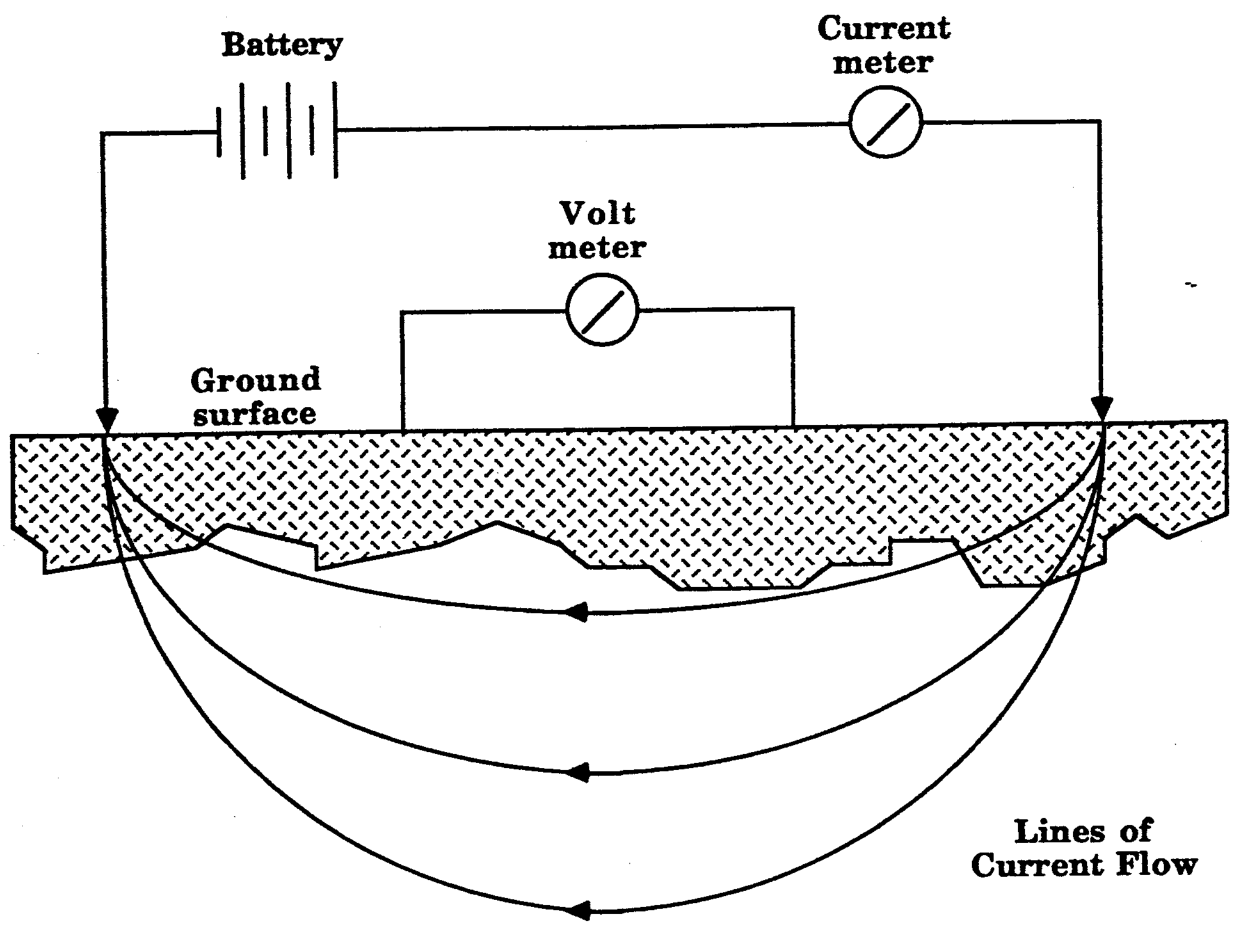

FIGURE 3-7 SCHEMATIC DIAGRAM OF A RESISTIVITY INSTRUMENT

number of geologic layers with contrasting electrical properties. Horizontal variations (profiling) in resistivity are observed by moving the entire array laterally over the surface. This approach can be used to map the horizontal extent of contaminant plumes in groundwater. Vertical variations (sounding) are obtained by observing the resistivities that result from progressively greater electrode spacings which lead to greater depths of penetration.

3.2.4.3 Limitations

The limitations of this method are similar to the limitations of the electrical conductivity method. In this case the differences in electrical resistivity (inverse of electrical conductivity) of lead, copper, and iron are not large enough to furnish a characteristic profile for each material. Similarly, if the resistivities of lead and copper differed by a higher order of magnitude, this method would possibly identify the material type independent of site variations in subsurface strata, composition, and pipe depth.

Another limitation is that the resistivity instruments are negatively affected by cultural features that are common to residential areas. In addition, urban site conditions, such as dry surface materials, and concrete or paved roads, preclude the use of this method because they behave as insulators.

3.2.5 Magnetometer

3.2.5.1 Theory

The magnetic method detects variations in magnetic susceptibility within the subsurface environment, this being a physical property of matter that describes the ease of its magnetization (Telford, 1984). When the earth's magnetic field encounters a material having a high magnetic susceptibility, induced magnetization occurs. The material is magnetized and the resulting induced magnetic field is the product of its volume magnetic susceptibility and the earth's field intensity. A magnetometer measures the vector sum of the earth's magnetic field and the induced magnetic field (GISCO, 1980).

Figure 3-8 is a schematic diagram of a magnetometer system that shows a concentration of ferromagnetic material, in this case a steel drum that acts as a magnetic dipole and distorts the total magnetic field. Figure 3-9 is a sample output of data obtained over a trench with buried steel drums, which shows the anomalies in the earth's magnetic field as a result of disturbances caused by changes in the magnetization of the drums. A magnetic profile over a magnetically homogeneous region does not contain any anomalies (Tuagi, 1982).

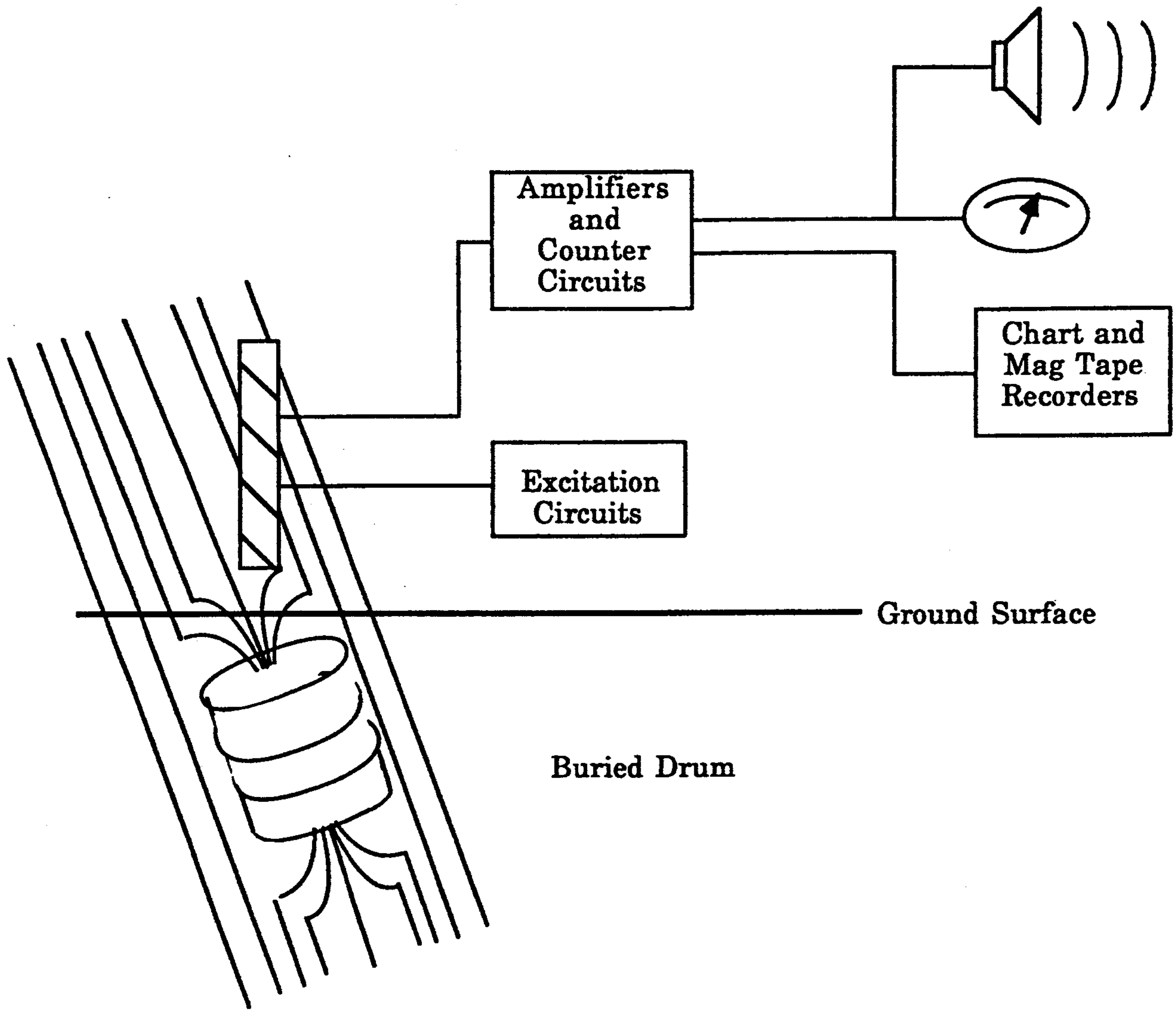

FIGURE 3-8 SCHEMATIC DIAGRAM OF A MAGNETOMETER

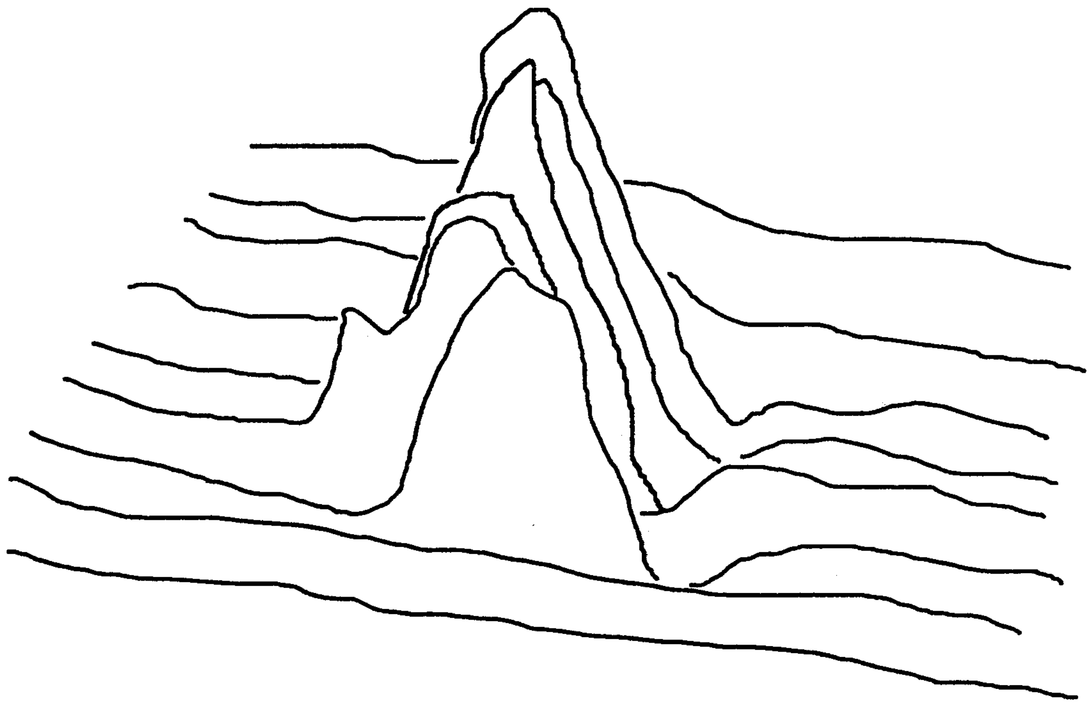

FIGURE 3-9 MAGNETOMETER DATA OVER TRENCH WITH BURIED METAL

3.2.5.2 General Applications

The magnetometer is commonly used to locate ferrous metals because their presence creates variations in the local strength of the magnetic field, permitting their detection. The response is proportional to the mass of the ferrous target (Fowler, 1985).

3.2.5.3 Limitations

Magnetometers detect only ferrous metals such as underground iron pipes or tanks (Geonics, 1980). Since magnetometers do not respond to nonferrous metals such as lead and copper, they are, therefore, unsuitable for locating and identifying buried lead service lines.

3.2.6 Fiber-Optic Instruments

3.2.6.1 Theory

A fiberscope comprises a light source unit, an eyepiece, and a flexible probe containing optical fibers that transmit the image. Additional instruments can include a still-camera or video system for the eyepiece, metal armor and waterproof sheathing for the probe, and steering mechanisms (Carruthers and Evins, 1985).

Figure 3-10 is a schematic diagram of a fiber-optic instrument. Charge-coupled devices (CCDs), developed by Bell Research Laboratories, have replaced the add-on cameras that, in general, are bulky and cumbersome. These new silicon semiconductor components are able to perform image sensing, analog signal processing, and digital or analog memory.

The CCD is a unique method of generating, storing, and conveying images to a viewing monitor by means of electrical signals. The CCD imager is a solid-state silicon chip similar in structure to a photovoltaic cell, but more complex; and it carries the information needed to form an image. Because of the CCD's diminutive size, the silicon chip can be placed within the tip of a small-diameter probe capable of penetrating the smallest apertures, which enables the CCD to function as a miniature TV camera able to record and display images on a video monitor with great clarity.

3.2.6.2 General Applications

Fiberscopes have been used as inspection tools in aircraft engines and 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 visual inspection of inaccessible pipelines without having to cut a short sample of pipe.

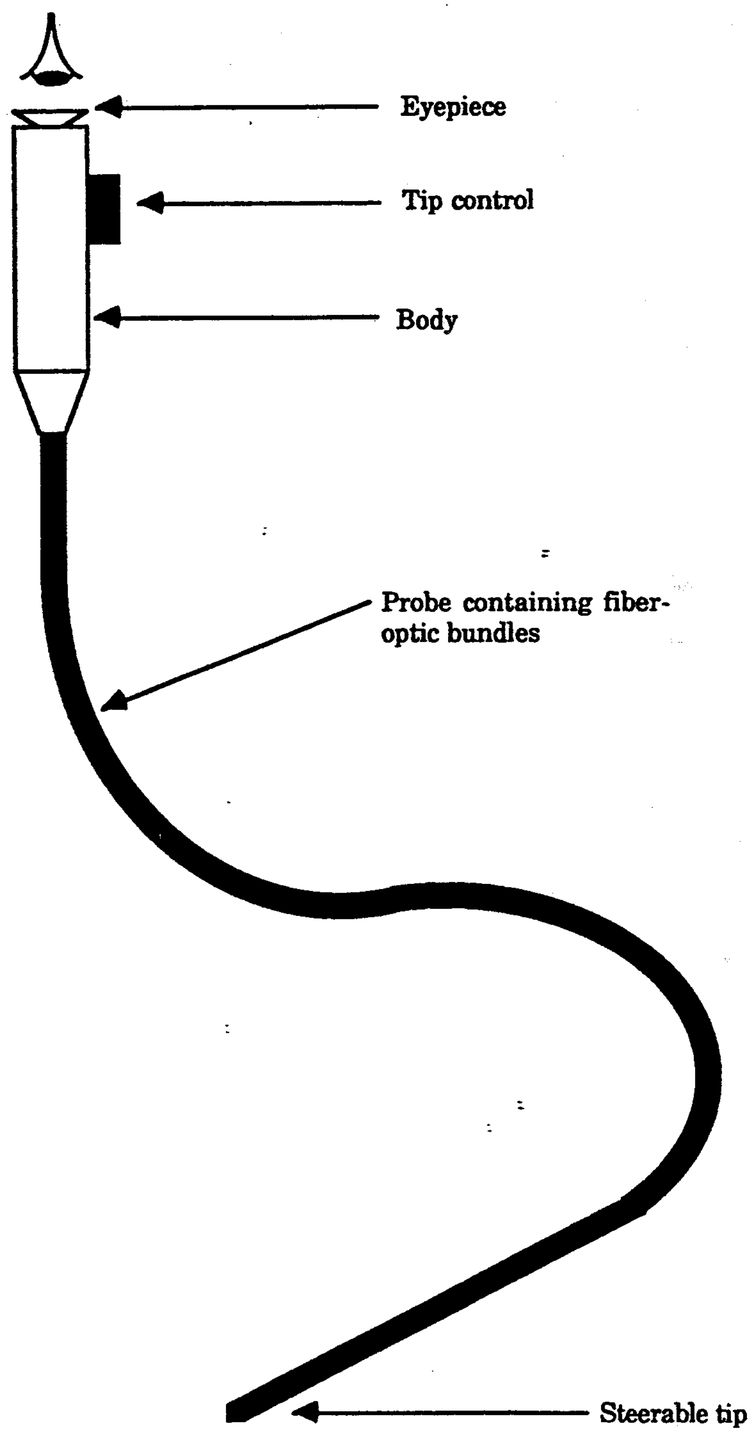

FIGURE 3-10 SCHEMATIC DIAGRAM OF A FIBERSCOPE

Silica-based fiberscopes feature ultra-thin scopes with diameters down to 0.5 mm and remote steering, with cord lengths from 50 to 100 feet.

Common entry points for fiberscopes to water mains are fire hydrants (Carruthers and Evins, 1985). Figure 3-11 shows how to insert a fiberscope into a hydrant. It is preferable to inspect mains when they are depressurized to avoid subjecting the fiberscope to pressure and to facilitate the insertion procedure. Inspection can be performed quickly, usually in 30 minutes or less. Another possible entry point into the water system is the water meter. The water meter is typically connected to two risers that connect with the customer's service line. Meters, when not located in the customer's basement, are usually accessible through meter pits.

3.2.6.3 Limitations

A field test of the ability of a fiberscope to detect lead service lines was conducted on 16 August 1989 at three residences in the District having lead service lines. Attempts were made to: (1) observe the outside of the service line at the curb cock (shut off) and (2) observe the interior of the service line by removing the water meter and inserting the fiberscope through the riser. The first approach was not successful because of the presence of water, mud, and debris around the curb cock. At one residence, the service line was deeper than 10 feet and was beyond the reach of the fiberscope being used for the demonstration. The second approach was not successful because the fiberscope was not flexible enough to negotiate the gooseneck bends in the riser pipes.

Currently available fiberscopes do not appear to be a solution to the problem of locating buried lead service lines.

3.3 CONCLUSIONS AND RECOMMENDATIONS

3.3.1 Conclusions

Currently available geophysical methods evolved in the mining and oil exploration industries, and are also applied today in hazardous waste site investigations to evaluate much deeper and larger targets than buried service lines.

Because ground penetrating radar is unable to penetrate conductors, it cannot be used to distinguish among metal pipes, and thus is unsuitable for our purposes.

The electrical conductivity method provides insufficient data for a small metal object in a large soil mass since the difference in conductivity among various metal pipes would be insignificant with respect to normal conductivity variations of the soil. The electrical conductivity method, with direct connection, is able to distinguish among metal pipes, but requires entry into the residence and/or excavation of the service line.

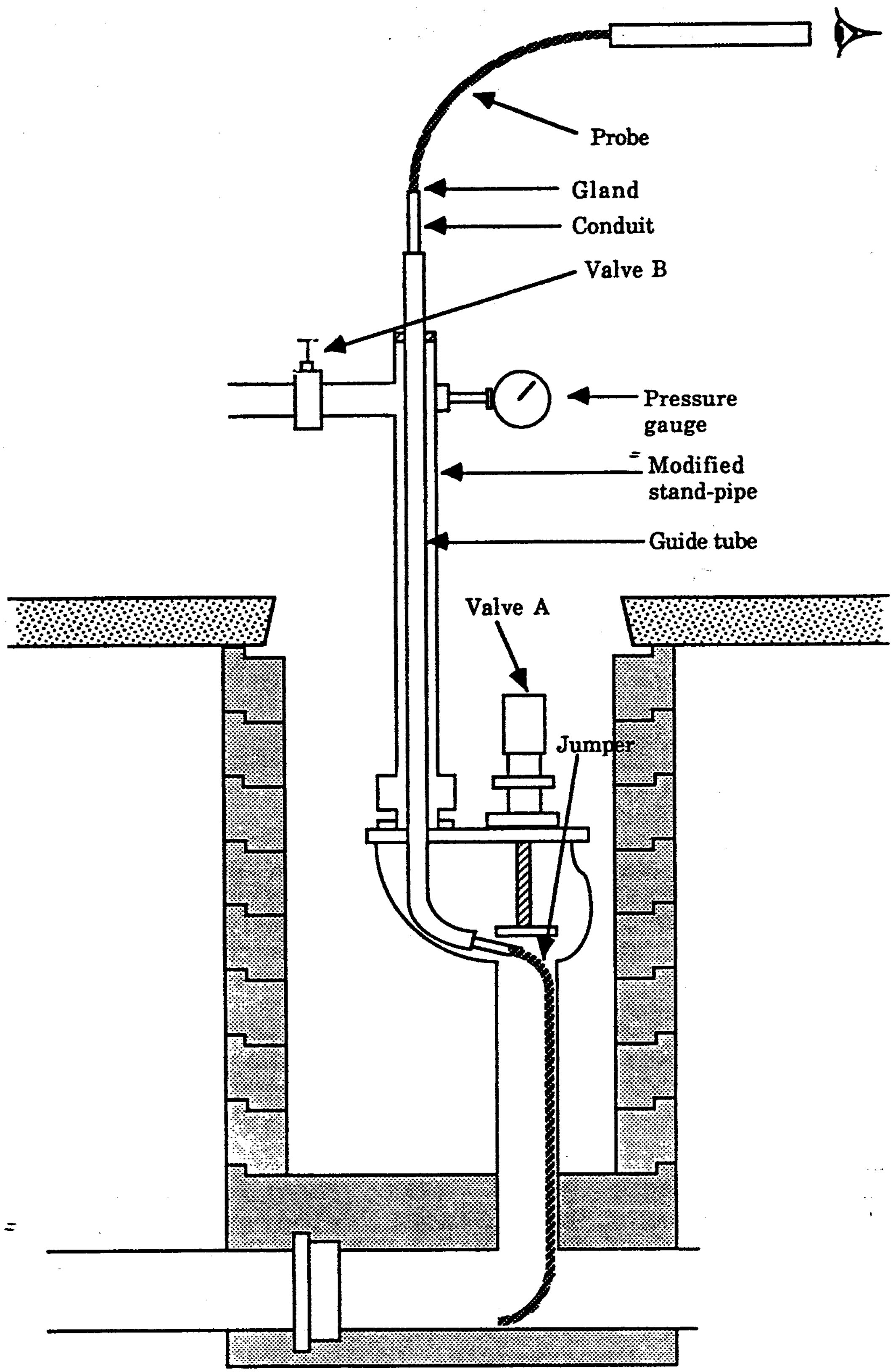

FIGURE 3-11 INSERTING A FIBERSCOPE INTO A HYDRANT

Currently available metal detectors are marginally able to distinguish between buried lead and copper pipes. This may be a possibility in the future, but additional research will have to be conducted before the method can be considered reliable. Currently, only pipe material buried less than 12 inches below the surface can be distinguished. Therefore, and based on a survey of more than 20 manufacturers of metal detectors as well as recommendations from staff members, it is concluded that metal detectors would not currently be able to distinguish copper from lead service lines for typical residential installations.

The resistivity method is unsuitable for reasons similar to those of the electrical conductivity-induced field method.

The magnetometer detects only ferrous metals and is, therefore, unsuitable for our purposes, given that lead is a nonferrous metal.

Fiberscopes do not appear to be a practical tool for identifying lead service lines. A more flexible fiberscope than the one tested might be able to identify lead service lines.

The many technical limitations of the geophysical methods investigated for our particular purposes have been described in this review, and it was found that most geophysical techniques would not provide the reliable location and identification of lead pipes.

3.3.2 Recommendations

As a result of the research conducted in this task, the following recommendations are made:

- A metal detector pilot study should be conducted to determine its practical feasibility of detecting buried lead service lines. Additional research should be followed closely as manufacturers may develop more appropriate detectors in the future.
- A more flexible fiberscope should be identified and tested to see: (1) whether it can negotiate the gooseneck in the riser pipe, and (2) whether the service line material can be reliably identified.

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SECTION 4

METHODOLOGY FOR IDENTIFYING LEAD SERVICE LINES

4.1 INTRODUCTION AND OBJECTIVES

One of the objectives of this project was to identify a procedure or procedures for predicting the probability of a lead service line existing at a given address. These probabilities were then to be used to determine the extent of lead service lines throughout the District.

The work relied greatly on the databases developed as part of this study, as described in Section 1. These databases were analyzed to identify trends that could be used to develop predictive techniques. The methods developed by using these techniques were then to be calibrated using the results of service line excavations performed as part of this study.

4.2 DESCRIPTION OF THE DATABASES

The methodology relied on the databases that were developed previously. To clearly understand the analyses that were performed, it is necessary to review the makeup of each database. The following subsections briefly describe each of the two databases and the analyses that were performed on them. Refer to Section 1 for a more detailed description of the databases and the methods by which they were assembled.

4.2.1 Tap File Database

The Tap File Database consists of data on residential service connections throughout the District. The database was developed using data from a variety of sources. The main sources of data were the Tap File maintained at the Bureau of Water Measurement and Billing (BWMB), the Meter File of the Department of Public Works Office of Information Systems (OIS), the Project Locator File, and the Maintenance File, also maintained by BWMB. These sources were used to obtain the basic data included in the Tap File Database. Other sources, such as Meter Relocation Program records and Street Replacement Program records, were used to update the service line material for individual addresses.

The structure of the Tap File Database is presented in Table 4-1.

The completed database consisted of a total of 126,099 records. However, the database was not completely without error. As an example, 30 records were identified that had an installation date

Table 4-1

Structure of the Tap File Database

Field Name	Description	Data Source
SCHEDNUM	Schedule number	Tap File, Meter File
DATE	Service line installation date	Tap File, Meter File
ADDNUM	Street number	Tap File, Meter File
STRADDR	Street name	Tap File, Meter File
QUADRANT	Quadrant	Tap File, Meter File
PIPESIZE	Diameter of service line	Tap File
PIPEMATL	Service line material indicated in Tap File or Meter File	Tap File, Meter File
REPLACED	Logical (i.e., true or false) indicating that the service line has been replaced	Lead Service Replacement Program, Meter Relocation Program, Street Replacement Program
ABAN_REPL	Indicates an abandoned service line with an "X"	Tap File
SQUARE	Square	Tap File
WARD	Political ward	Planning Commission Data File
CUSTSERV	Service line material indicated in Project Locator File	Project Locator File

outside the date range of 1900 to 1989. Because the installation date is an important indicator of a possible lead service line (as explained in Subsection 4.3), these 30 records were not considered in analyzing the database.

4.2.2 Water Quality Database

The Water Quality Database consists of the results of three sampling programs for lead in water conducted by the Department of Consumer and Regulatory Affairs (DCRA). The three sampling programs were described in detail in Section 1. Some common terminology is defined in this subsection, followed by a description of the database developed from the results of the sampling. The definitions of sample types follow:

- First Flush Sample -- A first flush sample is a set of water samples that is taken first thing in the morning, before any water use has occurred in the household. The set of samples consists of up to three water samples taken at the cold water kitchen tap and labeled Sample A, Sample B, and Sample C.

  - Sample A -- The first sample taken from the faucet: Its purpose was to determine the contribution of interior plumbing (i.e., brass fixtures and lead solder) to lead levels at the tap.

  - Sample B -- The second sample taken from the faucet: Its purpose was to determine the contribution of the service line to lead levels at the tap.

  - Sample C -- The third sample taken from the tap: Its purpose was to identify the contribution of the distribution main to lead levels at the tap.

- Midday Sample -- A 1-liter sample collected during the day, generally, though not always, taken from the kitchen tap. It was meant to represent typical exposure levels to lead in drinking water.

The results of the three sampling programs were entered into a common database. The structure of the database is shown in Table 4-2.

The addresses in the Water Quality Database were matched with addresses in the Tap File Database to obtain information about the service line. However, not all addresses in the Water Quality Database had a match in the Tap File Database. For those addresses that did not have a match, the service line material was considered to be unknown.

WESTON

Table 4-2

Structure of the Water Quality Database

Field Name	Description
ADDNUM	Street number
STRADDR	Street name
QUAD	Quadrant
SQUARE	Square
WARD	Political ward
ZIPCODE	Zipcode
SAMPIDMID	Sample identification for midday sample
MIDRESULT	Midday sample result
SAMPIDFF	Sample identification for first flush sample
ARESULT	Sample A result
BRESULT	Sample B result
CRESULT	Sample C result
PIPEMATL	Service line material (from Tap File or Meter Data File)
CUSTSERV	Service line material (from Project Locator File)
DATE	Service line installation date
REPLACED	Logical (i.e., true or false) indicating that the service line has been replaced

DCRA did an extensive statistical analysis of the data generated by these three sampling programs. One result of this analysis was the development of equations that would predict the probability of a service line being lead based on the lead concentration of a midday sample.

4.3 DATABASE ANALYSIS

The two databases developed were to be analyzed to develop techniques for predicting the occurrence of lead service lines. Each database focused on a different aspect of the problem. The Tap File Database contained data on Known Lead Service Line installations. The Water Quality Database contained results of sampling for lead in drinking water. The analyses performed on the individual databases are described in the following subsections.

4.3.1 Tap File Database

All analyses performed on the Tap File Database were done on a District-wide level and on a ward-by-ward basis. Before discussing the analyses that were performed it is necessary to define several terms relating to the database:

- **Known Lead Service Line** refers to an address for which there is a positive indication that the service line is lead. This indication may come from the BWMB Tap File, the Project Locator File, or both.
- **Unknown Service Line** refers to an address for which there is no indication of material type, either from the BWMB Tap File or the Project Locator File.
- **Nonlead Service Line** refers to an address for which there is positive indication that the service line is not lead. This indication may come from either the BWMB Tap File or the Project Locator File, or both.
- **Known Service Lines** refers to the total number of records for which there is an indication of service line material, either lead or nonlead. It is calculated as the sum of Known Lead Service Lines plus Nonlead Service Lines.
- **Total Number of Service Lines** refers to the total number of addresses in the database (126,069 records, excluding the 30 records outside the date range of 1900 to 1989). It is also the sum of Known Service Lines plus Unknown Service Lines.
- **Ratio of Known Service Lines** refers to the ratio of Known Service Lines to the Total Number of Services Lines.
- **Ratio of Lead Service Lines** refers to the ratio of Known Lead Service Lines to the number of Known Service Lines.

Next, it is important to discuss the priorities given to the BWMB Tap File and Project Locator File when conflicts arose in assigning a material type to each record. The highest priority was given to indications of a lead service line. If <u>either</u> the BWMB Tap File or Project Locator File indicated a lead service line, the address was considered to be a Known Lead Service Line, regardless of any other indication of material type. In cases in which there was no indication of a lead service line, but there was a discrepancy between the material indicated in the BWMB Tap File and Project Locator File, the Project Locator File material type was used since these data were collected more recently. The complete list of priorities used is given in Table 4-3.

Finally, it should be noted that lead service lines that have been replaced in recent years were still treated as Known Lead Service Lines for analysis purposes. This was done because these service lines are part of the overall trend of lead installations. Lead service lines that have been replaced are considered in Subsection 4.4, in which the number of lead service lines still in place in the District is discussed.

The first step was to calculate the number of Known Lead Service Lines, Unknown Service Lines, Nonlead Service Lines, etc., for each year from 1900 to 1988. These data were compiled on District-wide and ward-by-ward bases. The results were entered into a Lotus 1-2-3 spreadsheet for additional data manipulation. A printout of a small portion of this spreadsheet is shown in Figure 4-1, and the entire spreadsheet can be found in Appendix D.

Graphs were developed from this spreadsheet showing trends of service line installations since 1900. These graphs are discussed later in this section. It should be noted that service line installations listed for the year 1911 include installations done up to and including 1911. For this reason, the year 1911 was treated carefully when identifying installation trends.

The first plots (Figure 4-2 through 4-4) show distribution of service line installations on District-wide and ward-by-ward bases. The purpose of these plots was to examine the general growth of the District's water system. Figure 4-2 shows that on a District level, service line installations peaked in the mid-1920s, the late 1930s through the early 1940s, and late 1940s through early 1950s. The rate of service line installation at all other times was approximately 1,000 service lines per year.

Figures 4-3 and 4-4, which show service line installation on a ward-by-ward basis, illustrate how the various District wards grew over time. Wards 1,2,5, and 6 are older wards, with most service lines installed in or prior to 1911. Wards 3,4,7, and 8 were developed later, with most service lines installed in the period of 1920 through the mid-1950s.

WESTON

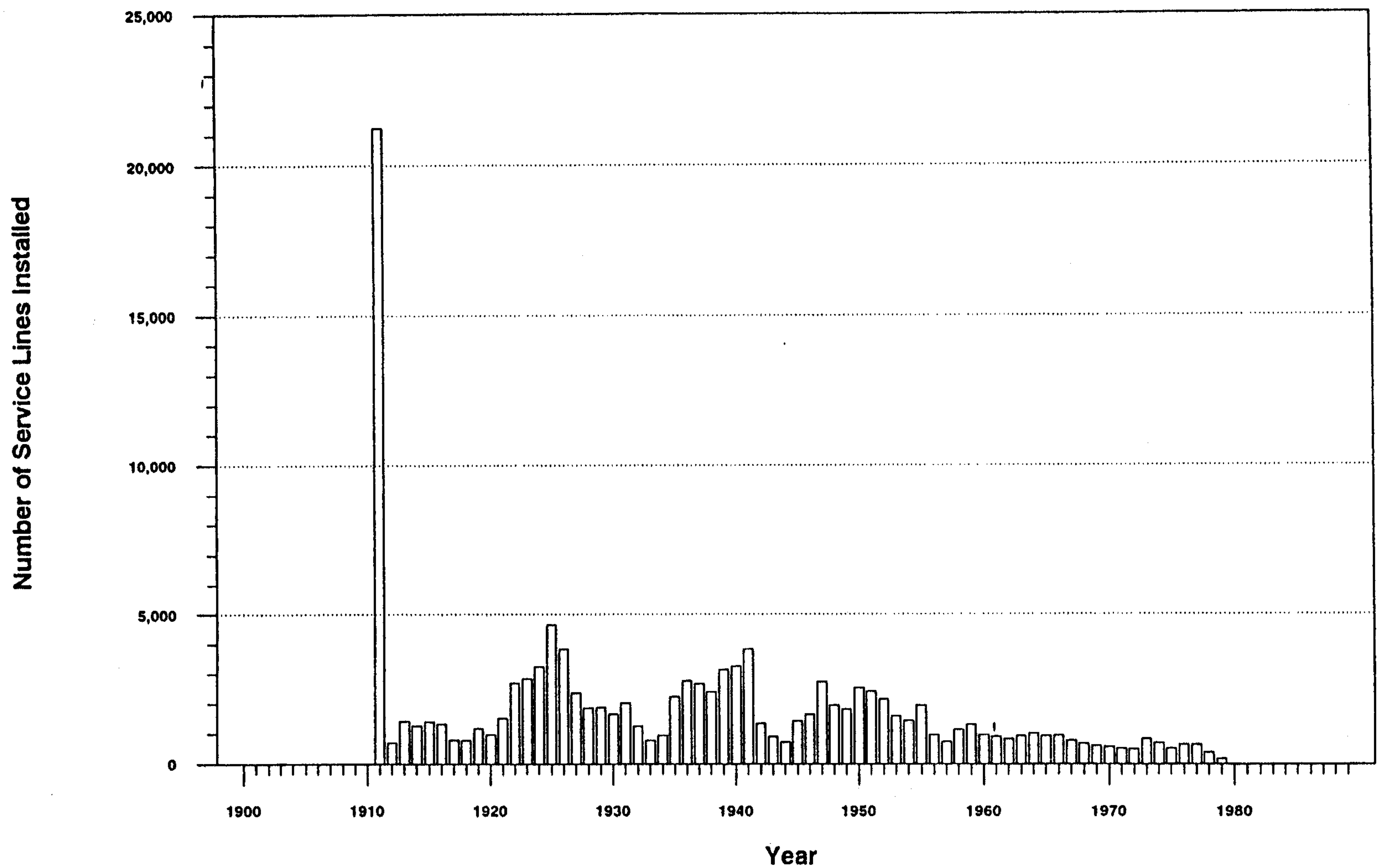
Table 4-3

Priorities Among Data Sources

Indicator		
BWMB Tap File	Project Locator File	Material Assigned
Lead	Lead	Lead
Copper Iron Other Unknown	Lead	Lead
Lead	Copper Iron Unknown	Lead
Copper	Copper	Copper
Copper	Iron	Iron

YEAR	WARD 1 TOTAL SERVICES	WARD 1 KNOWN SERVICES	WARD 1 UNKNOWN SERVICES	WARD 1 % KNOWN	WARD 1 LEAD SERVICES	WARD 1 % LEAD	WARD 1 ASSUM LEAD	WARD 1 TOTAL LEAD	WARD 2 TOTAL SERVICES	WARD 2 KNOWN SERVICES	WARD 2 UNKNOWN SERVICES	WARD 2 % KNOWN	WARD 2 LEAD SERVICES	WARD 2 % LEAD	WARD 2 ASSUM LEAD	WARD 2 TOTAL LEAD
1900	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1901	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1902	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1903	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1904	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1905	0	0	0	0.00	0	0.00	0	0	1	1	0	1.00	0	0.00	0	0
1906	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1907	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1908	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1909	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1910	0	0	0	0.00	0	0.00	0	0 **	0	0	0	0.00	0	0.00	0	0 **
1911	5260	1090	4170	0.21	356	0.33	1362	1718	4387	872	3515	0.20	196	0.22	790	986
1912	159	15	144	0.09	14	0.93	134	148	101	1	100	0.01	0	0.00	0	0
1913	464	61	403	0.13	7	0.11	46	53	162	7	155	0.04	1	0.14	22	23
1914	324	33	291	0.10	9	0.27	79	88	110	6	104	0.05	0	0.00	0	0
1915	319	42	277	0.13	4	0.10	26	30	142	10	132	0.07	4	0.40	53	57
1916	180	16	164	0.09	5	0.31	51	56	141	12	129	0.09	2	0.17	22	24
1917	68	12	56	0.18	3	0.25	14	17	86	4	82	0.05	0	0.00	0	0
1918	46	7	39	0.15	0	0.00	0	0	105	11	94	0.10	3	0.27	26	29
1919	157	47	110	0.30	8	0.17	19	27	76	9	67	0.12	4	0.44	30	34
1920	156	43	113	0.28	12	0.28	32	44 **	82	4	78	0.05	2	0.50	39	41 **
1921	239	101	138	0.42	26	0.26	36	62	92	12	80	0.13	4	0.33	27	31
1922	293	74	219	0.25	18	0.24	53	71	170	21	149	0.12	3	0.14	21	24
1923	264	105	159	0.40	27	0.26	41	68	230	58	172	0.25	10	0.17	30	40
1924	179	55	124	0.31	9	0.16	20	29	263	33	230	0.13	2	0.06	14	16
1925	180	74	106	0.41	13	0.18	19	32	209	39	170	0.19	2	0.05	9	11
1926	213	145	68	0.68	12	0.08	6	18	161	76	85	0.47	6	0.08	7	13
1927	73	52	21	0.71	21	0.40	8	29	174	111	63	0.64	46	0.41	26	72
1928	72	59	13	0.82	27	0.46	6	33	111	89	22	0.80	39	0.44	10	49
1929	67	54	13	0.81	14	0.26	3	17	77	45	32	0.58	10	0.22	7	17
1930	40	30	10	0.75	6	0.20	2	8 **	81	70	11	0.86	18	0.26	3	21 **
1931	52	48	4	0.92	3	0.06	0	3	80	57	23	0.71	13	0.23	5	18
1932	42	36	6	0.86	3	0.08	1	4	67	44	23	0.66	10	0.23	5	15
1933	44	41	3	0.93	0	0.00	0	0	68	51	17	0.75	4	0.08	1	5

FIGURE 4-1 SAMPLE OF PORTION OF SUMMARY SPREADSHEET OF SERVICE LINE INSTALLATIONS



Service line installations indicated for 1911
include years up to and including 1911.

FIGURE 4-2 DISTRIBUTION OF SERVICE LINE INSTALLATIONS FOR THE DISTRICT

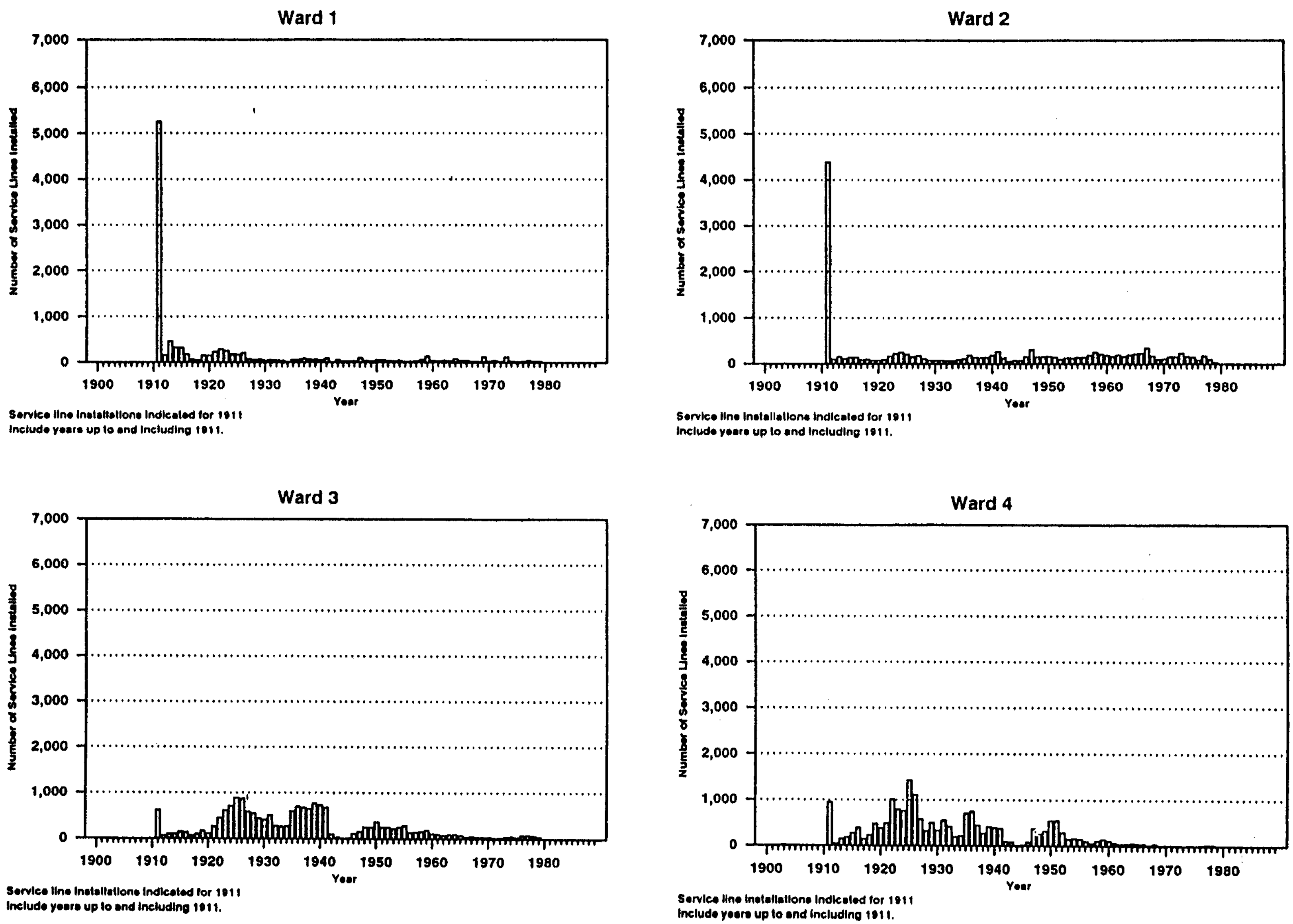


FIGURE 4-3 DISTRIBUTION OF SERVICE LINE INSTALLATIONS BY WARD (WARDS 1 THROUGH 4)

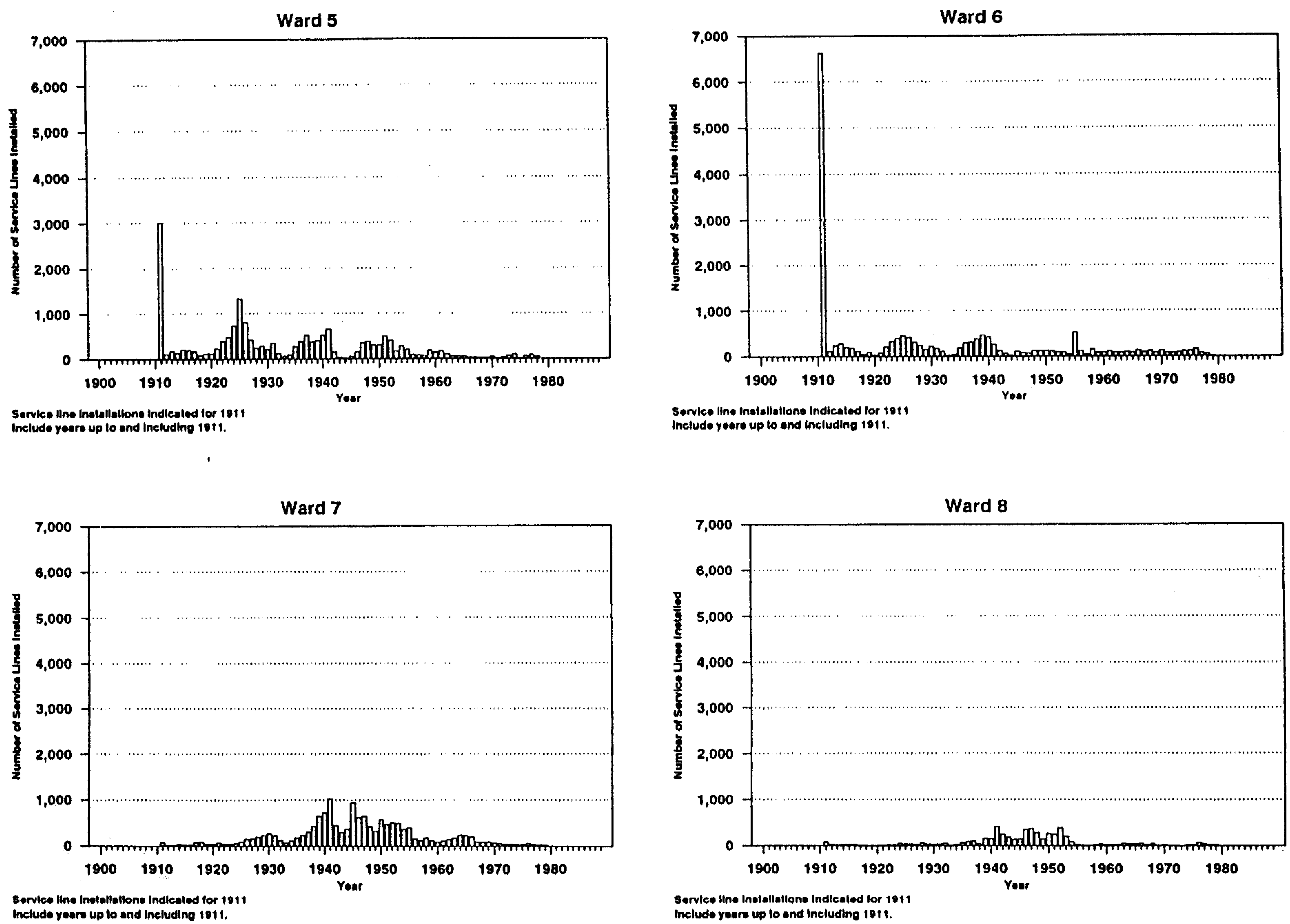


FIGURE 4-4 DISTRIBUTION OF SERVICE LINE INSTALLATIONS BY WARD (WARDS 5 THROUGH 8)

Next, it was necessary to examine the distribution of the Ratio of Known Service Lines over time. Figure 4-5 shows the Ratio of Known Service Lines to Total Number of Service Lines for the District as a whole. The Ratio of Known Service Lines over the period 1927 to 1968 was consistently greater than 0.80. Outside of this time period, however, the Ratio of Known Service Lines was generally less than 0.20. It is not surprising that the Ratio of Known Service Lines during the early part of the century is low, given the age of the data and the fact that many early Tap Cards (from which the database was collected) were unavailable because they had been incorporated into the Maintenance File. However, the sudden drop-off in the Ratio of Known Service Lines in 1970 must be explained. To do so, it is necessary to review briefly the data entry procedure.

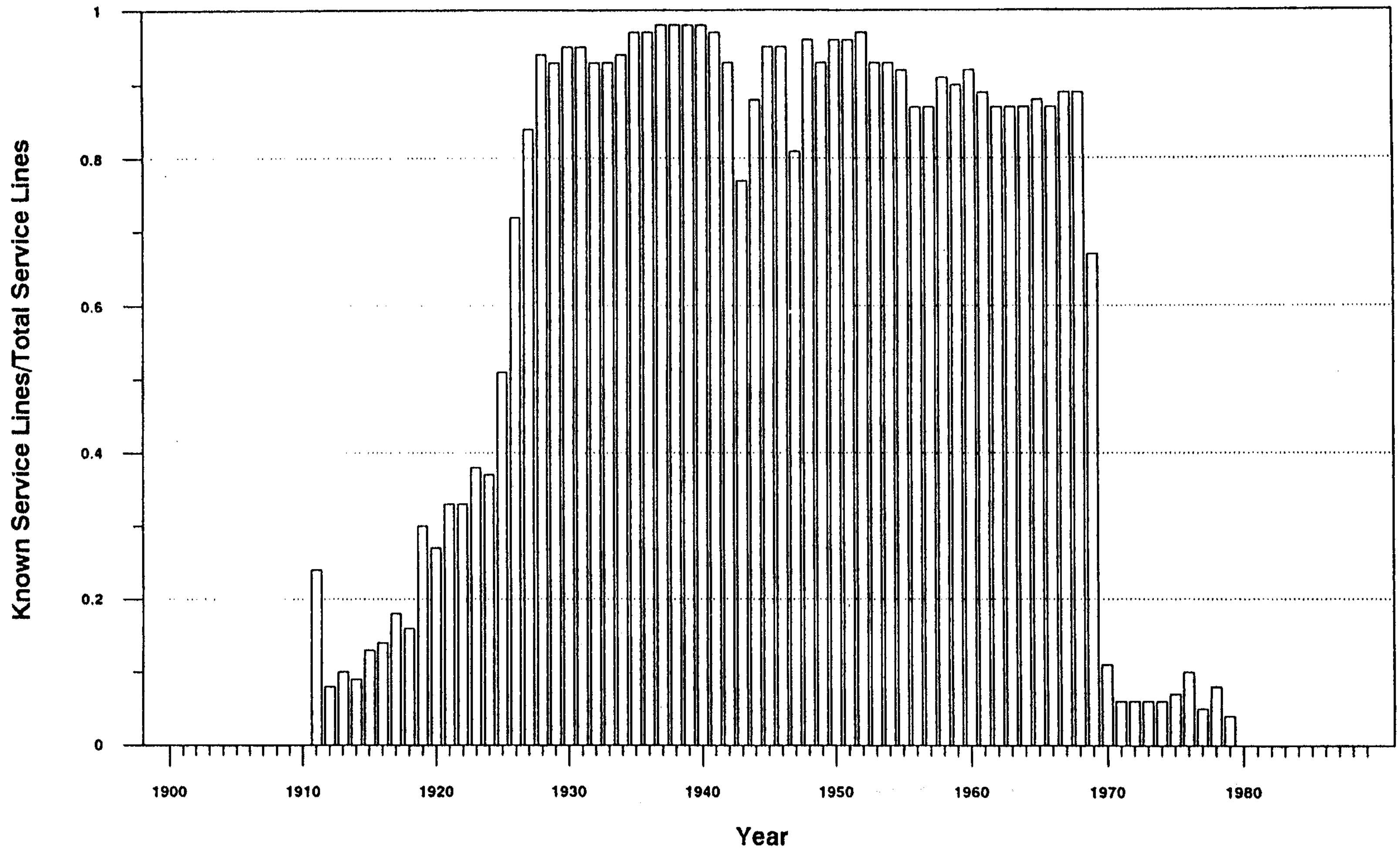
The major source of data on service line material was the Tap Card. These Tap Cards from the 1920s through the 1960s often had an indication of pipe material written somewhere on the card. Cards from 1970 onward rarely had such an indication. It is unknown whether this is because of some formal reason, or whether the practice was simply dropped. It also should be noted that service lines installed in the period after 1970 can probably be assumed to be nonlead.

Table 4-4 summarizes the service line installations by ward. Wards 1,2, and 6 show the smallest Ratio of Known Service Lines. These wards also correspond to the older areas of the District (as shown in Figure 4-3). Table 4-4 also shows that approximately 65 percent of the service lines in the database have a known material.

Having established this background, the examination of Known Lead Service Lines can begin. Figure 4-6 shows plots of the ratio of Known Lead Service Lines to Known Service Lines over time for the District. This plot shows a general trend of lead service line installation ending at approximately 1935, beginning again during the early 1940s, and then ending again by 1946. The apparent significant usage of lead service lines beginning again in 1970 can best be explained by reexamining Figure 4-5. Because there are so few Known Service Lines during the 1970s, even a very few Known Lead Service Lines will cause Figure 4-6 to show a relatively significant amount of lead usage during this period.

Figures 4-7 and 4-8 show the same breakdown of Known Lead Service Lines by ward. It is interesting to note that the same basic pattern of lead usage is repeated in each ward.

It is important to note that the aforementioned plots (Figures 4-6, 4-7, and 4-8) show only the ratio between Known Lead Service Lines and Total Known Service Lines. It is necessary at this point to examine the actual number of lead service lines installed.



Service line installations indicated for 1911 include years up to and including 1911.

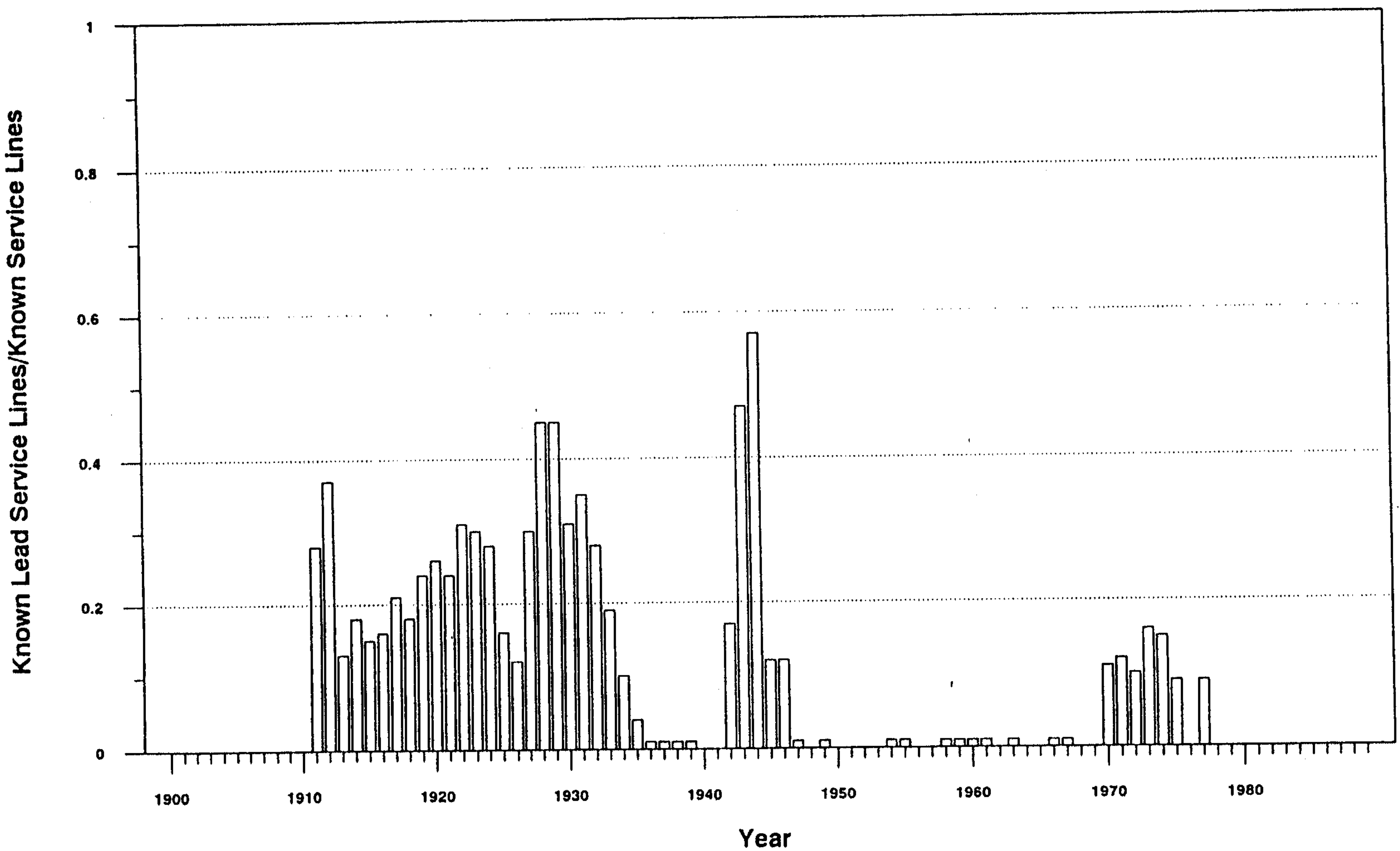
FIGURE 4-5 DISTRIBUTION OF KNOWN SERVICE LINES FOR THE DISTRICT

WESTON

Table 4-4

Summary of Service Line Installations

Ward	Total Number of Service Lines	Number of Known Service Lines	Percent of Known Service Lines
1	11,082	3,779	34
2	14,655	6,633	45
3	17,996	14,423	80
4	19,518	13,564	69
5	18,369	12,196	66
6	17,851	9,668	54
7	15,004	13,579	91
8	5,549	4,816	87
Ward not indicated	6,045	2,698	45
	126,069	81,356	65



Service line installations indicated for 1911 include years up to and including 1911.

FIGURE 4-6 RATIO OF KNOWN LEAD SERVICE LINES TO KNOWN SERVICE LINES FOR THE DISTRICT

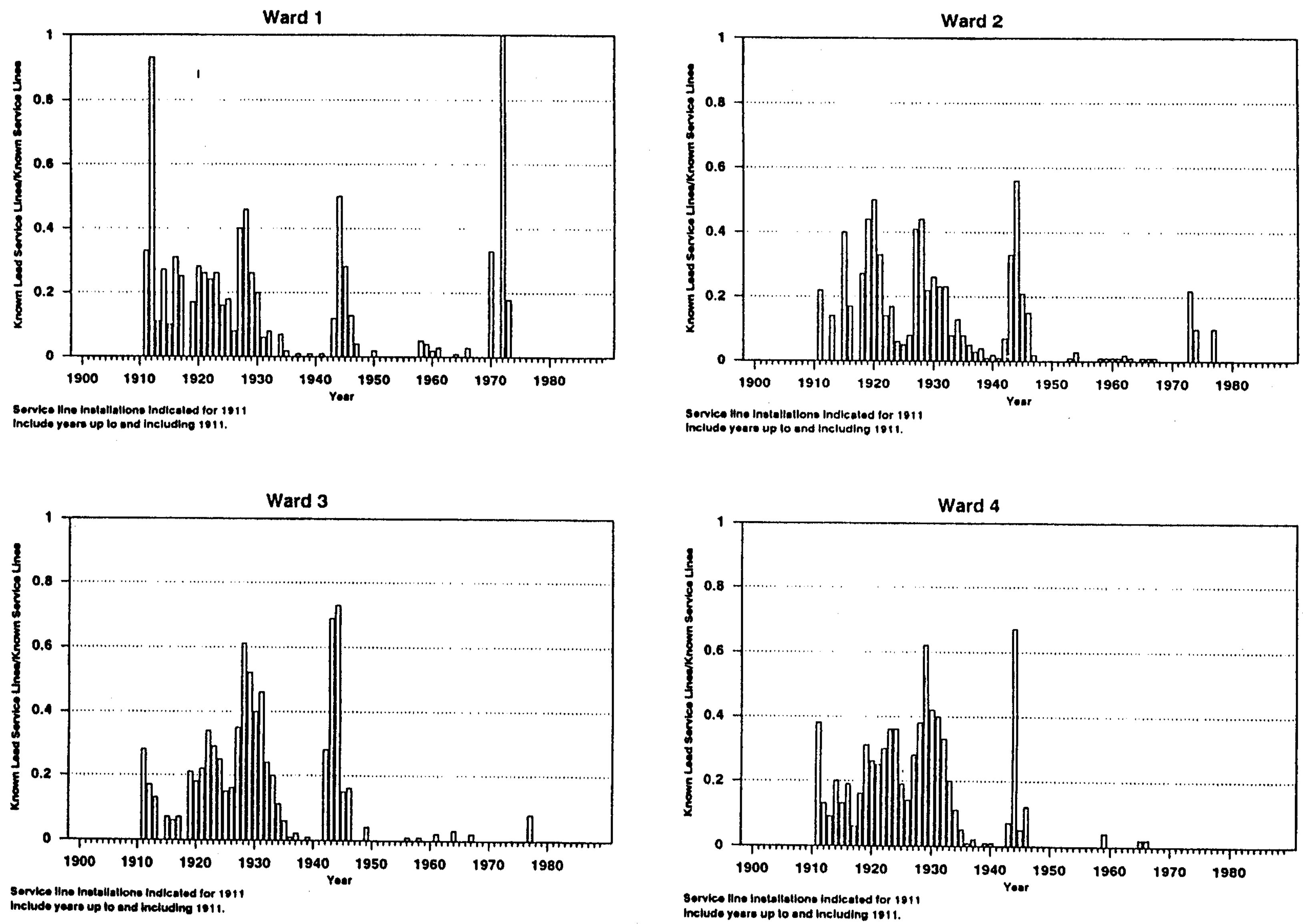


FIGURE 4-7 RATIO OF KNOWN LEAD SERVICE LINES TO KNOWN SERVICE LINES BY WARD (WARDS 1 THROUGH 4)

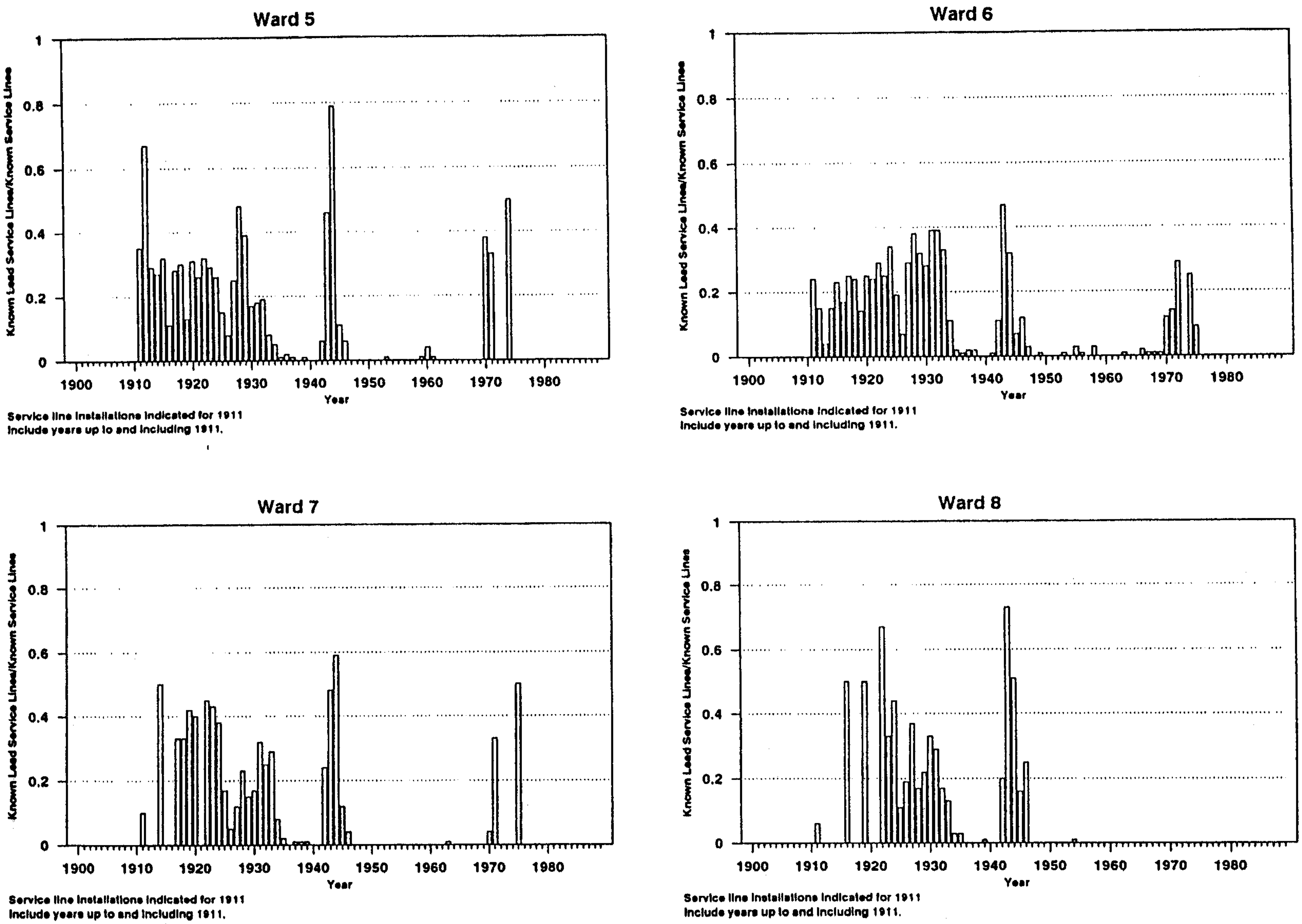


FIGURE 4-8 RATIO OF KNOWN LEAD SERVICE LINES TO KNOWN SERVICE LINES BY WARD (WARDS 5 THROUGH 8)

Figure 4-9 shows the number of Known Lead Service Lines installed in each year. Again, the same basic pattern emerges: relatively high lead usage in the 1920s and early 1930s (with a peak around 1930), followed by a drop-off in usage through the 1930s, and another peak during the 1940s. Note that the peaks in lead usage shown for the 1970s in previous figures do not appear in Figure 4-9. This is because the actual number of Known Lead Service Lines indicated for these years is small in comparison to other time periods.

Figures 4-10 and 4-11 show similar breakdowns of Known Lead Service Line installations by ward. Once again, the same basic pattern of lead usage appears in each ward. It is also interesting to note that in the older Wards 1, 2, 5, and 6, the majority of lead usage occurred in 1911 (i.e., 1911 and prior) and the early 1920s; while for the newer Wards 3, 4, 7, and 8, the majority of lead usage occurred in the late 1920s, early 1930s, and 1940s.

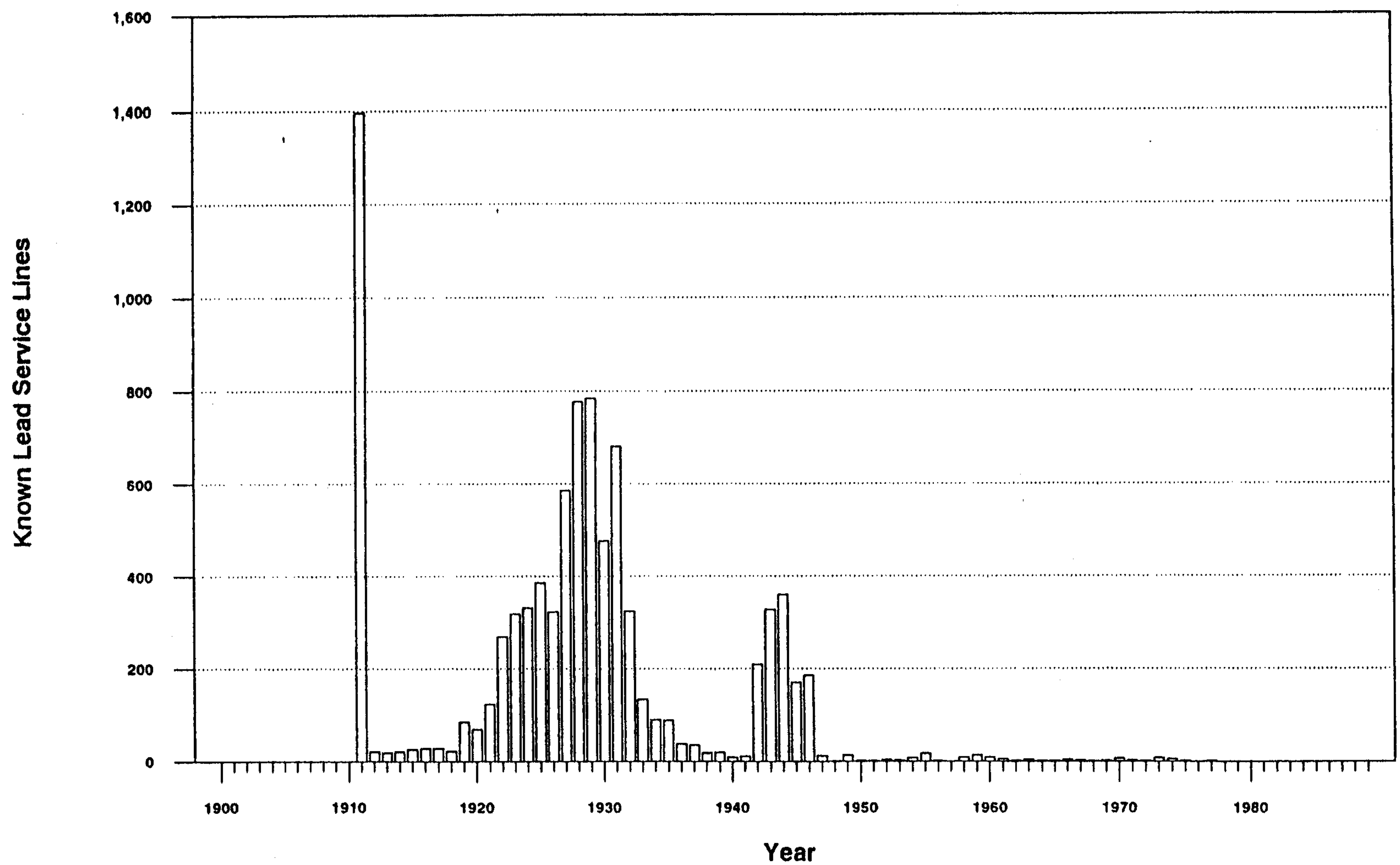
A summary of Known Lead Service Line data in relation to the Ratio of Known Service Lines is given in Table 4-5 for each ward.

The previous analyses focus on Known Service Lines. At this point it may be useful to take a different approach and examine the distribution of Unknown Service Lines. Figure 4-12 is a plot of the ratio of Unknown Service Lines to Total Service Lines over time for the District. This plot emphasizes the time periods in which additional work should be concentrated to fill in missing lead service line data. It should be emphasized once again that the large numbers of unknowns in the 1970s could be eliminated by assuming that they are all nonlead.

Another consideration that was investigated was the location of a house having a Known Lead Service Line with respect to other addresses having Unknown Service Lines and installed during the same time period. It was thought that in many cases whole blocks of homes may have had their service lines installed at the same time. Thus, if one or more of these addresses had a Known Lead Service Line, there is a good probability that some or all of the Unknown Service Lines would also be lead.

This approach was used to select addresses for excavation conducted to calibrate the methodology. The Tap File Database was examined manually by looking at groups of addresses and selecting an address that was surrounded by houses having Known Lead Service Lines. This technique works well when attempting to select a small number of addresses because it is relatively easy to identify a likely address when looking at a group of addresses. However, this technique is difficult to quantify, and even more difficult to convert to a computer application.

However, the concept of a proximity criterion is sound; and an attempt was made to analyze the Tap File Database on this basis. In this case, rather than look at individual addresses along a



Service line installations indicated for 1911
include years up to and including 1911.

FIGURE 4-9 DISTRIBUTION OF KNOWN LEAD SERVICE LINES FOR THE DISTRICT

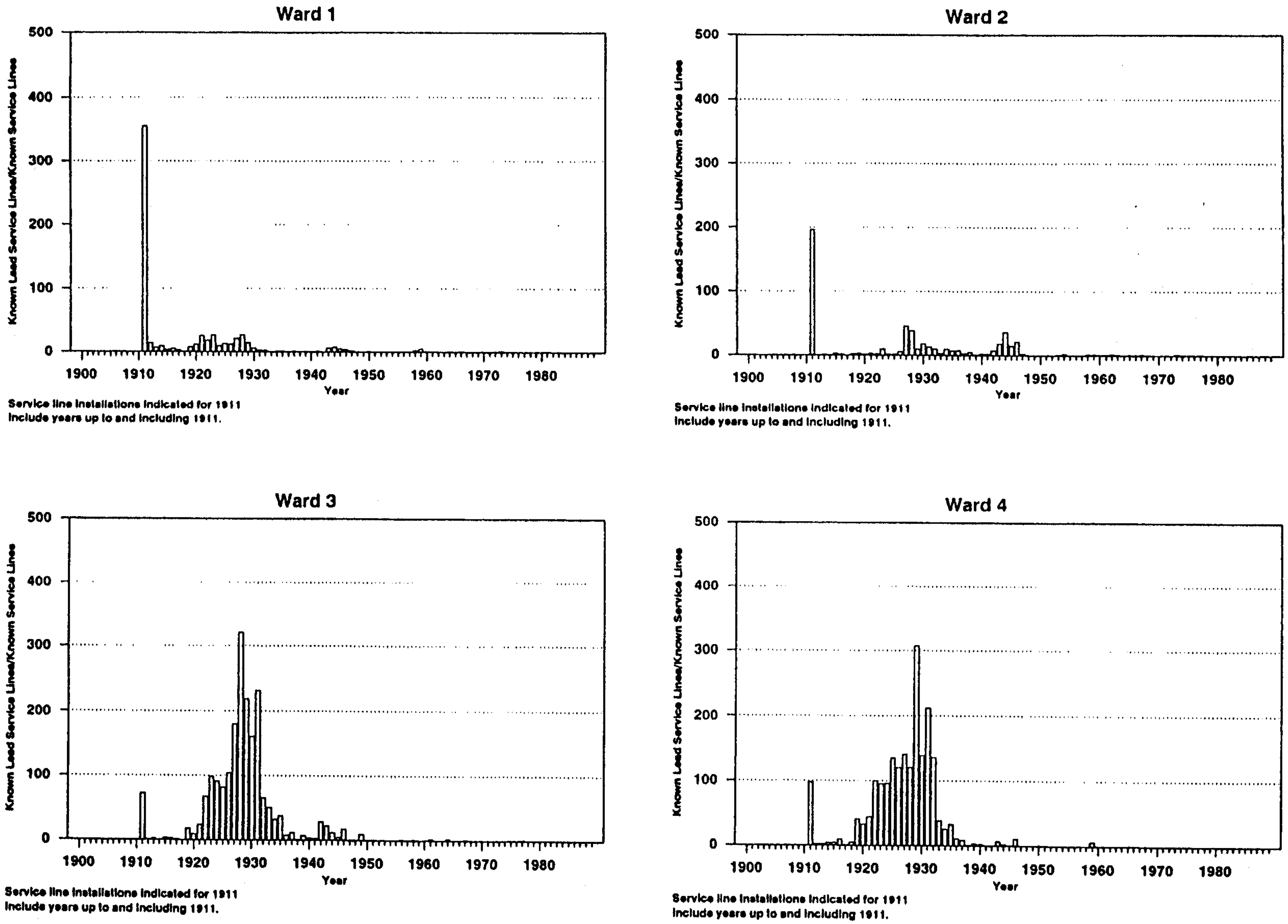
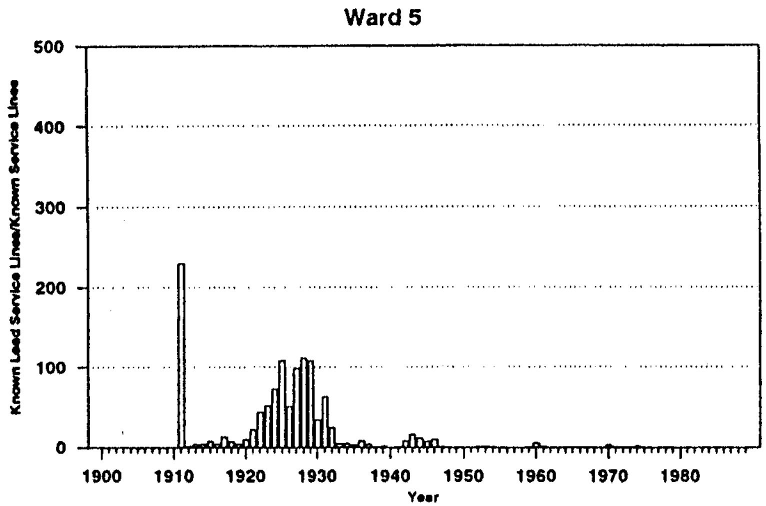
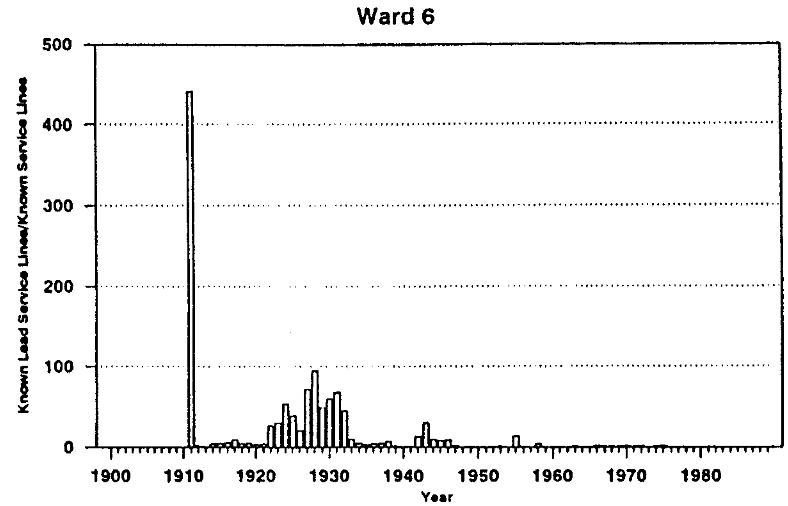


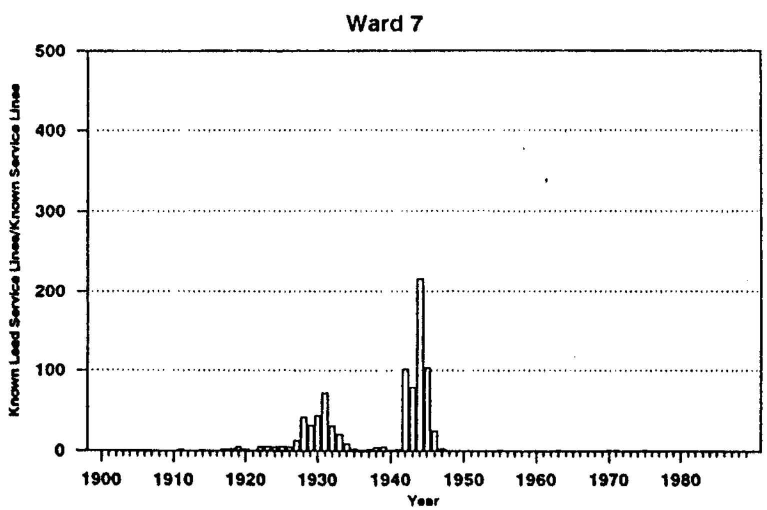
FIGURE 4-10 DISTRIBUTION OF KNOWN LEAD SERVICE LINES BY WARD (WARDS 1 THROUGH 4)



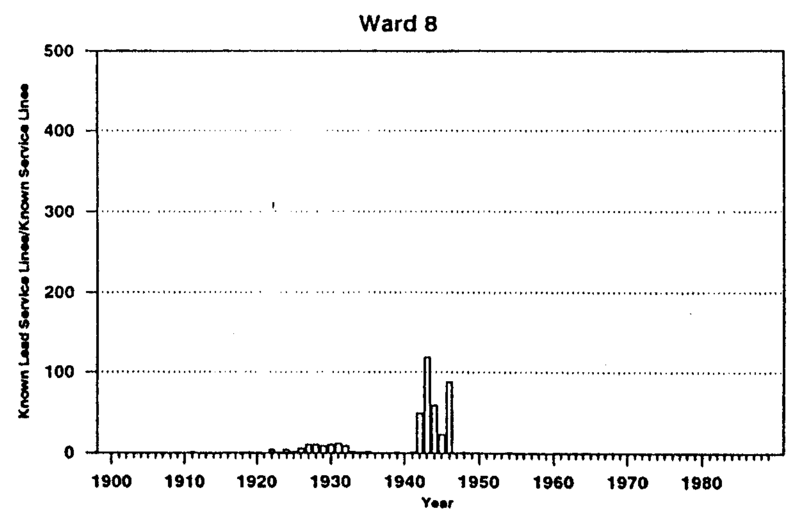
Service line installations indicated for 1911
include years up to and including 1911.



Service line installations indicated for 1911
include years up to and including 1911.



Service line installations indicated for 1911
include years up to and including 1911.



Service line installations indicated for 1911
include years up to and including 1911.

FIGURE 4-11 DISTRIBUTION OF KNOWN LEAD SERVICE LINES BY WARD (WARDS 5 THROUGH 8)

given street, the entire city block was used to group addresses considered to be in proximity to one another. In the District, blocks are identified by a unique number known as a square.

The Tap File Database was first sorted by installation date and square. Using the installation date in combination with the square ensures that addresses in proximity to one another also had service lines installed during the same time period. Next, the number of Known Service Lines and Known Lead Service Lines for each distinct combination of installation date and square was determined. Then a probability could be assigned to each installation date/square combination, calculated as the number of Known Lead Service Lines divided by the number of Known Service Lines for each combination. This procedure, illustrated in Figure 4-13, was performed for each square in the Tap File Database.

A total of 24,892 combinations of installation date and square was identified. Predicted lead probabilities for these combinations ranged from 0.0 (i.e., no Known Lead Service Lines in a given square installed in a given year) to 1.0 (i.e., all of the Known Service Lines in a given square installed in a given year were known to be lead).

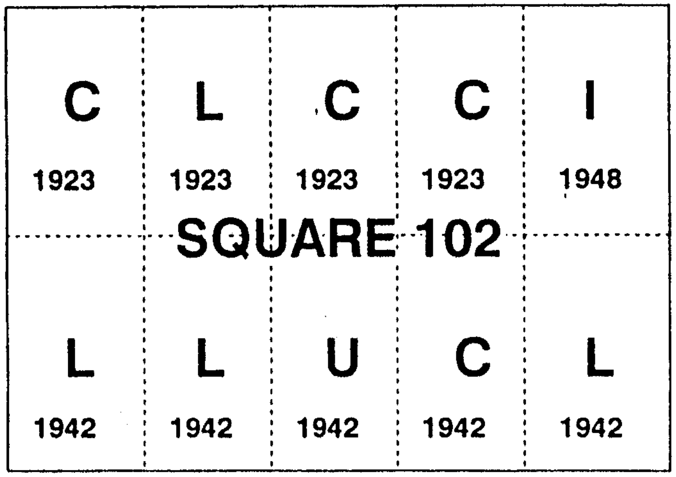
4.3.2 Water Quality Database

The Water Quality Database consisted of a total of 2,271 addresses at which water quality sampling was performed. Of this total, 1,050 had a Known Service Line. Only 213 of these had a Known Lead Service Line. Of the 1,221 addresses with Unknown Service Lines, 762 were unknown because the address was not a part of the Tap File Database. The remaining 459 were found in the Tap File Database, but had Unknown Service Lines.

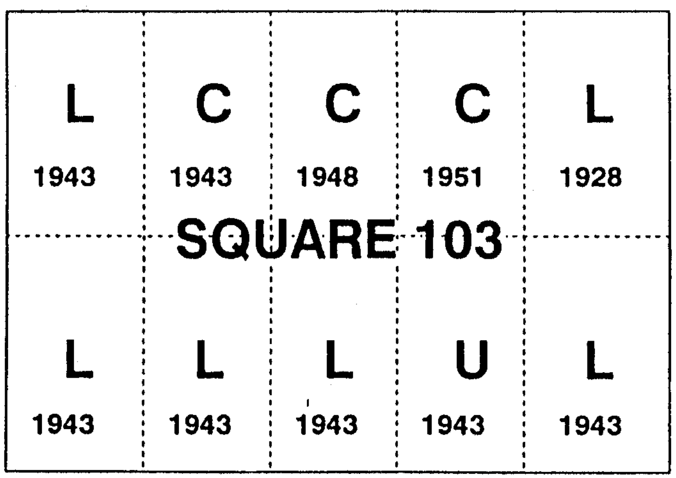
The analysis focused on those addresses for which first flush data were available and for which the service line material was known. First flush data were available for 154 Known Lead Service Lines, and for 524 Known Nonlead Service Lines. The average, minimum, and maximum lead concentrations for the Known Lead and Known Nonlead Service Lines are summarized in Table 4-6.

Two different approaches were followed in attempting to use water quality results to identify lead service lines. One focused solely on the lead concentration in Sample B. The second examined the relationship between Sample B and Sample A. Neither approach proved completely adequate in predicting the presence of a lead service line based on the available data. The two approaches were used, however, to select service lines for excavation as described in Subsection 4.4.

Initially, an attempt was made to determine a lead concentration in the Sample B that would indicate the presence of a lead service line since Sample B represents water standing in the service line. However, because of the difficulties inherent in relying on the



Installation Date/ Square Combination	# of Known Service Lines	# of Known Lead Service Lines	Lead Probability
1923/102	4	1	25%
1948/102	1	0	0
1942/102	4	3	75%



Installation Date/ Square Combination	# of Known Service Lines	# of Known Lead Service Lines	Lead Probability
1943/103	6	5	83%
1928/103	1	1	100%
1951/103	1	0	0
1948/103	1	0	0

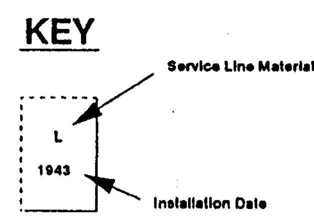


FIGURE 4-13 EXAMPLE OF PROCEDURE FOR CALCULATING INSTALLATION DATE/SQUARE LEAD PROBABILITIES

Table 4-6

Summary of Water Quality Data for Known Service Lines[1]

	Sample A		Sample B		Sample C	
	Known Lead	Known Nonlead	Known Lead	Known Nonlead	Known Lead	Known Nonlead
Avg[2]	20.00	10.75	19.56	8.21	2.00	1.61
Min	<2	<2	<2	<2	<2	<2
Max	390	558	134	308	53	47

[1]All results are in ug/L.

[2]Average values calculated using a value of 1 ug/L for all samples less than the detection limit of 2 ug/L.

184C/S4

homeowner to collect the sample, there is no way to determine which samples actually represent water from the service line. Also, because of variable water quality parameters such as temperature, pH, alkalinity, etc., lead concentrations contributed by a lead service line might vary from day to day, or even from house to house on a given day.

Ideally, one would expect the Sample B result to be greater than the Sample A result for houses having a Known Lead Service Line, again since Sample B represents water that has been standing in the service line. This does not appear to be the case, however, as the average of Sample A results for Known Lead Service Lines (20.00 ug/L) is actually greater than the average of Sample B results (19.56 ug/L). Additionally, the number of Known Lead Service Lines for which Sample B > Sample A (45 out of 154, or 29 percent) is only slightly larger than that for Known Nonlead Service Lines (89 out of 524, or 17 percent).

4.4 SERVICE LINE EXCAVATION SUMMARY

To test the validity of the basic conclusions drawn from the analysis of the Tap File Database and Water Quality Database, a group of 120 addresses was selected to have their service lines excavated and the service line material identified. All 120 addresses were to have Unknown Service Lines. The addresses were to be equitably distributed throughout the District.

The first step in selecting the addresses was to determine how many service lines were to be excavated in each ward. It was decided that the number of excavations in each ward would be based on the ratio of Unknown Service Lines to Total Service Lines for that ward. Thus, a ward with the highest percentage of Unknown Service Lines would have the most excavations.

Next, specific addresses were selected to meet the following criteria discovered during the database analyses:

- **Installation Date** -- Addresses were selected in each ward based on their service line installation date. Typically, 3 years that had the highest ratio of Known Lead Service Lines to Known Service Lines were chosen. Addresses were then selected in each ward that had an Unknown Service Line and an installation date in one of these years.

- **Proximity to Known Lead Service Lines** -- Addresses with Unknown Service Lines were chosen that were located on the same block and same side of the street as addresses with Known Lead Service Lines provided that they had the same installation date.

- **Water Quality Results** -- Addresses were selected that had an Unknown Service Line and showed the first flush Sample B result greater than 2 times the Sample A result, or where lead levels were relatively high (>40 ug/L). In Wards 7 and 8 there were no addresses that met this criterion.

A list of 120 addresses was then generated using these criteria. An additional 60 addresses were also selected as backups in case one of the original 120 could not be excavated. The next step was to obtain excavation permits for the 120 sites. It was at this point that difficulties were encountered.

It was hoped to limit the excavations to the grassy tree space area to facilitate the process. Therefore, addresses were eliminated from the original list of 120 that required excavation outside this area. (Ultimately, 11 excavations were done in concrete sidewalks, and 2 more were done in brick sidewalks.) In addition, since most of the excavations were to be done at older addresses, some of the addresses that had been selected from the Tap File Database no longer existed, or were now commercial rather than residential. Again, these addresses were eliminated from the list.

As addresses were eliminated from the original list, other addresses were substituted. However, the original list of 180 addresses (120 plus 60 backups) was an ideal list. Addresses that were substituted for these did not always match the selection criteria as well as the originals. It was also necessary to change the distribution of excavations between wards as it became difficult to locate suitable residential locations in some wards.

Finally, service lines could not always be located during excavation. As a result, 124 excavations were performed, but only 119 service lines were identified.

Table 4-7 summarizes the 119 successful excavations. This table shows the address, square, ward, installation date, service line material, reason for excavation, and whether the address was on the original list. It also shows the predicted lead probability resulting from the installation date/square technique discussed in Subsection 4.3.1.

4.5 PREDICTIVE TECHNIQUES

Three approaches for predicting the probability of a lead service line were identified upon examining the data collected during the review of water distribution system records. Two of the approaches are based on trends observed in the Tap File Database. The third evolved from examination of the Water Quality Database. The three approaches are described in detail in the following subsections.

Each of these approaches, examined individually, has shortcomings that prevent its sole use in predicting the occurrence of lead service lines throughout the District. The final methodology developed combines features of the three approaches, and certain other basic assumptions, to determine lead service line probabilities.

WESTON

Table 4-7

Excavation Summary

EXCAVATION NUMBER	SQUARE	WARD	INSTALLATION DATE	SERVICE LINE MATERIAL	REASON FOR EXCAVATION	ORIGINAL LIST? (YES OR NO)	PREDICTED PROBABILITY **
1	1741	3E	1928	COPPER	DATE	YES	9.99
2	3334	4B	1931	LEAD	DATE	YES	0.17
3	3107	5C	1911	LEAD	PROXIMITY	YES	0.92
4	1097	6B	1924	LEAD	DATE	YES	0.29
5	3501	5C	1918	COPPER	DATE	YES	0.50
6	2848	1A	1911	LEAD	PROXIMITY	YES	0.53
7	5150	7C	1919	LEAD	PROXIMITY	YES	0.50
8	3921	5A	1925	LEAD	WQSAMP	YES	0.33
9	3031	1A	1920	LEAD	DATE	YES	0.13
10	2835	1A	1911	LEAD	PROXIMITY	YES	0.47
11	2722	4A	1912	LEAD	WQSAMP	YES	9.99
12	2836	1A	1911	LEAD	PROXIMITY	YES	0.42
13	3551	5C	1928	LEAD	DATE	YES	9.99
14	2869	1B	1912	LEAD	DATE	YES	1.00
15	2865	1B	1911	LEAD	PROXIMITY	YES	0.38
16	2800	1E	1920	COPPER	DATE	YES	0.20
17	2841	1A	1911	LEAD	PROXIMITY	YES	0.56
18	3150	4D	1925	LEAD	PROXIMITY	YES	0.63
19	4127	5B	1920	COPPER	DATE	YES	9.99
20	3958	6C	1918	LEAD	DATE	YES	9.99
21	4213	5B	1928	LEAD	DATE	YES	0.56
22	4061	5B	1925	LEAD	PROXIMITY	YES	0.38
23	3557	5C	1921	LEAD	PROXIMITY	YES	0.25
24	4339	5A	1916	LEAD	WQSAMP	YES	9.99
25	1851	3E	1925	LEAD	WQSAMP	YES	0.08
26	1748	3G	1921	LEAD	WQSAMP	YES	0.00
27	3174	4B	1911	COPPER	WQSAMP	YES	1.00
28	155	2B	1911	IRON	DATE	YES	0.20
29	1908	3C	1928	COPPER	DATE	YES	9.99
30	1031	6A	1915	COPPER	PROXIMITY	YES	0.67
31	4060	5B	1925	LEAD	PROXIMITY	YES	0.29
32	2702	4C	1915	LEAD	WQSAMP	YES	9.99
33	2806	4C	1919	IRON	WQSAMP	YES	0.00
34	5787	8A	1925	LEAD	PROXIMITY	YES	0.50
35	2866	1B	1912	LEAD	DATE	YES	9.99
36	2580	1C	1914	COPPER	WQSAMP	YES	0.00
37	65	2B	1911	COPPER	PROXIMITY	YES	0.00
38	133	2B	1911	COPPER	PROXIMITY	YES	0.43
39	1257	2E	1911	IRON	PROXIMITY	YES	0.43
40	923	6B	1911	IRON	WQSAMP	YES	0.27
41	3254	4D	1927	LEAD	PROXIMITY	YES	0.82
42	2964	4A	1922	LEAD	WQSAMP	YES	9.99
43	3252	4D	1931	COPPER	DATE	YES	0.00

* P NONLEAD represents addresses that are in proximity to addresses with a nonlead service line.

** Addresses with a Predicted Probability equal to 9.99 had "no match" in the Installation Date/Square database.

184C/S4

Table 4-7
(continued)

EXCAVATION NUMBER	SQUARE	WARD	INSTALLATION DATE	SERVICE LINE MATERIAL	REASON FOR EXCAVATION	ORIGINAL LIST? (YES OR NO)	PREDICTED PROBABILITY **
44	2964	4A	1920	LEAD	WQSAMP	YES	9.99
45	1873	3G	1912	LEAD	WQSAMP	YES	9.99
46	5573	6C	1926	COPPER	PROXIMITY	YES	0.29
47				COPPER	PROXIMITY	YES	9.99
48	1269	2E	1911	LEAD	PROXIMITY	YES	0.67
49	1264	2E	1911	IRON	WQSAMP	YES	0.27
50				LEAD	PROXIMITY	YES	9.99
51	1072	6B	1911	LEAD	WQSAMP	NO	0.33
52	5535	8A	1950	LEAD	DATE	NO	9.99
53	309	2C	1911	LEAD	PROXIMITY	NO	0.50
54	3112	5C	1911	COPPER	PROXIMITY	NO	0.67
55	3504	5C	1920	COPPER	DATE	NO	9.99
56	651	2D	1911	LEAD	PROXIMITY	NO	0.27
57	2602	1E	1911	LEAD	PROXIMITY	NO	0.58
58	2891	1A	1920	LEAD	DATE	NO	9.99
59	3311	4C	1922	LEAD	PROXIMITY	NO	0.75
60	2856	1B	1911	LEAD	PROXIMITY	NO	0.86
61	3252	4D	1931	IRON	DATE	NO	0.00
62	1075	6B	1911	COPPER	PROXIMITY	NO	0.31
63	3047	1A	1923	COPPER	PROXIMITY	NO	0.50
64	3034	1A	1920	LEAD	DATE	NO	0.50
65	2990	4B	1922	LEAD		NO	0.00
66	957	6A	1911	LEAD		NO	0.60
67	1053	6A	1924	COPPER	DATE	NO	0.60
68	1352	3B	1928	COPPER	DATE	NO	0.88
69	2596	1E	1915	LEAD		NO	0.00
70		1		COPPER	DATE	NO	9.99
71	514	2C	1911	LEAD		NO	0.00
72	2884	1B	1911	COPPER	P NONLEAD*	NO	0.25
73	2971	4B	1925	LEAD		NO	0.00
74	2818	1E	1922	LEAD	PROXIMITY	NO	0.25
75	4070	5B	1918	LEAD	DATE	NO	0.40
76	4063	5B	1918	LEAD	DATE	NO	0.50
77	4009	5A	1918	COPPER	DATE	NO	1.00
78	4016	5A	1928	IRON	DATE	NO	0.00
79	3873	5C	1918	LEAD	DATE	NO	0.00
80	3927	5A	1918	LEAD	DATE	NO	9.99
81	3639	5C	1920	LEAD	DATE	NO	9.99
82	4341	5A	1918	LEAD	DATE	NO	0.00
83	3501	5C	1920	LEAD	DATE	NO	0.25
84	3920	5A	1920	COPPER	DATE	NO	0.20
85	5125	7C	1919	COPPER		NO	9.99
86	5160	7C	1920	LEAD	DATE	NO	9.99

* P NONLEAD represents addresses that are in proximity to addresses with a nonlead service line.

** Addresses with a Predicted Probability equal to 9.99 had "no match" in the Installation Date/Square database.

184C/S4

WESTON

Table 4-7
(continued)

EXCAVATION NUMBER	SQUARE	WARD	INSTALLATION DATE	SERVICE LINE MATERIAL	REASON FOR EXCAVATION	ORIGINAL LIST? (YES OR NO)	PREDICTED PROBABILITY **
87	3933	5A	1918	LEAD	DATE	NO	9.99
88	3927	5A	1918	LEAD	DATE	NO	9.99
89		7		COPPER		NO	9.99
90	5129	7D	1926	COPPER	DATE NON	NO	9.99
91	5990	8C	1925	LEAD		NO	9.99
92	5972	8C	1925	LEAD		NO	9.99
93	4064	5B	1925	COPPER	P NONLEAD*	NO	0.25
94				LEAD	P NONLEAD*	NO	9.99
95	5945	8E	1925	COPPER	P NONLEAD*	NO	0.00
96	5624	6C	1925	LEAD		NO	0.00
97	5602	6C	1924	LEAD	DATE	NO	0.67
98				LEAD		NO	9.99
99	1100	6B	1924	LEAD	DATE	NO	0.25
100	1102	6B	1924	LEAD	DATE	NO	0.27
101	1062	6B	1911	COPPER	PROXIMITY	NO	0.45
102	1110	6B	1924	COPPER	DATE	NO	1.00
103	1086	6B	1924	LEAD	DATE	NO	0.00
104	1091	6B	1946	LEAD	DATE	NO	0.00
105	1055	6A	1924	IRON	DATE	NO	0.25
106	5150	7C	1925	IRON		NO	0.00
107	5580	7B	1919	LEAD	DATE	NO	9.99
108	5691	7B	1937	IRON	P NONLEAD*	NO	0.00
109	5773	6C	1924	LEAD	DATE	NO	9.99
110	5603	6C	1924	LEAD	DATE	NO	0.67
111	5577	6C	1950	COPPER	DATE	NO	0.00
112	5777	6C	1924	COPPER	DATE	NO	9.99
113	569		1969	COPPER	DATE	NO	9.99
114	240	2C	1927	LEAD	DATE	NO	9.99
115	523	2C	1966	COPPER	DATE	NO	0.00
116	XXXX		1973	LEAD	DATE	NO	0.28
117				LEAD		NO	9.99
118	1268	2E	1911	COPPER		NO	9.99
119	151	1C	1911	LEAD	PROXIMITY	NO	0.82

* P NONLEAD represents addresses that are in proximity to addresses with a nonlead service line.

** Addresses with a Predicted Probability equal to 9.99 had "no match" in the Installation Date/Square database.

The results of the service line excavations will be used to assess the accuracy of lead probabilities predicted by the three methods. The addresses selected for excavations were originally chosen using the basic parameters of installation date, proximity, and water quality results. However, because of circumstances encountered in the field, not all of the originally selected addresses could be excavated. For this reason, only 105 of the 119 addresses excavated successfully could be used in this analysis.

4.5.1 Installation Date

It was the opinion of District personnel that the use of lead service lines generally stopped sometime during the 1950s. An examination of the Tap File Database developed previously generally confirmed this opinion, and also showed that there were fairly distinct periods of lead service line use within each ward. This fact allowed the development of a simple predictive technique based solely on the installation date and ward given in the Tap File Database.

The spreadsheet described in Subsection 4.3.1 was used to make a rough approximation of the total number of lead service lines in the District. The Ratio of Lead Service Lines for each year in each ward was applied to the Unknown Service Line value for that year and in that ward. The resulting value, referred to as Assumed Lead Service Lines, was then added to the number of Known Lead Service Lines to give the Total Lead Service Lines for each year in each ward. This analysis results in an approximation of 18,525 lead service lines in the District. This represents approximately 15 percent of the 126,099 service lines in the database.

The trend of lead service line installation is fairly consistent throughout the District and over time; and, therefore, extrapolation of the ratio of Lead Service Lines to Unknown Service Lines is appropriate for a rough estimate. However, it cannot be applied as successfully to individual addresses.

A total of 52 service lines were excavated based on their installation dates. Of these, 44 were excavated because their installation dates indicated a relatively high probability of a lead service line. These probabilities were based on the installation date and ward of the particular address (as shown in Appendix D). The remaining eight service lines were excavated because their installation dates indicated a low probability of a lead service line (see Appendix D).

Of the 44 expected lead service lines, 28 were actually lead. Thus, the installation date method correctly predicted approximately 64 percent of the lead service lines. Of the 8 expected nonlead service lines, 5 actually turned out to be nonlead.

4.5.2 Proximity to Known Lead Service Lines

The basic premise of this technique is that a house located near another house that has a lead service line also is likely to have a lead service line, provided that the service lines were installed at the same time. To analyze the records in the Tap File Database, houses were considered to be in proximity if they were located in the same square. To ensure that these same houses all had service lines installed at approximately the same time, the installation date for each was also considered. Thus, this approach is basically a refinement of the simple installation date method.

As described in Subsection 4.3.1, the 81,356 records with Known Service Lines were examined to develop installation date/square combination lead probabilities. The resulting 24,892 combinations were then applied to the 44,734 records with Unknown Service Lines. This was done by examining each of the addresses with an Unknown Service Line, taking the installation date and square for this address, and searching the 24,892 installation date/square combinations for a match. The corresponding lead probability was then assigned to the address with the Unknown Service Line. Table 4-8 summarizes the results of this analysis.

The large number of records listed as having no match represents addresses whose particular installation date/square combination did not exist in the installation date/square combination database. There are several reasons why this might occur. First, there are addresses in the Tap File Database that do not have a square assigned to them. Second, all addresses in a given square for a given installation date may be Unknown Service Lines, thus making it impossible to assign a probability to the installation date/square combinations.

If it is assumed that addresses with predicted lead probabilities of greater than 0.5 have lead service lines, this technique predicts 4,946 lead service lines among the 44,734 remaining addresses with Unknown Service Lines. It should be noted that this is a minimum figure, as there may be lead service lines among the 15,905 addresses with no match against the installation date/square combination database.

Examination of the 15,905 addresses with no match shows that 10,253 fall in the time period 1900 to 1925 and another 3,142 fall in the time period 1970 to 1989. These time periods correspond to the periods of high Unknown Service Lines (as shown in Figure 4-12). Again, service lines installed in the period after 1970 can be assumed to be nonlead.

A total of 38 addresses was selected for excavation based on their proximity to Known Lead Service Lines. These addresses were selected after a very detailed examination of the Tap File Database. Thus, these 38 addresses are ideal examples of the proximity method. Of the 38, 26 (or 68 percent) had the expected service line material.

WESTON

Table 4-8

Summary of Installation Date/Square Analysis

Probability Range	Number of Records
0.0 to 0.1	12,085
0.1 to 0.2	3,018
0.2 to 0.3	3,170
0.3 to 0.4	2,654
0.4 to 0.5	2,956
0.5 to 0.6	845
0.6 to 0.7	1,244
0.7 to 0.8	512
0.8 to 0.9	334
0.9 to 1.0	2,011
No match	15,905
	44,734

The new proximity method, which is based on installation date and square, was also applied to the 119 excavations. A summary of the results of this analysis is given in Table 4-9.

The results of the excavations show that this technique alone cannot be used to accurately predict the existence of a lead service line. Of the 49 lead service lines excavated for which a lead probability could be assigned, only 15 had a probability of >0.5. At the same time, 10 of these 49 addresses had a predicted probability of 0.0.

One explanation for this is that the technique relies on Known Service Lines and Known Lead Service Lines within each square. Thus, if there is only one Known Service Line in a square for a given installation date, and it is nonlead, then the predicted lead service line probability for all other addresses in that square with that installation date will be 0.0.

The results of the excavation program can be used to calibrate the installation date/square method for predicting service line material. Table 4-10 is a reproduction of Table 4-9 that includes a column entitled "Actual Probability." This column represents the actual probability found in the excavation program, and is calculated as the number of lead service lines found divided by the total number of service lines within each predicted probability range.

For calibration of predicted probabilities obtained from installation date/square combinations, the actual probabilities are then plotted against the predicted probabilities as shown in Figure 4-14. A regression line is plotted using the midpoint of each predicted probability range, and excluding the point for the predicted probability range 0.9 to 1.0. The line relates calibrated probability with predicted probability, and results in the following equation:

$$\text{Calibrated Probability} = 0.46 + (0.49 \times \text{Predicted Probability}) \quad \text{(Eq. 4.1)}$$

4.5.3 <u>Water Quality</u>

The DCRA Water Quality Database is too small to be of use in predicting lead service lines throughout the District. However, the excavation data were used to verify whether lead levels in water could be used to indicate a lead service line. A total of 14 service lines were excavated based on water quality sampling results. All 14 were expected to be lead.

Table 4-11 shows the lead levels found at the 14 addresses, along with the service line material identified during excavation.

WESTON

Table 4-9

Results of Installation Date/Square Method Applied to Excavation Sites

Predicted Probability	Actual Material Lead	Actual Material Nonlead	Total
0.0 to 0.1	11	11	22
0.1 to 0.2	2	3	5
0.2 to 0.3	9	6	15
0.3 to 0.4	5	1	6
0.4 to 0.5	7	5	12
0.5 to 0.6	5	1	6
0.6 to 0.7	4	2	6
0.7 to 0.8	1	0	1
0.8 to 0.9	3	1	4
0.9 to 1.0	2	3	5
	49	33	82*

*Does not include 37 records for which an installation date/square combination did not exist.

WESTON

Table 4-10

Calibration of Installation Date/Square Method Using Excavation Sites

Predicted Probability	Actual Material Lead	Actual Material Nonlead	Total	Actual Probability
0.0 to 0.1	11	11	22	0.50
0.1 to 0.2	2	3	5	0.40
0.2 to 0.3	9	6	15	0.60
0.3 to 0.4	5	1	6	0.83
0.4 to 0.5	7	5	12	0.58
0.5 to 0.6	5	1	6	0.83
0.6 to 0.7	4	2	6	0.67
0.7 to 0.8	1	0	1	1.00
0.8 to 0.9	3	1	4	0.75
0.9 to 1.0	2	3	5	0.40
	49	33	82*	

*Does not include 37 records for which an installation date/square combination did not exist.

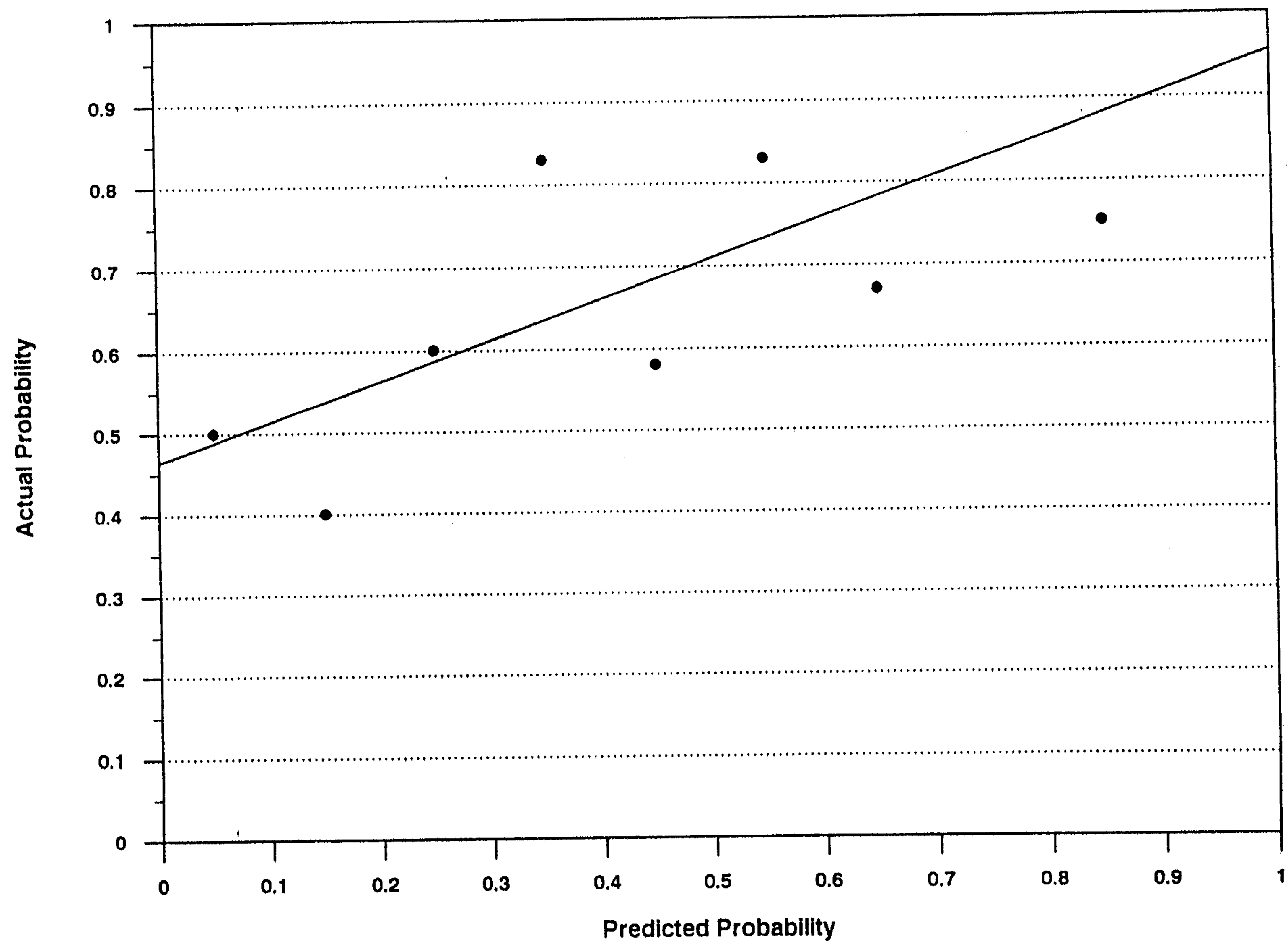


FIGURE 4-14 PLOT OF PREDICTED VERSUS ACTUAL LEAD PROBABILITIES

Table 4-11

Comparison of Lead Levels with Service Line Material

Excavation Number	Sample A (ug/L)	Sample B (ug/L)	Sample C (ug/L)	Service Line Material
13	59	75	0	Lead
18	13	45	0	Lead
34	50	152	0	Lead
35	11	91	0	Lead
36	11	30	0	Lead
38	24	74	0	Copper
46	4	12	0	Lead
47	10	24	0	Iron
55	5	10	0	Copper
62	77	108	0	Iron
64	77	292	0	Lead
67	5	15	0	Lead
103	46	255	0	Lead
115	19	324	0	Iron

4.6 GEOGRAPHIC BREAKDOWN OF LEAD SERVICE LINES

Using the techniques described in Subsection 4.5 it is now possible to estimate the number of lead service lines that are currently in place in the District. It is necessary to examine the number of lead service lines that have been replaced over the last several years. The Tap File Database tracks this information in the REPLACED field. This is a logical field (i.e., true or false) that indicates whether a service line has been replaced (true) or not (false).

At this time, the Tap File Database contains 716 records for which the REPLACED field indicates that a lead service line has been replaced. This number should be updated continually as additional lead service lines are replaced through the Meter Replacement and Street Replacement Programs. A breakdown of these replaced lead service lines is given in Table 4-12.

Now it is necessary to examine the 44,734 Unknown Service Lines. Subsection 4.5.2 describes the basic installation date/square combination technique and the refinement based on the results of the excavation program. Using Equation 4.1 for the midpoint range of predicted probability values, corresponding calibrated probability values were calculated and are shown in Table 4-13. This refined installation date/square technique results in 17,098 probable lead service lines (as shown in Table 4-13). A breakdown by ward of these probable lead service lines is given in Table 4-14. However, this technique could not match 15,905 addresses for which no probability could be assigned.

Out of the 15,905 addresses that could not be assigned a probability, a total of 4,428 addresses had a service line installation date between 1947 and the present. These are assumed to be nonlead based upon previous analysis of lead service line installation trends. Thus, 11,477 addresses remain that must be assigned as lead or nonlead.

These 11,477 addresses will be assigned a service line material by examining the installation date and ward for each address as discussed in Subsection 4.5.1. While this technique is not refined enough to predict service line materials for particular addresses, it will provide an overall approximation of the number of lead service lines by ward. Applying this technique to the 11,477 addresses results in a total of 2,795 additional addresses that can be predicted to have lead service lines. A breakdown by ward of these probable lead service lines is given in Table 4-15.

It is now possible to combine Tables 4-12, 4-14, and 4-15 to obtain an estimate of the distribution of the remaining lead service lines throughout the District as shown in Table 4-16. The values in the column titled "Number of Lead Service Lines" is simply the sum of the "Number of Lead Service Lines Remaining" from

Table 4-12

Breakdown of Lead Service Line Replacements

Ward	Number of Known Lead Service Lines	Number of Known Lead Service Lines Replaced	Number of Known Lead Service Lines Remaining
1	644	85	559
2	545	88	457
3	1,997	141	1,856
4	1,990	89	1,901
5	1,174	121	1,053
6	1,186	134	1,052
7	854	43	811
8	430	5	425
Ward not indicated	167	10	157
	8,987	716	8,271

Table 4-13

Summary of Probable Lead Service Lines Using Equation 4.1

Predicted Probability	Calibrated Probability[1]	Number of Records[2]	Number of Probable Lead Service Lines
0.0 to 0.1	0.48	12,085	5,801
0.1 to 0.2	0.53	3,018	1,600
0.2 to 0.3	0.58	3,170	1,839
0.3 to 0.4	0.63	2,654	1,672
0.4 to 0.5	0.68	2,956	2,010
0.5 to 0.6	0.73	845	617
0.6 to 0.7	0.78	1,244	970
0.7 to 0.8	0.83	512	425
0.8 to 0.9	0.88	334	294
0.9 to 1.0	0.93	2,011	1,870
			17,098

[1]Using Equation 4.1 and midpoint of range.
[2]From Table 4-8.

WESTON

Table 4-14

Breakdown of Probable Lead Service Lines Using the Installation Date/Square Method

Ward	Number of Probable Lead Service Lines
1	3,184
2	2,393
3	1,068
4	2,417
5	2,657
6	3,644
7	302
8	87
Ward not indicated	1,343
	17,095*

*Total does not match Table 4-13 due to rounding.

Table 4-15

Breakdown of Remaining Probable Lead Service Lines Using Installation Date and Ward

Ward	Number of Probable Lead Service Lines
1	510
2	475
3	234
4	427
5	437
6	317
7	142
8	65
Ward not indicated	188
	2,795

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Table 4-16

Distribution of Lead Service Lines

Ward	Total Number of Service Lines	Number of Lead Service Lines*	Percent Lead	Percent of Total
1	11,082	4,253	38.4	15.1
2	14,655	3,325	22.7	11.8
3	17,996	3,158	17.5	11.2
4	19,518	4,745	24.3	16.8
5	18,369	4,147	22.6	14.7
6	17,851	5,013	28.1	17.8
7	15,004	1,255	8.4	4.5
8	5,549	577	10.5	2.0
Ward not indicated	6,045	1,688	27.9	6.0
	126,069	28,161	22.3	100

*Includes Known Lead Service Lines and Probable Lead Service Lines.

Table 4-12, plus the "Number of Probable Lead Service Lines" from Table 4-14, plus the "Number of Probable Lead Service Lines" from Table 4-15.

4.7 PROCEDURE FOR IDENTIFYING SERVICE LINE MATERIAL

Having examined the various data sources available to the District, it is now possible to outline a procedure for identifying addresses that have a high probability of possessing a lead service line. Specifically, a method is presented that will allow the District to examine addresses on a case-by-case basis in planning for service line replacement programs. A flow diagram of this method is given in Figure 4-15, and is explained in detail in the remainder of this subsection.

The first step is to check the address in the Tap File Database. In some cases, the address may not exist because of a variety of reasons, e.g., street names that have changed over time, or errors in the keypunching process. If the address cannot be found in the Tap File Database, additional information about the address (i.e., installation date, square, ward, service line material, etc.) may be obtained from the files of BWMB.

Once the address is located in the Tap File Database, two fields should be examined to determine the service line material. Either the PIPEMATL field or CUSTSERV field may indicate the service line material. Again, the PIPEMATL indication was obtained from the BWMB Tap File, while the CUSTSERV came from the Project Locator File. If either of these fields indicate that the service line is nonlead, the procedure is complete. If either indicates a lead service line, or there is no indication, then the procedure continues accordingly.

If the Tap File Database indicates a lead service line, the next step is to make sure that the service has not already been replaced. Currently, the Tap File Database indicates 716 replaced service lines as recorded in the REPLACED field. If this field is "true" (i.e., the service has been replaced) the service line can be considered nonlead. If this field is "false," further examination of other lead replacement program records must be done because not all replaced service lines have been updated in the Tap File Database at the present time. If no indication of replacement is found, then the service line can be considered lead.

If there is no indication in the Tap File Database of service line material, then the predictive techniques discussed in Subsection 4.4 must be used. First, the Tap File Database is used to identify the installation date, square, and ward of the address. Next, a search is made of the installation date/square combination database for the particular address's installation date and square. Again, it is possible that the installation date and square for the address will not exist in the installation date/square combination database.

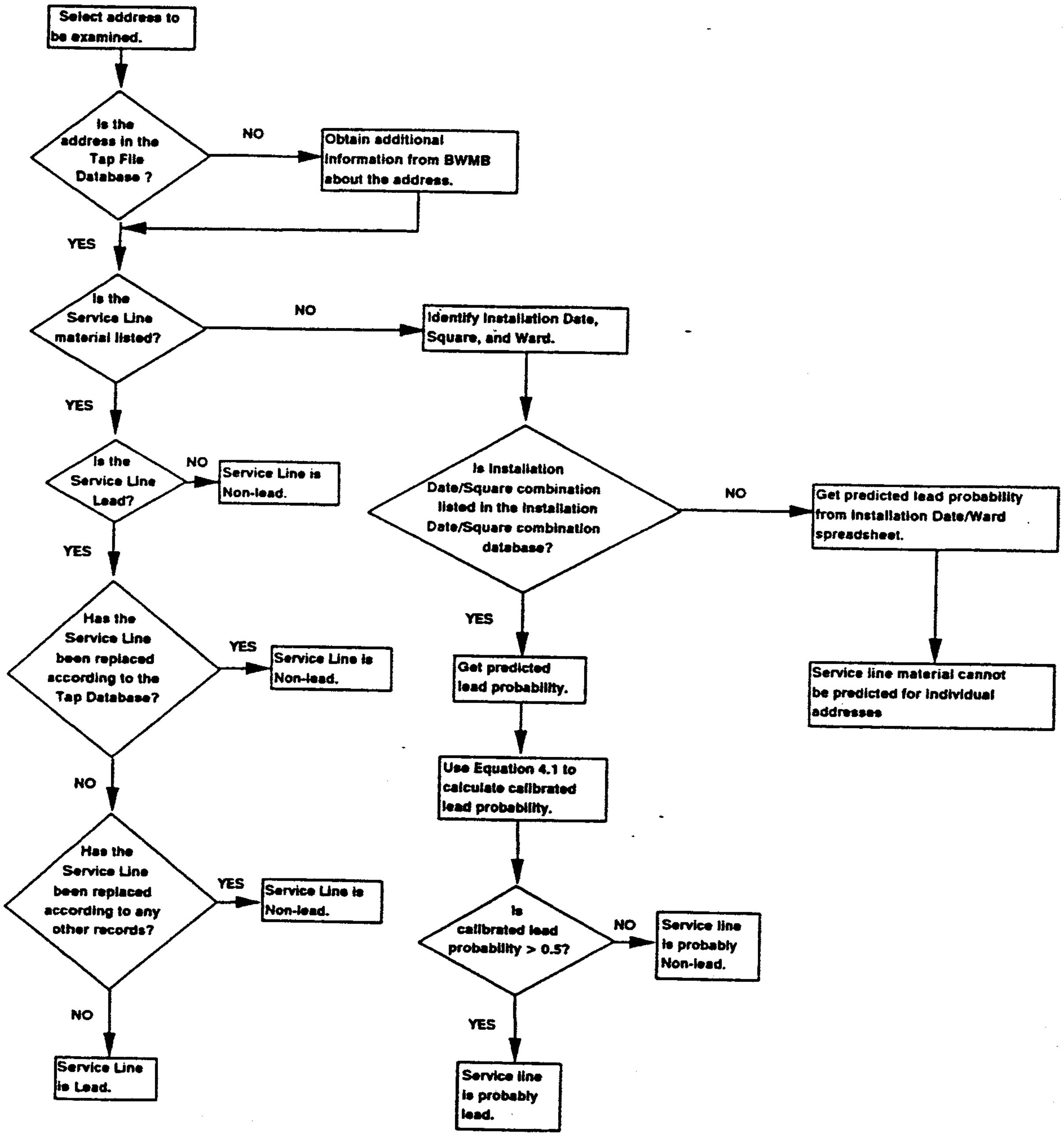

FIGURE 4-15 METHODOLOGY FOR IDENTIFYING SERVICE LINE MATERIAL

Assuming that the installation date/square combination does exist, a predicted lead probability can be obtained. Equation 4.1 can then be used to calculate the calibrated lead probability.

If the installation date/square combination does not exist, then the next step is to use the combination of installation date and ward to determine a predicted lead probability. These probabilities can be obtained from the spreadsheet given in Appendix D. It must be noted that this approach is much less refined than the installation date/square approach, since it considers probabilities within wards rather than the much smaller square. Predicted lead probabilities for a given installation date rarely exceed 50 percent within a ward. It is not possible, therefore, to predict the service line material for specific addresses following this approach.

The use of the Water Quality Database in determining service line material has not been included in the method presented in Figure 4-14. Because of the relatively small size of this database, and the difficulties involved in predicting service line material based on lead in water concentrations, it is unlikely that water quality results could be of significant use at the present time in determining service line material.

4.8 SUMMARY AND CONCLUSIONS

The databases that were developed previously were used extensively in determining the number and distribution of lead service lines in the District, as well as developing a methodology for identifying lead service lines. Both the Tap File Database, which included data on service line installations, and the Water Quality Database, which included data from previous DCRA sampling programs, were used in this effort.

The Tap File Database was used to examine the history of service line installations in the District and, in particular, lead service line installations over time. Overall, the service line material is known (i.e., identified as lead or nonlead) for approximately 65 percent of the 126,069 records in the Tap File Database. This percentage is generally close to 90 for the years 1927 to 1969.

Lead service line installations followed the same basic pattern in each ward over time, i.e., increasing lead usage beginning around 1920 and continuing to a peak around 1930. Lead usage also was significant in the pre-1911 period; however, it is difficult to segregate it into individual years. Lead usage then drops off to a fairly insignificant amount in the mid-1930s, then peaks again for about 5 years during World War II. Though few in number, the Tap File Database did show lead service line installations continuing through 1977.

The technique for predicting lead service lines that evolved from this analysis is called the Proximity Technique. The basic premise is that groups of service lines were often installed on the same block at the same time, by the same contractor, and of the same material. Thus, one can assign a probability of a service line being lead to an address based on the ratio of Lead Service Lines to Known Service Lines in the area.

The Water Quality Database also was examined in an attempt to identify trends that would indicate the occurrence of a lead service line. No such trends were found. Even if they had, this database is too small to draw broad conclusions about the number and distribution of lead service lines in the District. However, water quality data were one factor considered when selecting sites for service line excavations.

Excavations were made at 124 addresses throughout the District, and service line materials identified at 119. These sites were originally chosen on the basis of installation date, proximity to Known Lead Service Lines, and water quality data. The results of the excavation task were then used to calibrate the Proximity Technique for predicting lead service lines.

The previous analyses show the difficulties in accurately predicting the existence of a lead service line at a specific address. Factors that must be considered when attempting such predictions include date of installation of the service line, location of the address within the District (i.e., ward or square), proximity of the addresses to Known Lead Service Lines, and water quality data. Examining all of these factors is necessary to achieve a relatively accurate prediction of the occurrence of lead service lines.

While predicting for individual addresses is an inexact science at best, the techniques developed should work better on a larger scale. Thus, the distribution of lead service lines on a ward-by-ward basis should be fairly accurate, even if individual addresses are not as predictable.

The total number of lead service lines remaining in the District is estimated at 28,161 using these techniques. This figure represents the total lead service lines remaining after the 716 service line replacements indicated in the Tap File Database are deducted. The number of lead service lines also should be reduced by any recent replacements.

The highest percentage of lead service lines appears in Ward 1, where 38.3 percent of all service lines are estimated to be lead. The largest number of lead service lines appears in Ward 6. The 5,013 lead service lines in Ward 6 represent almost 18 percent of the total service lines in the entire District.

SECTION 5

PRIORITIZED LEAD SERVICE REPLACEMENT PROGRAM

5.1 INTRODUCTION

Replacing lead service lines throughout the District is a massive undertaking. The number of lead service lines within the District has been estimated at more than 28,000 (see Section 4). The District is currently replacing approximately 375 of these service lines per year. At this rate, it would take approximately 75 years to replace all the lead service lines. The cost of replacing the District's portion of a single service line is approximately $2,890. This cost includes the labor cost of all employees involved in the program (including employee benefits), the cost of equipment needed (taking into account purchase price and useable life), and the cost of supplies needed.

Obviously, the Lead Service Replacement Program must be prioritized so that lead service lines are replaced as efficiently as possible. Those service lines that are replaced first should have the greatest impact on reducing lead levels in water to the populations at the greatest risk (i.e., children and pregnant women). After the replacement of these identified worst-case lead service lines, the replacement program should work to systematically replace lead service lines on a square-by-square basis.

Water sampling studies have shown that the presence of a lead service line does not always result in high lead levels in drinking water. The highest priority should, therefore, be placed on removing lead service lines at those addresses where the lead service line has been shown to contribute to high lead levels at the tap. The results of the previously conducted water quality sampling programs can be used to identify these addresses.

Any lead service replacement program should be coordinated closely with other ongoing construction programs within the District government. As an example, the Street Replacement Program calls for the replacement of all service lines along a street undergoing reconstruction. Careful scheduling of lead service line replacements can take advantage of this requirement.

The Lead Service Replacement Program should be organized so that a number of crews are continually working at systematically replacing lead service lines on a square-by-square basis. At least one crew, however, should be available to respond to customer requests for replacement, or to replace lead service lines at addresses which are subsequently found to have high lead concentrations at the tap.

Finally, some attention should be given to those addresses that showed a high concentration of lead in a water sample supposedly representative of water in the service line, but for which records show that the service line is <u>not</u> lead. It is possible that the information available on service line material for these addresses may be incorrect. Another possibility may be that the information indicates the service line material for only a portion of the service line, and that the remaining portion of the service line is actually lead. Finally, it could be that the water sample was taken incorrectly (i.e., that the water sample is actually from the interior home plumbing system rather than the service line), and that the service line is <u>not</u> responsible for the high lead concentration.

5.2 METHODOLOGY

The basic methodology followed in prioritizing the lead service line replacement program is shown in Figure 5-1. The basic idea is to replace lead service lines on a square-by-square basis, starting with squares in which water quality sampling showed an effect on lead levels at the tap. Figure 5-1 also illustrates how blood lead data could also be utilized in this process, should they become available.

The first step was to use the methodology presented in Section 4 to identify the addresses of all Known and Probable Lead Service Lines in the District. A total of 25,590 such addresses was identified. An additional 2,795 lead service lines are predicted using the methodology described in Section 4. However, no specific address could be assigned for these service lines.

Simultaneously, the water quality data collected by both the District and WESTON (see Section 7) were used to rank addresses based on the lead concentrations. The addresses were assigned to one of four replacement categories based on lead levels found in any one sample at a particular address. That is, no differentiation was made between a Sample C result and a midday result, for example, even though the samples may actually represent water from different points in the home plumbing. The four replacement categories used were as follows:

- Replacement Category 1 -- all results <10 ug/L.
- Replacement Category 2 -- at least one result >10 ug/L but ≤ 20 ug/L.
- Replacement Category 3 -- at least one result >20 ug/L but ≤ 50 ug/L.
- Replacement Category 4 -- at least one result >50 ug/L.

The individual address replacement categories were then applied to each square. The replacement category for a square was taken as the largest replacement category for any individual address within

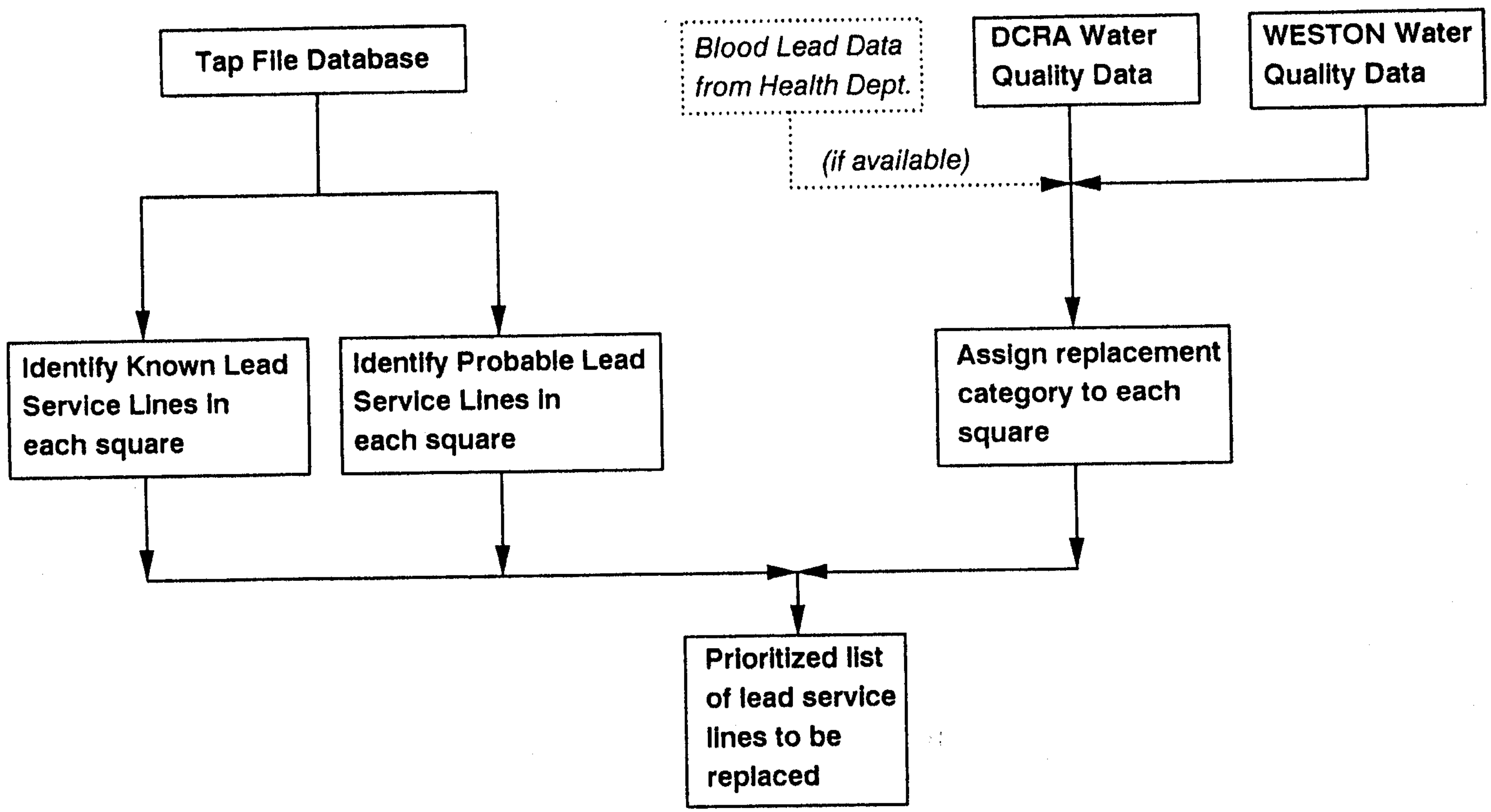

FIGURE 5-1 METHODOLOGY FOR PRIORITIZING THE LEAD SERVICE REPLACEMENT PROGRAM

that square. Thus, if a particular square had 10 homes for which water quality sampling results were available, and all results were <10 ug/L, the replacement category for that square would be 1. If, however, one of the homes had a lead concentration >50 ug/L for any one sample, the replacement category for the entire square would be 4.

Water quality sampling for lead has not been conducted in all portions of the District, however. For those squares for which no water quality results are available, the replacement category was left blank. Addresses with lead service lines in these squares are thus given a lower replacement priority than addresses in squares for which water quality data are available.

The replacement category information for each square was then combined with the database of Known and Probable Lead Service Lines to produce the final prioritized list of addresses for replacement. The final list is sorted by replacement category (with squares in Replacement Category 4 having the highest priority, followed by Replacement Category 3, etc.); square (squares with the greatest number of Known plus Probable Lead Service Lines having the greater priority); quadrant; street; and, finally, service line type (either Known Lead, L; or Probable Lead, pl). The complete list of addresses for replacement is presented in Appendix E.

A total of 1,273 addresses with lead service lines (Known plus Probable) fell into Replacement Category 4. These service lines are considered to be of the highest priority for replacement. Under the existing replacement rate of 375 services per year, it would take about 3.5 years to replace these services. The number of lead service lines in Replacement Categories 3, 2, and 1 are 1,625, 1,587, and 6,557, respectively. The remaining 14,548 lead service lines are located in squares in which no water quality data are available, and, thus, were not assigned to a replacement category.

This priority system should be considered flexible and should be modified during the implementation of the lead service line replacement program when other addresses are identified with high concentrations of lead in water. The program must also be closely coordinated with any other ongoing District activities, such as the Street Replacement Program. **Finally, those addresses listed as Probable Lead Service Lines should be inspected in the field prior to excavation to verify that they are actually lead.**

5.3 CONCLUSIONS AND RECOMMENDATIONS

The replacement of lead service lines throughout the District is a formidable task. The replacements must be scheduled so that homes exhibiting the greatest effect from the lead service line have the highest priority. However, with so many replacements to be performed, it is also very important that they be scheduled in the most efficient manner possible. For this reason it is recommended that the District follow the replacement schedule presented herein. That is, replace all lead service lines within a square at the same time, thus saving on the cost of moving equipment and personnel around the District. Squares have been ranked based on water quality results so that those areas that have shown problems with lead in drinking water are considered first.

It is recommended that the District begin replacement of lead service lines in Replacement Categories 4 and 3 immediately. Replacement of the 2,898 lead service lines in these categories would cost approximately $8.4 million. The replacement of these 2,898 service lines should be completed over a 2-year time frame.

The remaining 25,263 lead service lines in the District (28,161 minus 2,898) should then be systematically replaced in the order presented in Appendix E. The time frame for these replacements will depend greatly on the content of EPA's final lead regulations, and on available funds within the District.

The District also must remain conscious of those customers who have shown an interest in replacing their portion of the lead service lines. Homes at which high lead concentrations in drinking water are subsequently found also should be given higher priorities for replacement. The priorities developed here can be changed in response to specific cases in which: (1) the homeowner is willing to replace his/her portion of the lead service line, (2) unusually high lead in water concentrations are found, (3) high blood lead levels are identified, or (4) other unusual circumstances occur.

It is also recommended that the District obtain blood lead data collected by the Health Department and incorporate the information into a database. These data could then be compared to the list of Known and Probable Lead Service Line addresses in order to assign a higher priority to those homes for which the blood lead data showed a problem with lead in children. Although it cannot be proven what, if any, contribution the lead service line may have made to overall blood lead levels to people at the house, common sense dictates that the lead service line should be removed.

The District should conduct additional water quality sampling at houses with Known or Probable Lead Service Lines located in squares for which, at present, no water quality results are available. Low existing priorities assigned to these addresses should be changed when water quality data are available.

SECTION 6

EVALUATION OF FINANCIAL ALTERNATIVES

6.1 INTRODUCTION

The purpose of this analysis is to identify potential mechanisms of financing the costs of replacing lead service lines both within the jurisdiction of the District and for individual homeowners. Since the lead service lines can be found in both the public and private (i.e., homeowner) sectors, the mechanisms available to finance these service line replacements need to be broad-based to enable large public investments and individual homeowner service line replacement. This section, therefore, addresses the financing issue from the perspective of both the District and homeowners.

The total cost of the District's portion of the lead service line replacement (i.e., that portion of the service line within the direct responsibility of the District) has been estimated in this study at approximately $80 million. This estimate is based on the current cost of replacement of $2,890 per service line, and an approximate total of 24,000 lead service lines in the District. It is important to note that the estimated cost includes replacement of only those lead service lines that can be located at a specific address, and for those addresses that can be assigned to a particular ward. This obviously represents a large expenditure of District funds.

In order to finance the cost of a project such as this, a determination needs to be made as to whether the lead service line replacement should be accomplished in a short time frame (i.e., within the next 3 or 5 years), or be extended over a longer time frame (i.e., over the next 20 years). The decision on the time frame to be adopted is a function of the total project cost, as well as a number of other factors, such as:

- The urgency to replace lead service connections, determined by the threat to human health, or required by regulations.
- The ability of the District to absorb the costs as part of its operating budget (i.e., whether outside sources of financial aid are available).
- The ability of the District to develop a complete replacement program that provides the mechanism for replacing lead service line connections on both District and private property (i.e., to achieve a complete lead service line replacement).
- The compatibility of the Lead Service Replacement Program with other projects within the District.

6.2 FINANCING OF WATER SERVICE IN THE DISTRICT

Water service in the District is financed through customer service charges. In past years, water and sewer services have been subsidized by the District's general funds. However, in an attempt to make the water and sewer services become more self-sufficient, an enterprise fund concept was adopted in 1984 and subsequent increases in water and sewer rates were approved.

In an enterprise fund service concept, the revenue from utility operations must be sufficient to cover the cost of debt service (or borrowing) and operating costs. That is, it must be self-sustaining. As such, the District cannot use property taxes as a source of revenue. In the case of water supply service, the District sets its water rates to meet the expected demand for debt services and operating costs.

According to the District's financial reports, the Water and Sewer Enterprise Fund has been operating in a net positive balance in fiscal years 1987, 1988, and 1989. This positive situation has continued without a rate increase since 1987. The positive balances will be used for capital expenditures on a "pay-as-you-go" basis, and for emergency requirements. A planned 10-percent rate increase, originally scheduled to be effective in October 1988, has been cancelled by decision of the Mayor and the Council.

At issue, therefore, is whether the District can afford to pay for the needed lead service line replacements out of its existing fund balance, or finance the costs through a capital improvement project. This depends on the competition for available funds that exists at that time among the other water and sewer projects. The estimated cost of replacing the District's portion of the lead service lines is estimated to be in the range of $70 to $80 million.

6.2.1 Capital Improvements

The District identifies and plans for new facility construction, infrastructure improvements, and repair and replacement through the District government's Capital Improvement Program (CIP).[1] The CIP consists of projects authorized in fiscal year 1990, as well as projects authorized in prior years that are still in progress. In fiscal year 1990, there are 17 water supply projects out of 536 total active capital improvement projects. The water supply projects represent a capital budget allocation of $75 million and account for 3 percent of the total capital project budgets in the CIP.

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[1]Information on the District's Capital Improvement Program can be found in INDICES: A Statistical Index to District of Columbia Services.

About two-thirds of all capital improvements work in the District is funded with long-term borrowing. General obligation bonds are the principal method used by the District to borrow money for capital improvement projects. Debt service costs, however, are rapidly growing each year, and there is great concern that future debt be entered into for only the most critically needed projects. The District's criteria for determination of need consist of factors such as health and safety issues, project feasibility, and project costs and benefits in relation to the District's Comprehensive Plan. In an effort to address the statutory limit on the District government's appropriated spending on debt service, the use of revenue bonds for long-term borrowing is currently under consideration.

6.2.2 Federal Grants

Federal grants are a major source of funding for the District's capital improvement projects. Currently, there is no major Federal grant (or loan) program available to assist in the financing of lead service replacement lines.[2] The District does operate a Community Development Block Grant (CDBG) Program (funded in the past by the U.S. Department of Housing and Urban Development). Housing assistance programs for single-family rehabilitation and multifamily rehabilitation is provided through the District's Department of Housing and Community Development and Department of Public and Assisted Housing. Competition for these funds for housing rehabilitation is significant. These programs would be more geared toward the financing of the homeowner lead service line replacements than the District's portion of the lead service lines.

EPA, however, is in the process of finalizing its proposed rule regarding lead service line replacement. The proposed rule is expected to be finalized later this year. Once the rule becomes final, a request to Congress to fund a Lead Service Replacement Program on a national basis may be possible. At that time, a determination of sources of Federal financial assistance should be accomplished. Without Federal assistance, the District will have to finance the cost of lead service line replacement on its own.

6.2.3 Financing Options

The options available to the District to finance the entire project are as follows:

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[2] Contacts were made with the U.S. Department of Housing and Urban Development, the U.S. Department of Health and Human Services, the U.S. Environmental Protection Agency, the National League of Cities, the Association of Metropolitan Agencies, and the American Water Works Association.

- Incorporate the project as part of the District operations to be financed through its operating budget (i.e., the pay-as-you-go approach, within 20 years).

- Designate the project as a major infrastructure replacement to be financed as part of the District's Capital Improvement Program (within 5 years).

The first option can be accomplished over the longer term (i.e., 10 to 20 years) since the current District operating budget cannot accommodate a major project without some form of capitalization effort. The second option is a project that can be accomplished in the short-term and would be capitalized (i.e., through the issuance of bonds to raise the necessary capital).

6.3 HOMEOWNER FINANCING OPPORTUNITIES

As stated in the previous subsection, the homeowner is responsible for the replacement of the lead service line that is situated on his/her property. Currently, there are no identified source(s) of financial aid available to homeowners to finance the cost of the lead service line replacement (which could include not only the service line to the home but internal piping as well). Should the costs for homeowner service line replacement be carried solely by the homeowner, then alternative means of financial assistance must be made available by the District to provide the necessary incentive for homeowner cooperation. It should be noted, however, that the District's share of the costs for a financial assistance program to homeowners would be raised as part of the water utility budget. Therefore, future water rates would account for the costs of establishing and administering a program such as this one.

There are many potential financing mechanisms available to the District for assisting homeowners in the replacement of household lead service lines. The financing mechanisms have been arranged in a tabular form (see Table 6-1), with comments concerning each mechanism's advantage(s) and disadvantage(s). The financing mechanisms are divided into four categories: grants and rebates, loans and interest subsidies, direct revenue streams, and other.

The CDBG Program is one potential source of homeowner financial assistance. CDBGs are provided annually to communities by the U.S. Department of Housing and Urban Development (HUD) to carry out a wide range of community development activities directed toward neighborhood revitalization, economic development, and improved community facilities and services. CDBGs are provided annually to the District on a formula basis, and could be used for rehabilitation of residential properties by low- and middle-income persons. Lead service line replacement is a type of rehabilitation activity under the CDBG program. It should be noted, however, that CDBG funds are generally earmarked in advance for certain activities.

Table 6-1

Summary of Types of Financing Mechanisms

Financing Mechanisms	Description	Party for Replacement Work	Advantage	Disadvantage
GRANTS AND REBATES				
DIRECT GRANT	Cash grant made to property owner to cover cost of repair, in whole or in part. The property owner does not repay the grant.	Property owner could use a contractor provided by the District or use a contractor chosen by the property owner.	• Direct grant may be a necessity for those in low-level income group. • The property owner does not have to repay. • May be able to obtain grants from HUD's Community Development Block Grant Program (CDBG).	• May be difficult to obtain HUD CDBG funds, putting the cost burden directly on the District.
PARTIAL GRANT OR REBATE (OR PRINCIPAL REDUCTION GRANT)	Paid directly to the property owner to be applied to the replacement cost. Typically, this is deposited in an escrow account prior to performance of the work. The partial grant reduces the amount of principal or loan required, which reduces the monthly payments for the property owner. The grant can be made on a deferred basis; i.e., a lien is placed on the property for the amount of the grant. The lien is reduced gradually as payments are made.	Property owner could use a contractor provided by the District or use a contractor chosen by the property owner.	• Deferred partial grant encourages people to remain in the neighborhood. • Reduces the amount the owner must borrow. • Reduces monthly payments that the owner must make.	• Does not always account for varying income levels.
a. Flat percentage grant	Amount of grant computed as a flat percentage of the cost of the work.			
b. Percentage grant based on income	Links percentage of grant directly to the income of the owner.			
c. Grant adjusted to income and housing costs	Ties grant to housing costs and percentage of monthly income of the owner.			
d. Interest reduction grant	Makes a grant to reduce the amount the owner has to borrow from a private lender.			

WESTON

Table 6-1
(continued)

Financing Mechanisms	Description	Party for Replacement Work	Advantage	Disadvantage
GRANT PROPERTY TAX REBATE	District could reduce the amount of property taxes that the owner must pay by a fixed percentage.	Property owner could use a contractor provided by the District or use a contractor chosen by the property owner.	• Good mechanism for property-rich but cash-poor people such as the elderly.	• Lag time between paying for repair and receiving benefits. • Administration costs may outweigh the benefits.
DIRECT REBATE	Full or partial costs paid directly to the home-owner after replacement and repair on their own initiative.	Property owner would secure repair services on his/her own.	• Would be relatively easy for the District to administer. • District would eliminate any possibility of liability connected with providing its own contractors.	• Excludes income groups that cannot finance on their own initiative upfront.
LOANS AND INTEREST SUBSIDIES				
DIRECT LOAN	Direct loan made to property owner to cover the cost of repair, in whole or in part.	Property owner could use a contractor provided by the District or use a contractor chosen by the property owner.	• Can vary the interest rates, depending on the income of the owner (i.e., below-market interest rates). • The loans could carry a below-market interest rate and a longer term of repayment than available from private lenders. • Loan repayments may be used to make new loans (revolving feature).	• The cost of administrating a direct loan program may outweigh the benefits. • Places significant administrative burden on the District.
DEFERRED PAYMENT LOAN	A front-end cash distribution to the property owner for part or all of the cost of repair, secured by a promissory note and mortgage. Essentially, this is a loan against future equity in the property. The loan comes due in a lump sum (or balloon payment) when the borrower sells/vacates or otherwise disposes of the property.	Property owner could use a contractor provided by the District or use a contractor chosen by the property owner.	• No monthly payments by property owners. • Good mechanism for property-rich but cash-poor people, such as the elderly. • Can be used to supplement a direct loan.	• Available only to homeowners. • Places significant administrative burden on the District.

Table 6-1
(continued)

Financing Mechanisms	Description	Party for Replacement Work	Advantage	Disadvantage
INTEREST SUBSIDIZED LOAN	A subsidy is paid directly to the lender to induce the lender to make a below-market interest rate loan to the owner to cover full cost of the work. A subsidy prepaid in a lump sum when the loan is issued is a Prepaid Interest Subsidy.	Property owner could use a contractor provided by the District or use a contractor chosen by the property owner.	• The monthly payments are reduced because of a reduced interest rate. • Interest rates could be set to address varying income levels.	• This mechanism has a higher rate of loan rejections since the lender must approve the loan.
LOAN GUARANTEE OR COMPENSATION BALANCE	Under the HUD CDBG program, CDBG funds are placed in an account with a private lending institution and are used to guarantee, either in full or in part, conventional home improvement loans made to property owners at below-market interest rates. The amount of funds used is equal to either the full guaranteed amount of the outstanding principal balance of all guaranteed loans, or a percentage of the guaranteed amount.	Property owner could use a contractor provided by the District or could use contractor chosen by the property owner.	• The guarantee fund can earn a substantial amount of interest while on deposit with the lender. • Loan repayments may be used to make new loans.	• May be difficult to obtain HUD and CDBG funds.
TAX-EXEMPT CREDIT PAYMENT	Interest paid to the private financing institutions by a public agency is exempt from Federal income taxation. Therefore, funds may be borrowed at below-market interest rates. This would enable the District to make loans to property owners at below-market interest rates. The loan repayment may be guaranteed by a loan guarantee fund or by FHA Title I Property Improvement Loan Insurance.	Property owner could use a contractor provided by the District or could use a contractor chosen by the property owner.	• Potentially provides a program with access to a virtually unlimited supply of private capital. • Attractive alternative for raising very large amounts of private capital.	• FHA Title I Property Improvement Loans are not provided by any banks in the District. • Local lenders have limited private capital for credit agreement because of limits on the amount of tax-exempt investments that can be absorbed and because banks need to diversify investments.
FULL PRIVATE FINANCING -- INSTALLMENT LOAN	Loan obtained by property owner.	Property owner could use a contractor provided by the District or use a contractor chosen by the property owner.	• District would not be involved in administering the financing of the program. • Private lender handles all of the loan processing.	• Have to pay market interest rates. • Excludes many property owners who do not have sufficient credit rating.

Table 6-1
(continued)

Financing Mechanisms	Description	Party for Replacement Work	Advantage	Disadvantage
DIRECT REVENUE STREAMS				
FEES (e.g., water rates)	Includes various fees imposed on local governments (e.g. water rates set by the District).	District would have to provide a contractor since it would receive the fees to pay for the lead service line replacement.	• Provide alternatives for raising very large amounts of private capital. • Potential adjunct to District's water conservation program.	• Probably would be difficult to raise substantial sums to pay for entire homeowner service line replacement costs.
TAX-EXEMPT REVENUE BONDS	Private capital borrowed on tax-exempt and revenue secured basis; these funds are used to make loans for repair or replacement.	Property owner could use a contractor provided by the District or could use a contractor chosen by the property owner.	• Publicly issued bonds provide access to unlimited supply of private capital. • Can raise very large amounts of private capital. • Allows program to borrow at a lower interest rate. • Can be financed by FHA Title I Insurance.	• FHA insurance funds may not be available. • FHA only extends insurance when both the borrower and the property meet stringent underwriting standards.
OTHER				
LOW-COST REPLACEMENT LABOR	Replacement work would be performed at prices below the market rate.	District would need to provide contractors who would perform work at below-market prices or the District would provide the labor source directly.	• Meets cash flow needs of some low- and moderate-income persons.	• This method may increase the District's potential liability connected with providing contractors.

Additionally, efforts to make CDBG funds available for homeowner replacement of lead service lines would also require the approval of the District's Council. Additional funding for CDBGs is provided through income received from the repayment of CDBG loans and from the sale of urban renewal land. In fiscal year 1989, CDBG expenditures to the District were more than $43.7 million, of which $10.8 million was used for housing rehabilitation.

In analyzing the various financing mechanisms available for household lead service line replacement, emphasis needs to be placed on the use of appropriate financing mechanisms for different income groups involved in the Lead Service Replacement Program. For example, families with household incomes less than the poverty level may be reasonably addressed with some form of financing that does not require repayment in order to provide sufficient incentive to participate in the service line replacement program. In such cases, a **direct grant** program is appropriate. Families with incomes above the poverty level should be served exclusively by private lenders (i.e., reserving the subsidy for lower income groups), and a **full private financing installment loan** may be appropriate. In such a case, the District would not be involved in administering the program and the lender would handle all of the loan processing. If a family in this category cannot obtain financing because of credit problems, perhaps a loan guarantee could be provided.

6.3.1 Costs for Service Line Replacement

The cost to the District in replacing the homeowner's side of the lead service connections has been worked out in greater detail as follows. The most recent and published income distribution of the District is the 1980 census. Thus, data from the census were used to perform the financial analysis. In 1980, the average family size in the District was 2.4, and the poverty threshold for a family size of 2 and 3 was $4,723 and $5,787 in yearly household income, respectively.[3] Assuming the family size to be 2.4, the poverty threshold worked out to approximately $5,000 in 1980. Thus, $5,000 was used as a cut-off figure in determining the poverty level. Tables 6-2 and 6-3 show the income distribution in each ward per the 1980 census. Table 6-2 shows that 15 percent of the population is below the poverty level. This is the population that would require help from the government in the replacement program. An assumption made here is that the ratio of the population below and above the poverty level has not altered drastically in 1990. Once the data for the 1990 census are published, this fact can be verified and the cost estimates may be reevaluated, if needed, by just changing some key figures.

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[3]Information from Indices: A Statistical Index to District of Columbia Services.

Table 6-2

Distribution of Household Incomes (1980)
Below the Poverty Level (<$5,000)

WARD	TOTAL # OF SERVICE LINES (1)	TOTAL # OF LEAD SERVICE LINES (2)	# OF HOUSEHOLDS WITH ANNUAL INCOMES OF ... < $2,500	$2,500 to $4,999	TOTAL	PERCENTAGE BELOW THE POVERTY LEVEL(3)
1A	3,498	1,510	801	770	1,571	22
1B	3,643	1,133	1,095	1,370	2,465	27
1C	1,828	754	671	731	1,402	14
1D	591	146	62	80	142	9
1E	1,528	504	420	363	783	17
2A	1,356	118	494	454	948	14
2B	2,218	416	550	467	1,017	11
2C	6,311	1,541	1,577	2,271	3,848	30
2D	1,537	124	452	810	1,262	17
2E	3,235	686	148	105	253	6
3B	2,480	838	264	240	504	7
3C	2,886	635	266	413	679	7
3D	3,043	379	98	58	156	4
3E	3,189	270	169	143	312	7
3F	2,004	279	271	233	504	6
3G	4,395	378	189	256	445	8
4A	3,859	445	299	365	664	9
4B	6,234	697	258	284	542	7
4C	4,106	1,331	400	448	848	14
4D	5,319	1,738	619	494	1,113	13
5A	8,439	827	467	776	1,243	12
5B	4,630	625	973	1,308	2,281	24
5C	5,301	2,419	796	980	1,776	20
6A	7,664	2,548	801	745	1,546	14
6B	6,532	2,080	505	747	1,252	13
6C	3,658	523	839	876	1,715	19
7A	1,451	107	239	376	615	20
7B	3,688	142	268	317	585	9
7C	3,414	376	496	640	1,136	23
7D	2,538	187	395	553	948	19
7E	2,956	52	459	621	1,080	17
7F	957	54	377	330	707	19
8A	1,000	91	429	374	803	25
8B	1,046	116	633	703	1,336	24
8C	1,240	85	357	343	700	12
8D	1,038	100	404	365	769	15
8E	1,225	66	455	524	979	19
TOTAL	120,037	24,320	17,996	20,933	38,929	15

(1) There are 6,062 addresses which could not be assigned to a ward, and are therefore not included in this table.

(2) Includes only those lead service lines which could be located at a specific address.

(3) Taken from 1980 Census Data

Table 6-3

Distribution of Household Incomes (1980) Above the Poverty Level (>$5,000)

WARD	TOTAL # OF SERVICE LINES (1)	TOTAL # OF LEAD SERVICE LINES(2)	# OF HOUSEHOLDS WITH ANNUAL INCOMES OF ...																PERCENTAGE ABOVE THE POVERTY LEVEL(3)
			$5,000 to $7,499	$7,500 to $9,999	$10,000 to $12,499	$12,500 to $14,999	$15,000 to $17,499	$17,500 to $19,999	$20,000 to $22,499	$22,500 to $24,999	$25,000 to $27,499	$27,500 to $29,999	$30,000 to $34,999	$35,000 to $39,999	$40,000 to $49,999	$50,000 to $74,999	> $75,000	TOTAL	
1A	3,496	1,610	787	842	586	576	530	403	335	332	217	178	366	151	200	141	49	5,693	78
1B	3,643	1,133	1,137	920	963	611	531	532	386	281	269	159	361	135	241	118	60	6,724	73
1C	1,828	754	840	899	1,200	812	710	570	659	357	393	316	567	329	451	432	196	8,821	86
1D	591	146	46	105	94	106	43	97	71	46	71	51	97	97	106	133	277	1,440	91
1E	1,526	504	334	481	384	414	303	206	196	193	144	151	172	107	340	241	66	3,731	83
2A	1,356	118	400	362	472	480	599	554	460	300	320	238	424	253	381	463	296	6,004	86
2B	2,218	416	630	831	954	883	746	591	602	375	337	327	413	369	308	283	186	7,835	89
2C	6,311	1,541	1,095	1,307	1,240	1,010	844	585	639	434	409	269	391	283	204	201	151	9,062	70
2D	1,537	124	481	496	514	472	445	514	439	339	318	313	471	306	546	514	189	6,359	83
2E	3,235	686	150	135	201	132	240	235	247	156	223	181	269	215	403	540	541	3,868	94
3B	2,480	838	374	355	540	451	572	460	444	289	309	207	494	393	458	639	356	6,341	93
3C	2,886	635	468	656	734	728	668	593	620	430	480	244	710	498	605	946	845	9,225	93
3D	3,043	379	100	128	170	128	118	102	139	122	153	97	305	219	360	725	920	3,786	96
3E	3,189	270	215	254	189	264	243	202	179	168	205	161	386	306	436	638	218	4,064	93
3F	2,004	279	304	334	503	430	673	540	461	492	461	349	533	358	642	808	476	7,364	94
3G	4,396	378	223	285	274	207	266	301	241	146	235	143	406	357	746	1,135	496	5,461	92
4A	3,859	445	288	517	506	406	483	338	437	327	352	208	492	266	586	832	380	6,418	91
4B	6,234	697	350	543	494	417	610	503	527	386	403	336	582	519	666	410	140	6,886	93
4C	4,106	1,331	360	490	458	432	461	323	339	286	317	222	431	264	401	264	84	5,132	86
4D	5,319	1,738	545	692	729	824	771	605	553	519	404	323	486	407	374	217	80	7,629	87
5A	8,439	827	491	554	515	522	736	643	639	426	588	558	937	737	933	562	84	8,925	88
5B	4,630	625	908	1,012	832	822	772	578	542	360	333	313	348	157	288	149	11	7,425	76
5C	5,301	2,419	930	660	911	709	616	552	540	264	357	293	451	306	270	205	70	7,133	80
6A	7,664	2,548	986	743	885	768	676	710	557	448	548	334	753	514	634	464	141	9,161	86
6B	6,532	2,080	644	572	636	430	717	512	487	400	478	308	771	467	730	766	272	8,188	87
6C	3,858	523	675	886	920	826	635	680	535	415	392	326	424	254	211	143	0	7,321	81
7A	1,461	107	338	331	251	277	186	194	160	94	173	131	101	67	110	53	15	2,481	80
7B	3,688	142	368	449	589	562	503	491	561	364	377	213	489	347	526	369	57	6,265	91
7C	3,414	376	433	528	505	412	334	325	238	281	149	134	214	182	107	20	9	3,871	77
7D	2,538	187	379	464	418	478	365	352	273	184	172	178	250	145	161	101	12	3,932	81
7E	2,956	52	494	647	653	517	578	325	399	305	351	201	363	224	195	107	32	5,391	83
7F	957	54	277	355	406	415	360	193	292	156	168	89	147	117	66	47	12	3,100	81
8A	1,000	91	215	297	296	310	334	165	173	94	128	97	96	66	106	28	0	2,405	75
8B	1,046	116	618	597	629	461	417	336	257	229	155	97	204	89	30	34	6	4,159	76
8C	1,240	85	399	524	708	597	476	506	443	315	266	117	179	149	161	97	7	4,944	88
8D	1,038	100	386	615	666	468	546	405	325	128	216	198	135	125	101	28	7	4,349	85
8E	1,225	66	521	512	582	428	492	382	353	181	187	154	261	121	89	41	5	4,309	81
TOTAL	120,037	24,320	18,289	20,380	21,627	18,785	18,598	15,603	14,747	10,622	11,056	8,213	14,469	9,899	13,172	12,894	6,748	215,102	85

(1) There are 6,062 addresses which could not be assigned to a ward, and are therefore not included in this table.

(2) Includes only those lead service lines which could be located at a specific address.

(3) Taken from 1980 Census Data

After the ratio of households in the two income categories was established, the total lead service lines in each subward was divided by the same ratio to determine the number of lead service lines in each category on a subward basis. Furthermore, Tables 6-4 through 6-8 show the suggested replacement schedule. The replacement program would typically last for 5 years if it were to be funded by a Capital Improvement Program. A reasonable starting period for the replacement program could be 1992, and, thus, the program would continue until 1996 as shown in the calculations. The cost of lead service line replacement on the homeowner's side was taken as $2,290. The present cost for the District in replacing the lead service line on the public side is $2,890, which includes $600 for repair of the roadway. Since on the homeowner's side there would be no cost for repavement of the sidewalk and the other costs would more or less remain the same, the cost to replace the lead service line on the homeowner's side on an average can be assumed as $2,890 - $600 = $2,290.

As an example, in Table 6-4, there are 291 lead service lines to be replaced in Ward 1A in the first year. There are 63 (i.e., 22 percent) homes below the poverty level in Ward 1A for which direct government assistance would be required in replacing the lead service lines. Seventy-eight percent of the population, or the remaining 228 homes above the poverty level, would be responsible for replacing their own lead service lines. The table also shows the District's and the homeowner's portions of the cost involved in replacing the lead service lines.

Table 6-9 gives a summary of the costs involved, assuming that the Lead Service Replacement Program starts in 1992. The public side of the service line would have to be replaced by the District at $2,890 per service line. The last column shows the District's total cost if it were to replace all lead service lines on the public side, which would amount to $70,284,800, and also the homeowner's side of some homes, when the household income is less than the poverty level, which would amount to $8,807,340. Thus, the total cost for the District would amount to $79,092,140, or approximately $80 million. The sum total of the homeowners' share of the replacement cost will be $46,100,000. The District has two options in spreading the costs over the years. It can initiate a Capital Improvement Program, as described earlier, or bear the cost through its operations and maintenance budget. A Capital Improvement Program would normally take 5 years to accomplish. Thus, the District would require a maximum of $16 million (in 1990 dollars) per year for 5 years. If the District decides to fund the replacement of lead service lines through its operations and maintenance budget it could spread the costs over a longer term (e.g., a 20-year period), which would bring the cost of replacement to a maximum of $4 million (in 1990 dollars) per year for 20 years. All the dollar figures shown in the tables refer to 1990 dollars. The dollar figures will change over time due to inflation, but the annual cost of lead service line replacement for any year later than 1990 can always be calculated by using the known inflation rate at that time and using 1990 as the base index.

Table 6-4

Five-Year Lead Service Line Replacement Schedule for the Homeowner's Side (Year 1)

WARD	# OF LEAD SERVICE LINES REPLACED	PERCENTAGE BELOW THE POVERTY LEVEL	REPLACEMENT COSTS FOR HOMEOWNER'S SIDE			
			ABOVE POVERTY LEVEL		BELOW POVERTY LEVEL	
			# OF LEAD SERVICE LINES	COST (1) (HOMEOWNER)	# OF LEAD SERVICE LINES	COST (1) (DISTRICT)
1A	291	22	228	$522,120	63	$144,270
1B	77	27	56	$128,240	21	$48,090
1C	291	14	251	$574,790	40	$91,600
1D	32	9	29	$66,410	3	$6,870
1E	227	17	188	$430,520	39	$89,310
2A	21	14	18	$41,220	3	$6,870
2B	104	11	92	$210,680	12	$27,480
2C	86	30	60	$137,400	26	$59,540
2D	60	17	50	$114,500	10	$22,900
2E	156	6	146	$334,340	10	$22,900
3B	564	7	522	$1,195,380	42	$96,180
3C	301	7	280	$641,200	21	$48,090
3D	133	4	128	$293,120	5	$11,450
3E	136	7	126	$288,540	10	$22,900
3F	146	6	137	$313,730	9	$20,610
3G	197	8	182	$416,780	15	$34,350
4A	189	9	171	$391,590	18	$41,220
4B	196	7	182	$416,780	14	$32,060
4C	145	14	124	$283,960	21	$48,090
4D	289	13	252	$577,080	37	$84,730
5A	88	12	77	$176,330	11	$25,190
5B	1	24	1	$2,290	0	$0
5C	242	20	194	$444,260	48	$109,920
6A	544	14	465	$1,064,850	79	$180,910
6B	469	13	407	$932,030	62	$141,980
6C	51	19	41	$93,890	10	$22,900
7A	0	20	0	$0	0	$0
7B	1	9	1	$2,290	0	$0
7C	80	23	62	$141,980	18	$41,220
7D	1	19	1	$2,290	0	$0
7E	0	17	0	$0	0	$0
7F	0	19	0	$0	0	$0
8A	0	25	0	$0	0	$0
8B	0	24	0	$0	0	$0
8C	0	12	0	$0	0	$0
8D	0	15	0	$0	0	$0
8E	0	19	0	$0	0	$0
TOTAL	5,118	15	4,471	$10,238,590	647	$1,481,630

(1) The cost of replacing the homeowner's portion of a lead service line has been estimated at $2,290 (1990 $'s).

WESTON

Table 6-5

Five-Year Lead Service Line Replacement Schedule
for the Homeowner's Side (Year 2)

WARD	# OF LEAD SERVICE LINES REPLACED	PERCENTAGE BELOW THE POVERTY LEVEL	REPLACEMENT COSTS FOR HOMEOWNER'S SIDE — ABOVE POVERTY LEVEL		BELOW POVERTY LEVEL	
			# OF LEAD SERVICE LINES	COST (1) (HOMEOWNER)	# OF LEAD SERVICE LINES	COST (1) (DISTRICT)
1A	382	22	299	$684,710	83	$190,070
1B	326	27	239	$547,310	87	$199,230
1C	224	14	193	$441,970	31	$70,990
1D	21	9	19	$43,510	2	$4,580
1E	117	17	97	$222,130	20	$45,800
2A	13	14	11	$25,190	2	$4,580
2B	157	11	139	$318,310	18	$41,220
2C	281	30	197	$451,130	84	$192,360
2D	0	17	0	$0	0	$0
2E	263	6	247	$565,630	16	$36,640
3B	215	7	199	$455,710	16	$36,640
3C	135	7	126	$288,540	9	$20,610
3D	41	4	39	$89,310	2	$4,580
3E	24	7	22	$50,380	2	$4,580
3F	40	6	37	$84,730	3	$6,870
3G	0	8	0	$0	0	$0
4A	101	9	92	$210,680	9	$20,610
4B	114	7	106	$242,740	8	$18,320
4C	187	14	160	$366,400	27	$61,830
4D	204	13	178	$407,620	26	$59,540
5A	97	12	85	$194,650	12	$27,480
5B	67	24	51	$116,790	16	$36,640
5C	574	20	460	$1,053,400	114	$261,060
6A	722	14	618	$1,415,220	104	$238,160
6B	551	13	478	$1,094,620	73	$167,170
6C	87	19	70	$160,300	17	$38,930
7A	47	20	38	$87,020	9	$20,610
7B	0	9	0	$0	0	$0
7C	62	23	48	$109,920	14	$32,060
7D	31	19	25	$57,250	6	$13,740
7E	0	17	0	$0	0	$0
7F	0	19	0	$0	0	$0
8A	0	25	0	$0	0	$0
8B	0	24	0	$0	0	$0
8C	22	12	19	$43,510	3	$6,870
8D	0	15	0	$0	0	$0
8E	13	19	11	$25,190	2	$4,580
TOTAL	5,118	15	4,303	$9,853,870	815	$1,866,350

(1) The cost of replacing the homeowner's portion of a lead service line has been estimated at $2,290 (1990 $'s).

WESTON

Table 6-6

Five-Year Lead Service Line Replacement Schedule for the Homeowner's Side (Year 3)

WARD	# OF LEAD SERVICE LINES REPLACED	PERCENTAGE BELOW THE POVERTY LEVEL	REPLACEMENT COSTS FOR HOMEOWNER'S SIDE: ABOVE POVERTY LEVEL: # OF LEAD SERVICE LINES	ABOVE POVERTY LEVEL: COST (1) (HOMEOWNER)	BELOW POVERTY LEVEL: # OF LEAD SERVICE LINES	BELOW POVERTY LEVEL: COST (1) (DISTRICT)
1A	297	22	233	$533,570	64	$146,560
1B	265	27	194	$444,260	71	$162,590
1C	40	14	35	$80,150	5	$11,450
1D	16	9	15	$34,350	1	$2,290
1E	70	17	58	$132,820	12	$27,480
2A	8	14	7	$16,030	1	$2,290
2B	90	11	80	$183,200	10	$22,900
2C	532	30	373	$854,170	159	$364,110
2D	4	17	3	$6,870	1	$2,290
2E	23	6	22	$50,380	1	$2,290
3B	32	7	30	$68,700	2	$4,580
3C	111	7	103	$235,870	8	$18,320
3D	70	4	67	$153,430	3	$6,870
3E	50	7	46	$105,340	4	$9,160
3F	25	6	23	$52,670	2	$4,580
3G	77	8	71	$162,590	6	$13,740
4A	33	9	30	$68,700	3	$6,870
4B	51	7	47	$107,630	4	$9,160
4C	130	14	112	$256,480	18	$41,220
4D	367	13	320	$732,800	47	$107,630
5A	70	12	61	$139,690	9	$20,610
5B	70	24	54	$123,660	16	$36,640
5C	694	20	556	$1,273,240	138	$316,020
6A	320	14	274	$627,460	46	$105,340
6B	305	13	265	$606,850	40	$91,600
6C	61	19	49	$112,210	12	$27,480
7A	21	20	17	$38,930	4	$9,160
7B	21	9	19	$43,510	2	$4,580
7C	11	23	9	$20,610	2	$4,580
7D	2	19	2	$4,580	0	$0
7E	5	17	4	$9,160	1	$2,290
7F	7	19	6	$13,740	1	$2,290
8A	17	25	13	$29,770	4	$9,160
8B	60	24	45	$103,050	15	$34,350
8C	4	12	4	$9,160	0	$0
8D	7	15	6	$13,740	1	$2,290
8E	6	19	5	$11,450	1	$2,290
TOTAL	3,972	15	3,258	$7,460,820	714	$1,635,060

(1) The cost of replacing the homeowner's portion of a lead service line has been estimated at $2,290 (1990 $'s).

186C/S6

Table 6-7

Five-Year Lead Service Line Replacement Schedule for the Homeowner's Side (Year 4)

WARD	# OF LEAD SERVICE LINES REPLACED	PERCENTAGE BELOW THE POVERTY LEVEL	REPLACEMENT COSTS FOR HOMEOWNER'S SIDE — ABOVE POVERTY LEVEL: # OF LEAD SERVICE LINES	ABOVE POVERTY LEVEL: COST (1) (HOMEOWNER)	BELOW POVERTY LEVEL: # OF LEAD SERVICE LINES	BELOW POVERTY LEVEL: COST (1) (DISTRICT)
1A	379	22	297	$680,130	82	$187,780
1B	295	27	216	$494,640	79	$180,910
1C	109	14	94	$215,260	15	$34,350
1D	17	9	15	$34,350	2	$4,580
1E	33	17	27	$61,830	6	$13,740
2A	0	14	0	$0	0	$0
2B	19	11	17	$38,930	2	$4,580
2C	359	30	252	$577,080	107	$245,030
2D	0	17	0	$0	0	$0
2E	132	6	124	$283,960	8	$18,320
3B	0	7	0	$0	0	$0
3C	19	7	18	$41,220	1	$2,290
3D	47	4	45	$103,050	2	$4,580
3E	0	7	0	$0	0	$0
3F	0	6	0	$0	0	$0
3G	36	8	33	$75,570	3	$6,870
4A	0	9	0	$0	0	$0
4B	91	7	84	$192,360	7	$16,030
4C	620	14	532	$1,218,280	88	$201,520
4D	613	13	534	$1,222,860	79	$180,910
5A	66	12	58	$132,820	8	$18,320
5B	243	24	186	$425,940	57	$130,530
5C	597	20	478	$1,094,620	119	$272,510
6A	707	14	605	$1,385,450	102	$233,580
6B	427	13	370	$847,300	57	$130,530
6C	83	19	67	$153,430	16	$36,640
7A	21	20	17	$38,930	4	$9,160
7B	35	9	32	$73,280	3	$6,870
7C	23	23	18	$41,220	5	$11,450
7D	0	19	0	$0	0	$0
7E	0	17	0	$0	0	$0
7F	0	19	0	$0	0	$0
8A	20	25	15	$34,350	5	$11,450
8B	22	24	17	$38,930	5	$11,450
8C	0	12	0	$0	0	$0
8D	37	15	31	$70,990	6	$13,740
8E	0	19	0	$0	0	$0
TOTAL	5,050	553	4,182	$9,576,780	868	$1,987,720

(1) The cost of replacing the homeowner's portion of a lead service line has been estimated at $2,290 (1990 $'s).

WESTON

Table 6-8

Five-Year Lead Service Line Replacement Schedule for the Homeowner's Side (Year 5)

WARD	# OF LEAD SERVICE LINES REPLACED	PERCENTAGE BELOW THE POVERTY LEVEL	REPLACEMENT COSTS FOR HOMEOWNER'S SIDE			
			ABOVE POVERTY LEVEL		BELOW POVERTY LEVEL	
			# OF LEAD SERVICE LINES	COST (1) (HOMEOWNER)	# OF LEAD SERVICE LINES	COST (1) (DISTRICT)
1A	161	22	126	$288,540	35	$80,150
1B	170	27	124	$260,400	46	$105,340
1C	90	14	78	$163,800	12	$27,480
1D	60	9	55	$115,500	5	$11,450
1E	57	17	47	$98,700	10	$22,900
2A	76	14	66	$138,600	10	$22,900
2B	46	11	41	$86,100	5	$11,450
2C	283	30	199	$417,900	84	$192,360
2D	60	17	50	$105,000	10	$22,900
2E	112	6	105	$220,500	7	$16,030
3B	27	7	25	$52,500	2	$4,580
3C	69	7	64	$134,400	5	$11,450
3D	88	4	85	$178,500	3	$6,870
3E	60	7	56	$117,600	4	$9,160
3F	68	6	64	$134,400	4	$9,160
3G	68	8	63	$132,300	5	$11,450
4A	122	9	111	$233,100	11	$25,190
4B	245	7	227	$476,700	18	$41,220
4C	249	14	214	$449,400	35	$80,150
4D	265	13	231	$485,100	34	$77,860
5A	506	12	444	$932,400	62	$141,980
5B	244	24	187	$392,700	57	$130,530
5C	312	20	250	$525,000	62	$141,980
6A	255	14	218	$457,800	37	$84,730
6B	328	13	284	$596,400	44	$100,760
6C	241	19	195	$409,500	46	$105,340
7A	18	20	14	$29,400	4	$9,160
7B	85	9	78	$163,800	7	$16,030
7C	200	23	155	$325,500	45	$103,050
7D	153	19	123	$258,300	30	$68,700
7E	47	17	39	$81,900	8	$18,320
7F	47	19	38	$79,800	9	$20,610
8A	54	25	40	$84,000	14	$32,060
8B	34	24	26	$54,600	8	$18,320
8C	59	12	52	$109,200	7	$16,030
8D	56	15	48	$100,800	8	$18,320
8E	47	19	38	$79,800	9	$20,610
TOTAL	5,062	15	4,260	$8,969,940	802	$1,836,580

(1) The cost of replacing the homeowner's portion of a lead service line has been estimated at $2,290 (1990 $'s).

WESTON.

Table 6-9

Summary of Total Costs to Replace Lead Service Connections

YEAR	# OF LEAD SERVICE LINES AT ADDRESSES .... ABOVE POVERTY LEVEL	BELOW POVERTY LEVEL	HOMEOWNER PORTION (1) HOMEOWNER'S COST OF REPLACEMENT	DISTRICT'S COST OF REPLACEMENT	DISTRICT PORTION (2) DISTRICT'S COST OF REPLACEMENT	TOTAL COST TO THE DISTRICT FOR LEAD SERVICE LINE REPLACEMENT (3)
1992	4,471	647	$10,238,590	$1,481,630	$14,791,020	$16,272,650
1993	4,303	815	$9,853,870	$1,866,350	$14,791,020	$16,657,370
1994	3,258	714	$7,460,820	$1,635,060	$11,479,080	$13,114,140
1995	4,182	868	$9,576,780	$1,987,720	$14,594,500	$16,582,220
1996	4,260	802	$8,969,940	$1,836,580	$14,629,180	$16,465,760
TOTAL	20,474	3,846	$46,100,000	$8,807,340	$70,284,800	$79,092,140

(1) Replacement cost of homeowner's side assumed at $ 2,290 (1990 $'s)

(2) Replacement cost of District side assumed at $ 2,890 (1990 $'s)

(3) Total cost includes replacing District portion of lead service lines as well as contribution of funds to assist some homeowners (i.e., those below the poverty level) with replacement of their portion. The number of lead service lines used for this estimate is 24,320 (20,474 + 3,846), which is the number of lead service lines which can be identified at specific addresses and assigned to the appropriate subward.

6.3.2 Replacing Service Lines on Private Property

As mentioned previously, to achieve the full benefit of the Lead Service Replacement Program, it is desirable for both the District's portion of the service line and the homeowner's portion to be replaced. Presumably it would be cost-effective to perform the replacements at the same time. In order to accomplish the goal of simultaneous replacements, it is necessary to coordinate the replacement efforts and provide a mechanism for homeowners to access the services of competent technicians to perform the work.

The options available to the homeowners include:

- Having District personnel perform the replacement (at the same time that the District's portion is done).

- Hiring a private contractor to perform the replacement.

Should the District perform the replacement for the homeowner the issue of liability to the District for performing work on private property can be significant. The District is currently examining the liability issue through its Water Conservation Retrofit Program. In this program, the District would conduct a water conservation audit and then make the necessary repairs or improvements to the household plumbing to achieve the desired conservation goals.

Providing the opportunity for contractor involvement in the Lead Service Replacement Program could help avoid many of the liability concerns, but could also raise other problems associated with contractor procurement, quality of work, and availability to perform the replacement at the same time that the District's lines are replaced. The following issues would need to be addressed:

- Who will hire the contractor? The District or the homeowner?

- How will the contractors be selected?

- What will be the nature of the agreement between the District and the contractor?

- What operational procedures will be employed in dealing with the contractors to ensure proper service and conduct in the field?

The District has an established program that is satisfactorily dealing with assisting District homeowners with public utility issues. It is the D.C. Energy Office (DCEO). The DCEO, created in 1981, is the lead agency for all energy policy and programs in the District. The DCEO programs that are relevant to the lead service line replacement needs for homeowners in the District include:

- **Low-Income Home Energy Assistance Program (LIHEAP)** helps needy District residents pay their heating and cooling bills, and provides emergency assistance to households that have had their electric or gas service disconnected, or have been denied fuel oil delivery. The amount of assistance is based on family size, income, and type of dwelling. (The DCEO uses Federal grants from the Department of Health and Human Services for this program.)

- **Complementary Energy Assistance Program (CEAP)** provides monthly financial assistance to eligible low-income working families participating in the subsidized Adoption Program, the Vocational Rehabilitation Program, or the Foster Care Program.

- **Utility Discount Programs** offer special rates on utility services for District customers who are certified as eligible by the DCEO:

  - **Residential Aid Rider (RAR)** offers a discount to income-eligible Potomac Electric Power Company customers on their monthly electric bill.

  - **Residential Essential Service (RES)** offers qualifying District of Columbia Natural Gas customers a discount rate on natural gas used during the months of December through March.

- **Residential Conservation Service (RCS)** offers free on-site home energy audits to District residents. The audit, performed by the electric and gas utility companies, identifies ways to reduce energy costs in single-family homes, apartment buildings of up to four units, and individually metered apartments of five or more units.

- **Multifamily Demonstration Program** provides grants and loans for conservation improvements to low-income apartment buildings.

- **Weatherization Assistance Program (WAP)** makes free weatherization improvements such as caulking, weatherstripping, and insulation on the homes of low-income persons; DCEO accepts applications for this program, which is administered by the District Department of Housing and Community Development.

- **Energy Bank Program** provides grants and loan subsidies to eligible District residents to install energy conservation measures identified in RCS home energy audits. The DCEO issues contracts to nonprofit groups [Community Based Organizations (CBOs)] to make the energy system replacements or improvements. The CBOs then select private contractors to perform the energy system retrofits. In this way, the District does not become directly involved in performing utility improvements on private property.

- **Energy Extension Service (EES)**, the educational component of DCEO, seeks to provide useful information to small-scale users of energy through the following programs:

  - **Energy Conservation Workshops** feature low-cost/no-cost techniques that homeowners or renters can use to lower their fuel bills. Sessions are held at the DCEO, on request, to groups and organizations throughout the city.

  - **Small Grants Program** provides funds to local groups and individuals for energy conservation outreach activities such as energy fairs, publications, and the demonstration of new technologies.

As shown previously, DCEO has an effective multifaceted program for providing not only energy system retrofits and replacements on private properties, but financial assistance to homeowners to meet energy bills. Such a program serves as a readily adaptable model for the implementation of a District-wide Lead Service Replacement Program.

6.4 RECOMMENDATIONS

An evaluation of the adequacy of the District's current water rate structure and user fee system should be performed to determine the most cost-effective plan for financing the Lead Service Replacement Program. A rate study is needed to fully analyze the cost implications of this project on the District's operating budget and Capital Improvement Program.

There are several methods outlined in this section that can be applied effectively to assist homeowners in financing the costs of lead service line replacement on private property. The determination of the precise financing mechanism to be used is a function of the degree to which the District wishes to or can afford to assist homeowners. The District should consider providing funding to homeowners whose income is below the poverty level to assist them in replacing their portion of the lead service line. As recommended earlier, a water rate study that fully addresses the costs to the District for implementing a homeowner assistance program needs to be prepared.

SECTION 7

WATER QUALITY SAMPLING

7.1 INTRODUCTION

Water quality samples were collected from a total of 163 homes (159 full-scale sampling, and 4 detailed sampling) throughout the District with two goals in mind. One goal was to identify, if possible, the relationship between lead service lines and concentrations of lead in water at the kitchen tap. The second goal was to attempt to quantify the contributions of various sources to lead concentrations at the kitchen tap, that is, the amount of lead contributed by the sink fixtures, solder joints, service lines, and distribution system water.

Sample bottles and instructions were delivered to the homes. The first flush water samples were then collected by the homeowners. The samples were subsequently collected and sent to a laboratory for analysis. Unmarked blank and spiked samples were included with each shipment of samples as a quality control check on the laboratory.

The results of this sampling program were compared to the results of earlier sampling efforts. Several houses that had been sampled during previous studies and showed high levels of lead were sampled again. The average values for the various sample types were compared in an attempt to find differences in results over time, or because of differences in sampling technique.

Prior to beginning the full-scale sampling, four homes were sampled in detail. This detailed sampling involved entering each home and measuring the diameter and length of pipe from the service line to the kitchen sink. A series of twenty 500-ml, first flush samples were then collected from the kitchen faucet. The source of each sample could be located using the pipe diameter and length measurements, and calculating the volume of water held in the pipes. The objective of this detailed sampling was to identify sources of lead and to develop a sampling protocol for large-scale sampling.

7.2 PURPOSE

The two main purposes of the water sampling program were: (1) to identify the relationship between a lead service line and lead concentrations at the kitchen tap, and (2) to determine the contributions of lead at the tap from various sources. The results of the sampling could then be used to aid in the development of a lead service line replacement schedule. A third purpose was to resample some homes that had shown very high concentrations of lead during previous water quality sampling.

Lead service lines may or may not contribute significant quantities of lead to water at the tap, depending on the particular water quality. Identifying lead concentrations in water at the tap that would indicate the presence of a lead service line would allow the District to locate lead service lines without having to resort to test excavations.

Lead can be introduced to drinking water at several points before it reaches the customer's tap. Lead can be present in water in the distribution main, it can leach from lead service lines, it can leach from lead solder joints, or it can leach from brass faucets and fittings. Water in the District's distribution mains is generally free of any significant concentrations of lead (typically less than 5 ug/L). Therefore, the main contributors to lead at the tap are lead service lines, solder joints, and brass fixtures. The age of the house will also affect the contribution of lead from the various sources, as lead leaching rates from lead solder and brass fixtures are generally reduced after a period of approximately 5 years.

The District has conducted several water quality sampling studies in the last several years to assess the problem of lead at the tap. Several of these homes exhibited extremely high concentrations of lead in water (greater than 100 ug/L). A few of these homes were resampled to determine whether lead levels changed in the intervening years.

7.3 DESCRIPTION OF THE DETAILED SAMPLING

Four employees of the District volunteered their homes for use in the detailed sampling effort. Two of the homes had lead service lines, while the other two had nonlead service lines. Interior plumbing from the point at which the service line enters the house to the kitchen sink was sketched and measured. The length of the service line from the curb to the outside of the house was also measured, or estimated when this was not feasible. The volume of water contained in the interior plumbing and the service line was then calculated.

The residents of each home were instructed to avoid any water use for at least 8 hours overnight. Each home was visited early in the morning, and twenty 500-ml samples were collected from the kitchen sink. Using the volumes calculated from measuring the pipes, it was possible to locate where the water in each sample had been standing overnight. Thus, it was possible to verify that samples had been taken from both the service line and the distribution main.

The water samples were analyzed for lead using the LEADTRAK 100 kit manufactured by the Hach Company. Duplicate and spike samples were analyzed for each set for quality assurance. The results of the detailed sampling effort are presented in Table 7-1.

WESTON

Table 7-1

Detailed Sampling Results

SAMPLE NUMBER	HOUSE # 1 (NON-LEAD)	HOUSE # 2 (NON-LEAD)	HOUSE # 3 (LEAD)	HOUSE # 4 (LEAD)
1	ND	ND	12	ND
2	ND	ND	3	ND
3	ND	ND	18	ND
4	ND	ND	9	ND
5	ND	ND	5	ND
6	ND	17	3	ND
7	ND	9	5	ND
8	ND	8	4	ND
9	ND	ND	ND	ND
10	ND	ND	ND	ND
11	ND	ND	ND	ND
12	ND	ND	2	ND
13	ND	ND	ND	ND
14	ND	ND	ND	ND
15	ND	ND	ND	ND
16	ND	ND	ND	ND
17	ND	ND	ND	ND
18	ND	ND	ND	ND
19	ND	ND	ND	ND
20	ND	ND	ND	ND
SPIKE OF 1	10	–	–	–
SPIKE OF 4	–	–	–	6
SPIKE OF 6	–	31	–	–
SPIKE OF 15	–	–	10	–
DUPLICATE OF 2	–	–	13	–
DUPLICATE OF 8	–	8	–	–
DUPLICATE OF 10	ND	–	–	–
DUPLICATE OF 13	–	–	–	ND

Shaded areas represent samples taken from the service line.
All sample results given in ug/L (parts per billion).
Values listed as "ND" were less than the detection limit of 2 ug/L.
Spike samples should read 10 ug/L greater than original sample result.

The detailed sampling effort illustrated some specific points about the issue of lead in drinking water in the District, as well as several general points about water quality sampling in private homes. Neither of the two homes that had lead service lines showed any lead concentrations above the detection limit of 2 ug/L for any of the samples that represented water standing in the service line. This shows that a lead service line does not always result in elevated lead concentrations in water.

The first general observation is that there is no such thing as a "typical" house. The diameters and lengths of pipe within each house varied a great deal. This makes it difficult to establish a common set of sampling instructions that will ensure a valid sample taken from the service line. Second, there are an infinite variety of situations that may arise which can affect the sample collection. It must be remembered that these are private homes, and even though the homeowners were most cooperative, unexpected problems often arose that required flexibility in response to get a proper sample. Homeowners collecting the samples on their own, however, cannot be expected to make those sorts of adjustments to make the sample collection match the specific circumstances.

7.4 DESCRIPTION OF THE FULL-SCALE SAMPLING PROGRAM

A set of four samples was collected from each home to analyze contributions of lead from the various sources. The four samples, labeled A, B, C, and D, were collected to represent water from the tap, the pipe below the sink, the service line, and the distribution main, respectively. To account for the age of the plumbing and the service line material, homes were assigned to one of four risk categories. The four risk categories were defined as follows:

- **Risk Category 1** -- Homes that are less than 2 years old. These are assumed to have a nonlead service line and lead-free solder joints.
- **Risk Category 2** -- Homes that are between 2 and 5 years old. These are assumed to have a nonlead service line, but may have lead solder joints.
- **Risk Category 3** -- Homes that are more than 5 years old, and are known to have a nonlead service line and lead solder joints.
- **Risk Category 4** -- Homes that are more than 5 years old, and are known to have a lead service line and lead solder joints.

The set of water samples was collected by the homeowner in the morning before any water had been used in the house. The four samples are shown schematically in Figure 7-1 and are described as follows:

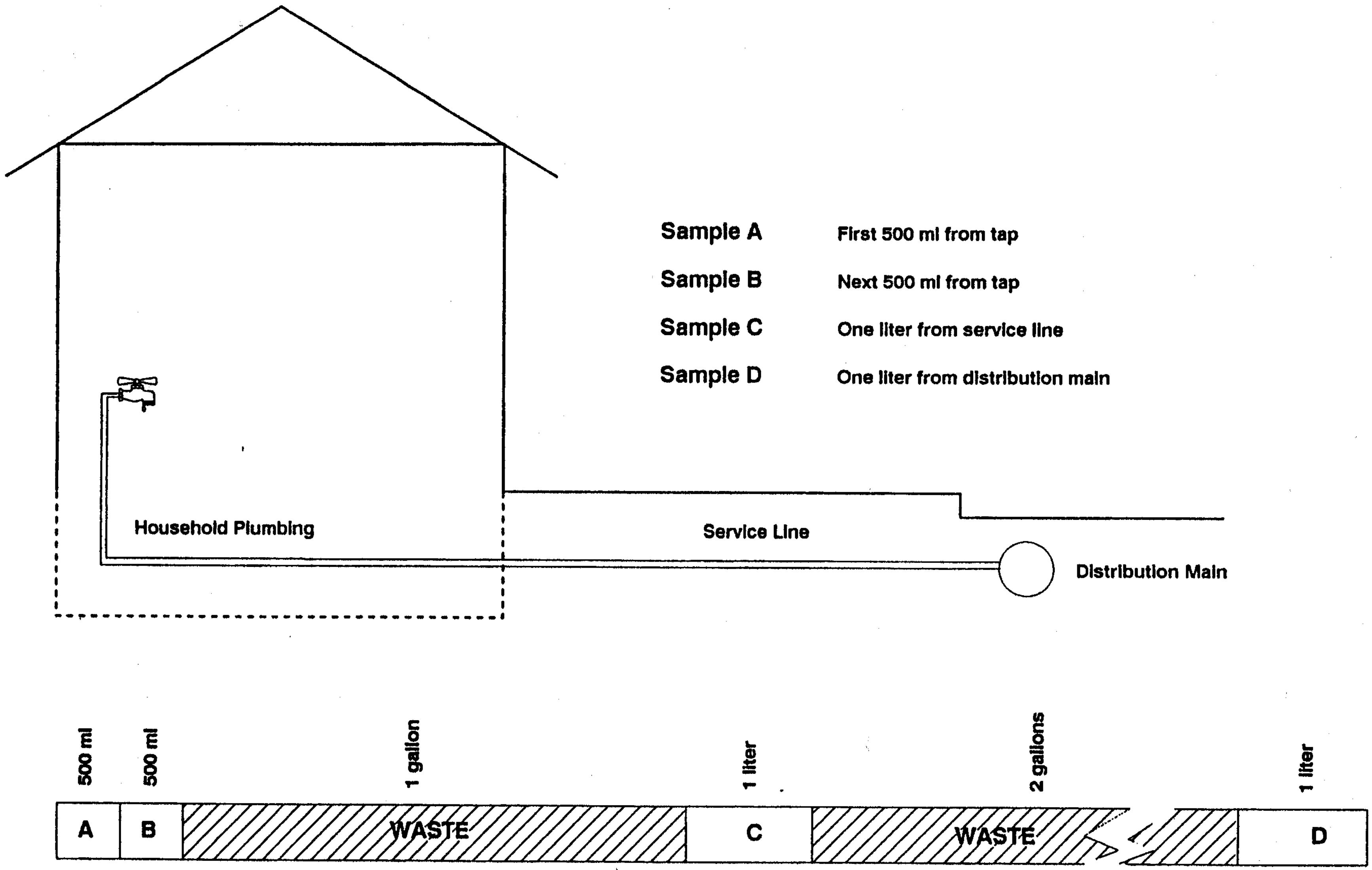

FIGURE 7-1 SCHEMATIC OF SAMPLING PROTOCOL

- Sample A -- The first 500 ml of water from the kitchen tap.
- Sample B -- The next 500 ml of water from the kitchen tap.
- Sample C -- A 1-liter sample taken after collecting Samples A and B, and after allowing 1 additional gallon of water to be wasted.
- Sample D -- A 1-liter sample taken after collecting Samples A, B, and C, and after allowing 2 additional gallons of water to be wasted.

To obtain a representative sampling, homes were selected at random from throughout the District. It was originally proposed that an equal number of homes in each risk category be sampled in each ward. Thus, 5 homes in each of the 4 risk categories in each of the 8 wards would be sampled, for a total of 160 homes. More than 400 addresses were selected at random from the Tap File Database. The owners of these homes were then identified and the list approved by the District prior to contacting homeowners.

The first step was to send a letter to each of the 400+ homeowners asking for their cooperation in collecting water samples. A self-addressed, stamped postcard was included with the letter to allow the homeowners to respond. After 2 weeks time, approximately 120 positive responses were received. At this point, a reminder letter was sent to those homeowners who had yet to respond to the original letter, and a list of District employees willing to participate in the sampling program was obtained. From the reminder letter and the employee list, a sufficient number of homes for sampling was obtained.

The desired distribution among the eight wards and four risk categories could not be achieved, however. Most of the homes were located in Wards 3 and 4, and there was a far greater number of homes in Risk Categories 3 and 4. This is to be expected since these risk categories represent the older (greater than 5 years old) homes in the District. Rather than delay the sampling effort further while attempting to locate willing participants in other wards and risk categories, the sampling was conducted on the first 160 homes that had responded. The resulting distribution of sampled homes is shown in Table 7-2.

The sampling was conducted in two parts. The first round consisted of the 120 homes that responded within the first 2 weeks after the mass mailing. A letter was sent to these homeowners advising them of when they would receive the sample bottles, along with detailed instructions on how and when to collect the samples. On the appropriate day, a sampling kit was delivered to each home that consisted of the four sample bottles, a 1-gallon plastic bucket, a set of sampling instructions (shown in Appendix F), and a short questionnaire (shown in Appendix G). The samples were collected

Table 7-2

Distribution of Homes in the Full-Scale Sampling Program

WARD	RISK CATEGORY 1	2	3	4	TOTAL
1	2	2	8	8	20
2	2	2	5	3	12
3	3	0	10	13	26
4	2	4	13	10	29
5	3	0	8	8	19
6	1	3	9	5	18
7	1	2	13	6	22
8	0	0	8	5	13
TOTAL	14	13	74	58	159

by the homeowner the following morning, and the sample bottles were picked up for delivery to the laboratory.

The second sampling round occurred about 2 weeks after the completion of the first round. These 40 homeowners were contacted by telephone rather than through the mail. Again, a sampling kit was delivered to each home, and the filled sample bottles were collected the next day.

The sample bottles were packed in coolers and delivered by overnight mail to the laboratory for analysis. Upon arrival at the laboratory, the samples were preserved by the addition of acid. Acid preservation at the laboratory, rather than prior to sample collection, was conducted in previous sampling efforts, and proved effective. It also eliminates the possibility of a homeowner coming in contact with the acid.

The sampling program was affected by inevitable delays as homeowners either forgot to collect the samples, or forgot to leave the bottles where they could be collected. Sometimes the bottles could not be collected on the arranged day, since the bottles had been put out after the home was visited in the morning. However, most of the homeowners were contacted by telephone to make alternate arrangements to collect the sample bottles. The homeowner was instructed to redo the sampling if the bottles could not be picked up within a reasonable time after the original sampling had occurred. Ultimately, samples were collected from 159 of the 160 homes and sent by overnight mail to the laboratory for analysis.

7.5 RESULTS

The laboratory results of the 159 sampled homes are given in Table 7-3. It is important to note that results given as "ND" represent samples that were less than the detection limit of 3.0 ug/L.

The data were analyzed by risk category and ward. These results are summarized in Tables 7-4 through 7-7. It should be noted that all samples below the detection limit of 3.0 ug/L were treated as being 1.5 ug/L for performing calculations.

7.6 QUALITY CONTROL

Included with each shipment of samples to the laboratory was a set of four sample bottles for quality control (QC) purposes. These QC samples were given sample IDs of the same form as the actual samples so that the laboratory could not distinguish between the two. Two of the four bottles in the QC set contained distilled water with no lead, while the other two were spiked with a known amount of lead solution.

Table 7-3

Laboratory Results for the 159 Full-Scale Sampling Homes

SAMPLE ID	WARD	RISK CAT.	SAMPLE DATE	SAMPLE RESULTS A	B	C	D
111	1	1	April 18, 1990	3.0	ND	ND	ND
112	1	1	April 18, 1990	24.0	7.0	3.0	3.0
121	1	2	April 18, 1990	39.0	8.0	4.0	3.0
122	1	2	April 18, 1990	6.0	3.0	6.0	ND
131	1	3	April 18, 1990	5.0	ND	ND	ND
132	1	3	April 18, 1990	ND	ND	ND	ND
133	1	3	April 18, 1990	ND	ND	3.0	ND
134	1	3	April 18, 1990	5.0	5.0	3.0	ND
135	1	3	May 4, 1990	ND	ND	3.7	ND
136	1	3	May 2, 1990	ND	ND	ND	ND
137	1	3	May 3, 1990	ND	ND	ND	ND
138	1	3	May 11, 1990	ND	ND	ND	ND
141	1	4	April 20, 1990	4.8	ND	ND	ND
142	1	4	April 18, 1990	14.0	5.0	5.0	4.0
143	1	4	April 18, 1990	3.0	5.0	4.0	ND
144	1	4	April 18, 1990	ND	ND	ND	ND
145	1	4	April 18, 1990	48.0	36.0	14.0	4.0
146	1	4	April 18, 1990	3.0	ND	ND	ND
147	1	4	April 18, 1990	27.0	50.0	11.0	11.0
149	1	4	May 1, 1990	ND	ND	ND	ND
211	2	1	April 25, 1990	30.0	6.4	ND	ND
212	2	1	May 3, 1990	3.3	3.4	ND	ND
221	2	2	April 18, 1990	3.0	ND	ND	ND
222	2	2	May 1, 1990	3.6	ND	ND	ND
231	2	3	April 17, 1990	ND	ND	ND	ND
232	2	3	April 17, 1990	ND	ND	8.0	ND
233	2	3	May 1, 1990	8.2	ND	ND	ND
234	2	3	April 17, 1990	ND	ND	ND	ND
235	2	3	May 2, 1990	ND	ND	ND	ND
241	2	4	April 17, 1990	ND	ND	ND	ND
242	2	4	April 17, 1990	6.0	ND	ND	ND
243	2	4	April 17, 1990	48.0	8.0	5.0	8.0
311	3	1	April 17, 1990	3.0	ND	ND	ND
312	3	1	April 17, 1990	ND	ND	ND	ND
313	3	1	May 2, 1990	ND	ND	ND	ND
331	3	3	April 17, 1990	10.0	10.0	ND	ND
332	3	3	April 17, 1990	ND	ND	ND	ND
333	3	3	April 18, 1990	4.1	ND	ND	ND
334	3	3	April 26, 1990	ND	ND	ND	ND
335	3	3	April 26, 1990	ND	ND	ND	ND
336	3	3	April 17, 1990	ND	ND	ND	ND
337	3	3	April 26, 1990	ND	ND	ND	ND
338	3	3	April 21, 1990	ND	ND	ND	ND
3310	3	3	April 17, 1990	ND	ND	ND	ND
3311	3	3	April 17, 1990	13.0	6.0	7.0	6.0

All values given in ug/L.

Values listed as "ND" represent samples below the detection limit of 3.0 ug/L.

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7-3
nued)

		SAMPLE DATE
	4	ril 17, 1990
		ril 17, 1990
		ril 17, 1990
	4	ril 26, 1990
	4	pril 17, 1990
		pril 17, 1990
	4	pril 17, 1990
	4	pril 26, 1990
		pril 17, 1990
		pril 17, 1990
		April 18, 1990
		April 17, 199
		May 3, 1990
		April 18, 1990
		May 4, 1990
		April 18, 199
		April 18, 1990
		April 18, 199
		April 19, 199
		April 18, 1990
		May 8,1990
		May 2, 1990
		May 2, 1990
		May 2, 1990
		April 18, 199
		April 18, 199
		April 17, 1990
		April 18, 199
		April 19, 199
		April 18, 1990
		May 2, 1990
		May 17, 1990
		April 18, 19
	4	April 25, 1990
	4	April 18, 19
	4	April 18, 19
4	4	April 18, 1990
4	4	April 18, 19
	4	April 18, 19
	4	April 27, 1990
4	4	April 18, 1990
	4	May 2, 1990
	1	April 19, 19
5	1	April 19, 1990
5	1	April 25, 19

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WESTON

Table 7-3
(continued)

SAMPLE ID	WARD	RISK CAT.	SAMPLE DATE	SAMPLE RESULTS A	B	C	D
531	5	3	April 19, 1990	70.0	50.0	70.6	96.7
532	5	3	April 19, 1990	ND	ND	ND	ND
533	5	3	April 25, 1990	ND	ND	ND	ND
534	5	3	April 19, 1990	ND	ND	ND	ND
535	5	3	April 25, 1990	ND	ND	ND	ND
536	5	3	April 25, 1990	ND	ND	ND	ND
537	5	3	May 2, 1990	ND	ND	ND	ND
538	5	3	May 2, 1990	ND	5.0	ND	ND
541	5	4	April 18, 1990	ND	ND	ND	ND
542	5	4	April 19, 1990	ND	ND	ND	ND
543	5	4	April 19, 1990	ND	ND	ND	ND
545	5	4	May 2, 1990	ND	ND	ND	ND
546	5	4	May 2, 1990	ND	ND	ND	ND
547	5	4	May 2, 1990	14.1	20.4	26.0	8.3
548	5	4	May 3, 1990	ND	ND	ND	ND
549	5	4	May 2, 1990	ND	ND	ND	ND
611	6	1	April 19, 1990	11.9	5.2	ND	ND
621	6	2	April 19, 1990	52.4	18.1	6.5	5.5
622	6	2	April 19, 1990	128.0	44.0	13.9	4.9
623	6	2	May 1, 1990	ND	ND	ND	ND
631	6	3	April 18, 1990	ND	ND	ND	ND
632	6	3	April 19, 1990	4.8	ND	ND	ND
633	6	3	April 19, 1990	ND	ND	ND	ND
634	6	3	April 19, 1990	12.6	14.2	16.9	20.6
635	6	3	April 25, 1990	ND	ND	ND	ND
636	6	3	April 19, 1990	ND	ND	ND	ND
637	6	3	April 19, 1990	ND	ND	22.4	ND
638	6	3	May 3, 1990	ND	ND	ND	ND
639	6	3	May 4, 1990	ND	ND	ND	ND
641	6	4	April 19, 1990	4.9	3.4	10.4	3.8
642	6	4	April 19, 1990	10.9	12.5	3.6	ND
643	6	4	April 25, 1990	ND	ND	ND	ND
644	6	4	April 19, 1990	ND	ND	ND	ND
645	6	4	April 19, 1990	ND	ND	ND	ND
711	7	1	April 20, 1990	ND	ND	ND	ND
721	7	2	April 20, 1990	ND	ND	ND	ND
722	7	2	April 19, 1990	ND	ND	ND	ND
731	7	3	April 20, 1990	ND	ND	ND	ND
732	7	3	April 21, 1990	3.2	ND	ND	ND
733	7	3	April 20, 1990	ND	ND	ND	ND
734	7	3	April 20, 1990	ND	ND	ND	ND
735	7	3	April 19, 1990	ND	ND	ND	ND
736	7	3	April 19, 1990	ND	ND	ND	ND
737	7	3	April 19, 1990	ND	ND	ND	ND
738	7	3	April 20, 1990	ND	ND	ND	7.0

All values given in ug/L.

Values listed as "ND" represent samples below the detection limit of 3.0 ug/L.

WESTON

Table 7-3
(continued)

SAMPLE ID	WARD	RISK CAT.	SAMPLE DATE	SAMPLE RESULTS A	B	C	D
739	7	3	May 2, 1990	ND	ND	ND	ND
7310	7	3	May 3, 1990	ND	ND	43.2	24.6
7311	7	3	May 2, 1990	ND	ND	ND	ND
7312	7	3	May 2, 1990	ND	ND	ND	ND
7313	7	3	May 1, 1990	ND	ND	ND	ND
741	7	4	April 20, 1990	ND	ND	ND	ND
742	7	4	April 20, 1990	ND	ND	ND	ND
743	7	4	April 20, 1990	4.5	6.3	ND	ND
744	7	4	April 20, 1990	ND	ND	ND	ND
745	7	4	April 23, 1990	ND	ND	ND	ND
746	7	4	April 26, 1990	ND	ND	ND	ND
831	8	3	April 22, 1990	ND	ND	ND	ND
832	8	3	April 19, 1990	ND	ND	ND	ND
833	8	3	April 20, 1990	ND	ND	ND	ND
834	8	3	April 20, 1990	7.7	ND	ND	ND
835	8	3	May 2, 1990	ND	ND	4.6	ND
836	8	3	May 4, 1990	ND	ND	ND	ND
837	8	3	May 5, 1990	ND	ND	ND	ND
838	8	3	May 3, 1990	ND	ND	ND	ND
841	8	4	April 20, 1990	3.2	ND	ND	ND
842	8	4	April 20, 1990	ND	ND	ND	ND
843	8	4	April 26, 1990	ND	ND	ND	ND
845	8	4	May 2, 1990	ND	ND	ND	ND
846	8	4	May 2, 1990	5.8	ND	ND	3.9

All values given in ug/L.
Values listed as "ND" represent samples below the detection limit of 3.0 ug/L.

WESTON

Table 7-4

Summary of Data for Risk Category 1

WARD	HOUSES SAMPLED	AVERAGE				MAXIMUM				MINIMUM			
		ARESULT	BRESULT	CRESULT	DRESULT	ARESULT	BRESULT	CRESULT	DRESULT	ARESULT	BRESULT	CRESULT	DRESULT
1	2	13.5	4.25	2.25	2.25	24	7	3	3	3	1.5	1.5	1.5
2	2	16.65	4.9	1.5	1.5	30	6.4	1.5	1.5	3.3	3.4	1.5	1.5
3	3	2	1.5	1.5	1.5	3	1.5	1.5	1.5	1.5	1.5	1.5	1.5
4	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
5	3	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
6	1	11.9	5.2	1.5	1.5	11.9	5.2	1.5	1.5	11.9	5.2	1.5	1.5
7	1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
8	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOTAL	14	6.23	2.64	1.61	1.61	30	7	3	3	1.5	1.5	1.5	1.5
STD DEVIATION		8.95	1.95	0.39	0.39								

All values given in ug/L (parts per billion). Values given as 1.5 ug/L represent samples below detection limit of 3.0 ug/L.

Table 7-5

Summary of Data for Risk Category 2

WARD	HOUSES SAMPLED	AVERAGE				MAXIMUM				MINIMUM			
		ARESULT	BRESULT	CRESULT	DRESULT	ARESULT	BRESULT	CRESULT	DRESULT	ARESULT	BRESULT	CRESULT	DRESULT
1	2	22.5	5.5	5	2.25	39	8	6	3	6	3	4	1.5
2	2	3.3	1.5	1.5	1.5	3.6	1.5	1.5	1.5	3	1.5	1.5	1.5
3	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4	4	13.03	5.95	8.05	3.58	22.8	14.3	14.8	6.7	1.5	1.5	1.5	1.5
5	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	3	60.63	21.2	7.3	3.97	128	44	13.9	5.5	1.5	1.5	1.5	1.5
7	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
8	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOTAL	13	22.2	8.03	5.39	2.82	128	44	14.8	6.7	1.5	1.5	1.5	1.5
STD DEVIATION		34.26	11.60	5.20	1.83								

All values given in ug/L (parts per billion). Values given as 1.5 ug/L represent samples below detection limit of 3.0 ug/L.

Table 7-6

Summary of Data for Risk Category 3

WARD	HOUSES SAMPLED	AVERAGE				MAXIMUM				MINIMUM			
		ARESULT	BRESULT	CRESULT	DRESULT	ARESULT	BRESULT	CRESULT	DRESULT	ARESULT	BRESULT	CRESULT	DRESULT
1	8	2.38	1.94	2.15	1.5	5	5	3.7	1.5	1.5	1.5	1.5	1.5
2	5	2.84	1.5	2.8	1.5	8.2	1.5	8.7	1.5	1.5	1.5	1.5	1.5
3	10	3.76	2.8	2.05	1.95	13.2	10.5	7.7	6.5	1.5	1.5	1.5	1.5
4	13	6.38	5.57	7.42	3.39	41.2	35.1	42.5	14.1	1.5	1.5	1.5	1.5
5	8	10.06	8	10.14	13.4	70.2	50.1	70.6	96.7	1.5	1.5	1.5	1.5
6	9	3.1	2.91	5.53	3.62	12.6	14.2	22.4	20.6	1.5	1.5	1.5	1.5
7	13	1.63	1.5	4.71	3.7	3.2	1.5	43.2	24.6	1.5	1.5	1.5	1.5
8	8	2.28	1.5	1.89	1.5	7.7	1.5	4.6	1.5	1.5	1.5	1.5	1.5
TOTAL	74	4.08	3.31	4.8	3.82	70.2	50.1	70.6	96.7	1.5	1.5	1.5	1.5
STD DEVIATION		9.32	7.10	11.30	11.58								

All values given in ug/L (parts per billion). Values given as 1.5 ug/L represent samples below detection limit of 3.0 ug/L.

Table 7-7

Summary of Data for Risk Category 4

		AVERAGE				MAXIMUM				MINIMUM			
WARD	HOUSES SAMPLED	ARESULT	BRESULT	CRESULT	DRESULT	ARESULT	BRESULT	CRESULT	DRESULT	ARESULT	BRESULT	CRESULT	DRESULT
1	8	12.85	12.75	5.15	3.31	48	50	14	11	1.5	1.5	1.5	1.5
2	3	18.5	3.67	2.67	3.67	48	8	5	8	1.5	1.5	1.5	1.5
3	13	10.77	10.46	13.29	6.51	42	32.8	50	35.6	1.5	1.5	1.5	1.5
4	10	14.4	11.67	14.48	7.7	60	27.6	51	34.6	1.5	1.5	1.5	1.5
5	8	3.08	3.86	4.56	2.35	14.1	20.4	26	8.3	1.5	1.5	1.5	1.5
6	5	4.06	4.08	3.7	1.96	10.9	12.5	10.4	3.8	1.5	1.5	1.5	1.5
7	6	2.63	2.3	1.5	1.5	4.5	6.3	1.5	1.5	1.5	1.5	1.5	1.5
8	5	2.7	1.5	1.5	1.98	5.8	1.5	1.5	3.9	1.5	1.5	1.5	1.5
TOTAL	58	8.84	7.56	7.54	4.25	60	50	51	35.6	1.5	1.5	1.5	1.5
STD DEVIATION		12.60	9.95	12.60	6.42								

All values given in ug/L (parts per billion). Values given as 1.5 ug/L represent samples below detection limit of 3.0 ug/L.

The results of the QC samples are given in Table 7-8. This table also lists the concentrations of lead that were expected based upon the amount of lead solution added to each sample. Two of the four samples in each set were spiked with the lead solution to a concentration of 10 ug/L, while the other two were plain distilled water containing no lead. It should be noted that the lead solution was not added under strict laboratory conditions, and therefore, the concentration of lead in the final sample may have varied slightly from the expected concentration of 10 ug/L.

7.7 COMPARISON TO PREVIOUS SAMPLING EFFORTS

Table 7-9 compares the results for individual homes that had been sampled during previous studies. The earlier sampling efforts collected only three samples, rather than the four collected during this study. The 3 samples were each 1 liter in volume, and represented water from the faucet, the service line, and the distribution main. The three sample results were renamed A, C, and D to correspond to the current sampling program. Therefore, Table 7-9 lists NA (not applicable) for all B results for the previous studies.

Comparison of the results shows that 10 out of 13 homes showed significantly reduced lead levels for the current sampling effort. The other three homes exhibited similar lead concentrations during both sampling efforts.

The previous studies did not segregate homes into the four risk categories used in this study. It is possible, however, to identify most of the homes as having either a lead or nonlead service line. Average, maximum, and minimum values have been calculated for the results of the previous study for both lead and nonlead service lines. These results are summarized and compared to the results for Risk Category 3 and 4 homes of the current study in Table 7-10.

7.8 CONCLUSIONS AND RECOMMENDATIONS

Two important facts must be considered when assessing the results of the sampling program. The first is that it is impossible to guarantee that any individual sample was collected properly by the homeowner. However, the database as a whole will be reliable. Although the homeowners were very cooperative, there is no way to verify that they followed the sampling instructions properly. Second, all of the homes were sampled following the same directions. Specifically, 1 gallon of water was wasted between Samples B and C, and 2 gallons wasted between Samples C and D. Without actually inspecting and measuring the plumbing of each house, there is no way of knowing whether Samples C and D actually represented water from the service line and distribution main as desired.

Tables 7-4 through 7-7 show that Risk Category 4 did indeed have the highest average lead level for Sample C. This was expected, since Risk Category 4 represents those homes with Known Lead

Table 7-8

Laboratory Results for the QC Samples

SAMPLE	SAMPLE A		SAMPLE B		SAMPLE C		SAMPLE D	
	EXPECTED	OBSERVED	EXPECTED	OBSERVED	EXPECTED	OBSERVED	EXPECTED	OBSERVED
QC 1	10	7.7	0	ND	10	8.4	0	ND
QC 2	10	7.3	10	7.4	0	ND	0	ND
QC 3	0	ND	10	12.0	10	13.0	0	ND
QC 4	10	11.0	10	10.7	10	ND	0	ND
QC 5	0	ND	10	12.0	10	14.0	0	ND
QC 6	10	13.6	10	13.0	0	ND	0	ND
QC 7	10	11.1	0	ND	10	13.1	0	ND
QC 8	0	ND	10	11.8	10	12.1	0	ND
QC 9	10	10.0	10	12.5	0	ND	0	ND
QC 10	10	11.1	0	ND	10	12.2	0	ND

All values given in ug/L (parts per billion).

Values listed as "ND" represent samples below the detection limit of 3.0 ug/L.

Table 7-9

Lead Concentrations for Previously Sampled Homes

LOCATION	PREVIOUS STUDIES				CURRENT STUDY			
	A	B	C	D	A	B	C	D
1	50	NA	3	ND	ND	ND	ND	ND
2	558	NA	38	ND	70	50	70.6	96.7
3	13	NA	154	ND	ND	ND	8	ND
4	31	NA	138	ND	13	6	7	6
5	39	NA	125	ND	42	32.8	49.2	35.6
6	15	NA	279	ND	4.1	ND	ND	ND
7	399	NA	308	ND	ND	ND	ND	ND
8	1	NA	78	ND	ND	ND	ND	ND
9	50	NA	4	ND	10.8	7.6	37.5	13.5
10	35	NA	62	ND	41	35.1	42.5	14.1
11	20	NA	52	ND	26	14.9	51	14.4
12	5	NA	130	ND	9	12	23	6
13	123	NA	58	ND	8	7	7	3

All values given in ug/L (parts per billion)
NA = Not Applicable
ND = Less than Detection limit

Table 7-10

Comparison of Results to Previous Sampling Efforts

WATER SAMPLE	AVERAGE LEAD CONCENTRATION			
	PREVIOUS SAMPLING		CURRENT SAMPLING	
	LEAD SERVICES	NON-LEAD SERVICES	LEAD SERVICES	NON-LEAD SERVICES
First water from tap	20	10.75	8.84	4.08
Service line	19.56	8.21	7.54	4.8
Distribution main	2	1.61	4.25	3.82

All values given in ug/L.

service Lines. However, when examined on a house-by-house basis, there are actually quite a few homes in Risk Category 3 (nonlead service lines) that have higher Sample C values than those in Risk Category 4. In fact, the highest Sample C value, 70.6 ug/L, was recorded at a Risk Category 3 home. Therefore, although, in general, homes with lead service lines show a higher lead concentration in Sample C on average, it would be difficult to use the sample results for an individual address to predict the existence of a lead service line.

Homes in Risk Categories 1 and 2 have their highest lead concentrations in Samples A and B. Risk Category 2 homes also show greater lead concentrations than Risk Category 1 homes. This may be because of the ban on lead-bearing plumbing materials that was enacted prior to the construction of Risk Category 1 homes.

The concentration of lead in Sample D was unexpectedly high in several of the homes sampled. Sample D should represent water from the distribution main, and should be relatively lead-free based on past examination of distribution system lead levels. In Risk Category 4 the high lead levels in Sample D may be explained by the fact that the water may actually have come from the lead service line because not enough water was wasted between samples. High Sample D lead levels in Risk Category 3 homes cannot be explained as easily since these are supposedly nonlead service lines. One possibility is that the District's portion of the service line is correctly recorded as nonlead, while the customer's side is actually lead. Another possibility is that the service line is galvanized iron, and lead is leaching from the 2- to 4-foot section of lead pipe used to connect the service line to the distribution main.

It is recommended that additional sampling of homes with lead service lines be conducted as funds allow. This will provide additional information to be used in prioritizing lead service line replacement.

SECTION 8

OPTIONS FOR REDUCING EXPOSURE TO LEAD IN DRINKING WATER

Section 2 identified techniques that can be used to reduce exposure to lead in drinking water. While all of these techniques are considered for evaluation, some can be eliminated as being too costly or impractical. The remaining techniques can then be combined to produce viable options for reducing consumers' exposure to lead in the District's drinking water.

Table 8-1 lists the techniques given to reduce the intake of lead in drinking water and rates them on the following four criteria:

- Feasibility -- Table 8-1 lists either YES or NO for the feasibility of a particular technique. Techniques that require actions clearly outside of the District's control were considered to be not feasible, and were removed from further consideration. All other techniques were considered feasible.

- Practicality -- The practicality of each technique was evaluated based on the ability of the District to implement the technique under current conditions. A ranking of 1 indicates that the technique could be acted on quite easily, while a ranking of 5 indicates that the technique would be difficult, if not impossible, to implement.

- Performance -- The performance of a particular technique was based on the extent to which lead intake from drinking water would be reduced upon implementation of the technique. A ranking of 1 indicates that the technique results in the virtual elimination of lead intake from drinking water. A ranking of 5 was given to techniques that result in only minor reductions in lead intake at the tap. Techniques for which the reduction in lead intake affected only a portion of the customers, or had an indefinite reduction were given a ranking between 1 and 5.

- Cost -- The capital and operating costs of each technique were given, when they were available. All costs were given on a per household basis by dividing the total technique cost by the number of residential customers in the District (approximately 126,000).

Table 8-1 can be used to help in developing program options for reducing the intake of lead from drinking water. The rankings in Table 8-1 must be used with caution. Current ongoing programs, as

Table 8-1

Rating of Techniques to Reduce Lead in Drinking Water

LEAD REDUCTION TECHNIQUES	FEASIBILITY (Note 1)	PRACTICALITY (Note 2)	PERFORMANCE (Note 3)	COST	
				CAPITAL ($/household)	OPERATING ($/household/yr)
CENTRALIZED TREATMENT					
1) Adjustment of pH and alkalinity	YES	1	3	$0	$0.10
2) Calcium carbonate precipitation	YES	1	2	$0	$0.10
3) Orthophosphate addition	YES	3	2	$16	$0.74
4) pH and control with orthophosphate addition	YES	4	1	NA	$7.81
POINT OF USE DEVICES					
1) Reverse osmosis	YES	5	1	$800	$50
2) Granular activated carbon	YES	5	5	$215	$48
3) Distillation	YES	5	1	$850	NA
REMOVAL OF LEAD MATERIAL					
1) Lead service line replacement (partial)	YES	3	2	$2,890	$0
2) Lead service line replacement (total)	YES	4	2	$5,780	$0
3) Replacement of soldered joints	NO	-	-	-	-
4) Replacement of brass faucets and fixtures	NO	-	-	-	-
PLUMBING CODE MODIFICATIONS AND ENFORCEMENT	YES	1	2	$0	$0
PUBLIC EDUCATION	YES	1	1	$2	$0
ALTERNATIVE DISTRIBUTION TECHNIQUES					
1) Bottled water	YES	2	1	$0	$2,000
2) Dual water distribution system	NO	-	-	-	-

Note 1. An option is considered feasible if the actions required are within the District's control.

Note 2. Practicality ranges from 1 (very practical - easily implemented) to 5 (very impractical - difficult to implement).

Note 3. Performance ranges from 1 (essentially eliminates lead intake from drinking water) to 5 (only minor reductions in lead intake from drinking water).

NA = Not available

well as the anticipated final lead regulations to be issued by EPA, must be taken into account. Therefore, three options for reducing lead intake through drinking water are proposed as follows:

- Option 1 -- This option includes the continued replacement of lead service lines and the implementation of a public education program to instruct customers on ways to reduce their exposure to lead in drinking water.

- Option 2 -- This option includes all components of Option 1, as well as changes in the treatment plant operation to increase the pH of treated water to above 8.0.

- Option 3 -- This option calls for pH control and orthophosphate addition at the treatment plant, along with all components of Option 1.

These options take into account the latest version of EPA's proposed lead and copper regulations (August 1988), as well as the expected contents of the final regulations, which are not expected until sometime in 1990. As described in a previous subsection, the proposed rules set certain no-action levels that must be met to avoid taking action to reduce exposure to lead. Failure to meet other no-action levels requires the water system to develop and implement a public education program. One of the no-action levels calls for the pH to be greater than or equal to 8.0. The final regulations are expected to include a provision calling for mandatory replacement of lead service lines if it is shown that they are contributing to excessive levels of lead at the tap.

All three options include a public education program and the continued replacement of lead service lines. A public education program is probably the most effective way to eliminate the ingestion of significant quantities of lead through drinking water. Simple actions such as flushing standing water from faucets and pipes, and using only the cold water tap for drinking and cooking would basically eliminate the problem of lead corrosion. While not all lead service lines result in high lead levels at the tap, a prioritized lead service replacement program would eliminate one source of lead at those homes with high concentrations of lead at the tap.

Option 1

Water quality sampling has shown that there is very little lead present in water in the District's distribution system. High lead levels at the tap are the result of lead leaching from either a lead service line or lead solder joints and brass fixtures in interior home plumbing. The leaching of lead from these sources is highly variable and dependent on a number of factors, including water quality parameters, age, and composition of interior plumbing materials, and time of contact between the water and the lead. Option 1 attempts to reduce customers' exposure to lead at the tap by eliminating one possible source of lead (i.e., lead service lines), and educating customers on how to avoid ingesting water with potentially high lead levels.

The District has an ongoing program to replace its portion of lead service lines. There are an estimated 28,385 lead service lines in use throughout the District. At the current rate of 375 lead service line replacements per year, it would take about 75 years to completely replace all of the lead service lines. However, not all lead service lines contribute to high lead levels at the tap, as shown by recent water quality sampling. Therefore, the prioritized program presented in Section 5 should be followed to first replace those service lines that have demonstrated, through water quality sampling results, that they are causing high lead levels at the tap.

Replacing the District's portion of a lead service line is only a partial solution, however. The District does contact the homeowner whenever it replaces a lead service line, and recommends that the homeowner replace his/her portion of the lead service line. However, the homeowner may or may not choose to replace his/her portion of the service line when it is identified as lead. Homeowners should be encouraged to replace their lead service lines when they are identified. One way to do this is as part of a public education program. The possible adverse health effects, especially for children and pregnant women, should be highlighted to stress the importance of the problem.

A public education program for lead in drinking water can be combined with other lead reduction education programs sponsored by the District. Lead from drinking water is only one way that lead is ingested. A comprehensive education program dealing with the overall problem of lead will have a greater impact than one focusing solely on lead in drinking water.

The basic message of a public education for reducing exposure to lead through drinking water should be three-fold:

- Awareness -- Learn about the possible health effects of lead. Check your home for the presence of lead pipes, including a lead service line.

- Testing -- If you think your water may contain high lead levels, have it tested by the District at a nominal cost.

- Action -- Replace any lead plumbing in your home, including a lead service line. Use only lead-free products when repairing or replacing plumbing. Run water from the tap if water has been sitting for an extended period. Use only the cold water tap for cooking and drinking purposes.

The public education program can be presented in many ways. Newspaper, television, and radio advertisements are an effective way to reach a large number of people. Envelope stuffers will reach all customers of the water system, but customers often ignore extraneous material in a billing. Special programs can be directed at schools and hospitals which will have a higher percentage of persons at increased risk from exposure to lead. It is recommended that a good public education program be developed for implementation in the District.

One suggestion is to produce a videotape illustrating methods of identifying lead material in the plumbing system, along with ways to reduce exposure to lead in water. Such a videotape could be developed in conjunction with the Health Department, and could also include methods of dealing with other sources of lead such as paint. The videotape could be advertised and made available through schools and libraries. It could also be provided to neighborhood committees which would distribute it among the residents.

Option 2

Option 2 includes all of the recommendations of Option 1. It also calls for adjusting the pH at the treatment plant to be consistently greater than 8.0. The pH of water leaving each of the treatment plants is often less than 8.0. Raising the pH above 8.0 may not necessarily result in lower lead concentrations at the tap, as stated in Subsection 2.4.1.1. However, it may be necessary to take this action in order to meet the no-action levels established by EPA.

Raising the pH should not involve major changes in operation at either water treatment plant. The effectiveness of raising the pH should be examined by collecting water samples from addresses that have shown high lead concentrations in water from the tap. Homes sampled in previous water quality studies could be used for this purpose.

Option 3

Option 3 also includes the recommendations of Option 1. In addition, it calls for significant changes in water chemistry at the treatment plants to reduce lead solubility in the distribution system. Careful control of pH, along with the addition of orthophosphates, has been shown to be effective in reducing lead solubility. Pilot plant and/or pipe loop testing would be necessary to establish the exact parameters for such a plan.

This option would not be necessary if water quality studies done after adjusting the pH (Option 2) showed that pH was sufficient to lower lead solubilities in the distribution system. If orthophosphate addition did become necessary, a water quality sampling program would be necessary to verify its effectiveness in controlling lead at the tap.

WESTON

SECTION 9

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made about lead in drinking water in the District:

- A wealth of service line information is available to the District from a variety of sources. However, the data sources are scattered among a number of agencies and/or departments. Individual agencies/departments often are not aware of the information available from other sources.
- The District's Tap File, which contains information about services line installations, is incomplete and/or outdated in some cases.
- No proven technology is currently on the market that could be used to identify a lead service line without physical inspections.
- The raw water supply of the District contains low concentrations of lead, typically <5 ug/L.
- Lead concentrations in water in the distribution system are typically <5 ug/L.
- High concentrations of lead in tap water, more than 500 ug/L in one case, can be found in some homes in the District.
- High concentrations of lead in tap water may result from corrosion of lead in brass fixtures, lead-bearing solder, or the District- and homeowner-owned lead service lines.
- The presence of a lead service line does not necessarily result in elevated lead levels in water at the tap.
- There are approximately 28,000 lead service lines remaining in service in the District.
- The current cost incurred by the District to replace the District's portion of a single lead service line is approximately $2,900.
- Financing options available for replacement of the District's portion of lead service lines depend on whether the replacements are treated as part of the District's operating budget, or as a major infrastructure improvement financed as part of the District's Capital Improvement Program.

- Financial assistance to homeowners with incomes below the poverty level for replacing their portion of a lead service line may come from the District.

- The collection of water samples by homeowners is not an exact science. Each home has unique characteristics that make the development of a single set of simple sampling instructions almost impossible. This makes it difficult to positively identify a sample as originating in the service line, for example.

Based on these conclusions, a number of recommendations can be made to deal with the issue of lead in drinking water. Many of these recommendations are general in nature and should be acted on regardless of the content of the final EPA lead regulations. Those recommendations dealing with the District's specific actions to meet EPA guidelines may need to be modified based on the final content of the regulations. The recommendations are as follows:

- The Tap File Database should be installed on a computer(s) and used by District personnel to assist in the Lead Service Replacement Program. The Tap File Database User's Guide presented in Appendix H can be used to familiarize personnel with the database.

- Data from the Meter Relocation Program, Street Replacement Program, and Lead Service Replacement Program should be used to keep the Tap File Database current.

- The District should continue to maintain contact with remote sensing and metal detection companies in the event these technologies improve enough to provide a means to remotely detect lead service lines.

- A public education program should be instituted to teach customers how to reduce their exposure to lead in drinking water. One suggestion is to develop a videotape, in conjunction with the Health Department, pointing out the dangers of lead ingestion in general, and giving specifics on how to deal with lead paint, how to identify lead pipe, and ways to lessen possible exposure to lead in water at the tap. The District could distribute such a videotape through the neighborhood committees.

- The rate of lead service line replacements in the District should be increased by adding crews and following the prioritized lead service line replacement list given in Appendix E.

- Homeowners should be instructed to notify the District if they identify their service line as being lead. This should be done in conjunction with the public education program.

- Treatment processes at the water treatment plants should be modified to increase the pH of water above 8.0 on a consistent basis. After the pH adjustment has been made, water quality samples should be taken at homes that had high lead levels (as identified by previous sampling studies) to determine the effectiveness of pH adjustment.

- If pH adjustment proves ineffective in reducing lead levels at the tap, orthophosphate addition at the water treatment plants to reduce the solubility of lead in water in the distribution system should be considered. Pipe loop studies should be conducted first to determine the optimum concentration of orthophosphates to be added. As with pH adjustment, water quality samples should be collected from homes to determine the effectiveness of orthophosphate addition.

- Homeowners willing to participate in an ongoing water quality sampling program should be located. These homes should be equally distributed throughout the District and consist of homes in different age categories and having different service line materials. The homeowners should be willing to have District personnel inspect their home plumbing systems so that water samples from specific locations can be identified. These homes would then be used for long-term monitoring to assess the effects of the different lead reduction strategies implemented at the water treatment plants, as well as for compliance monitoring for the EPA lead rule.

APPENDIX A

INTERVIEWS OF DISTRIBUTION SYSTEM MAINTENANCE PERSONNEL

DC LEAD PERSONNEL QUESTIONNAIRE

NAME : A. Cave
POSITION : Foreman
YRS. EXPERIENCE : 29- Years
INTERVIEWER : D. Nwabuisi & S. Sarikar
DATE : 6-15-89

1. How often do your crews work on service lines(i.e., #/week) ?

   Everyday

2. How far in advance do you know where your upcoming jobs will be ?

   Scheduled by Health Department

3. Do you do any preparation for a service job ?

   Check
   - utility lines
   - No Parking signs & site clearing.
   - Contact/notify home owner if necessary.

4. Do you have access or ever call in to learn about previous history or maintenance at a location ?

   Not in service repair

5. How long have you been replacing defective lead services with copper instead of repairing them ?

   Since 1985

6. Have you ever put in a lead service line ? If so, when was the last time you did this?

   No

7. Do you have expectations as to the type of material you will find when you dig up a service ? If so, about how often do you find a nonlead service when you expected to find lead ?

   Sometimes, depending on whether or not it is indicated in the assignment card.

   Not very often.

8. Do you think lead is more prevalent in any particular geographic regions of the city ? If so, which sections ?

Yes, new areas in general.

9. How often is the customer service and the city side of the curb stop a different material ?

About 4 out of 7 times

10. Under what circumstances, if any, do city crews perform work on the customer side of the curb stop ?

Never.

11. What percent of the time do you see the customer's side of the service ?

Almost everytime.

12. What is the range of depth of service lines from the surface ?

3' +

13. Explain a 'typical' service replacement job :

a) How deep is the hole (feet) ? 3'.6' - 5'

b) How wide is the hole (feet) ? 2'-3'

c) Do city crews ever dig the hole by hand ? If so: Sometimes
   1. How many men are needed ? 4-men
   2. How long does it take ? up-to-3 days.

d) What other material (sidewalks, macadam) is removed ?
Concrete

e) Who repairs the sidewalks, streets etc. ?
Contractors.

DC LEAD PERSONNEL QUESTIONNAIRE

NAME : E. Miller
POSITION : Crew Chief.
YRS. EXPERIENCE : 8-yrs.
INTERVIEWER : David C. Nwabuisi & Sudipto Sarkar
DATE : 6-15-89

1. How often do your crews work on service lines(i.e., #/week) ?

   Everyday

2. How far in advance do you know where your upcoming jobs will be ?

   Scheduled on daily basis

3. Do you do any preparation for a service job ?

   (a) Utility checks through utility companies
   (b) Check location of water main etc.

4. Do you have access or ever call in to learn about previous history or maintenance at a location ?

   Sometimes; especially where there has been history of multiple connections..

5. How long have you been replacing defective lead services with copper instead of repairing them ?

   Five years (5 yrs)

6. Have you ever put in a lead service line ? If so, when was the last time you did this?

   No

7. Do you have expectations as to the type of material you will find when you dig up a service ? If so, about how often do you find a nonlead service when you expected to find lead ?

   (a) Known only when indicated on the assignment card
   (b) Not very often.

8. Do you think lead is more prevalent in any particular geographic regions of the city ? If so, which sections ?

Yes, S.E

9. How often is the customer service and the city side of the curb stop a different material ?

Fifty percent of the time

10. Under what circumstances, if any, do city crews perform work on the customer side of the curb stop ?

None

11. What percent of the time do you see the customer's side of the service ?

Nearly all the time

12. What is the range of depth of service lines from the surface ?

5' to 6'

13. Explain a 'typical' service replacement job :

a). How deep is the hole (feet) ? 5'

b) How wide is the hole (feet) ? 3'

c) Do city crews ever dig the hole by hand ? If so: Yes
   1. How many men are needed ? 3 men Crew
   2. How long does it take ? 2 - 3 days

d) What other material (sidewalks, macadam) is removed ?
   Brick walls, Concrete & Flowers.

e) Who repairs the sidewalks, streets etc. ?
   Hyw Department.

DC LEAD PERSONNEL QUESTIONNAIRE

NAME : James D. Patterson
POSITION : Crew Chief.
YRS. EXPERIENCE : 12-yrs.
INTERVIEWER : S. Sarkar
DATE : 6-21-89

1. How often do your crews work on service lines(i.e., #/week) ?

   Everyday. Normally a job a day.

2. How far in advance do you know where your upcoming jobs will be ?

   Schedule is got in the morning of the same day.
   The supervisor makes the schedule.

3. Do you do any preparation for a service job ?

   Check on utility lines.

4. Do you have access or ever call in to learn about previous history or maintenance at a location ?

   Yes, most of the time

5. How long have you been replacing defective lead services with copper instead of repairing them ?

   It is mandatory for 3 years to replace. Before that worker may or may not replace.

6. Have you ever put in a lead service line ? If so, when was the last time you did this?

   No.
   Normally Cu lines are put in now.

7. Do you have expectations as to the type of material you will find when you dig up a service ? If so, about how often do you find a nonlead service when you expected to find lead ?

   Sometimes. By looking at the riser.
   Occasionally.

8. Do you think lead is more prevalent in any particular geographic regions of the city ? If so, which sections ?

About equal in all quandrants.

9. How often is the customer service and the city side of the curb stop a different material ?

Sometimes they are different. Normally they are same.

10. Under what circumstances, if any, do city crews perform work on the customer side of the curb stop ?

Very rarely. It is done only when the sewer Authority messes up

11. What percent of the time do you see the customer's side of the service ?

Everytime a service line is replaced.

12. What is the range of depth of service lines from the surface ?

5' - 6'

13. Explain a 'typical' service replacement job :

a) How deep is the hole (feet) ? 5'

b) How wide is the hole (feet) ? 3'-4'

c) Do city crews ever dig the hole by hand ? If so: Yes
   1. How many men are needed ? 3 men + Crew Chief
   2. How long does it take ? 2-days depending on the site

d) What other material (sidewalks, macadam) is removed ?

Brick, Asphalt roadway.

e) Who repairs the sidewalks, streets etc. ?

The Highway Dept/Contractors.

DC LEAD PERSONNEL QUESTIONNAIRE

NAME : H. Bost.
POSITION : Crew Chief.
YRS. EXPERIENCE : 22-years
INTERVIEWER : David Nwabueze & Sudipto Sarkar
DATE : 6-15-89

1. How often do your crews work on service lines(i.e., #/week) ?

   Everyday.

2. How far in advance do you know where your upcoming jobs will be ?

   Scheduled on daily basis

3. Do you do any preparation for a service job ?
   - Call for utility check, • Note utility lines
   - Check for type of service, if available on assignment card

4. Do you have access or ever call in to learn about previous history or maintenance at a location ?

   No

5. How long have you been replacing defective lead services with copper instead of repairing them ?

   2-years; since 1987

6. Have you ever put in a lead service line ? If so, when was the last time you did this?

   No

7. Do you have expectations as to the type of material you will find when you dig up a service ? If so, about how often do you find a nonlead service when you expected to find lead ?
   - Never known until excavation is done unless information had been indicated in assignment card.
   - About 4-5 times a month.

8. Do you think lead is more prevalent in any particular geographic regions of the city ? If so, which sections ?

Yes – N.W. & particularly the old areas of D.C. –

9. How often is the customer service and the city side of the curb stop a different material ?

Not frequently, only when customer has done previous renovation work.

10. Under what circumstances, if any, do city crews perform work on the customer side of the curb stop ?

Only when the backhoe mistakenly pull the service on the customer side.

11. What percent of the time do you see the customer's side of the service ?

Almost every time excavation for repair is performed.

12. What is the range of depth of service lines from the surface ?

4–5' in most cases, but could go up to 6'–7'

13. Explain a 'typical' service replacement job :

a) How deep is the hole (feet) ? 5'

b) How wide is the hole (feet) ? 4'

c) Do city crews ever dig the hole by hand ? If so: Yes
   1. How many men are needed ? 3–4 men crew
   2. How long does it take ? 2½ – 3 days.

d) What other material (sidewalks, macadam) is removed ?
   Dirt.

e) Who repairs the sidewalks, streets etc. ?
   Hwy Department.

DC LEAD PERSONNEL QUESTIONNAIRE

NAME : A. McClain
POSITION : Crew Chief.
YRS. EXPERIENCE : 31-Years
INTERVIEWER : David Nwabuin & S. Sarkar
DATE : 6-15-89

1. How often do your crews work on service lines(i.e., #/week) ?

   3 to 4 times a week.

2. How far in advance do you know where your upcoming jobs will be ?

   Scheduled on daily basis

3. Do you do any preparation for a service job ?

   Check location of service line

4. Do you have access or ever call in to learn about previous history or maintenance at a location ?

   Yes

5. How long have you been replacing defective lead services with copper instead of repairing them ?

   Eleven years

6. Have you ever put in a lead service line ? If so, when was the last time you did this?

   No

7. Do you have expectations as to the type of material you will find when you dig up a service ? If so, about how often do you find a nonlead service when you expected to find lead ?

   No
   No

8. Do you think lead is more prevalent in any particular geographic regions of the city ? If so, which sections ?

N.W. particularly Georgetown areas.

9. How often is the customer service and the city side of the curb stop a different material ?

Fifty percent of the time.

10. Under what circumstances, if any, do city crews perform work on the customer side of the curb stop ?

Only when work in the public space interferes with customer's side.

11. What percent of the time do you see the customer's side of the service ?

Forty to fifty percent of the time.

12. What is the range of depth of service lines from the surface ?

3' - 5'

13. Explain a 'typical' service replacement job :

a) How deep is the hole (feet) ? 4'

b) How wide is the hole (feet) ? 5'

c) Do city crews ever dig the hole by hand ? If so:
   1. How many men are needed ? 3 - 4
   2. How long does it take ? 3 - 4 hrs depending on soil mat.

d) What other material (sidewalks, macadam) is removed ?
   Concrete, Tree space, Brick walk.

e) Who repairs the sidewalks, streets etc. ?
   Contractors.

DC LEAD PERSONNEL QUESTIONNAIRE

NAME : McKenzie
POSITION : Crew Chief.
YRS. EXPERIENCE : 14 - Years
INTERVIEWER : David C. Nwabuisi & Sudipto Sarkar
DATE : 6 - 16 - 89

1. How often do your crews work on service lines(i.e., #/week) ?

   Everyday

2. How far in advance do you know where your upcoming jobs will be ?

   Scheduled on daily basis

3. Do you do any preparation for a service job ?

   Utility Checks

4. Do you have access or ever call in to learn about previous history or maintenance at a location ?

   Through other mantenance records.

5. How long have you been replacing defective lead services with copper instead of repairing them ?

   One year and 6 months. (1½ yrs)

6. Have you ever put in a lead service line ? If so, when was the last time you did this?

   No

7. Do you have expectations as to the type of material you will find when you dig up a service ? If so, about how often do you find a nonlead service when you expected to find lead ?

   Through assignment cards

   Oncece in a while.

8. Do you think lead is more prevalent in any particular geographic regions of the city ? If so, which sections ?

About the same in the whole city

9. How often is the customer service and the city side of the curb stop a different material ?

Very seldom

10. Under what circumstances, if any, do city crews perform work on the customer side of the curb stop ?

In cases where work had been previously done on the customer side by another DCDPW agency.

11. What percent of the time do you see the customer's side of the service ?

Almost everytime.

12. What is the range of depth of service lines from the surface ?

3' - 7'

13. Explain a 'typical' service replacement job :

a) How deep is the hole (feet) ? 4' - 5'

b) How wide is the hole (feet) ? 4'

c) Do city crews ever dig the hole by hand ? If so: Yes
    1. How many men are needed ? 3-men crew
    2. How long does it take ? Depending on materia encountered in soil

d) What other material (sidewalks, macadam) is removed ?
Concrete

e) Who repairs the sidewalks, streets etc. ?
Hwy Department.

DC LEAD PERSONNEL QUESTIONNAIRE

NAME : John Peete
POSITION : Crew Chief.
YRS. EXPERIENCE : 14-YRS
INTERVIEWER : David C. Nwabuisi
DATE : 06-16-1989

1. How often do your crews work on service lines(i.e., #/week) ?

Everyday

2. How far in advance do you know where your upcoming jobs will be ?

Scheduled

3. Do you do any preparation for a service job ?

(a) Consult utility companies for utility check before excavation
(b) Locate water mains etc.

4. Do you have access or ever call in to learn about previous history or maintenance at a location ?

Yes, through the dispatchers

5. How long have you been replacing defective lead services with copper instead of repairing them ?

2-years

6. Have you ever put in a lead service line ? If so, when was the last time you did this?

No

7. Do you have expectations as to the type of material you will find when you dig up a service ? If so, about how often do you find a nonlead service when you expected to find lead ?

Yes
None

8. Do you think lead is more prevalent in any particular geographic regions of the city ? If so, which sections ?

About the same in all sections of the City.

9. How often is the customer service and the city side of the curb stop a different material ?

Not very often; only when there had been some repair work done previously.

10. Under what circumstances, if any, do city crews perform work on the customer side of the curb stop ?

None

11. What percent of the time do you see the customer's side of the service ?

About 9 out of 10 times

12. What is the range of depth of service lines from the surface ?

4' - 5'

13. Explain a 'typical' service replacement job :

a) How deep is the hole (feet) ? 4' - 5'

b) How wide is the hole (feet) ? 4'

c) Do city crews ever dig the hole by hand ? If so: Yes
  1. How many men are needed ? 3-men crew
  2. How long does it take ? 2-days

d) What other material (sidewalks, macadam) is removed ?
Concrete S/W

e) Who repairs the sidewalks, streets etc. ?
Hyw. Department.

DC LEAD PERSONNEL QUESTIONNAIRE

NAME : W. Wilkins
POSITION : Forman - Service repair/Tap removal
YRS. EXPERIENCE : 25-Years
INTERVIEWER : D. Nwabuin/S. Sarkar
DATE : 6-16-89

1. How often do your crews work on service lines(i.e., #/week) ?

   Daily

2. How far in advance do you know where your upcoming jobs will be ?

   Scheduled on daily basis

3. Do you do any preparation for a service job ?

   Utility Check

4. Do you have access or ever call in to learn about previous history or maintenance at a location ?

   No

5. How long have you been replacing defective lead services with copper instead of repairing them ?

   3-years.

6. Have you ever put in a lead service line ? If so, when was the last time you did this?

   No

7. Do you have expectations as to the type of material you will find when you dig up a service ? If so, about how often do you find a nonlead service when you expected to find lead ?

   - No.
   - Once in a while

8. Do you think lead is more prevalent in any particular geographic regions of the city ? If so, which sections ?

Yes ; North West section

9. How often is the customer service and the city side of the curb stop a different material ?

Not often, unless customer has done some rehabilitation which entails change of service line.

10. Under what circumstances, if any, do city crews perform work on the customer side of the curb stop ?

Only when another agency of the Distric Government has done some damage on the Customer side

11. What percent of the time do you see the customer's side of the service ?

Nearly all the time work is performed

12. What is the range of depth of service lines from the surface ?

4' – 10'

13. Explain a 'typical' service replacement job :

a) How deep is the hole (feet) ? 4'

b) How wide is the hole (feet) ? 2'

c) Do city crews ever dig the hole by hand ? If so: Yes
   1. How many men are needed ? 4-men crew
   2. How long does it take ? 2 – 3 days

d) What other material (sidewalks, macadam) is removed ?
   Concrete

e) Who repairs the sidewalks, streets etc. ?
   Hwy – Contractors

APPENDIX B

MASTER PLUMBER INTERVIEWS

D.C. LEAD IN WATER STUDY
INTERVIEW WITH PRACTICING PLUMBERS

- Name of Respondent — Mr. Raleigh Hayward — Plumbing & Heating Inc.
- Position — Vice President
- Date of Interview — 7/18/89
- Type of Services — Plumbing installation & repair
- Age of Business — 17-years
- Interviewer — David C. Nwabuisi

1. What type of pipe materials have you been working on for the last 10 years?

   Cast iron, copper, black pipe, galvanized iron PVC with respect to installation.

   Lead, lead with copper in case of repair works.

2. Can you recollect the last time you installed/repaired a lead service and or used lead solder?

   1980

3. Are your plumbing works, sales, services, etc., evenly distributed/or concentrated to specific Section of D.C. ?

   Concentrated in N.W, N.E, and S.E; More so in N.W areas.

4. Other than your own practice, what can you say about the history of lead services in the District of Columbia?

   When a lead joint is not properly connected it becomes a weak point and subsequently creates problem.

5. Was use of lead services in the past due to the fact that there were more of them, ease of use, least expensive etc?

   They are easy to use; they come in rolled lengths.

6. Were there any problems associated with the use of lead pipes to the best of your knowledge? What type of problem were they?

   None

7. Do you have a knowledge of the following?

a. When was the use of lead pipes discontinued? Not aware of exactly when but none is in use today.

b. When was the use of lead pipes banned formally? 2-years ago or thereabout

c. When was the useof lead solder discontinued? 1985 August.

d. When was the use of lead solder banned? Completely banned at present.

Do not know

D.C. LEAD IN WATER STUDY
INTERVIEW WITH PRACTICING PLUMBERS

- Name of Respondent Mr. J.C. Dorsey — John C. Dorsey Inc.
- Position President
- Date of Interview 7/5/89
- Type of Services Installation, repair & replacement.
- Age of Business 18 - years.
- Interviewer David C. Nwabuisi

1. What type of pipe materials have you been working on for the last 10 years?

   Copper, cast iron, pvc, brass and alloys
   lead (in which case, they are usually replaced with other acceptable materials)

2. Can you recollect the last time you installed/repaired a lead service and or used lead solder?

   For this business, it is as far back as 40 years ago. No installations or other work other than replacement has involved lead since that time. Nobody in the establishment at present knows how to work with lead pipes.

3. Are your plumbing works, sales, services, etc., evenly distributed/or concentrated to specific Section of D.C. ?

   Evenly distributed.

4. Other than your own practice, what can you say about the history of lead services in the District of Columbia?

   Being aware of the fact that lead services were very common in the years preceding 1940s or thereabout.

5. Was use of lead services in the past due to the fact that there were more of them, ease of use, least expensive etc?

   It could be due to any of the listed reasons or a combination of some of them.

6. Were there any problems associated with the use of lead pipes to the best of your knowledge? What type of problem were they?

   Cannot really tell.

7. Do you have a knowledge of the following?

a. When was the use of lead pipes discontinued? Dont know exactly when. It has not been use recently since 40 yrs ago.

b. When was the use of lead pipes banned formally? Couple of year ago formally

c. When was the useof lead solder discontinued? Not completely except for water service lines.

d. When was the use of lead solder banned?

D.C. LEAD IN WATER STUDY
INTERVIEW WITH PRACTICING PLUMBERS

- Name of Respondent   Ms. Cora William — Ideal Electronic Security Co.
- Position   President
- Date of Interview   6/1/89
- Type of Services   Wholesales/Distribution of security, electrical & plumbing supplies
- Age of Business   7-years.
- Interviewer

1. What type of pipe materials have you been working on for the last 10 years?

   Not applicable; business is only in supply and distribution

2. Can you recollect the last time you installed/repaired a lead service and or used lead solder?

   Not applicable because of nature of business.

3. Are your plumbing works, sales, services, etc., evenly distributed/or concentrated to specific Section of D.C. ?

   Other services like distribution of electrical & security supplies are evenly distributed. But plumbing supply has only been supplied to D.C. Dept. of Public Works - Blue Plains.

4. Other than your own practice, what can you say about the history of lead services in the District of Columbia?

   Not really

5. Was use of lead services in the past due to the fact that there were more of them, ease of use, least expensive etc?

   Not applicable due to nature of business

6. Were there any problems associated with the use of lead pipes to the best of your knowledge? What type of problem were they?

   Not applicable.

7. Do you have a knowledge of the following?

a. When was the use of lead pipes discontinued? N/A

b. When was the use of lead pipes banned formally? N/A

c. When was the useof lead solder discontinued? N/A

d. When was the use of lead solder banned? N/A

D.C. LEAD IN WATER STUDY
INTERVIEW WITH PRACTICING PLUMBERS

- Name of Respondent: Mr. H.D. Johnson — Plumbing & Heating H.D. Johnson, Inc.
- Position: President
- Date of Interview: 7/17/89
- Type of Services: Repair & replacement of existing services
- Age of Business: 55 years
- Interviewer: David C. Nwabusi

1. What type of pipe materials have you been working on for the last 10 years?

   Galvanized iron, red iron, lead, and copper.

2. Can you recollect the last time you installed/repaired a lead service and or used lead solder?

   About 1½ years ago

3. Are your plumbing works, sales, services, etc., evenly distributed/or concentrated to specific Section of D.C. ?

   Evenly distributed in the District of Columbia.

4. Other than your own practice, what can you say about the history of lead services in the District of Columbia?

   Between 1910 - 1946 lead pipes were the only material in use for water services. Good attributes of lead services are ① They came in rolled lengths, ② have longer (3) reduce the need for joining or coupling (4) easily installed

5. Was use of lead services in the past due to the fact that there were more of them, ease of use, least expensive etc?

   The use of lead service in the past was due mainly to the reasons listed — more prevalent, easy to work on and inexpensive.

6. Were there any problems associated with the use of lead pipes to the best of your knowledge? What type of problem were they?

   None whatsoever.

7. Do you have a knowledge of the following? Yes

a. When was the use of lead pipes discontinued? In 1940s thereabout

b. When was the use of lead pipes banned formally? Two to three years ago

c. When was the useof lead solder discontinued? Two years ago

d. When was the use of lead solder banned? Not until two years ago

D.C. LEAD IN WATER STUDY
INTERVIEW WITH PRACTICING PLUMBERS

- Name of Respondent — Mr. Edward Neddle — Atlantic Plumbing Supply Co. Inc
- Position — President
- Date of Interview — 7/17/89
- Type of Services — Plumbing supplies
- Age of Business — 32-years
- Interviewer — David C. Nwabuisi

1. What type of pipe materials have you been working on for the last 10 years?

   Copper, cast iron, Brass, and some other alloys

2. Can you recollect the last time you installed/repaired a lead service and or used lead solder?

   Not applicable; do not install, replace or repair water service lines.

3. Are your plumbing works, sales, services, etc., evenly distributed/or concentrated to specific Section of D.C. ?

   Evenly distributed around the District of Columbia; plumbers come from every part to purchase materials.

4. Other than your own practice, what can you say about the history of lead services in the District of Columbia?

   The lead service has long been discontinued.

5. Was use of lead services in the past due to the fact that there were more of them, ease of use, least expensive etc?

   Easier to work on, and also cheaper than brass at the period they were used.

6. Were there any problems associated with the use of lead pipes to the best of your knowledge? What type of problem were they?

   Not applicable, have never worked on lead pipes.

7. Do you have a knowledge of the following?

   a. When was the use of lead pipes discontinued? – About 15 yrs ago

   b. When was the use of lead pipes banned formally? A couple of years ago

   c. When was the useof lead solder discontinued? – Lead solder or alloy of lead solder is still in use for drainage, wastes & vents but not for water lines

   d. When was the use of lead solder banned?
   A couple of years ago for water lines only.

Additional Comments:

Alloys such as 50% lead and 50% Tin
Alloys " " 95% Tin and 5% Animony
} still used for drainage, waste and vents

Alloy – 95% Tin, 4.5% Copper and 0.5% Silver which is considered lead-free is used for water service lines.

APPENDIX C

WATER QUALITY DATA

WASHINGTON AQUEDUCT DIVISION

U.S. ARMY ENGINEER DISTRICT, BALTIMORE

COMPOSITE ANALYSIS OF WATER
BY DALECARLIA LABORATORY

POTOMAC RIVER RAW WATER SUPPLY

1984	pH	MO Alkalinity as $CaCO_3$	Turbidity	Temperature	Total Solids	Hardness as $CaCO_3$	Chlorine Residual DPD Free	Choride	Fluoride	Total Dissolved phosphorous	Dissolved Silica	Sulfates Dissolved	Nitrate Nitrogen	Nitrite Nitrogen	Ammonia Nitrogen	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Zinc
		mg/l	NTU	°F	mg/l	mg/l	mg/.	mg/.	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
January	8.0	71	14	39	217	123	-	16.2	.22	.048	8.9	33.2	3.44	.059	.095	.46	.001	.058	.0001	35	.002	.003	.80	.0023	9	.050	.0000	.002	2.6	.001	.0001	8.4	.17	.004
February	7.7	48	66	46	168	92		13.7	.20	.107	9.1	24.3	2.86	.178	.160	2.66	.002	.059	.0000	25	.004	.025	1.20	.0016	7	.092	.0000	.003	2.9	.002	.0001	7.8	.16	.010
March	7.9	53	38	48	158	96	-	12.8	.18	.068	7.9	25.5	3.06	.130	.052	3.27	.001	.051	.0000	27	.004	.005	.95	.0012	7	.061	.0000	.003	2.1	.001	.0000	5.4	.11	.004
April	7.8	54	43	57	207	88	-	8.1	.14	.033	8.3	22.7	1.87	.097	.041	6.4	.001	.063	.0000	25	.005	.007	3.67	.0027	6	.071	.0000	.003	2.0	.002	.0000	4.1	.11	.016
May	8.1	66	28	71	206	109	-	10.3	.16	[illegible]	9.1	22.4	2.02	.017	.024	2.8	.001	.059	.0003	31	.003	.005	1.04	.0016	7	.110	.0002	.003	1.9	.000	.0001	5.3	.12	.006
June	8.3	93	14	81	242	139	-	24.6	.19	.027	4.1	31.7	1.42	.024	.034	2.04	.001	.071	.0001	41	.002	.004	1.02	.0009	9	.068	.0001	.004	2.2	.001	.0001	8.2	.20	.004
July	8.2	89	15	85	237	149	-	14.6	.17	.060	4.0	27.4	2.36	.032	.025	17.2	.001	.050	.0000	42	.004	.011	7.40	.0035	11	.179	.0000	.003	4.4	.001	.0000	6.4	.14	.010
August	7.8	76	27	83	209	120	-	12.3	.17	.049	3.9	27.2	1.11	.027	.046	3.46	.001	.042	.0000	36	.005	.014	1.57	.0020	7	.111	.0001	.002	2.7	.000	.0000	10.7	.18	.008
September	8.1	99	13	76	234	161	-	16.5	.20	.034	3.2	39.1	1.46	.017	.033	2.36	.000	.057	.0000	46	.003	.008	1.55	.0016	11	.079	.0000	.002	2.8	.000	.0001	11.6	.25	.005
October	8.2	109	11	67	284	177	-	19.6	.19	.034	1.7	51.1	2.09	.012	.032	2.91	.001	.055	.0001	53	.002	.008	1.26	.0037	11	.067	.0000	.003	2.9	.000	.0001	13.7	.24	.004
November	8.2	96	10	55	215	158	-	21.2	.19	.102	2.4	48.0	2.41	.018	.066	1.54	.001	.049	.0000	49	.003	.008	.81	.0015	9	.058	.0000	.004	3.5	.000	.0001	13.4	.23	.005
December	8.0	65	15	50	197	118	-	13.5	.11	.085	4.1	26.0	2.37	.021	.065	.51	.001	.033	.0001	32	.006	.008	2.20	.0021	8	.092	.0000	.004	2.7	.001	.0000	7.0	.13	.004
Average	8.0	77	24	63	214	127	-	15.3	.18	.059	5.5	31.5	2.18	.053	.058	3.80	.001	.054	.0001	37	.004	.009	1.89	.0020	8	.087	.0000	.003	2.7	.001	.0001	8.5	.17	.007
Maximum	8.3	109	66	85	284	177	-	24.6	.22	.102	9.1	51.1	3.44	.178	.180	17.2	.002	.071	.0003	53	.006	.025	7.40	.0037	11	.050	.0002	.004	4.4	.002	.0001	13.7	.25	.016
Minimum	7.7	48	10	39	158	88	-	8.1	.11	.027	1.7	22.4	1.11	.012	.024	.46	.000	.033	.0000	25	.002	.003	.81	.0009	6	.179	.0000	.002	1.9	.000	.0000	4.1	.11	.004

DALECARLIA WATER TREATMENT PLANT FINISHED WATER

1984	pH	M.O. Alkalinity as $CaCO_3$	Turbidity	Temperature	Total Solids	Hardness as $CaCO_3$	Chlorine Residual DPD Free	Choride	Fluoride	Total Disolved phosphorous	Disolved Silica	Sulfates Disolved	Nitrate Nitrogen	Nitrite Nitrogen	Ammonia Nitrogen	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Zinc
		mg/l	NTU	°F	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
January	7.6	65	1.18	38	226	130	2.1	21.9	1.04	.022	9.0	37.2	3.87	.004	.016	.76	.001	.058	.0000	38	.001	.013	.187	.0002	9	.014	.0002	.002	2.5	.001	.0001	8.4	.15	.002
February	7.6	46	.43	45	191	108	2.3	19.4	1.14	.009	8.2	32.0	4.08	.002	.027	.14	.001	.054	.0001	32	.001	.006	.032	.0003	7	.004	.0002	.003	2.9	.002	.0001	8.0	.16	.003
March	7.7	50	.22	47	162	106	2.3	18.6	1.00	.016	6.8	29.7	3.63	.007	.012	.05	.001	.037	.0000	31	.000	.005	.008	.0003	7	.002	.0001	.001	2.1	.001	.0000	7.8	.12	.001
April	7.7	52	.24	56	158	106	2.2	12.1	.95	.001	7.3	35.6	2.82	.011	.011	.05	.001	.054	.0000	31	.000	.005	.015	.0002	7	.002	.0000	.001	1.9	.001	.0000	4.2	.10	.002
May	7.8	62	.17	67	182	120	2.2	14.7	1.00	.010	7.6	29.7	2.03	.001	.016	.05	.001	.067	.0002	36	.001	.012	.026	.0002	7	.011	.0000	.002	1.9	.001	.0000	5.3	.14	.001
June	7.7	88	.48	78	243	146	2.5	31.6	1.01	.007	3.1	38.7	1.60	.003	.011	.40	.001	.069	.0001	43	.001	.013	.015	.0005	9	.005	.0002	.001	2.2	.001	.0000	8.1	.19	.001
July	7.8	91	.34	81	254	158	2.0	17.8	.87	.004	3.4	34.3	2.24	.005	.009	.07	.001	.047	.0000	47	.001	.010	.014	.0000	10	.004	.0000	.002	3.8	.001	.0001	9.0	.18	.001
August	7.7	75	.28	81	221	135	2.3	18.0	1.03	.022	3.2	35.0	1.21	.006	.007	.15	.000	.047	.0000	41	.001	.005	.009	.0004	8	.003	.0001	.001	2.7	.000	.0001	10.3	.19	.001
September	7.7	96	.22	74	219	162	2.3	22.4	1.09	.007	4.3	44.4	1.80	.002	.009	.09	.000	.050	.0000	51	.001	.005	.009	.0003	10	.004	.0000	.001	2.7	.000	.0001	11.7	.25	.001
October	7.7	99	.19	67	262	181	2.2	25.8	.98	.016	1.8	55.5	2.35	.001	.013	.15	.000	.043	.0001	54	.001	.004	.011	.0001	11	.004	.0000	.002	2.9	.000	.0001	16.1	.21	.001
November	7.7	94	.30	55	267	169	2.5	28.4	.94	.031	2.3	54.6	2.69	.001	.028	.15	.001	.050	.0000	52	.001	.005	.024	.0003	9	.004	.0001	.004	3.1	.001	.0001	13.4	.24	.001
December	7.6	62	.44	50	199	123	2.2	19.4	.96	.017	3.8	31.1	2.69	.001	.011	.08	.001	.029	.0000	37	.001	.003	.025	.0018	7	.003	.0000	.002	2.6	.001	.0002	6.1	.14	.002
Average	7.7	73	.37	62	215	136	2.3	20.8	1.00	.014	5.1	38.1	2.58	.004	.014	.18	.001	.051	.0000	41	.001	.007	.031	.0004	8	.005	.0001	.002	2.6	.001	.0001	9.9	.16	.001
Maximum	7.8	99	1.18	81	267	181	2.5	31.6	1.14	.031	9.0	55.5	4.08	.011	.028	.76	.001	.069	.0002	54	.001	.013	.187	.0018	11	.014	.0002	.004	3.8	.002	.0002	16.1	.25	.003
Minimum	7.6	46	.17	38	158	106	2.0	12.1	.87	.001	1.8	29.7	1.21	.001	.007	.05	.000	.029	.0000	31	.000	.003	.008	.0000	7	.002	.0000	.001	1.9	.000	.0000	4.2	.10	.001

McMILLAN WATER TREATMENT PLANT FINISHED WATER

1984	pH	M.O. Alkalinity as $CaCO_3$	Turbidity	Temperature	Total Solids	Hardness as $CaCO_3$	Chlorine Residual DPD Free	Chloride	Fluoride	Total Disolved phosphorous	Disolved Silica	Sulfates Disolved	Nitrate Nitrogen	Nitrite Nitrogen	Ammonia Nitrogen	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Zinc
		mg/l	NTU	°F	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
January	7.6	59	.42	37	221	125	2.5	21.0	1.05	.019	8.9	38.1	2.44	.006	.008	.11	.001	.059	.0000	37	.001	.069	[illegible]	.0003	9	.011	.0003	.003	2.8	.002	.0001	8.8	.15	[illegible]
February	7.6	48	.30	42	208	114	2.0	18.9	1.05	.010	8.0	35.0	3.95	.002	.023	.05	.001	.059	.0000	33	.001	.042	.034	.0006	8	.004	.0001	.003	2.9	.002	.0001	9.1	.19	.003
March	7.7	41	.29	46	157	104	2.0	18.8	1.22	.019	7.4	33.6	3.36	.004	.008	.10	.001	.040	.0001	31	.000	.031	.007	.0003	7	.003	.0000	.001	2.2	.001	.0000	5.4	.13	.002
April	7.8	39	.17	53	156	98	2.0	14.0	1.05	.001	7.2	37.4	2.01	.004	.011	.03	.001	.060	.0000	29	.001	.019	.004	.0002	6	.019	.0000	.001	1.7	.001	.0000	5.7	.12	.003
May	7.8	50	.19	65	191	114	2.0	15.5	1.10	.020	6.5	35.6	1.74	.001	.02	.03	.001	.054	.0001	33	.000	.020	.008	.0006	8	.001	.0000	.002	1.7	.000	.000	4.8	.14	.001
June	7.7	78	.13	77	220	141	2.1	33.0	1.12	.007	3.0	40.3	1.44	.003	.008	.05	.001	.073	.0001	42	.000	.026	.009	.0004	9	.006	.0003	.001	2.4	.001	.0000	7.2	.22	.001
July	7.8	82	.28	79	236	161	2.2	18.4	1.09	.001	4.4	44.0	1.77	.005	.008	.05	.001	.049	.0002	49	.001	.032	.005	.0010	10	.002	.0000	.100	2.9	.001	.0001	11.1	.26	.428
August	7.9	69	.33	81	221	135	2.3	21.1	1.00	.019	2.4	41.9	1.39	.007	.007	.05	.000	.044	.0000	41	.001	.022	.004	.0000	8	.002	.0000	.001	2.6	.000	.0001	11.3	.21	.001
September	7.8	82	.33	76	185	157	2.2	21.5	1.29	.009	4.1	41.7	1.37	.001	.006	.14	.001	.055	.0000	47	.001	.077	.078	.0009	10	.002	.0000	.002	2.6	.000	.0000	9.6	.19	.018
October	7.7	97	.15	67	268	184	2.1	27.7	1.12	.009	1.7	57.3	1.93	.001	.007	.05	.000	.058	.0001	54	.001	.043	.014	.0001	12	.001	.0000	.004	2.9	.000	.0001	14.3	.25	.002
November	7.7	89	.20	57	269	172	2.2	29.8	1.12	.016	2.2	57.4	2.48	.001	.028	.05	.007	.047	.0000	52	.001	.045	.014	.0006	10	.001	.0001	.004	3.5	.000	.0001	15.9	.25	.001
December	7.6	63	.21	47	184	138	2.3	22.4	.96	.019	2.9	40.6	2.34	.001	.026	.05	.001	.040	.0000	40	.001	.051	.020	.0005	9	.002	.0000	.004	3.0	.002	.0002	9.2	.19	.005
Average	7.7	66	.25	60	210	137	2.2	21.8	1.10	.012	4.9	41.9	2.18	.003	.013	.06	.001	.052	.0001	41	.001	.040	.017	.0005	9	.005	.0001	.011	2.6	.001	.0000	9.4	.19	.039
Maximum	7.9	97	.42	81	269	184	2.5	33.0	1.29	.020	8.9	57.3	3.95	.007	.028	.14	.007	.073	.0002	[illegible]	.001	.077	.078	.0010	12	.019	.0003	.100	3.5	.002	.0002	15.9	.26	.428
Minimum	7.6	39	.13	37	156	98	2.0	14.0	.96	.001	1.7	33.6	1.37	.001	.006	.03	.000	.040	.0000	2.	.000	.019	.003	.0000	6	.001	.0000	.001	1.7	.000	.0000	4.8	.12	.001

NAB Form 648 rev. April "80"

W. A. Dwg. No.100.1-4.14-5

WASHINGTON AQUEDUCT DIVISION

U.S. ARMY ENGINEER DISTRICT, BALTIMORE

COMPOSITE ANALYSIS OF WATER BY DALECARLIA LABORATORY

POTOMAC RIVER RAW WATER SUPPLY

1984	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP(Silvex) ug/l	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Disolved Oxygen mg/l	Conductivity mohoms/cm	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226-228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l	Total Coliform MPN	Fecal Coliform MPN	Fecal Strep MPN	Fecal Strep MF Org./ml	Salmonella MPN/IOL	Stapylococcus aureus Org/ml	Pseudomonas Aeruginosa MPN	Algae Count Org/ml	Bacterial Endotoxin ng/ml
January	-	-	-	-	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.26	8	13	347						37950	290	15		0	0	7		
February	-	-	-	-	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.11	18	13	270						89070	3820	150		0	0	7		
March	-	-	-	-	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.14	15	13	283						17780	340	80		4	0	≥2400		
April	-	-	-	-	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.05	6	13	226						32630	2290	3920		23	0	0		
May	-	-	-	-	NR	NR	NR	NR	NR	NR	.14	17	10	230						39110	4070	110		4	0	0		
June	-	-	-	-	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.13	14	8	324						11570	1570	90		9	0	5	7360	
July	-	-	-	-	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.09	14	8	357						1630	260	160		4	0	20		
August	-	-	-	-	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.14	23	7	316						2380	790	420		9	0	-		
September	-	-	-	-	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.03	15	8	421						470	90	60		0	0	21		
October	-	-	-	-	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.04	17	8	474						2060	450	160		0	0	0		
November	-	-	-	-	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.04	8	8	375						1470	350	70		0	0	21		
December	-	-	-	-	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.02	9	8	300						12440	2070	290		0	1	21		
Average	-	-	-	-	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.10	14	10	327						20713	1366	294		4	.08	208	7360	
Maximum	-	-	-	-	-	-	-	-	-	-	.26	23	13	474						89070	3820	3920		23	1	≥2400	7360	
Minimum	-	-	-	-	-	-	-	-	-	-	.02	6	7	226						470	90	60		0	0	0	7360	

DALECARLIA WATER TREATMENT PLANT FINISHED WATER

1984	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP(Silvex) ug/l	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Disolved Oxygen mg/l	Conductivity mohoms/cm	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226-228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l	Total Coliform MPN	Fecal Coliform MPN	Fecal Strep MPN	Fecal Strep MF Org./ml	Salmonella MPN/IOL	Stapylococcus aureus Org/ml	Pseudomonas Aeruginosa MPN	Algae Count Org/ml	Bacterial Endotoxin ng/ml
January	15	5.5	1.5	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.10	8	13	388	<2.2	<3.7		<3.1	<343	0					0.2	0		
February	32	6.2	0.9	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.08	7	12	320						0					0	0		
March	22	5.9	1.1	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.03	5	13	318						0					0	0		
April	30	5.1	.7	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.04	8	13	271	<3.0	<3.4		<2.9	<580	0					0	0		
May	45	8.2	1.5	0	NR	NR	NR	NR	NR	NR	.10	3	10	306						0					0	0		
June	78	13.9	2	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.06	3	9	384						0.04					0	0		
July	80	13.7	1.4	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.07	7	9	396	<2.3	<6.7		<5.6	<353	0					0	0		
August	77	12.7	1.3	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.07	11	9	355						0.04					0	-		
September	66	14.0	2.0	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.03	5	9	419						0.03					0	0		
October	65	11.7	1.1	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.02	4	10	506	<1.0	<3.6		<1.2	<520	0.09					0	23		
November	52	9.9	1.9	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.01	4	8	395						0					0	0		
December	39	5.9	.8	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.01	3	8	338						0.17					0	0		
Average	50	9.4	1.3	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.05	6	10	366	<2.1	<4.4		<3.2	<449	0.03					0.016	2		
Maximum	80	14.0	2.0	0	-	-	-	-	-	-	.10	11	13	506	<3.0	<6.7		<5.6	<580	0.09					0.2	23		
Minimum	15	5.1	.7	0	-	-	-	-	-	-	.01	3	8	271	<1.0	<3.4		<1.2	<343	0					0	0		

McMILLAN WATER TREATMENT PLANT FINISHED WATER

1984	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP(Silvex) ug/l	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Disolved Oxygen mg/l	Conductivity mohoms/cm	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226-228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l	Total Coliform MPN	Fecal Coliform MPN	Fecal Strep MPN	Fecal Strep MF Org./ml	Salmonella MPN/IOL	Stapylococcus aureus Org/ml	Pseudomonas Aeruginosa MPN	Algae Count Org/ml	Bacterial Endotoxin ng/ml
January	41	7.6	0.9	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.14	6	-	366	<2.1	<2.9		<2.5	<714	0					0	0		
February	48	8.7	1.9	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.06	8	-	330						0					0	0		
March	34	6.2	1.2	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.03	4	-	305						0.018					0	0		
April	37	5.6	1.3	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.04	2	-	258	<1.3	<2.9		<2.4	<610	0					0	0		
May	32	7.5	2	0	NS	NR	NR	NR	NR	NR	.12	5	-	297						0					0	0		
June	49	9.9	2.1	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.06	5	-	331						0					0	0		
July	59	12.9	1.7	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.06	4	-	402	<2.9	<5.2		<4.4	<292	0.04					0	0		
August	69	12.9	1.9	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.05	6	-	369						0.04					0	0		
September	64	14.7	3.0	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.03	3	-	402						0.22					0	0		
October	61	13.2	2.6	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.02	4	-	498	<1.0	<3.5		<0.5	<520	0					0	0		
November	59	10.2	2.0	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.01	3	-	420						0.04					0	0		
December	55	8.9	1.8	0	<.1	<.2	<1.0	<2.0	NS	NS	.01	0	-	373						0					0	0		
Average	51	9.9	1.9	0	<.1	<.2	<1.0	<2.0	<1.0	<1.0	.05	4		362	<1.8	<3.6		<2.4	<534	0.03					0	0		
Maximum	69	14.7	3.0	0	-	-	-	-	-	-	.14	8		498	<2.9	<5.2		<4.4	<714	0.22					0	0		
Minimum	32	5.6	.9	0	-	-	-	-	-	-	.01	0		258	<1.0	<2.9		<0.5	<292	0					0	0		

NAB Form 648 rev. JAN "81"

W. A. Dwg. No. 100.1-4.14-4

WASHINGTON AQUEDUCT DIVISION

U.S. ARMY ENGINEER DISTRICT, BALTIMORE

COMPOSITE ANALYSIS OF WATER BY DALECARLIA LABORATORY

POTOMAC RIVER RAW WATER SUPPLY

1985	pH	M.O. Alkalinity as $CaCO_3$ (mg/l)	Turbidity (NTU)	Temperature (°F)	Total Solids (mg/l)	Hardness as $CaCO_3$ (mg/l)	Chlorine Residual DPD Free (mg/l)	Chloride (mg/l)	Fluoride (mg/l)	Total Dissolved phosphorous (mg/l)	Silica (mg/l)	Sulfates Dissolved (mg/l)	Nitrate Nitrogen (mg/l)	Nitrite Nitrogen (mg/l)	Ammonia Nitrogen (mg/l)
January	8.2	75	7.4	43	374	119	—	14.0	0.16	0.054	3.2	31.8	3.06	0.027	0.014
February	7.8	[illegible]	30.1	43	406	107	—	16.3	0.18	0.040	6.8	32.2	1.80	0.026	0.056
March	7.9	57	12.6	54	356	100	—	10.7	0.14	0.039	6.6	43.5	3.44	0.023	0.049
April	8.0	[illegible]	12.0	66	320	99	—	11.2	0.13	0.044	3.0	28.3	1.76	0.032	0.037
May	7.6	69	10.0	73	400	107	—	11.4	0.13	0.040	1.8	45.6	1.82	0.037	0.020
June	7.7	67	23.9	77	438	112	—	11.4	0.14	0.040	3.2	32.0	1.36	0.048	0.064
July	7.6	66	22.4	84	430	116	—	15.5	0.20	0.041	1.6	46.5	0.80	0.034	0.052
August	7.6	75	11.0	84	543	131	—	23.3	0.16	0.063	2.0	67.1	1.38	0.053	0.037
September	7.9	86	7.8	79	566	150	—	23.0	0.17	0.078	2.8	52.0	2.18	0.036	0.020
October	7.9	91	7.3	68	612	161	—	30.6	0.18	0.061	1.6	56.4	1.04	0.052	0.034
November	7.8	56	125	56	336	111	—	8.2	0.14	0.045	4.2	33.6	1.67	0.086	0.207
December	7.7	56	14.8	45	282	120	—	10.2	0.16	0.000	4.2	38.0	1.80	0.040	0.044
Average	7.8	69	23.7	64	424	120	—	15.6	0.15	0.047	3.6	42.5	1.83	0.046	0.054
Maximum	8.2	91	125	84	612	161	—	30.6	0.20	0.063	6.8	67.1	3.44	0.086	0.207
Minimum	7.6	56	7.3	43	282	99	—	8.2	0.13	0.000	1.6	28.3	0.80	0.023	0.014

1985	Aluminum (mg/l)	Arsenic (mg/l)	Barium (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Chromium (mg/l)	Copper (mg/l)	Iron (mg/l)	Lead (mg/l)	Magnesium (mg/l)	Manganese (mg/l)	Mercury (mg/l)	Nickel (mg/l)	Potassium (mg/l)	Selenium (mg/l)	Silver (mg/l)	Sodium (mg/l)	Strontium (mg/l)	Zinc (mg/l)
January	1.23	0.001	0.042	0.0001	35	0.003	0.006	0.970	0.0012	8	0.067	0.0000	0.003	2.00	0.001	[illegible]	6.90	0.190	0.000
February	12.17	0.005	0.088	0.0001	30	0.012	0.014	4.80	0.0050	8	0.141	0.0000	0.011	3.30	0.001	0.0000	12.88	0.400	0.012
March	1.34	0.001	0.081	0.0000	29	0.003	0.006	0.840	0.0012	6	0.113	0.0001	0.003	1.73	0.001	0.0000	6.40	0.140	0.009
April	5.88	0.001	0.080	0.0001	30	0.003	0.005	3.74	0.0019	6	0.081	0.0000	0.003	1.60	0.002	0.0001	9.80	0.111	0.011
May	1.67	0.001	0.060	0.0000	32	0.002	0.008	1.05	0.0014	7	0.115	0.0003	0.002	2.21	0.000	0.0000	9.96	0.196	0.004
June	14.47	0.002	0.054	0.0000	33	0.016	0.014	0.640	0.0036	9	0.112	0.0003	0.007	2.28	0.002	0.0000	7.86	0.148	0.079
July	0.754	0.000	0.0?4	0.0000	33	0.001	0.003	0.800	0.0018	8	0.127	0.0001	0.003	2.80	0.001	0.0000	11.20	0.311	0.069
August	0.303	0.001	0.055	0.0000	36	0.002	0.003	0.467	0.0007	9	0.097	0.0010	0.002	3.20	0.000	0.0000	15.20	0.390	0.069
September	0.290	0.002	0.063	0.0000	43	0.001	0.003	0.248	0.0007	10	0.041	0.0000	0.001	3.06	0.000	0.0000	19.90	0.292	0.002
October	0.440	0.001	0.065	0.0000	48	0.001	0.003	0.473	0.0007	12	0.043	0.0002	0.002	3.75	0.000	0.0000	14.20	0.256	0.004
November	1.59	0.001	0.066	0.0001	32	0.007	0.003	1.59	0.0034	22	0.107	0.0000	0.003	3.06	0.000	0.0000	7.15	0.160	0.012
December	0.390	0.001	0.070	0.0000	34	0.001	0.004	0.540	0.0014	9	0.065	0.0000	0.003	2.37	0.001	0.0000	4.86	0.130	0.012
Average	3.36	0.001	0.061	0.0000	34	0.004	0.006	1.35	0.0019	9	0.092	0.0000	0.004	2.61	0.001	0.0000	10.14	0.197	0.009
Maximum	14.47	0.005	0.088	0.0001	48	0.016	0.014	4.80	0.0050	22	0.141	0.0010	0.011	3.75	0.002	0.0000	19.80	0.392	0.082
Minimum	0.280	0.000	0.042	0.0000	29	0.001	0.003	0.248	0.0007	6	0.041	0.0000	0.001	1.73	0.000	0.0000	4.86	0.111	0.002

DALECARLIA WATER TREATMENT PLANT FINISHED WATER

1985	pH	M.O. Alkalinity as $CaCO_3$ (mg/l)	Turbidity (NTU)	Temperature (°F)	Total Solids (mg/l)	Hardness as $CaCO_3$ (mg/l)	Chlorine Residual DPD Free (mg/l)	Chloride (mg/l)	Fluoride (mg/l)	Total Dissolved phosphorous (mg/l)	Silica (mg/l)	Sulfates Dissolved (mg/l)	Nitrate Nitrogen (mg/l)	Nitrite Nitrogen (mg/l)	Ammonia Nitrogen (mg/l)
January	7.6	69	0.41	42	366	127	2.16	17.0	1.01	0.018	3.3	38.6	2.59	0.001	0.000
February	7.8	63	0.45	42	437	126	2.05	24.3	1.00	0.016	6.0	39.8	2.11	0.004	0.018
March	8.1	56	0.28	53	325	113	2.04	13.9	0.96	0.005	6.3	48.5	3.12	0.001	0.000
April	8.1	58	0.41	64	353	109	2.06	20.5	1.03	0.001	2.8	34.5	2.25	0.006	0.015
May	7.8	66	[illegible]	73	379	121	2.10	17.6	1.03	0.007	1.9	56.3	1.78	0.001	0.014
June	7.8	66	0.38	77	371	125	2.11	15.6	1.03	0.004	3.2	41.6	1.31	0.004	0.007
July	7.7	69	0.36	83	475	129	2.18	21.6	0.88	0.000	2.2	53.4	0.62	0.002	0.001
August	7.7	73	0.20	83	565	144	2.52	28.4	0.86	0.006	1.8	66.8	1.38	0.007	0.001
September	7.9	81	0.21	79	462	137	2.45	27.3	0.93	0.003	2.6	58.5	2.16	0.009	0.001
October	7.7	87	0.23	69	586	172	2.54	33.9	0.90	0.005	1.6	62.6	1.33	0.026	0.004
November	7.7	55	0.50	61	390	129	2.72	17.1	0.94	0.000	4.8	46.7	1.78	0.022	0.002
December	7.7	60	0.36	48	325	125	2.63	12.3	1.05	0.000	4.4	45.0	1.80	0.000	0.008
Average	7.8	67	0.34	64	421	131	2.30	20.8	0.97	0.006	3.4	49.5	1.85	0.007	0.006
Maximum	8.1	87	0.50	83	586	172	2.72	33.9	1.05	0.018	6.3	66.8	3.12	0.026	0.018
Minimum	7.6	55	0.20	42	325	108	2.04	12.3	0.88	0.000	1.6	34.5	0.62	0.000	0.000

1985	Aluminum (mg/l)	Arsenic (mg/l)	Barium (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Chromium (mg/l)	Copper (mg/l)	Iron (mg/l)	Lead (mg/l)	Magnesium (mg/l)	Manganese (mg/l)	Mercury (mg/l)	Nickel (mg/l)	Potassium (mg/l)	Selenium (mg/l)	Silver (mg/l)	Sodium (mg/l)	Strontium (mg/l)	Zinc (mg/l)
January	0.072	0.001	0.034	0.0000	38	0.001	0.004	0.009	0.0013	8	0.002	0.0001	0.002	1.90	0.001	0.0001	8.80	0.160	0.001
February	0.146	0.001	0.040	0.0000	37	0.001	0.003	0.023	0.0002	8	0.004	0.0001	0.003	3.00	0.001	0.0000	13.60	0.184	0.002
March	0.083	0.001	0.048	0.0000	35	0.001	0.005	0.023	0.0002	6	0.007	0.0000	0.003	1.67	0.001	0.0000	8.10	0.151	0.004
April	0.090	0.001	0.046	0.0001	34	0.001	0.004	0.058	0.0005	6	0.006	0.0000	0.002	1.90	0.001	0.0001	5.80	0.119	0.002
May	0.347	0.001	0.052	0.0000	36	0.001	0.004	0.062	0.0006	7	0.011	0.0000	0.002	2.17	0.001	0.0000	10.70	0.212	0.001
June	0.091	0.001	0.087	0.0000	38	0.001	0.007	0.040	0.0003	7	0.003	0.0003	0.002	2.32	0.000	0.0000	6.00	0.156	0.001
July	0.196	0.001	0.047	0.0000	39	0.001	0.006	0.013	0.0001	7	0.009	0.0002	0.002	2.45	0.001	0.0001	11.15	0.223	0.001
August	0.130	0.001	0.055	0.0000	41	0.000	0.009	0.012	0.0001	10	0.006	0.0004	0.002	3.10	0.000	0.0000	14.75	0.250	0.001
September	0.183	0.001	0.066	0.0000	47	0.001	0.006	0.099	0.0002	10	0.002	0.0004	0.001	3.26	0.000	0.0000	18.75	0.298	0.003
October	0.171	0.001	0.062	0.0000	51	0.001	0.015	0.022	0.0004	11	0.004	0.0006	0.002	3.70	0.000	0.0000	14.46	0.253	0.002
November	0.199	0.001	0.090	0.0000	39	0.001	0.004	0.038	0.0000	8	0.007	0.0007	0.002	2.86	0.000	0.0000	8.17	0.178	0.001
December	0.064	0.001	0.065	0.0000	37	0.000	0.005	0.014	0.0005	7	0.002	0.0000	0.002	2.36	0.001	0.0000	4.56	0.133	0.001
Average	0.161	0.001	0.061	0.0000	40	0.001	0.007	0.038	0.0004	8	0.006	0.0002	0.002	2.61	0.001	0.0000	11.07	0.211	0.002
Maximum	0.347	0.001	0.090	0.0001	51	0.001	0.015	0.099	0.0013	11	0.011	0.0007	0.003	3.70	0.001	0.0001	18.75	0.298	0.004
Minimum	0.064	0.001	0.034	0.0000	34	0.000	0.003	0.009	0.0000	6	0.002	0.0000	0.001	1.66	0.000	0.0000	4.56	0.119	0.001

McMILLAN WATER TREATMENT PLANT FINISHED WATER

1985	pH	M.O. Alkalinity as $CaCO_3$ (mg/l)	Turbidity (NTU)	Temperature (°F)	Total Solids (mg/l)	Hardness as $CaCO_3$ (mg/l)	Chlorine Residual DPD Free (mg/l)	Chloride (mg/l)	Fluoride (mg/l)	Total Dissolved phosphorous (mg/l)	Silica (mg/l)	Sulfates Dissolved (mg/l)	Nitrate Nitrogen (mg/l)	Nitrite Nitrogen (mg/l)	Ammonia Nitrogen (mg/l)
January	7.6	57	0.21	42	305	123	2.25	18.7	1.10	0.018	3.4	41.4	2.74	0.001	0.007
February	7.7	66	0.32	40	452	137	2.23	23.8	1.03	0.015	4.5	51.4	2.36	0.004	0.018
March	8.0	45	0.29	50	351	110	2.19	19.8	1.20	0.006	7.1	55.8	2.56	0.004	0.003
April	7.7	48	0.24	60	361	105	2.21	20.4	1.16	0.001	2.7	43.0	2.22	0.007	0.011
May	7.6	60	0.33	71	386	115	2.27	19.6	1.05	0.000	1.6	54.4	1.50	0.003	0.014
June	7.8	53	0.40	76	448	116	2.27	19.4	1.03	0.003	2.9	53.7	1.52	0.004	0.007
July	7.7	62	0.47	81	454	128	2.32	20.5	0.95	0.003	2.5	53.9	0.49	0.002	0.003
August	7.8	56	0.44	83	487	131	2.37	24.9	0.98	0.006	13.5	68.2	1.12	0.006	0.001
September	7.6	71	0.30	79	510	151	2.37	28.2	1.07	0.001	2.8	56.9	2.06	0.012	0.001
October	7.6	85	0.31	68	508	173	2.39	31.8	1.03	0.003	1.8	68.3	1.01	0.020	0.004
November	7.6	56	0.34	62	447	143	2.48	16.8	0.93	0.000	4.1	66.4	1.56	0.018	0.002
December	7.8	43	0.27	48	307	122	2.29	15.0	1.10	0.000	4.5	50.0	1.74	0.000	0.008
Average	7.7	59	0.33	63	418	130	2.30	21.6	1.06	0.005	4.3	55.4	1.74	0.007	0.007
Maximum	8.0	85	0.47	83	510	173	2.48	31.8	1.20	0.018	13.5	68.3	2.74	0.018	0.018
Minimum	7.6	43	0.21	40	305	105	2.19	15.0	0.93	0.000	1.6	41.4	0.49	0.000	0.001

1985	Aluminum (mg/l)	Arsenic (mg/l)	Barium (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Chromium (mg/l)	Copper (mg/l)	Iron (mg/l)	Lead (mg/l)	Magnesium (mg/l)	Manganese (mg/l)	Mercury (mg/l)	Nickel (mg/l)	Potassium (mg/l)	Selenium (mg/l)	Silver (mg/l)	Sodium (mg/l)	Strontium (mg/l)	Zinc (mg/l)
January	0.045	0.001	0.040	0.0000	36	0.001	0.060	0.007	0.0008	8	0.001	0.0001	0.002	2.40	0.002	0.0002	7.80	0.180	0.002
February	0.095	0.001	0.050	0.0001	43	0.001	0.088	0.010	0.0001	7	0.002	0.0001	0.003	2.60	0.002	0.0000	15.40	0.209	0.004
March	0.064	0.001	0.043	0.0000	34	0.001	0.037	0.007	0.0001	6	0.001	0.0000	0.003	2.06	0.002	0.0000	6.85	0.120	0.008
April	0.033	0.001	0.042	0.0000	31	0.001	0.038	0.006	0.0009	6	0.002	0.0000	0.002	1.90	0.001	0.0001	6.90	0.138	0.008
May	0.173	0.000	0.047	0.0000	35	0.001	0.096	0.247	0.0124	7	0.009	0.0001	0.001	2.02	0.000	0.0000	9.20	0.195	0.014
June	0.101	0.002	0.041	0.0004	35	0.001	0.029	0.170	0.0134	7	0.012	0.0003	0.002	2.48	0.002	0.0000	8.90	0.197	0.008
July	0.047	0.000	0.048	0.0000	38	0.001	0.038	0.003	0.0003	8	0.001	0.0000	0.002	2.67	0.001	0.0001	12.10	0.208	0.004
August	0.028	0.001	0.045	0.0000	38	0.000	0.041	0.007	0.0001	9	0.003	0.0001	0.002	3.10	0.001	0.0000	14.15	0.198	0.003
September	0.058	0.001	0.055	0.0000	44	0.001	0.035	0.005	0.0001	10	0.001	0.0001	0.001	3.15	0.000	0.0001	16.20	0.236	0.003
October	0.127	0.000	0.066	0.0000	49	0.001	0.031	0.013	0.0002	12	0.001	0.0000	0.001	3.30	0.000	0.0000	21.15	0.280	0.002
November	0.055	0.001	0.061	0.0000	42	0.001	0.035	0.002	0.0001	10	0.001	0.0026	0.002	2.96	0.001	0.0000	9.83	0.283	0.002
December	0.071	0.001	0.062	0.0000	35	0.000	0.034	0.012	0.0002	9	0.003	0.0003	0.002	2.43	0.001	0.0000	2.56	0.138	0.003
Average	0.082	0.001	0.055	0.0000	38	0.001	0.051	0.044	0.0026	8	0.003	0.0003	0.002	2.62	0.001	0.0000	12.20	0.217	0.009
Maximum	0.173	0.002	0.066	0.0004	49	0.001	0.096	0.247	0.0134	12	0.012	0.0026	0.003	3.30	0.002	0.0002	21.15	0.283	0.014
Minimum	0.028	0.000	0.040	0.0000	31	0.000	0.029	0.002	0.0001	6	0.001	0.0000	0.001	1.90	0.000	0.0000	5.60	0.120	0.002

NAB Form 648 rev. JUNE "86"

W. A. Dwg. No.100.1-4.14-5

WASHINGTON AQUEDUCT DIVISION

U.S. ARMY ENGINEER DISTRICT, BALTIMORE

COMPOSITE ANALYSIS OF WATER BY DALECARLIA LABORATORY

POTOMAC RIVER RAW WATER SUPPLY

1985	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Total Trihalomethanes ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP (Silvex) ug/l	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Disolved Oxygen mg/l	Conductivity mohoms/cm	Total Coliform MPN	Fecal Coliform MPN	Fecal Strep MPN	Algae Count Org/ml	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226-228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l
January	—	—	—	—	—	0.1	0.2	1.0	2.0	1.0	1.0	0.023	12.4	9.8	345	1462	80	10	—					
February	—	—	—	—	—	0.1	0.2	1.0	2.0	1.0	1.0	0.030	13.0	9.3	314	71389	660	1256	—					
March	8.8	0.5	0.0	0.0	9.3	0.1	0.2	1.0	2.0	1.0	1.0	0.042	14.2	9.8	279	2953	124	1	—					
April	8.7	0.3	0.0	0.0	9.0	0.1	0.2	1.0	2.0	1.0	1.0	0.025	30.1	9.8	268	3093	1162	15	—					
May	9.0	0.4	0.1	0.0	9.5	0.1	0.2	1.0	2.0	1.0	1.0	0.034	15.0	8.0	290	12248	907	198	421					
June	[illegible]	0.3	0.0	0.0	6.6	0.1	0.2	1.0	2.0	1.0	1.0	0.027	13.8	7.4	297	12781	966	175	327					
July	[illegible]	0.6	0.0	0.0	8.1	0.1	0.2	1.0	2.0	1.0	1.0	0.039	30.4	8.1	350	9835	1729	641	374					
August	9.3	0.3	0.0	0.0	9.6	0.1	0.2	1.0	2.0	1.0	1.0	0.109	17.4	8.5	390	1394	135	98	373					
September	8.4	0.5	0.0	0.0	8.9	0.1	0.2	1.0	2.0	1.0	1.0	0.063	11.8	8.5	415	2816	873	40	—					
October	6.5	0.4	0.1	0.0	7.0	0.1	0.2	1.0	2.0	1.0	1.0	0.049	14.0	7.5	453	1889	2357	198	—					
November	5.7	0.2	0.	0.0	5.8	0.1	0.2	1.0	2.0	1.0	1.0	0.030	15.8	8.5	266	13023	3970	1798	—					
December	2.0	0.1	0.1	0.2	2.3	0.1	0.2	1.0	2.0	1.0	1.0	0.028	12.8	8.1	281	29059	2777	374	—					
Average	7.2	0.3	0.0	0.0	7.4	0.1	0.2	1.0	2.0	1.0	1.0	0.042	16.7	8.8	330	13811	1265	400	374					
Maximum	9.3	0.6	0.1	0.2	9.6	0.1	0.2	1.0	2.0	1.0	1.0	0.109	30.4	9.8	453	71389	3970	1798	421					
Minimum	2.0	0.1	0.0	0.0	2.3	0.1	0.2	1.0	2.0	1.0	1.0	0.023	11.8	7.4	266	1394	80	1	327					

DALECARLIA WATER TREATMENT PLANT FINISHED WATER

1985	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Total Trihalomethanes ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP (Silvex) ug/l	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Disolved Oxygen mg/l	Conductivity mohoms/cm	Total Coliform MPN	Fecal Coliform MPN	Fecal Strep MPN	Algae Count Org/ml	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226-228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l
January	24.6	6.5	1.4	0.0	32.7	0.1	0.2	1.0	2.0	1.0	1.0	0.009	2.7	9.5		0								
February	37.8	6.9	0.9	0.0	45.6	0.1	0.2	1.0	2.0	1.0	1.0	0.028	6.6	9.4		0								
March	39.4	7.6	1.1	0.0	48.0	0.1	0.2	1.0	2.0	1.0	1.0	0.032	3.2	9.8		0				< 0.8	2.2		< 0.37	< 590
April	55.6	9.7	1.7	0.0	67.0	0.1	0.2	1.0	2.0	1.0	1.0	0.025	5.1	9.7	299	0								
May	75.0	10.8	1.0	0.0	86.8	0.1	0.2	1.0	2.0	1.0	1.0	0.018	8.3	9.8	322	0								
June	70.0	13.5	1.8	0.0	85.3	0.1	0.3	1.0	2.0	1.0	1.0	0.007	6.8	7.7	327	0								
July	84.4	16.8	2.2	0.0	103.4	0.1	0.2	1.0	2.0	1.0	1.0	0.024	9.7	8.4	384	0								
August	68.1	15.3	1.9	0.0	85.3	0.1	0.2	1.0	2.0	1.0	1.0	0.054	7.7	8.8	417	0								
September	56.2	13.2	1.6	0.0	71.1	0.1	0.2	1.0	2.0	1.0	1.0	0.026	1.3	8.2	447	0				< 1.0	2.8		< 0.5	< 440
October	62.4	11.4	1.1	0.0	74.9	0.1	0.2	1.0	2.0	1.0	1.0	0.032	3.3	8.1	466	0								
November	34.7	5.0	0.5	0.0	40.2	0.1	0.2	1.0	2.0	1.0	1.0	0.030	3.8	8.9	318	0								
December	17.8	4.7	1.2	0.2	23.9	0.1	0.2	1.0	2.0	1.0	1.0	0.026	4.5	9.5	318	0				< 1.5	3.0		< 0.7	< 480
Average	52.2	10.1	1.4	0.0	63.7	0.1	0.2	1.0	2.0	1.0	1.0	0.026	5.2	8.9	362	0				< 1.1	2.8		< 0.58	< 483
Maximum	84.4	16.8	2.2	0.2	103.4	0.1	0.2	1.0	2.0	1.0	1.0	0.054	9.7	9.8	485	0				< 1.5	3.0		< 0.7	< 590
Minimum	17.8	4.7	0.5	0.0	23.9	0.1	0.2	1.0	2.0	1.0	1.0	0.007	1.3	7.7	299	0				< 0.8	2.2		< 0.5	< 440

McMILLAN WATER TREATMENT PLANT FINISHED WATER

1985	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Total Trihalomethanes ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP (Silvex) ug/l	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Disolved Oxygen mg/l	Conductivity mohoms/cm	Total Coliform MPN	Fecal Coliform MPN	Fecal Strep MPN	Algae Count Org/ml	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226-228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l
January	40.2	9.0	1.6	0.0	50.8	0.1	0.2	1.0	2.0	1.0	1.0	0.009	2.1	—	358	0								
February	49.9	9.4	1.2	0.0	60.5	0.1	0.2	1.0	2.0	1.0	1.0	0.024	4.6	—	378	0								
March	42.3	6.5	1.2	0.0	50.0	0.1	0.2	1.0	2.0	1.0	1.0	0.032	3.4	—	314	0				< 0.8	1.8		< 0.86	< 580
April	50.8	8.1	1.9	0.0	60.7	0.1	0.2	1.0	2.0	1.0	1.0	0.025	4.8	----	292	0								
May	51.5	8.6	1.9	0.0	62.2	0.1	0.2	1.0	2.0	1.0	1.0	0.013	6.3	----	319	0								
June	44.9	8.6	2.1	0.0	55.6	0.1	0.2	1.0	2.0	1.0	1.0	0.007	4.9	----	311	0								
July	50.9	10.4	2.9	0.0	64.2	0.1	0.2	1.0	2.0	1.0	1.0	0.024	9.9	—	362	0								
August	52.7	12.5	2.5	0.0	67.7	0.1	0.2	1.0	2.0	1.0	1.0	0.060	3.5	—	378	0								
September	59.6	15.0	3.2	0.0	77.8	0.1	0.2	1.0	2.0	1.0	1.0	0.026	3.7	—	420	0				< 1.0	2.5		< 0.5	< 440
October	56.0	11.7	1.9	0.0	69.6	0.1	0.2	1.0	2.0	1.0	1.0	0.032	6.3	—	487	0								
November	62.9	6.5	0.8	0.0	70.2	0.1	0.2	1.0	2.0	1.0	1.0	0.030	5.3	—	372	0								
December	36.4	5.1	1.0	0.2	42.7	0.1	0.2	1.0	2.0	1.0	1.0	0.026	4.4	—	310	0				< 1.8	4.3		< 0.6	< 490
Average	49.9	9.3	1.8	0.0	61.0	0.1	0.2	1.0	2.0	1.0	1.0	0.026	5.1	—	356	0				< 0.8	2.9		< 0.58	< 483
Maximum	62.9	15.0	3.2	0.2	77.8	0.1	0.2	1.0	2.0	1.0	1.0	0.060	9.9	—	487	0				< 1.8	4.3		< 0.6	< 590
Minimum	36.4	5.1	0.8	0.0	42.7	0.1	0.2	1.0	2.0	1.0	1.0	0.007	2.1	—	292	0				< 0.8	1.8		< 0.5	< 440

NAB Form 648 rev. JUNE "86"

W. A. Dwg. No 100.1-4 14-4

WASHINGTON AQUEDUCT DIVISION

U.S. ARMY ENGINEER DISTRICT, BALTIMORE

COMPOSITE ANALYSIS OF WATER BY DALECARLIA LABORATORY

POTOMAC RIVER RAW WATER SUPPLY

1986	pH	M.O. Alkalinity as $CaCO_3$	Turbidity	Temperature	Total Solids	Hardness as $CaCO_3$	Chlorine Residual DPD Free	Chloride	Fluoride	Total Disolved phosphorous	Silicates	Sulfates Disolved	Nitrate Nitrogen	Nitrite Nitrogen	Ammonia Nitrogen	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Zinc
		mg/l	NTU	°F	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
January	8.0	83	7.8	42	206	151	—	16.8	0.21	—	2.4	49.3	2.32	0.02	0.04	0.31	.001	.058	.0000	44	.002	.001	.29	.0000	9	.048	.0001	.004	2.01	.001	.0000	9.8	.234	.008
February	7.7	54	20.6	43	208	115	—	22.0	0.18	—	3.6	29.9	2.10	0.03	0.06	0.30	.001	.054	.0001	30	.001	.002	.29	.0006	9	.049	.0000	.003	2.10	.000	.0000	11.6	.169	.004
March	7.7	57	48.1	51	278	108	—	14.0	0.19	—	3.4	28.2	3.21	0.00	0.00	0.80	.001	.040	.0000	31	.001	.003	.28	.0004	7	.053	.0003	.002	1.79	.001	.0000	8.8	.158	.003
April	8.2	81	15.6	61	175	114	—	12.6	0.16	—	3.5	27.3	1.26	0.00	0.03	3.38	.001	.050	.0000	31	.005	.004	.59	.0005	8	.168	.0000	.003	2.11	.000	.0000	9.4	.196	.005
May	8.0	76	12.8	73	248	124	—	12.7	0.18	—	3.7	30.5	1.02	0.01	0.02	0.54	.001	.053	.0001	36	.001	.002	.93	.0004	8	.093	.0000	.002	1.30	.000	.0001	7.5	.167	.013
June	7.6	76	12.6	82	[illegible]	121	—	14.8	0.16	—	2.2	34.4	0.96	0.00	0.02	0.31	.001	.050	.0001	35	.001	.002	.48	.0013	8	.133	.0001	.002	2.25	.001	.0000	9.1	.187	.004
July	7.4	68	15.4	85	238	129	—	20.8	0.21	---	1.9	49.2	0.81	0.02	0.02	0.31	.002	.074	.0000	36	.001	.002	.49	.0007	9	.085	.0000	.003	3.02	.000	.0001	19.0	.222	.002
August	7.4	68	12.8	81	278	129	—	26.8	0.21	0.09	1.4	67.3	0.29	0.06	0.07	0.87	.000	.058	.0001	33	.001	.005	.70	.0006	11	.160	.0000	.005	3.14	.001	.0000	22.3	.182	.006
September	7.8	90	9.5	74	319	166	—	26.0	0.21	0.07	2.4	92.2	0.83	0.03	0.10	0.64	.002	.074	.0000	48	.001	.002	.50	.0010	10	.069	.0000	.002	3.45	.002	.0000	24.4	.294	.003
October	7.9	99	6.9	65	318	184	—	28.9	0.25	0.05	2.7	113.3	0.84	0.00	0.04	0.74	.024	.095	.0003	54	.001	.003	.84	.0016	12	.098	.0000	.004	3.39	.001	.0001	28.2	.371	.003
November	7.8	99	8.6	52	298	171	—	22.4	0.18	0.03	0.7	77.2	1.13	0.00	0.03	0.11	.001	.079	.0002	51	.000	.002	.43	.0095	10	.038	.0000	.003	3.21	.000	.0001	28.0	.276	.008
December	7.7	63	24.1	46	172	115	—	16.5	0.14	0.07	1.6	40.6	1.98	0.00	0.06	0.15	.000	.051	.0002	34	.000	.003	.81	.0018	7	.052	.0000	.003	3.25	.000	.0000	12.3	.183	.006
Average	7.8	74	16.2	63	247	136	—	19.5	0.19	0.06	2.5	53.3	1.36	0.01	0.04	0.69	.003	.061	.0001	39	.001	.002	.55	.0015	9	.089	.0000	.003	2.59	.001	.0000	15.9	.218	.005
Maximum	8.2	99	48.1	85	318	187	—	28.9	0.25	0.09	3.7	113.3	3.21	0.06	0.10	3.38	.024	.095	.0003	54	.005	.005	.93	.0095	12	.168	.0003	.005	3.45	.002	.0001	28.2	.371	.013
Minimum	7.4	54	6.9	42	172	108	—	12.6	0.14	0.03	0.7	27.3	0.29	0.00	0.00	0.11	.000	.040	.0000	30	.000	.001	.28	.0000	7	.038	.0000	.002	1.30	.000	.0000	7.5	.156	.002

DALECARLIA WATER TREATMENT PLANT FINISHED WATER

1986	pH	M.O. Alkalinity as $CaCO_3$	Turbidity	Temperature	Total Solids	Hardness as $CaCO_3$	Chlorine Residual DPD Free	Chloride	Fluoride	Total Disolved phosphorous	Silicates	Sulfates Disolved	Nitrate Nitrogen	Nitrite Nitrogen	Ammonia Nitrogen	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Zinc
		mg/l	NTU	°F	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
January	7.6	84	0.31	44	233	156	2.02	19.8	1.12	—	2.7	55.3	2.30	0.00	0.01	0.09	.001	.063	.0000	47	.001	.003	.014	.0000	9	.003	.0001	.003	2.01	.001	.0000	9.2	.204	.001
February	8.1	56	0.23	46	212	129	1.90	24.6	1.08	---	3.6	38.7	2.11	0.00	0.01	0.11	.000	.048	.000	36	.001	.002	.016	.0001	9	.003	.0000	.002	2.14	.001	.0001	12.3	.162	.001
March	8.2	59	0.19	53	196	122	1.87	16.6	0.99	---	3.2	35.6	3.21	0.00	0.00	0.10	.001	.043	.0000	36	.001	.001	.013	.0002	7	.002	.0000	.001	1.83	.001	.0000	8.8	.154	.001
April	8.1	81	0.43	64	150	123	1.95	18.0	0.89	---	3.5	35.6	1.37	0.00	0.00	0.31	.000	.049	.0000	35	.001	.002	.018	.0000	10	.004	.0000	.001	2.20	.000	.0001	9.2	.180	.005
May	7.8	74	0.82	71	234	131	2.00	17.8	0.84	---	2.8	37.6	1.01	0.00	0.00	0.83	.001	.057	.0001	37	.000	.003	.020	.0004	8	.005	.0000	.001	1.88	.000	.0001	7.6	.216	.017
June	7.7	73	0.67	80	246	136	2.20	20.5	0.92	—	1.7	42.8	0.93	0.00	0.00	0.19	.000	.043	.0001	39	.001	.004	.036	.0005	9	.007	.0000	.001	2.22	.001	.0000	8.9	.196	.002
July	7.7	70	0.71	83	222	147	2.26	27.9	0.95	—	1.7	59.0	0.36	0.00	0.00	0.42	.001	.061	.0000	43	.001	.006	.033	.0006	9	.016	.0000	.001	3.00	.000	.0000	18.8	.218	.001
August	7.7	71	0.40	80	233	144	2.36	31.5	0.92	0.00	1.3	74.9	0.31	0.00	0.03	0.27	.001	.058	.0001	39	.001	.005	.033	.0002	10	.027	.0000	.002	3.10	.001	.0000	27.7	.266	.003
September	7.6	87	0.38	74	306	167	2.15	29.7	0.89	0.00	2.1	96.4	0.62	0.00	0.04	0.36	.001	.051	.0000	51	.001	.005	.010	.0010	11	.006	.0000	.001	3.44	.002	.0000	[illegible]	.305	.007
October	7.9	96	0.22	65	330	196	2.14	30.9	0.93	0.00	2.7	119.0	0.89	0.00	0.01	0.06	.000	.101	.0003	58	.000	.006	.009	.0014	12	.007	.0000	.004	3.45	.000	.0001	28.9	.302	.002
November	7.8	87	0.28	54	329	181	2.22	27.8	0.95	0.01	0.5	88.2	1.21	0.00	0.00	0.06	.000	.058	.0003	55	.000	.003	.010	.0011	10	.002	.0000	.002	3.20	.000	.0001	22.0	.303	.017
December	7.8	62	0.26	49	180	130	2.27	20.1	0.99	0.00	1.4	51.9	2.19	0.00	0.00	0.10	.000	.069	.0001	39	.001	.004	.011	.0011	9	.002	.0000	.002	3.32	.000	.0001	12.0	.179	.004
Average	7.8	74	0.40	64	239	147	2.12	23.6	0.96	0.00	2.5	61.4	1.36	0.00	0.01	0.28	.001	.058	.0001	43	.001	.004	.019	.0006	10	.007	.0000	.002	2.65	.001	.0001	15.4	.223	.005
Maximum	8.2	96	0.71	83	330	196	2.36	31.5	1.12	0.01	4.8	119.0	3.21	0.00	0.04	0.83	.001	.101	.0003	58	.001	.006	.036	.0014	12	.027	.0001	.004	3.45	.002	.0001	28.9	.305	.017
Minimum	7.6	56	0.19	44	150	122	1.87	16.0	0.84	0.00	1.3	35.6	0.31	0.00	0.00	0.06	.000	.043	.0000	35	.000	.001	.009	.0000	7	.002	.0000	.001	1.83	.000	.0000	7.6	.154	.001

McMILLAN WATER TREATMENT PLANT FINISHED WATER

1986	pH	M.O. Alkalinity as $CaCO_3$	Turbidity	Temperature	Total Solids	Hardness as $CaCO_3$	Chlorine Residual DPD Free	Chloride	Fluoride	Total Disolved phosphorous	Silicates	Sulfates Disolved	Nitrate Nitrogen	Nitrite Nitrogen	Ammonia Nitrogen	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Zinc
		mg/l	NTU	°F	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
January	7.7	70	0.23	41	202	150	1.93	20.8	1.14	—	3.6	64.6	2.23	0.00	0.01	0.05	.001	.048	.0000	43	.001	.011	.007	.0007	10	.002	.0000	.003	1.71	.000	.0000	8.0	.217	.003
February	7.6	52	0.17	43	206	130	1.71	23.9	0.86	—	2.9	44.8	2.09	0.00	0.01	0.06	.000	.045	.0000	37	.000	.012	.016	.0005	9	.001	.0000	.002	1.48	.000	.0001	8.7	[illegible]	.008
March	7.7	43	0.15	42	269	109	1.90	18.5	0.90	---	3.3	36.6	3.21	0.00	0.00	0.40	.001	.042	.0000	32	.001	.004	.011	.0001	6	.002	.0006	.002	1.98	.001	.0000	8.8	.146	.008
April	7.6	57	0.49	50	145	120	1.94	17.4	0.86	---	2.6	36.0	1.56	0.00	0.00	0.15	.000	.045	.0000	35	.001	.012	.011	.0002	10	.003	.0001	.001	2.06	.000	.0001	7.7	.177	.003
May	7.7	67	0.47	59	231	129	1.95	17.1	0.87	—	2.4	38.2	0.99	0.01	0.00	0.06	.000	.058	.0001	36	.001	.010	.023	.0009	9	.002	.0003	.002	1.97	.000	.0001	7.3	.169	.001
June	7.7	70	0.77	68	240	130	2.11	19.6	0.95	—	1.3	42.7	3.48	0.00	0.00	0.12	.001	.061	.0001	38	.000	.013	.016	.0010	7	.009	.0001	.002	2.39	.001	.0000	8.9	.208	.003
July	7.9	65	0.91	73	239	141	2.23	29.8	1.20	—	1.4	60.6	0.48	0.00	0.00	0.30	.000	.067	.0000	40	.001	.023	.038	.0002	9	.011	0000	.002	2.97	.000	.0000	16.1	.220	.001
August	7.6	67	0.47	74	306	143	2.24	33.5	0.95	0.00	2.4	71.6	0.37	0.00	0.03	0.15	.000	.061	.0001	39	.001	.019	.024	.0004	10	.010	.0001	.002	3.12	.001	0000	19.1	.328	.003
September	7.9	88	0.64	70	314	175	2.31	30.2	0.94	0.00	2.1	99.6	0.62	0.00	0.05	0.49	.001	.066	.0000	51	.001	.049	.020	.0010	11	.006	.0000	.002	3.37	.002	.0000	24.4	.227	.002
October	7.6	91	0.33	67	326	189	2.29	32.0	0.92	0.00	2.7	113.0	0.72	0.00	0.01	0.09	.000	.061	.0006	55	.000	.043	.014	.0013	12	.014	.0000	.003	3.30	.000	.0000	27.3	.280	.010
November	7.7	89	0.27	60	293	184	2.24	30.2	0.82	0.00	0.7	99.1	0.95	0.00	0.00	0.08	.000	.069	.0003	56	.000	.060	.018	.0022	10	.002	.0000	.003	3.33	.000	.0001	28.0	.299	.081
December	7.7	61	0.33	51	172	128	2.18	19.7	0.88	0.00	1.7	58.8	1.79	0.00	0.00	0.04	.000	.029	.0002	39	.001	.016	.010	.0022	6	.001	.0000	.002	3.19	.000	.0001	12.5	.236	.012
Average	7.8	69	0.44	59	247	144	2.10	24.4	0.95	0.00	2.2	63.8	1.54	0.00	0.01	0.18	.000	.054	.0001	42	.001	.023	.017	.0009	10	.005	.0001	.002	2.56	.000	.0000	14.9	.220	.006
Maximum	7.9	91	0.91	74	326	189	2.34	33.5	1.20	0.00	3.6	113.0	3.48	0.01	0.05	0.49	.001	.069	.0006	56	.001	.060	.038	.0022	12	.014	.0006	.003	3.37	.002	.0001	28.0	.328	.081
Minimum	7.6	43	0.15	41	145	109	1.71	17.1	0.82	0.00	0.7	36.0	0.37	0.00	0.00	0.04	.000	.029	.0000	32	.000	.004	.007	.0001	6	.001	.0000	.001	1.61	.000	.0000	7.3	.126	.001

NAB Form 648 rev. JUNE "86"

W. A. Dwg. No. 100.1-4.14-5

WASHINGTON AQUEDUCT DIVISION

U. S. ARMY ENGINEER DISTRICT, BALTIMORE

COMPOSITE ANALYSIS OF WATER BY DALECARLIA LABORATORY

POTOMAC RIVER RAW WATER SUPPLY

1986	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Total Trihalomethanes ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP (Silvex) ug/l	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Dissolved Oxygen mg/l	Conductivity mohoms/cm	Total Coliform MPN	Fecal Coliform MPN	Fecal Strep MPN	Algae Count Org/ml	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226-228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l
January	1.3	0.4	0.0	0.0	1.7	0.1	0.2	1.0	2.0	1.0	1.0	0.19	5	7.5	404	2612	182	331	-					
February	0.4	0.0	0.0	0.0	0.4	0.1	0.2	1.0	2.0	1.0	1.0	0.04	5	7.7	314	30604	662	310	-					
March	1.2	0.3	0.1	0.0	1.6	0.1	0.2	1.0	2.0	1.0	1.0	0.02	10	7.8	285	7375	76	150	-					
April	1.4	0.1	0.0	0.0	1.5	0.1	0.2	1.0	2.0	1.0	1.0	0.02	13	8.3	290	10059	42	[illegible]	-					
May	2.7	0.2	0.0	0.0	2.9	0.1	0.2	1.0	2.0	1.0	1.0	0.02	17	7.5	298	2823	78	171	298					
June	1.3	0.3	0.1	0.0	1.7	0.1	0.2	1.0	2.0	1.0	1.0	0.03	13	8.2	345	12562	155	84	474					
July	1.2	0.3	0.1	0.0	1.8	0.1	0.2	1.0	2.0	1.0	1.0	0.00	26	4.6	381	2824	1478	12	279					
August	1.5	0.5	0.1	0.0	2.1	0.1	0.2	1.0	2.0	1.0	1.0	0.00	8	5.8	430	2576	80	62	266					
September	1.3	0.1	0.0	0.0	1.4	0.1	0.2	1.0	2.0	1.0	1.0	0.05	14	7.1	515	1163	39	9	0					
October	1.4	0.3	0.0	0.0	1.7	0.1	0.2	1.0	2.0	1.0	1.0	0.06	17	7.4	568	4285	364	82	-					
November	2.7	0.0	0.0	0.0	2.7	0.1	0.2	1.0	2.0	1.0	1.0	0.03	15	7.5	490	4931	847	1047	-					
December	1.3	0.3	0.0	0.0	1.6	0.1	0.2	1.0	2.0	1.0	1.0	0.04	3	8.5	326	74104	1470	482	-					
Average	1.5	0.2	0.0	0.0	1.7	0.1	0.2	1.0	2.0	1.0	1.0	0.04	12	7.2	388	12993	473	230	262					
Maximum	2.7	0.5	0.1	0.0	2.9	0.1	0.2	1.0	2.0	1.0	1.0	0.19	26	8.5	568	74104	1478	1047	474					
Minimum	0.4	0.0	0.0	0.0	0.4	0.1	0.2	1.0	2.0	1.0	1.0	0.00	3	4.6	285	1163	39	9	0					

DALECARLIA WATER TREATMENT PLANT FINISHED WATER

1986	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Total Trihalomethanes ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP (Silvex) ug/l	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Dissolved Oxygen mg/l	Conductivity mohoms/cm	Total Coliform MPN	Fecal Coliform MPN	Fecal Strep MPN	Algae Count Org/ml	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226-228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l
January	18.6	8.0	1.4	0.0	28	0.1	0.2	1.0	2.0	1.0	1.0	0.07	2	9.0	411	0.0				<1.0	2.3		<0.7	<440
February	26.6	5.6	0.6	0.0	33	0.1	0.2	1.0	2.0	1.0	1.0	0.02	2	9.0	341	0.2								
March	25.3	7.3	1.4	0.0	34	0.1	0.2	1.0	2.0	1.0	1.0	0.01	4	9.0	322	0.8								
April	49.0	11.3	1.6	0.0	63	0.1	0.2	1.0	2.0	1.0	1.0	0.00	3	9.6	332	0.9				<1.0	2.9		<0.6	<400
May	64.5	11.8	1.2	0.0	78	0.1	0.2	1.0	2.0	1.0	1.0	0.00	6	8.2	332	0.0								
June	74.1	14.7	1.9	0.0	91	0.1	0.2	1.0	2.0	1.0	1.0	0.01	6	8.0	379	0.0								
July	85.7	15.9	2.4	0.0	104	0.1	0.2	1.0	2.0	1.0	[illegible]	0.00	13	7.0	428	0.2				<1.5	4.6		<0.5	<400
August	86.9	15.4	1.3	0.1	84	0.1	0.2	1.0	2.0	1.0	1.0	0.00	6	8.0	455	2.5								
September	56.5	15.3	2.3	0.0	74	0.1	0.2	1.0	2.0	1.0	1.0	0.00	7	7.7	534	0.4								
October	49.2	12.4	1.6	0.0	63	0.1	0.2	1.0	2.0	1.0	1.0	0.03	6	8.1	598	0.0				<1.6	3.5		<0.3	<480
November	59.5	14.0	2.0	0.0	76	0.1	0.2	1.0	2.0	1.0	1.0	0.02	9	8.6	513	0.1								
December	19.1	4.1	0.7	0.0	24	0.1	0.2	1.0	2.0	1.0	1.0	0.00	4	8.7	[illegible]	0.3								
Average	49.6	11.3	1.6	0.0	63	0.1	0.2	1.0	2.0	1.0	1.0	0.01	6	8.6	417	0.4				<1.3	2.3		<0.6	<440
Maximum	85.7	15.9	2.4	0.1	104	0.1	0.2	1.0	2.0	1.0	1.0	0.07	13	9.7	599	2.5				<1.8	4.8		<0.8	<480
Minimum	18.6	4.1	0.7	0.0	24	0.1	0.2	1.0	2.0	1.0	1.0	0.00	2	7.0	322	0.0				<1.0	2.3		<0.5	<440

McMILLAN WATER TREATMENT PLANT FINISHED WATER

1986	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Total Trihalomethanes ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP (Silvex) ug/l	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Dissolved Oxygen mg/l	Conductivity mohoms/cm	Total Coliform MPN	Fecal Coliform MPN	Fecal Strep MPN	Algae Count Org/ml	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226-228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l
January	30.2	9.5	2.4	0.0	42	0.1	0.2	1.0	2.0	1.0	1.0	0.10	3	-	392	0.0				<1.1	1.8		<0.7	<440
February	44.2	10.4	1.9	0.0	57	0.1	0.2	1.0	2.0	1.0	1.0	0.02	2	-	348	0.0								
March	37.1	7.4	1.2	0.0	46	0.1	0.2	1.0	2.0	1.0	1.0	0.00	4	-	306	0.0								
April	50.8	10.0	1.6	0.0	62	0.1	0.2	1.0	2.0	1.0	1.0	0.00	2	-	319	0.0				<1.0	2.3		<0.8	<440
May	61.0	12.8	2.0	0.0	76	0.1	0.2	1.0	2.0	1.0	1.0	0.00	8	-	317	0.2								
June	70.6	14.5	2.5	0.0	88	0.1	0.2	1.0	2.0	1.0	1.0	0.00	9	-	356	0.0								
July	78.4	15.8	2.9	0.0	97	0.1	0.2	1.0	2.0	1.0	1.0	0.00	12	-	418	0.0				<1.2	3.8		<0.9	<480
August	72.6	14.2	1.6	0.0	89	0.1	0.2	1.0	2.0	1.0	1.0	0.00	5	-	455	0.0								
September	60.2	15.9	2.6	0.0	79	0.1	0.2	1.0	2.0	1.0	1.0	0.00	6	-	523	0.0								
October	55.6	13.1	1.7	0.0	70	0.1	0.2	1.0	2.0	1.0	1.0	0.03	7	-	578	0.0				<1.8	3.7		<0.6	<480
November	45.8	12.1	1.9	0.0	60	0.1	0.2	1.0	2.0	1.0	1.0	0.01	8	-	333	0.0								
December	21.9	4.5	0.8	0.0	27	0.1	0.2	1.0	2.0	1.0	1.0	0.01	6	-	364	0.0								
Average	52.4	11.7	1.9	0.0	66	0.1	0.2	1.0	2.0	1.0	1.0	0.01	6	-	409	0.0				<1.2	2.9		<0.8	[illegible]
Maximum	78.4	15.9	2.9	0.0	97	0.1	0.2	1.0	2.0	1.0	1.0	0.10	12	-	578	0.2				<1.2	3.8		<0.6	<480
Minimum	21.9	4.5	0.8	0.0	27	0.1	0.2	1.0	2.0	1.0	1.0	0.00	2	-	306	0.0				<1.0	1.8		<0.6	<440

NAB Form 648 rev. JUNE "86"

W. A. Dwg. No 100.1-4 14-4

WASHINGTON AQUEDUCT DIVISION

U.S. ARMY ENGINEER DISTRICT, BALTIMORE

COMPOSITE ANALYSIS OF WATER BY DALECARLIA LABORATORY

POTOMAC RIVER RAW WATER SUPPLY

1987	pH	M.O. Alkalinity as $CaCO_3$	Turbidity	Temperature	Total Solids	Hardness as $CaCO_3$	Chlorine Residual DPD Free	Chloride	Fluoride	Total Dissolved phosphorous	Silicates	Sulfates Dissolved	Nitrate Nitrogen	Nitrite Nitrogen	Ammonia Nitrogen	Aluminum	Arsenic	[illegible]	Cadmium	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Zinc
		mg/l	NTU	°F	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
January	7.9	62	30.0	36	230	100	-	18.9	.24	.02	3.8	37.9	2.41	0.00	.06	4.500	.000	.020	.0001	30	.002	.003	.844	.0024	8	.043	.0000	.001	2.18	.001	.0001	7.0	.187	.008
February	7.9	66	8.9	44	176	114	-	20.8	.18	.02	2.9	38.2	2.47	0.00	.04	0.834	.000	.028	.0002	32	.003	.004	.365	.0004	7	.032	.0001	.001	2.41	.002	.0001	22.3	.172	.008
March	7.8	80	15.8	66	184	102	-	14.8	.17	.06	2.3	33.5	1.82	0.01	.04	0.810	.000	.033	.0002	30	.002	.003	.400	.0014	6	.002	.0000	.002	2.46	.000	.003	5.6	.100	.017
April	7.8	51	34.3	69	208	87	-	10.2	.14	.14	3.2	25.7	1.40	0.01	.06	0.506	.001	.036	.0001	26	.001	.004	.410	.0025	5	.082	.0000	.002	2.06	.001	[illegible]	[illegible]	.088	.000
May	7.6	61	12.2	80	189	100	-	10.1	.11	.06	4.4	25.8	1.32	0.01	.03	0.476	.000	.042	.0001	29	.001	.003	.208	.0007	6	.080	.0000	.000	[illegible]	.001	.0000	[illegible]	.170	.002
June	7.7	81	9.4	80	161	128	-	14.5	.20	.06	3.8	30.1	1.40	0.00	.07	0.204	.000	.041	.0000	36	.001	.002	.296	.0008	8	.059	.0000	.002	2.20	.000	.0000	7.4	.148	.008
July	7.8	79	30.9	83	229	129	-	19.5	.19	.11	4.2	38.6	1.31	0.00	.04	0.440	.001	.040	.0000	37	.001	.004	.580	.0013	7	.104	.0000	.002	4.78	.001	.0000	6.0	.127	.004
August	7.7	86	7.5	80	310	156	-	26.5	.23	.14	2.5	62.6	1.01	0.00	.00	0.100	.001	.043	.0000	43	.001	.003	.285	.0002	11	.018	.0000	.002	3.40	.001	.0000	31.1	.239	.002
September	7.7	81	23.7	72	220	144	-	24.3	.18	.13	2.9	54.1	1.44	0.00	.00	0.385	.001	.073	.0001	41	.001	.004	.200	.0010	9	.064	.0000	.001	3.42	.001	.0000	30.0	.317	.002
October	8.1	83	8.8	58	238	150	-	19.8	.16	.08	3.4	43.5	1.30	0.00	.04	0.154	.001	.043	.0000	43	.001	.004	.316	.0008	10	.031	.0000	.003	3.03	.002	.0000	16.7	.258	.004
November	7.8	62	9.7	50	245	142	-	23.0	.15	.17	5.0	38.0	1.42	0.00	.06	0.080	.000	.033	.0001	41	.001	.007	.370	.0002	9	.069	.0000	.002	3.44	.000	.0001	19.1	.169	.002
December	7.8	58	17.7	46	180	106	-	12.1	.12	.02	4.2	23.6	2.41	0.00	.06	0.138	.000	.032	.0000	30	.001	.004	.307	.0005	7	.044	.0000	.001	2.82	.000	.0000	7.7	.132	.002
Average	7.8	72.4	17.2	63	215	122	-	17.9	.17	.08	3.6	37.2	1.03	0.00	.04	0.646	.000	.040	.0001	35	.001	.004	.474	.0010	8	.040	.0000	.002	2.83	.001	.0000	12.6	.170	.004
Maximum	8.1	86	34.3	83	310	156	-	26.5	.24	.17	5.0	62.6	2.47	0.01	.07	4.500	.001	.073	.0002	43	.003	.007	.370	.0025	8	.104	.0001	.003	4.78	.002	.0001	30.0	.317	.017
Minimum	7.5	51	8.8	36	161	80	-	10.1	.11	.02	2.3	23.6	1.01	0.00	.00	0.080	.000	.020	.0000	26	.001	.002	.200	.0002	11	.018	.0000	.000	1.90	.000	.0000	5.2	.088	.000

DALECARLIA WATER TREATMENT PLANT FINISHED WATER

1987	pH	M.O. Alkalinity as $CaCO_3$	Turbidity	Temperature	Total Solids	Hardness as $CaCO_3$	Chlorine Residual DPD Free	Chloride	Fluoride	Total Dissolved phosphorous	Silicates	Sulfates Dissolved	Nitrate Nitrogen	Nitrite Nitrogen	Ammonia Nitrogen	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Zinc	
		mg/l	NTU	°F	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	g/l	mg/l	mg/l	mg/l	mg/l	
January	8.0	64	0.36	38	214	118	1.7	22.8	.96	.00	2.1	47.2	2.80	0.00	.00	0.198	.000	.030	.0002	35	.002	.003	.027	.0019	7	.003	.0000	.001	2.23	.001	.0000	6.3	.110	.003	
February	7.9	66	0.42	46	186	124	2.1	26.3	1.07	.00	1.8	36.4	2.37	0.00	.00	0.468	.000	.022	.0001	36	.002	.001	.022	.0000	7	.003	.0001	.001	2.20	.002	.0001	16.0	.153	.004	
March	8.1	80	0.37	58	154	115	2.1	15.7	1.01	.02	2.8	37.0	1.90	0.00	.00	0.069	.000	.033	.0001	36	.001	.003	.015	.0009	6	.007	.0000	.002	2.16	.000	.0000	6.3	.100	.017	
April	8.1	54	0.30	68	158	107	2.1	13.4	1.06	.04	2.5	34.8	1.49	0.00	.00	0.085	.001	.033	.0001	33	.001	.002	.012	.0014	5	.014	.0000	.001	2.06	.001	.0000	8.3	.082	.000	
May	8.0	61	0.46	80	156	114	2.0	12.7	.96	.03	4.1	32.4	1.30	0.00	.00	0.046	.000	.036	.0000	35	.001	.003	.011	.0002	6	.003	.0002	.001	1.90	.000	.0000	6.5	.171	.001	
June	7.7	80	0.50	79	180	141	2.2	18.0	.98	.02	3.3	34.1	1.46	0.00	.01	0.112	.000	.042	.0000	45	.000	.005	.009	.0007	7	.003	.0000	.002	2.30	.000	.0000	7.3	.174	[illegible]	
July	7.5	61	0.37	83	230	149	2.3	23.4	.77	.01	3.5	44.3	1.85	0.00	.01	0.117	.000	.038	.0000	45	.001	.003	.031	.0000	9	.004	.0000	.002	4.40	.001	.0000	9.8	.118	.001	
August	7.7	81	0.43	80	264	171	2.3	32.3	.84	.02	2.5	67.3	.98	0.00	.00	0.152	.001	.054	.0000	48	.000	.008	.014	.0003	12	.003	.0000	.002	3.40	.001	.0000	11.0	.222	.002	
September	7.9	80	0.48	72	229	157	2.2	27.4	.90	.02	4.1	58.6	1.26	0.00	.00	0.242	.001	.071	.0001	47	.001	.005	.008	.0007	8	.002	.0001	.001	3.47	.001	.0000	30.0	.320	.003	
October	7.7	80	0.37	60	230	158	2.1	24.1	.90	.00	3.7	51.1	1.35	0.00	.00	0.143	.001	.048	.0000	46	.000	.005	.012	[illegible]	10	.001	.0000	.002	3.03	.002	.0000	17.0	.245	.001	
November	7.8	80	0.44	54	234	158	1.9	26.2	.90	.01	4.2	47.4	1.54	0.00	.00	0.122	.000	.031	.0000	47	.000	.004	.024	[illegible]	8	.005	.0000	.001	3.56	.000	.0000	13.4	.168	.001	
December	8.0	80	0.30	46	175	120	1.7	16.8	.93	.00	4.6	31.8	2.24	0.00	.00	0.056	.000	.030	.0000	36	.001	.004	.026	.0003	7	.005	.0000	.001	2.06	.000	.0000	7.8	.128	.001	
Average	7.8	72	0.40	64	206	138	2.1	21.6	.91	.01	3.3	43.9	1.86	0.00	.00	0.144	.000	.038	.0000	41	.001	.004	.018	.0006	8	.004	.0000	.001	2.79	.001	.0000	12.4	.167	.003	
Maximum	8.1	81	0.50	83	264	171	2.3	32.3	1.07	.04	4.6	67.3	2.80	0.00	.01	0.468	.001	.071	.0002	48	.002	.008	.031	.0019	12	.014	.0002	.002	4.40	.002	.0001	30.0	.246	.017	
Minimum	7.5	54	0.30	38	154	107	1.7	12.7	.77	.00	1.8	31.8	.98	0.00	.00	0.045	.000	.022	.0000	33	.000	.001	.008	.0000	5	.001	.0000	.001	1.90	.000	.0000	5.3	.110	.000	

McMILLAN WATER TREATMENT PLANT FINISHED WATER

1987	pH	M.O. Alkalinity as $CaCO_3$	Turbidity	Temperature	Total Solids	Hardness as $CaCO_3$	Chlorine Residual DPD Free	Chloride	Fluoride	Total Dissolved phosphorous	Silicates	Sulfates Dissolved	Nitrate Nitrogen	Nitrite Nitrogen	Ammonia Nitrogen	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Zinc	
		mg/l	NTU	°F	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
January	8.1	63	0.46	38	232	120	1.7	20.5	1.10	.00	2.4	48.3	2.32	0.00	.00	0.152	.000	.023	[illegible]	35	.001	.005	.007	.0018	8	.001	.0001	.001	2.47	.003	.0000	8.6	.114	.066	
February	8.0	56	0.24	42	179	117	2.2	24.5	1.17	.00	2.7	41.3	2.24	0.00	.00	0.530	.000	.026	.0000	35	.002	.011	.018	.0006	6	.005	.0000	.001	2.14	.002	.0000	11.8	.146	.007	
March	8.1	60	0.66	44	140	115	2.1	16.8	1.18	.01	1.3	38.1	1.90	0.00	.00	0.032	.000	.030	.0003	34	.000	.004	.011	.0010	6	.001	.0001	.000	2.04	.000	.0000	11.7	.130	.004	
April	8.0	50	0.40	50	150	102	2.1	14.8	1.11	.01	2.3	34.5	1.20	0.00	.00	0.114	.001	.033	.0001	31	.001	.006	.013	.0015	5	.002	.0000	.002	2.06	.001	.0000	6.0	.113	.000	
May	8.0	53	0.67	60	156	106	2.1	13.3	1.06	.01	4.2	24.6	1.23	0.00	.00	0.124	.000	.036	.0000	32	.001	.006	.013	.0003	5	.009	.0000	.001	2.00	.001	.0000	8.7	.149	.010	
June	7.7	72	0.96	65	164	131	1.9	18.0	.94	.02	3.5	34.0	1.46	0.00	.01	0.126	.001	.037	.0000	40	.000	.006	.015	.0007	7	.008	.0000	.002	2.30	.000	.0000	6.9	.131	.006	
July	7.8	75	0.96	77	256	141	2.2	23.2	.76	.02	3.4	41.4	1.77	0.00	.00	0.110	.001	.050	.0000	42	.001	.078	.032	.0001	8	.006	.0000	.002	3.94	.001	.0000	10.2	.164	.004	
August	7.7	86	1.22	78	284	161	2.1	31.0	.83	.03	2.2	63.7	.82	0.00	.00	0.136	.001	.049	.0000	46	.000	.036	.023	.0002	11	.002	.0000	.002	3.40	.001	.0000	17.3	.210	.006	
September	7.6	77	1.45	73	246	156	2.1	34.0	.82	.01	4.4	72.2	1.11	0.00	.00	0.357	.001	.072	.0001	47	.001	.062	.014	.0008	8	.002	.0001	.001	3.40	.001	.0000	26.6	.306	.007	
October	7.8	80	0.78	62	275	151	2.1	24.2	.86	.00	2.5	46.6	1.36	0.00	.00	0.071	.001	.040	.0000	46	.000	.066	.014	.0001	9	.001	.0000	.002	3.15	.002	.0000	13.2	.222	.004	
November	7.7	64	0.86	54	182	163	1.4	28.8	.90	.01	2.6	52.5	1.06	0.00	.00	0.192	.000	.035	.0000	40	.001	.036	.030	.0001	9	.005	.0000	.002	3.72	.000	.0000	16.1	.236	.006	
December	8.1	56	0.36	46	176	119	1.7	17.6	.97	.00	4.4	38.1	1.79	0.00	.00	0.083	.000	.030	.0001	36	.000	.025	.011	.0000	7	.001	.0000	.001	3.33	.000	.0000	6.2	.126	.008	
Average	7.9	66	0.75	57	207	132	2.0	22.2	.96	.01	3.0	44.8	1.56	0.00	.00	0.201	.001	.038	.0001	38	.001	.032	.017	.0006	7	.003	.0000	.001	2.80	.001	.0000	12.3	.172	.008	
Maximum	8.1	86	1.46	78	284	163	2.2	34.0	1.18	.03	4.4	72.2	2.32	0.00	.01	0.530	.001	.050	.0003	48	.002	.066	.032	.0018	5	.009	.0001	.002	3.94	.008	.0000	26.6	.306	.037	
Minimum	7.6	50	0.24	38	140	102	1.4	13.3	.76	.00	1.3	24.6	.82	0.00	.00	0.032	.000	.023	.0000	31	.000	.004	.007	.0000	11	.001	.0000	.000	2.00	.000	.0000	8.7	.114	.003	

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WASHINGTON AQUEDUCT DIVISION

U.S. ARMY ENGINEER DISTRICT, BALTIMORE

COMPOSITE ANALYSIS OF WATER
BY DALECARLIA LABORATORY

POTOMAC RIVER RAW WATER SUPPLY

1987	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Total Trihalomethanes ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP (Silvex) ug/l
January	2.4	.0	.0	.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0
February	2.8	.1	.2	.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0
March	1.8	.2	.1	.2	2.4	0.0	0.0	0.0	0.0	0.0	0.0
April	2.1	.4	.3	.3	3.2	0.0	0.0	0.0	0.0	0.0	0.0
May	3.5	.4	.0	.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0
June	3.4	.3	.0	.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0
July	4.4	.4	.0	.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0
August	6.7	1.7	.3	.1	8.8	0.0	0.0	0.0	0.0	0.0	0.0
September	2.3	.8	.3	.3	3.8	0.0	0.0	0.0	0.0	0.0	0.0
October	13.1	1.8	.8	.3	15.9	0.0	0.0	0.0	0.0	0.0	0.0
November	2.8	.3	.1	.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0
December	5.8	.7	.4	.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	4.3	.8	.2	.1	5.3	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	13.1	1.7	.8	.3	15.9	0.0	0.0	0.0	0.0	0.0	0.0
Minimum	1.8	.0	.0	.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0

1987	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Dissolved Oxygen mg/l	Conductivity mohoms/cm	Total Coliform MPN / 100 ml	Fecal Coliform MPN / 100 ml	Fecal Strep MPN / 100 ml	Algae Count Org/ml	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226 - 228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l
January	0.04	8	9.4	323	17418	2478	484	-					
February	0.05	2	8.2	321	547	74	23	-					
March	0.05	8	8.1	282	12850	378	858	-					
April	0.03	14	7.1	243	1138	2415	343	-					
May	0.02	12	7.0	275	3808	380	404	-					
June	0.02	11	7.4	345	33348	185	17298	965					
July	0.03	14	7.7	348	7388	1101	280	882					
August	0.04	9	7.7	445	258	78	21	1088					
September	0.05	10	7.8	330	17278	1448	850	-					
October	0.05	7	9.3	292	1540	224	12	178					
November	0.02	13	9.0	274	13848	810	9	-					
December	0.03	3	7.3	174	58408	2763	428	-					
Average	0.04	9	7.8	304	12384	1064	1736	814					
Maximum	0.05	14	9.4	445	58408	2782	17298	1088					
Minimum	0.02	2	7.0	174	258	74	9	178					

DALECARLIA WATER TREATMENT PLANT FINISHED WATER

1987	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Total Trihalomethanes ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP (Silvex) ug/l
January	14.8	5.1	1.4	.0	21	0.0	0.0	0.0	0.0	0.0	0.0
February	16.9	6.0	1.8	.0	25	0.0	0.0	0.0	0.0	0.0	0.0
March	20.5	7.3	1.9	.2	30	0.0	0.0	0.0	0.0	0.0	0.0
April	24.7	6.4	1.0	.1	32	0.0	0.0	0.0	0.0	0.0	0.0
May	43.5	11.1	1.2	.0	56	0.0	0.0	0.0	0.0	0.0	0.0
June	66.8	15.1	1.9	.0	84	0.0	0.0	0.0	0.0	0.0	0.0
July	102.8	13.8	1.0	.0	118	0.0	0.0	0.0	0.0	0.0	0.0
August	68.8	20.8	2.7	.1	92	0.0	0.0	0.0	0.0	0.0	0.0
September	81.5	15.4	2.3	.3	100	0.0	0.0	0.0	0.0	0.0	0.0
October	53.5	17.8	2.4	.4	74	0.0	0.0	0.0	0.0	0.0	0.0
November	52.8	14.4	1.5	.1	69	0.0	0.0	0.0	0.0	0.0	0.0
December	23.4	10.3	1.9	.1	36	0.0	0.0	0.0	0.0	0.0	0.0
Average	47.7	12.0	1.7	.1	62	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	102.8	20.8	2.7	.4	118	0.0	0.0	0.0	0.0	0.0	0.0
Minimum	14.8	5.1	1.0	.0	21	0.0	0.0	0.0	0.0	0.0	0.0

1987	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Dissolved Oxygen mg/l	Conductivity mohoms/cm	Total Coliform MPN / 100 ml	Fecal Coliform MPN / 100 ml	Fecal Strep MPN / 100 ml	Algae Count Org/ml	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226 - 228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l
January	0.00	3	10.4	342	.40				<1.0	3.8		<0.5	<470
February	0.00	1	8.3	363	.40								
March	0.00	8	8.3	313	.05								
April	0.00	3	8.1	263	.00				<0.9	2.2		<0.7	<530
May	0.00	1	8.1	306	.00								
June	0.00	2	8.2	370	.00								
July	0.00	8	8.3	387	.00				<1.2	3.8		<0.8	<570
August	0.00	5	8.4	470	.00								
September	0.00	6	8.3	356	.00								
October	0.00	6	8.4	313	.38								
November	0.00	9	7.8	306	.0								
December	0.00	0	8.0	202	.0				<1.4	3.1		-	<800
Average	0.00	4	8.4	334	0.10								
Maximum	0.01	9	10.4	470	.40								
Minimum	0.00	0	7.8	202	0								

McMILLAN WATER TREATMENT PLANT FINISHED WATER

1987	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Total Trihalomethanes ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP (Silvex) ug/l
January	14.8	4.7	.9	.0	20	0.0	0.0	0.0	0.0	0.0	0.0
February	17.9	5.5	1.3	.0	25	0.0	0.0	0.0	0.0	0.0	0.0
March	20.9	8.3	2.3	.3	32	0.0	0.0	0.0	0.0	0.0	0.0
April	25.5	7.7	1.4	.1	35	0.0	0.0	0.0	0.0	0.0	0.0
May	41.8	10.8	1.6	.1	54	0.0	0.0	0.0	0.0	0.0	0.0
June	56.7	13.5	1.9	.0	72	0.0	0.0	0.0	0.0	0.0	0.0
July	76.2	15.3	1.7	.1	93	0.0	0.0	0.0	0.0	0.0	0.0
August	46.3	15.7	2.8	.1	66	0.0	0.0	0.0	0.0	0.0	0.0
September	59.4	15.1	2.8	.3	78	0.0	0.0	0.0	0.0	0.0	0.0
October	54.8	18.5	2.5	.4	74	0.0	0.0	0.0	0.0	0.0	0.0
November	48.8	17.8	1.8	.1	68	0.0	0.0	0.0	0.0	0.0	0.0
December	34.0	10.8	1.5	.1	47	0.0	0.0	0.0	0.0	0.0	0.0
Average	41.8	11.8	1.8	.15	56	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	76.2	17.8	2.8	.5	93	0.0	0.0	0.0	0.0	0.0	0.0
Minimum	14.8	4.7	.9	.0	20	0.0	0.0	0.0	0.0	0.0	0.0

1987	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Dissolved Oxygen mg/l	Conductivity mohoms/cm	Total Coliform MPN / 100 ml	Fecal Coliform MPN / 100 ml	Fecal Strep MPN / 100 ml	Algae Count Org/ml	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226 - 228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l
January	0.00	3		320	0				<1.0	2.8		<0.5	<470
February	0.00	3		350	.013								
March	0.00	5		316	0								
April	0.00	1		284	.013				<0.8	<1.8		<0.8	<580
May	0.00	2		290	.014								
June	0.01	1		340	0								
July	0.00	4		352	0				<1.1	<4.4		<0.8	<580
August	0.02	4		405	.23								
September	0.00	3		359	0								
October	0.00	3		317	0								
November	0.00	6		350	0								
December	0.00	0		243	0				<1.3	3.0		-	<990
Average	0.00	3		327	.083								
Maximum	0.02	6		405	.23								
Minimum	0.00	0		243	0								

NAB Form 648 rev. JUNE "86"

W A Dwg No 1001-4 14-4

WASHINGTON AQUEDUCT DIVISION

U.S. ARMY ENGINEER DISTRICT, BALTIMORE

COMPOSITE ANALYSIS OF WATER BY DALECARLIA LABORATORY

POTOMAC RIVER RAW WATER SUPPLY

1988	pH	M.O. Alkalinity as $CaCO_3$	Turbidity	Temperature	Total Solids	Hardness as $CaCO_3$	Chlorine Residual DPD Free	Chloride	Fluoride	Total Dissolved phosphate	Silicates	Sulfates Dissolved	Nitrate Nitrogen	Nitrite Nitrogen	Ammonia Nitrogen	Aluminum	Arsenic	Borium	Cadmium	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Zinc
		mg/l	NTU	°F	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
January	7.8	81	26.2	36	183	110		13.2	.22	*	*	26.1	2.27	.03	.02	.120	.001	.090	.0000	28	.006	.007	3.11	.0041	9	.185	.0000	.005	3.70	.000	.0000	8.7	.080	.014
February	7.7	98	18.0	40	173	98		17.8	.15	.100	8.2	24.0	2.58	.07	.03	.647	.001	.032	.0000	28	.001	.004	.456	.0005	8	.029	.0000	.003	2.13	.000	.0000	7.8	.120	.002
March	8.0	82	12.1	50	138	102		15.1	.16	.053	6.6	27.0	2.12	.08	.07	.130	.000	.028	.0000	28	.001	.002	.250	.0011	7	.034	.0000	.002	2.42	.000	.0000	8.8	.123	.002
April	7.7	98	12.0	58	158	96		12.7	.20	.080	3.9	27.8	1.54	.03	.09	.450	.001	.038	.0000	27	.001	.005	.741	.0008	9	.056	.0000	.004	2.07	.000	.0000	5.2	.098	.004
May	7.6	52	45.5	63	178	87		9.8	.15	.077	7.5	25.8	1.24	.00	.05	.100	.001	.034	.0000	24	.001	.003	.235	.0005	6	.025	.0000	.001	2.03	.001	.0000	5.8	.114	.007
June	7.8	83	11.1	76	198	119		16.6	.21	.076	5.2	32.4	1.94	.00	.02	.082	.000	.028	.0000	35	.000	.003	.480	.0010	7	.058	.0000	.001	2.30	.000	.0000	6.1	.134	.003
July	7.6	90	14.8	82	245	133		25.2	.20	.147	8.2	57.6	1.20	.00	.02	.224	.000	.145	.0000	39	.001	.002	.340	.0016	9	.087	.0000	.003	2.81	.002	.0000	22.5	.240	.003
August	7.8	97	7.1	83	275	147		28.6	.22	.201	7.7	54.5	.94	.00	.03	.302	.000	.051	.0000	38	.001	.003	.197	.0009	10	.071	.0000	.002	3.88	.000	.0000	27.5	.237	.007
September	8.1	95	6.4	72	275	151		27.9	.22	.206	5.8	58.3	1.36	.00	.03	.154	.000	.038	.0000	44	.000	.004	.099	.0003	9	.030	.0000	.002	4.05	.000	.0000	18.0	.280	.001
October	8.3	104	5.4	56	318	173		28.7	.18	.131	2.5	78.7	.49	.00	.04	.180	.000	.034	.0000	50	.000	.003	.195	.0000	11	.020	.0000	.001	1.85	.000	.0000	27.7	.319	.001
November	8.1	93	8.8	51	272	155		28.8	.17	.596	1.6	87.7	.74	.00	.02	.103	.000	.059	.0000	50	.000	.003	.103	.0003	10	.023	.0001	.002	3.80	.000	.0000	25.8	.289	.003
December	8.3	84	5.0	41	228	134		21.7	.18	.117	1.7	45.7	2.09	.00	.03	.256	.000	.030	.0001	39	.003	.002	.798	.0005	8	.023	.0000	.002	2.95	.000	.0000	9.2	.223	.003
Average	7.9	77	14.3	59	220	125		20.5	.19	.183	5.4	43.8	1.54	.02	.04	.227	.000	.039	.0000	36	.001	.003	.378	.0009	9	.048	.0000	.002	2.98	.000	.0000	15.4	.188	.003
Maximum	8.3	104	45.5	83	318	173		28.8	.22	.596	8.2	78.7	2.58	.07	.09	.647	.001	.059	.0001	50	.006	.007	3.11	.0041	11	.185	.0001	.005	4.05	.002	.0000	27.7	.319	.014
Minimum	7.6	52	5.0	36	138	87		9.8	.15	.053	1.6	24.0	.49	.00	.02	.082	.000	.028	.0000	24	.000	.002	.099	.0000	6	.021	.0000	.001	2.03	.000	.0000	5.2	.080	.001

DALECARLIA WATER TREATMENT PLANT FINISHED WATER

1988	pH	M.O. Alkalinity as $CaCO_3$	Turbidity	Temperature	Total Solids	Hardness as $CaCO_3$	Chlorine Residual DPD Free	Chloride	Fluoride	Total Dissolved phosphate	Silicates	Sulfates Checked	Nitrate Nitrogen	Nitrite Nitrogen	Ammonia Nitrogen	Aluminum	Arsenic	Borium	Cadmium	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Zinc
		mg/l	NTU	°F	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
January	8.1	82	.38	39	192	117	1.8	12.0	.97	*	*	37.5	2.13	.03	.00	.048	.001	.057	.0001	34	.001	.003	.011	.0000	7	.004	.0000	.001	2.33	.000	.0000	12.0	.144	.001
February	8.3	88	.32	42	177	110	1.7	20.8	.94	.030	7.1	32.8	2.80	.08	.00	.050	.000	.032	.0000	33	.000	.002	.019	.0000	8	.007	.0000	.001	2.13	.000	.0000	7.8	.126	.001
March	8.4	63	.33	51	150	109	1.6	18.6	1.10	.017	5.7	36.8	2.18	.08	.00	.052	.000	.035	.0000	34	.000	.002	.014	.0012	5	.008	.0000	.002	2.00	.000	.0000	8.8	.131	.001
April	8.2	81	.38	58	164	104	1.7	14.8	.90	.015	4.1	34.8	1.50	.02	.00	.068	.000	.032	.0000	33	.001	.004	.039	.0001	5	.080	.0000	.001	2.18	.001	.0000	6.7	.148	.009
May	8.5	54	.36	64	175	104	1.8	13.8	.83	.088	5.7	36.4	1.43	.00	.01	.065	.000	.029	.0000	31	.000	.003	.013	.0002	6	.004	.0000	.001	2.03	.002	.0000	5.8	.114	.003
June	7.8	80	.31	78	201	128	1.8	20.8	.90	.018	3.8	38.2	1.88	.00	.01	.048	.000	.031	.0000	39	.000	.004	.011	.0008	7	.004	.0000	.002	2.26	.000	.0000	6.1	.139	.001
July	7.8	83	.34	88	287	150	2.0	32.0	.85	.081	5.2	69.6	1.24	.00	.00	.187	.000	.046	.0000	43	.000	.004	.017	.0003	9	.009	.0000	.001	2.73	.000	.0000	13.7	.238	.001
August	7.7	98	.36	82	290	180	2.1	33.2	.96	.035	6.5	80.2	.90	.00	.01	.133	.000	.044	.0000	44	.000	.005	.013	.0006	11	.002	.0000	.001	3.89	.000	.0000	22.3	.307	.002
September	7.8	95	.38	72	292	163	2.2	28.6	.86	.066	5.6	56.8	1.31	.00	.02	.202	.000	.040	.0000	47	.000	.004	.028	.0001	10	.005	.0000	.001	4.02	.000	.0000	18.8	.276	.002
October	7.9	102	.43	58	318	178	2.2	33.5	.71	.031	2.2	85.2	.52	.00	.00	.173	.000	.048	.0000	53	.000	.003	.006	.0005	11	.002	.0000	.000	3.64	.000	.0000	28.0	.347	.000
November	7.9	93	.50	52	283	169	2.2	34.8	.86	.109	1.0	80.9	.78	.00	.00	.122	.000	.034	.0000	50	.000	.003	.022	.0004	10	.002	.0000	.001	3.75	.000	.0000	26.0	.328	.000
December	8.1	81	.58	42	230	143	2.2	23.8	1.08	.042	2.8	50.2	1.83	.00	.02	.182	.000	.047	.0000	43	.002	.010	.022	.0006	8	.002	*	.001	2.96	.000	.0000	10.0	.188	.000
Average	8.0	79	.40	60	229	136	2.0	23.9	.90	.042	4.8	51.8	1.55	.02	.01	.118	.000	.039	.0000	40	.000	.004	.018	.0004	8	.008	.0000	.001	2.83	.000	.0000	13.8	.195	.001
Maximum	8.4	102	.52	82	318	178	2.2	34.8	1.10	.109	7.1	85.2	2.60	.08	.02	.237	.000	.057	.0001	53	.002	.010	.039	.0012	11	.020	.0000	.002	4.02	.002	.0000	26.0	.347	.003
Minimum	7.5	54	.31	39	150	104	1.8	12.0	.71	.010	1.0	32.8	.52	.00	.00	.048	.000	.029	.0000	31	.000	.002	.006	.0000	5	.002	.0000	.000	2.00	.000	.0000	5.8	.144	.000

McMILLAN WATER TREATMENT PLANT FINISHED WATER

1988	pH	M.O. Alkalinity as $CaCO_3$	Turbidity	Temperature	Total Solids	Hardness as $CaCO_3$	Chlorine Residual DPD Free	Chloride	Fluoride	Total Dissolved phosphate	Silicates	Sulfates Dissolved	Nitrate Nitrogen	Nitrite Nitrogen	Ammonia Nitrogen	Aluminum	Arsenic	Borium	Cadmium	Calcium	Chromium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Zinc
		mg/l	NTU	°F	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
January	8.2	82	.32	38	187	119	1.7	10.2	1.08	*	*	38.9	1.85	.05	.00	.049	.000	.034	.0000	34	.000	.007	.008	.0000	8	.006	.0000	.001	2.14	.000	.0000	10.2	.150	.002
February	8.2	40	.31	38	189	109	1.8	20.2	1.02	.010	7.1	37.2	2.31	.07	.00	.118	.000	.033	.0000	31	.000	.007	.016	.0000	6	.013	.0000	.001	2.32	.000	.0000	9.2	.119	.002
March	8.4	53	.28	44	148	109	1.8	18.3	1.04	.017	6.7	38.1	2.43	.08	.00	.040	.000	.029	.0000	33	.000	.005	.010	.0008	6	.003	.0000	.001	2.80	.000	.0000	8.8	.148	.002
April	8.2	54	.31	53	173	108	1.7	18.2	1.06	.020	4.3	37.8	1.57	.02	.00	.075	.000	.028	.0000	31	.001	.007	.015	.0001	6	.003	.0000	.001	2.31	.001	.0000	8.4	.149	.008
May	8.4	50	.30	60	174	103	1.8	14.7	.88	.010	5.1	36.3	1.46	.00	.01	.064	.000	.032	.0000	30	.000	.018	.020	.0004	8	.001	.0000	.001	1.98	.001	.0000	5.2	.111	.008
June	8.1	68	.47	69	184	118	1.8	20.5	1.03	.018	5.4	38.3	1.81	.00	.01	.044	.000	.033	.0000	38	.000	.040	.013	.0003	6	.002	.0000	.001	2.85	.001	.0000	4.7	.097	.008
July	7.8	88	.48	78	265	148	1.9	33.5	1.02	.070	4.4	68.1	1.13	.00	.00	.187	.000	.048	.0000	42	.000	.085	.014	.0001	10	.005	.0000	.001	2.59	.000	.0000	11.2	.231	.003
August	7.8	89	.48	79	298	154	2.0	36.1	.98	.029	6.8	61.6	.88	.00	.01	.200	.000	.044	.0000	43	.000	.082	.008	.0010	10	.005	.0000	.008	4.08	.000	.0000	18.6	.288	.003
September	7.9	91	.44	72	291	157	2.1	36.5	.98	.044	4.8	66.2	1.20	.00	.02	.104	.000	.033	.0000	47	.000	.098	.003	.0000	9	.002	.0000	.002	3.70	.000	.0000	23.7	.36	.008
October	7.8	98	.36	63	313	177	2.1	32.4	.91	.028	5.1	84.1	.50	.00	.03	.112	.000	.044	.0000	51	.000	.034	.007	.0000	12	.002	.0000	.001	3.43	.000	.0000	20.8	.282	.008
November	7.8	93	.35	54	305	178	2.1	35.8	.98	.041	1.0	87.6	.57	.00	.00	.057	.000	.039	.0000	51	.000	.036	.012	.0005	11	.001	.0000	.001	3.68	.000	.0000	23.2	.288	.002
December	8.1	78	.38	44	234	140	2.1	23.3	.98	.038	3.5	48.9	1.98	.00	.02	.052	.000	.030	.0000	48	.003	.015	.023	.0004	8	.002	.0000	.002	3.60	.000	.0000	10.4	.190	.002
Average	8.1	73	.37	58	228	135	1.9	25.1	.98	.029	4.4	53.9	1.48	.02	.01	.092	.000	.035	.0000	38	.000	.034	.012	.0003	8	.004	.0000	.001	2.94	.000	.0000	12.8	.188	.008
Maximum	8.4	98	.48	79	313	179	2.1	36.5	1.08	.070	7.1	87.8	2.43	.07	.03	.200	.000	.048	.0000	51	.003	.098	.023	.0010	12	.013	.0000	.002	4.08	.001	.0000	23.2	.36	.008
Minimum	7.8	49	.28	38	148	103	1.6	10.2	.88	.010	1.0	37.2	.50	.00	.00	.040	.000	.028	.0000	30	.000	.005	.002	.0000	6	.001	.0000	.001	1.99	.000	.0000	4.7	.097	.002

NAB Form 648 rev. JUNE "86"

* No Data

W. A. Dwg. No. 100.1-4.14-5

WASHINGTON AQUEDUCT DIVISION

U.S. ARMY ENGINEER DISTRICT, BALTIMORE

COMPOSITE ANALYSIS OF WATER
BY DALECARLIA LABORATORY

POTOMAC RIVER RAW WATER SUPPLY

1988	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Total Trihalomethanes ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP (Silvex) ug/l	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Dissolved Oxygen mg/l	Conductivity mohms/cm	Total Coliform MPN/100 ml	Fecal Coliform MPN/100 ml	Fecal Strep MPN/100 ml	Algae Count Org/ml	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226-228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l
January	2.2	.2	.2	.0	2.8	.0	.0	.0	.0	.0	.0	*	10	8.6	143	23000	1101	417						
February	4.0	.4	.2	.1	4.7	.0	.0	.0	.0	.0	.0	.08	13	8.2	135	38472	2201	209						
March	2.0	.7	.5	.0	3.2	.0	.0	.0	.0	.0	.0	.04	5	8.6	177	14980	256	44						
April	3.1	.4	.3	.1	6.1	.0	.0	.0	.0	.0	.0	.02	9	8.8	187	1131	137	15						
May	5.5	.4	.1	.0	6.0	.0	.0	.0	.0	.0	.0	.04	23	8.3	163	215084	27430	2083						
June	15.6	.6	.1	.0	16.3	.0	.0	.0	.0	.0	.0	.04	29	7.8	279	3428	44	7	1332					
July	11.2	.5	.1	.0	11.7	.0	.0	.0	.0	.0	.0	.03	21	7.1	388	3000	280	84	2280					
August	10.8	1.1	.1	.0	12.0	.0	.0	.0	.0	.0	.0	.04	11	7.8	419	1248	28	28	5364					
September	14.8	1.8	.2	.0	16.8	.0	.0	.0	.0	.0	.0	.01	4	9.2	344	818	32	45						
October	7.5	1.3	.0	.1	11.6	.0	.0	.0	.0	.0	.0	.02	8	9.0	390	177	41	22						
November	1.7	.4	.0	.0	2.1	.0	.0	.0	.0	.0	.0	.00	1	8.6	303	2708	205	338						
December	.4	.1	.2	.0	.7	.0	.0	.0	.0	.0	.0	.04	6	9.7	220	1256	10	11						
Average	6.7	.7	.2	.0	7.8	.0	.0	.0	.0	.0	.0	.03	12	8.5	283	25290	2854	325	2884					
Maximum	14.8	1.8	.5	.1	16.8	.0	.0	.0	.0	.0	.0	.08	29	9.7	419	215084	27430	2083	5364					
Minimum	.4	.1	.0	.0	.7	.0	.0	.0	.0	.0	.0	.00	1	7.1	143	177	10	7	1333					

DALECARLIA WATER TREATMENT PLANT FINISHED WATER

1988	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Total Trihalomethanes ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP (Silvex) ug/l	Benzene ug/l	Carbon Tetrachloride ug/l	1,2 Dichloroethylene ug/l	Trichloroethylene ug/l	Para-Dichlorobenzene ug/l	1,1-Dichloroethylene ug/l	1,1,1-Trichloroethane ug/l	Vinyl Chloride ug/l
January	19.6	6.7	1.8	.1	28	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
February	28.1	10.1	2.2	.0	40	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
March	23.6	10.0	3.1	.1	37	.0	.0	.0	.0	.0	.0								
April	44.6	11.4	2.2	.0	58	.0	.0	.0	.0	.0	.0								
May	46.4	8.6	1.4	.1	57	.0	.0	.0	.0	.0	.0								
June	44.2	12.4	1.8	.0	58	.0	.0	.0	.0	.0	.0								
July	66.0	14.5	1.1	.0	83	.0	.0	.0	.0	.0	.0								
August	83.6	21.4	1.9	.1	107	.0	.0	.0	.0	.0	.0								
September	44.5	15.4	1.2	.1	61	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
October	38.2	13.1	1.4	.0	48	.0	.0	.0	.0	.0	.0								
November	33.4	7.7	1.6	.0	43	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
December	64.0	15.5	4.4	.0	84	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
Average	44.5	12.3	2.0	.0	59	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
Maximum	83.6	21.4	4.4	.1	107	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
Minimum	19.6	6.7	1.1	.0	28	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND

1988	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Dissolved Oxygen mg/l	Conductivity mohms/cm	Total Coliform MPN/100 ml	Fecal Coliform MPN/100 ml	Fecal Strep MPN/100 ml	Algae Count Org/ml	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226-228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l
January	*	4	10.1	175	.00				< 1.3	2.1		< 0.8	< 300
February	.01	6	9.4	183	.00								
March	.01	3	9.3	203	.00								
April	.01	4	9.1	215	.00				< 1.2	2.1		< 0.8	< 310
May	.00	6	8.9	208	.00								
June	.01	9	8.3	305	.00								
July	.03	9	7.9	400	.00				< 3.2	3.1		< 0.6	< 300
August	.02	8	7.9	446	.00								
September	.00	5	9.3	394	.00								
October	.02	3	9.2	410	.00								
November	.00	9	9.2	348	.00				< 2.4	3.1		< 0.7	< 300
December	.08	6	10.4	247	.00								
Average	.02	7	9.1	296	.00				< 2.0	2.6		< .65	< 302
Maximum	.08	9	10.4	446	.00				< 3.2	3.1		< .7	< 310
Minimum	.00	3	7.9	175	.00				< 1.2	2.1		< .6	< 300

McMILLAN WATER TREATMENT PLANT FINISHED WATER

1988	Chloroform ug/l	Bromodichloromethane ug/l	Chlorodibromomethane ug/l	Bromoform ug/l	Total Trihalomethanes ug/l	Endrin ug/l	Lindane ug/l	Methoxychlor ug/l	Toxaphene ug/l	2,4-D ug/l	2,4,5-TP (Silvex) ug/l	Benzene ug/l	Carbon Tetrachloride ug/l	1,2 Dichloroethylene ug/l	Trichloroethylene ug/l	Para-Dichlorobenzene ug/l	1,1-Dichloroethylene ug/l	1,1,1-Trichloroethane ug/l	Vinyl Chloride ug/l
January	23.7	7.2	1.7	.0	33	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
February	24.6	8.8	2.0	.1	35	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
March	28.7	9.6	2.5	.1	38	.0	.0	.0	.0	0	.0								
April	42.3	11.3	2.2	.0	56	.0	.0	.0	.0	.0	.0								
May	66.6	10.2	1.4	.1	78	.0	.0	.0	.0	.0	.0								
June	44.6	10.7	1.6	.0	57	.0	.0	.0	.0	.0	.0								
July	78.0	16.9	1.5	.0	96	.0	.0	.0	.0	.0	.0								
August	86.0	20.2	2.5	.2	108	.0	.0	.0	.0	.0	.0								
September	54.1	16.6	1.3	.1	72	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
October	25.9	12.2	2.0	.1	40	.0	.0	.0	.0	.0	.0								
November	56.9	12.4	2.2	.0	71	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
December	40.7	13.1	4.2	.0	67	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
Average	47.8	11.6	2.1	.1	63	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
Maximum	86.0	20.2	4.2	.2	109	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND
Minimum	23.7	7.2	1.3	.0	33	.0	.0	.0	.0	.0	.0	< ND	< ND	< ND	< ND	< ND	< ND	< ND	< ND

1988	Methylene Blue Active Substances mg/l	Chemical Oxygen Demand mg/l	Dissolved Oxygen mg/l	Conductivity mohms/cm	Total Coliform MPN/100 ml	Fecal Coliform MPN/100 ml	Fecal Strep MPN/100 ml	Algae Count Org/ml	Gross Alpha pCi/l	Gross Beta pCi/l	Radium 226-228 pCi/l	Strontium-90 pCi/l	Tritium pCi/l
January	*	2		213	.00				< 1.3	2.5		< 0.7	< 300
February	0.1	1		197	.00								
March	.02	5		209	.00								
April	.01	4		204	.00				< 1.3	1.7		< 0.8	< 190
May	.00	8		205	.00								
June	.02	12		209	.00								
July	.03	6		284	.00				< 3.2	2.9		< 0.6	< 370
August	.01	7		398	.00								
September	.01	5		374	.00								
October	.02	3		383	.00								
November	.00	9		388	.00				< 2.4	3.8		< 0.7	< 400
December	.02	10		272	.00								
Average	.02	6		290	.00				< 2.1	2.73		< .69	< 320
Maximum	.03	12		398	.00				< 3.2	3.8		< .7	< 370
Minimum	.00	1		197	.00				< 1.3	1.7		< .6	< 400

NAB Form 648 rev. JUNE "86"

ND= Less than delectable limit (0.5 ug / l)

* No Data

W A Dwj No 1001-4 14 4

APPENDIX D

SUMMARY SPREADSHEET
OF SERVICE LINE INSTALLATION

YEAR	WARD 1 TOTAL SERVICES	WARD 1 KNOWN SERVICES	WARD 1 UNKNOWN SERVICES	WARD 1 % KNOWN	WARD 1 LEAD SERVICES	WARD 1 % LEAD	WARD 1 ASSUM: LEAD	WARD 1 TOTAL LEAD	WARD 2 TOTAL SERVICES	WARD 2 KNOWN SERVICES	WARD 2 UNKNOWN SERVICES	WARD 2 % KNOWN	WARD 2 LEAD SERVICES	WARD 2 % LEAD	WARD 2 ASSUM: LEAD	WARD 2 TOTAL LEAD
1900	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1901	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1902	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1903	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1904	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1905	0	0	0	0.00	0	0.00	0	0	1	1	0	1.00	0	0.00	0	0
1906	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1907	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1908	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1909	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1910	0	0	0	0.00	0	0.00	0	0 **	0	0	0	0.00	0	0.00	0	0 **
1911	5260	1090	4170	0.21	356	0.33	1362	1718	4387	872	3515	0.20	196	0.22	790	986
1912	159	15	144	0.09	14	0.93	134	148	101	1	100	0.01	0	0.00	0	0
1913	464	61	403	0.13	7	0.11	46	53	162	7	155	0.04	1	0.14	22	23
1914	324	33	291	0.10	9	0.27	79	88	110	6	104	0.05	0	0.00	0	0
1915	319	42	277	0.13	4	0.10	26	30	142	10	132	0.07	4	0.40	53	57
1916	180	16	164	0.09	5	0.31	51	56	141	12	129	0.09	2	0.17	22	24
1917	68	12	56	0.18	3	0.25	14	17	86	4	82	0.05	0	0.00	0	0
1918	46	7	39	0.15	0	0.00	0	0	105	11	94	0.10	3	0.27	26	29
1919	157	47	110	0.30	8	0.17	19	27	76	9	67	0.12	4	0.44	30	34
1920	156	43	113	0.28	12	0.28	32	44 **	82	4	78	0.05	2	0.50	39	41 **
1921	239	101	138	0.42	26	0.26	36	62	92	12	80	0.13	4	0.33	27	31
1922	293	74	219	0.25	18	0.24	53	71	170	21	149	0.12	3	0.14	21	24
1923	264	105	159	0.40	27	0.26	41	68	230	58	172	0.25	10	0.17	30	40
1924	179	55	124	0.31	9	0.16	20	29	263	33	230	0.13	2	0.06	14	16
1925	180	74	106	0.41	13	0.18	19	32	209	39	170	0.19	2	0.05	9	11
1926	213	145	68	0.68	12	0.08	6	18	161	76	85	0.47	6	0.08	7	13
1927	73	52	21	0.71	21	0.40	8	29	174	111	63	0.64	46	0.41	26	72
1928	72	59	13	0.82	27	0.46	6	33	111	89	22	0.80	39	0.44	10	49
1929	67	54	13	0.81	14	0.26	3	17	77	45	32	0.58	10	0.22	7	17
1930	40	30	10	0.75	6	0.20	2	8 **	81	70	11	0.86	18	0.26	3	21 **
1931	52	48	4	0.92	3	0.06	0	3	80	57	23	0.71	13	0.23	5	18
1932	42	36	6	0.86	3	0.08	1	4	67	44	23	0.66	10	0.23	5	15
1933	44	41	3	0.93	0	0.00	0	0	68	51	17	0.75	4	0.08	1	5
1934	14	14	0	1.00	1	0.07	0	1	87	75	12	0.86	10	0.13	2	12
1935	50	47	3	0.94	1	0.02	0	1	117	95	22	0.81	8	0.08	2	10
1936	62	57	5	0.92	0	0.00	0	0	192	165	27	0.86	8	0.05	1	9
1937	88	77	11	0.88	1	0.01	0	1	148	134	14	0.91	4	0.03	0	4
1938	70	65	5	0.93	0	0.00	0	0	131	117	14	0.89	5	0.04	1	6

YEAR	WARD 1 TOTAL SERVICES	WARD 1 KNOWN SERVICES	WARD 1 UNKNOWN SERVICES	WARD 1 % KNOWN	WARD 1 LEAD SERVICES	WARD 1 % LEAD	WARD 1 ASSUM: LEAD	WARD 1 TOTAL LEAD	WARD 2 TOTAL SERVICES	WARD 2 KNOWN SERVICES	WARD 2 UNKNOWN SERVICES	WARD 2 % KNOWN	WARD 2 LEAD SERVICES	WARD 2 % LEAD	WARD 2 ASSUM: LEAD	WARD 2 TOTAL LEAD
1939	72	67	5	0.93	1	0.01	0	1	151	137	14	0.91	1	0.01	0	1
1940	49	46	3	0.94	0	0.00	0	0 **	188	171	17	0.91	3	0.02	0	3 **
1941	86	82	4	0.95	1	0.01	0	1	272	238	34	0.88	3	0.01	0	3
1942	14	9	5	0.64	0	0.00	0	0	139	117	22	0.84	8	0.07	2	10
1943	51	50	1	0.98	6	0.12	0	6	56	55	1	0.98	18	0.33	0	18
1944	19	16	3	0.84	8	0.50	2	10	73	66	7	0.90	37	0.56	4	41
1945	18	18	0	1.00	5	0.28	0	5	80	73	7	0.91	15	0.21	1	16
1946	34	32	2	0.94	4	0.13	0	4	153	140	13	0.92	21	0.15	2	23
1947	103	56	47	0.54	2	0.04	2	4	319	174	145	0.55	3	0.02	3	6
1948	45	44	1	0.98	0	0.00	0	0	154	134	20	0.87	0	0.00	0	0
1949	37	23	14	0.62	0	0.00	0	0	161	140	21	0.87	0	0.00	0	0
1950	54	49	5	0.91	1	0.02	0	1 **	171	132	39	0.77	0	0.00	0	0 **
1951	52	38	14	0.73	0	0.00	0	0	146	113	33	0.77	0	0.00	0	0
1952	46	37	9	0.80	0	0.00	0	0	97	78	19	0.80	0	0.00	0	0
1953	35	31	4	0.89	0	0.00	0	0	134	100	34	0.75	1	0.01	0	1
1954	43	34	9	0.79	0	0.00	0	0	135	111	24	0.82	3	0.03	1	4
1955	25	23	2	0.92	0	0.00	0	0	146	122	24	0.84	0	0.00	0	0
1956	22	18	4	0.82	0	0.00	0	0	146	115	31	0.79	0	0.00	0	0
1957	32	27	5	0.84	0	0.00	0	0	195	147	48	0.75	0	0.00	0	0
1958	67	58	9	0.87	3	0.05	0	3	253	223	30	0.88	2	0.01	0	2
1959	131	122	9	0.93	5	0.04	0	5	211	180	31	0.85	2	0.01	0	2
1960	49	46	3	0.94	1	0.02	0	1 **	193	156	37	0.81	1	0.01	0	1 **
1961	34	32	2	0.94	1	0.03	0	1	172	128	44	0.74	1	0.01	0	1
1962	39	26	13	0.67	0	0.00	0	0	204	151	53	0.74	3	0.02	1	4
1963	34	25	9	0.74	0	0.00	0	0	170	119	51	0.70	1	0.01	0	1
1964	79	67	12	0.85	1	0.01	0	1	198	134	64	0.68	0	0.00	0	0
1965	43	35	8	0.81	0	0.00	0	0	223	182	41	0.82	1	0.01	0	1
1966	39	33	6	0.85	1	0.03	0	1	237	194	43	0.82	1	0.01	0	1
1967	17	14	3	0.82	0	0.00	0	0	347	311	36	0.90	2	0.01	0	2
1968	26	23	3	0.88	0	0.00	0	0	183	139	44	0.76	0	0.00	0	0
1969	126	78	48	0.62	0	0.00	0	0	106	57	49	0.54	0	0.00	0	0
1970	31	3	28	0.10	1	0.33	9	10 **	107	5	102	0.05	0	0.00	0	0 **
1971	46	2	44	0.04	0	0.00	0	0	160	15	145	0.09	0	0.00	0	0
1972	24	1	23	0.04	1	1.00	23	24	157	2	155	0.01	0	0.00	0	0
1973	127	11	116	0.09	2	0.18	21	23	239	9	230	0.04	2	0.22	51	53
1974	36	3	33	0.08	0	0.00	0	0	170	10	160	0.06	1	0.10	16	17
1975	13	0	13	0.00	0	0.00	0	0	158	1	157	0.01	0	0.00	0	0
1976	24	0	24	0.00	0	0.00	0	0	90	10	80	0.11	0	0.00	0	0
1977	43	0	43	0.00	0	0.00	0	0	174	10	164	0.06	1	0.10	16	17

YEAR	WARD 1 TOTAL SERVICES	WARD 1 KNOWN SERVICES	WARD 1 UNKNOWN SERVICES	WARD 1 % KNOWN	WARD 1 LEAD SERVICES	WARD 1 % LEAD	WARD 1 ASSUM: LEAD	WARD 1 TOTAL LEAD	WARD 2 TOTAL SERVICES	WARD 2 KNOWN SERVICES	WARD 2 UNKNOWN SERVICES	WARD 2 % KNOWN	WARD 2 LEAD SERVICES	WARD 2 % LEAD	WARD 2 ASSUM: LEAD	WARD 2 TOTAL LEAD
1978	22	0	22	0.00	0	0.00	0	0	101	5	96	0.05	0	0.00	0	0
1979	20	0	20	0.00	0	0.00	0	0	33	0	33	0.00	0	0.00	0	0
1980	0	0	0	0.00	0	0.00	0	0 **	0	0	0	0.00	0	0.00	0	0 **
1981	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1982	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1983	0	0	0	0.00	0	0.00	0	0	1	0	1	0.00	0	0.00	0	0
1984	0	0	0	0.00	0	0.00	0	0	1	0	1	0.00	0	0.00	0	0
1985	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1986	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1987	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1988	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1989	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
TOTAL	11082	3779	7303	0.34	644		2017	2661	14655	6633	8022	0.45	545		1252	1797

YEAR	WARD 3 TOTAL SERVICES	WARD 3 KNOWN SERVICES	WARD 3 UNKNOWN SERVICES	WARD 3 % KNOWN	WARD 3 LEAD SERVICES	WARD 3 % LEAD	WARD 3 ASSUM LEAD	WARD 3 TOTAL LEAD	WARD 4 TOTAL SERVICES	WARD 4 KNOWN SERVICES	WARD 4 UNKNOWN SERVICES	WARD 4 % KNOWN	WARD 4 LEAD SERVICES	WARD 4 % LEAD	WARD 4 ASSUM LEAD	WARD 4 TOTAL LEAD
1900	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1901	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1902	0	0	0	0.00	0	0.00	0	0	1	0	1	0.00	0	0.00	0	0
1903	0	0	0	0.00	0	0.00	0	0	11	3	8	0.27	0	0.00	0	0
1904	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1905	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1906	0	0	0	0.00	0	0.00	0	0	1	0	1	0.00	0	0.00	0	0
1907	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1908	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1909	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1910	0	0	0	0.00	0	0.00	0	0 **	0	0	0	0.00	0	0.00	0	0 **
1911	619	254	365	0.41	72	0.28	103	175	936	255	681	0.27	97	0.38	259	356
1912	69	6	63	0.09	1	0.17	11	12	56	15	41	0.27	2	0.13	5	7
1913	103	16	87	0.16	2	0.13	11	13	156	22	134	0.14	2	0.09	12	14
1914	97	14	83	0.14	0	0.00	0	0	182	20	162	0.11	4	0.20	32	36
1915	146	41	105	0.28	3	0.07	8	11	276	32	244	0.12	4	0.13	31	35
1916	131	35	96	0.27	2	0.06	5	7	384	48	336	0.13	9	0.19	63	72
1917	69	15	54	0.22	1	0.07	4	5	151	18	133	0.12	1	0.06	7	8
1918	100	27	73	0.27	0	0.00	0	0	228	32	196	0.14	5	0.16	31	36
1919	172	84	88	0.49	18	0.21	19	37	479	131	348	0.27	40	0.31	106	146
1920	118	49	69	0.42	9	0.18	13	22 **	379	121	258	0.32	32	0.26	68	100 **
1921	258	104	154	0.40	23	0.22	34	57	487	175	312	0.36	43	0.25	77	120
1922	455	195	260	0.43	67	0.34	89	156	1008	333	675	0.33	100	0.30	203	303
1923	614	334	280	0.54	98	0.29	82	180	794	263	531	0.33	95	0.36	192	287
1924	709	366	343	0.52	91	0.25	85	176	766	269	497	0.35	96	0.36	177	273
1925	897	556	341	0.62	81	0.15	50	131	1426	700	726	0.49	135	0.19	140	275
1926	871	641	230	0.74	104	0.16	37	141	1107	829	278	0.75	120	0.14	40	160
1927	588	519	69	0.88	180	0.35	24	204	576	507	69	0.88	141	0.28	19	160
1928	555	529	26	0.95	321	0.61	16	337	324	320	4	0.99	120	0.38	2	122
1929	439	421	18	0.96	219	0.52	9	228	502	495	7	0.99	308	0.62	4	312
1930	416	403	13	0.97	161	0.40	5	166 **	335	331	4	0.99	139	0.42	2	141 **
1931	510	499	11	0.98	232	0.46	5	237	549	530	19	0.97	213	0.40	8	221
1932	275	264	11	0.96	64	0.24	3	67	410	406	4	0.99	136	0.33	1	137
1933	255	245	10	0.96	50	0.20	2	52	198	193	5	0.97	38	0.20	1	39
1934	277	272	5	0.98	31	0.11	1	32	225	225	0	1.00	25	0.11	0	25
1935	601	595	6	0.99	37	0.06	0	37	707	704	3	1.00	32	0.05	0	32
1936	701	687	14	0.98	7	0.01	0	7	749	738	11	0.99	10	0.01	0	10
1937	679	676	3	1.00	11	0.02	0	11	448	448	0	1.00	8	0.02	0	8
1938	655	650	5	0.99	1	0.00	0	1	271	269	2	0.99	1	0.00	0	1

YEAR	WARD 3 TOTAL SERVICES	WARD 3 KNOWN SERVICES	WARD 3 UNKNOWN SERVICES	WARD 3 % KNOWN	WARD 3 LEAD SERVICES	WARD 3 % LEAD	WARD 3 ASSUM LEAD	WARD 3 TOTAL LEAD	WARD 4 TOTAL SERVICES	WARD 4 KNOWN SERVICES	WARD 4 UNKNOWN SERVICES	WARD 4 % KNOWN	WARD 4 LEAD SERVICES	WARD 4 % LEAD	WARD 4 ASSUM LEAD	WARD 4 TOTAL LEAD
1939	772	768	4	0.99	6	0.01	0	6	412	406	6	0.99	3	0.01	0	3
1940	731	722	9	0.99	3	0.00	0	3 **	388	387	1	1.00	2	0.01	0	2 **
1941	676	660	16	0.98	2	0.00	0	2	376	370	6	0.98	0	0.00	0	0
1942	104	100	4	0.96	28	0.28	1	29	100	100	0	1.00	0	0.00	0	0
1943	36	32	4	0.89	22	0.69	3	25	89	89	0	1.00	6	0.07	0	6
1944	15	15	0	1.00	11	0.73	0	11	4	3	1	0.75	2	0.67	1	3
1945	26	26	0	1.00	4	0.15	0	4	20	20	0	1.00	1	0.05	0	1
1946	108	105	3	0.97	17	0.16	0	17	84	83	1	0.99	10	0.12	0	10
1947	157	153	4	0.97	0	0.00	0	0	371	362	9	0.98	0	0.00	0	0
1948	247	244	3	0.99	0	0.00	0	0	261	256	5	0.98	0	0.00	0	0
1949	253	237	16	0.94	9	0.04	1	10	318	315	3	0.99	0	0.00	0	0
1950	359	353	6	0.98	0	0.00	0	0 **	547	539	8	0.99	1	0.00	0	1 **
1951	254	249	5	0.98	1	0.00	0	1	551	548	3	0.99	1	0.00	0	1
1952	254	247	7	0.97	0	0.00	0	0	291	289	2	0.99	0	0.00	0	0
1953	218	205	13	0.94	0	0.00	0	0	154	145	9	0.94	0	0.00	0	0
1954	250	238	12	0.95	0	0.00	0	0	159	156	3	0.98	0	0.00	0	0
1955	281	268	13	0.95	0	0.00	0	0	150	144	6	0.96	0	0.00	0	0
1956	138	131	7	0.95	1	0.01	0	1	105	100	5	0.95	0	0.00	0	0
1957	144	129	15	0.90	0	0.00	0	0	64	59	5	0.92	0	0.00	0	0
1958	158	144	14	0.91	1	0.01	0	1	115	111	4	0.97	0	0.00	0	0
1959	193	173	20	0.90	0	0.00	0	0	149	139	10	0.93	6	0.04	0	6
1960	113	106	7	0.94	0	0.00	0	0 **	113	113	0	1.00	0	0.00	0	0 **
1961	103	98	5	0.95	2	0.02	0	2	68	65	3	0.96	0	0.00	0	0
1962	85	79	6	0.93	0	0.00	0	0	49	45	4	0.92	0	0.00	0	0
1963	91	81	10	0.89	0	0.00	0	0	51	47	4	0.92	0	0.00	0	0
1964	97	80	17	0.82	2	0.03	0	2	64	54	10	0.84	0	0.00	0	0
1965	82	70	12	0.85	0	0.00	0	0	53	49	4	0.92	1	0.02	0	1
1966	42	36	6	0.86	0	0.00	0	0	51	48	3	0.94	1	0.02	0	1
1967	59	53	6	0.90	1	0.02	0	1	12	11	1	0.92	0	0.00	0	0
1968	47	43	4	0.91	0	0.00	0	0	51	48	3	0.94	0	0.00	0	0
1969	47	32	15	0.68	0	0.00	0	0	13	10	3	0.77	0	0.00	0	0
1970	42	5	37	0.12	0	0.00	0	0 **	15	0	15	0.00	0	0.00	0	0 **
1971	22	1	21	0.05	0	0.00	0	0	15	0	15	0.00	0	0.00	0	0
1972	23	4	19	0.17	0	0.00	0	0	14	1	13	0.07	0	0.00	0	0
1973	42	6	36	0.14	0	0.00	0	0	10	1	9	0.10	0	0.00	0	0
1974	55	2	53	0.04	0	0.00	0	0	19	1	18	0.05	0	0.00	0	0
1975	30	2	28	0.07	0	0.00	0	0	9	0	9	0.00	0	0.00	0	0
1976	75	6	69	0.08	0	0.00	0	0	22	4	18	0.18	0	0.00	0	0
1977	79	12	67	0.15	1	0.08	6	7	24	3	21	0.13	0	0.00	0	0

YEAR	WARD 3								WARD 4							
	TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM LEAD	TOTAL LEAD	TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM LEAD	TOTAL LEAD
1978	68	7	61	0.10	0	0.00	0	0	33	11	22	0.33	0	0.00	0	0
1979	41	4	37	0.10	0	0.00	0	0	2	0	2	0.00	0	0.00	0	0
1980	0	0	0	0.00	0	0.00	0	0 **	0	0	0	0.00	0	0.00	0	0 **
1981	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1982	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1983	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1984	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1985	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1986	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1987	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1988	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1989	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
TOTAL	17996	14423	3573	0.80	1997		628	2625	19518	13564	5954	0.69	1990		1482	3472

WARD 5

YEAR	TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM: LEAD	TOTAL LEAD
1900	0	0	0	0.00	0	0.00	0	0
1901	0	0	0	0.00	0	0.00	0	0
1902	0	0	0	0.00	0	0.00	0	0
1903	0	0	0	0.00	0	0.00	0	0
1904	0	0	0	0.00	0	0.00	0	0
1905	0	0	0	0.00	0	0.00	0	0
1906	0	0	0	0.00	0	0.00	0	0
1907	0	0	0	0.00	0	0.00	0	0
1908	0	0	0	0.00	0	0.00	0	0
1909	0	0	0	0.00	0	0.00	0	0
1910	0	0	0	0.00	0	0.00	0	0 **
1911	3003	660	2343	0.22	230	0.35	817	1047
1912	109	3	106	0.03	2	0.67	71	73
1913	175	14	161	0.08	4	0.29	46	50
1914	144	15	129	0.10	4	0.27	34	38
1915	210	22	188	0.10	7	0.32	60	67
1916	200	36	164	0.18	4	0.11	18	22
1917	163	46	117	0.28	13	0.28	33	46
1918	80	23	57	0.29	7	0.30	17	24
1919	119	31	88	0.26	4	0.13	11	15
1920	119	32	87	0.27	10	0.31	27	37 **
1921	232	84	148	0.36	22	0.26	39	61
1922	392	137	255	0.35	44	0.32	82	126
1923	475	179	296	0.38	52	0.29	86	138
1924	735	282	453	0.38	73	0.26	117	190
1925	1326	715	611	0.54	108	0.15	92	200
1926	823	635	188	0.77	51	0.08	15	66
1927	421	391	30	0.93	98	0.25	8	106
1928	241	230	11	0.95	111	0.48	5	116
1929	285	276	9	0.97	108	0.39	4	112
1930	216	206	10	0.95	34	0.17	2	36 **
1931	358	350	8	0.98	63	0.18	1	64
1932	129	124	5	0.96	24	0.19	1	25
1933	63	62	1	0.98	5	0.08	0	5
1934	97	95	2	0.98	5	0.05	0	5
1935	277	273	4	0.99	3	0.01	0	3
1936	388	384	4	0.99	8	0.02	0	8
1937	525	517	8	0.98	4	0.01	0	4
1938	375	373	2	0.99	1	0.00	0	1

WARD 6

YEAR	TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM: LEAD	TOTAL LEAD
1900	0	0	0	0.00	0	0.00	0	0
1901	0	0	0	0.00	0	0.00	0	0
1902	0	0	0	0.00	0	0.00	0	0
1903	0	0	0	0.00	0	0.00	0	0
1904	0	0	0	0.00	0	0.00	0	0
1905	0	0	0	0.00	0	0.00	0	0
1906	0	0	0	0.00	0	0.00	0	0
1907	0	0	0	0.00	0	0.00	0	0
1908	0	0	0	0.00	0	0.00	0	0
1909	0	0	0	0.00	0	0.00	0	0
1910	0	0	0	0.00	0	0.00	0	0 **
1911	6630	1835	4795	0.28	441	0.24	1152	1593
1912	121	13	108	0.11	2	0.15	17	19
1913	247	23	224	0.09	1	0.04	10	11
1914	284	27	257	0.10	4	0.15	38	42
1915	206	22	184	0.11	5	0.23	42	47
1916	186	36	150	0.19	6	0.17	25	31
1917	114	36	78	0.32	9	0.25	20	29
1918	52	17	35	0.33	4	0.24	8	12
1919	94	36	58	0.38	5	0.14	8	13
1920	38	12	26	0.32	3	0.25	7	10 **
1921	88	17	71	0.19	4	0.24	17	21
1922	225	91	134	0.40	26	0.29	38	64
1923	331	120	211	0.36	30	0.25	53	83
1924	399	157	242	0.39	53	0.34	82	135
1925	452	206	246	0.46	39	0.19	47	86
1926	426	293	133	0.69	20	0.07	9	29
1927	323	251	72	0.78	72	0.29	21	93
1928	252	248	4	0.98	94	0.38	2	96
1929	167	153	14	0.92	49	0.32	4	53
1930	226	214	12	0.95	60	0.28	3	63 **
1931	181	173	8	0.96	68	0.39	3	71
1932	120	114	6	0.95	45	0.39	2	47
1933	31	30	1	0.97	10	0.33	0	10
1934	47	45	2	0.96	5	0.11	0	5
1935	192	190	2	0.99	3	0.02	0	3
1936	304	300	4	0.99	4	0.01	0	4
1937	323	314	9	0.97	5	0.02	0	5
1938	394	306	8	0.98	7	0.02	0	7

	WARD 5								WARD 6							
YEAR	TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM: LEAD	TOTAL LEAD	TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM: LEAD	TOTAL LEAD
1939	403	392	11	0.97	2	0.01	0	2	472	471	1	1.00	2	0.00	0	2
1940	520	517	3	0.99	0	0.00	0	0 **	434	428	6	0.99	1	0.00	0	1 **
1941	664	659	5	0.99	1	0.00	0	1	269	266	3	0.99	2	0.01	0	2
1942	155	142	13	0.92	8	0.06	1	9	125	120	5	0.96	13	0.11	1	14
1943	37	35	2	0.95	16	0.46	1	17	69	64	5	0.93	30	0.47	2	32
1944	14	14	0	1.00	11	0.79	0	11	34	31	3	0.91	10	0.32	1	11
1945	66	64	2	0.97	7	0.11	0	7	114	112	2	0.98	8	0.07	0	8
1946	165	160	5	0.97	10	0.06	0	10	81	78	3	0.96	9	0.12	0	9
1947	351	337	14	0.96	1	0.00	0	1	75	71	4	0.95	2	0.03	0	2
1948	394	390	4	0.99	0	0.00	0	0	128	125	3	0.98	0	0.00	0	0
1949	312	303	9	0.97	0	0.00	0	0	127	123	4	0.97	1	0.01	0	1
1950	314	308	6	0.98	0	0.00	0	0 **	131	128	3	0.98	0	0.00	0	0 **
1951	498	489	9	0.98	0	0.00	0	0	121	118	3	0.98	0	0.00	0	0
1952	412	408	4	0.99	1	0.00	0	1	111	104	7	0.94	0	0.00	0	0
1953	178	175	3	0.98	2	0.01	0	2	99	89	10	0.90	1	0.01	0	1
1954	293	281	12	0.96	1	0.00	0	1	49	47	2	0.96	0	0.00	0	0
1955	206	201	5	0.98	0	0.00	0	0	535	494	41	0.92	14	0.03	1	15
1956	95	90	5	0.95	0	0.00	0	0	116	104	12	0.90	1	0.01	0	1
1957	89	83	6	0.93	0	0.00	0	0	50	48	2	0.96	0	0.00	0	0
1958	74	65	9	0.88	0	0.00	0	0	159	152	7	0.96	4	0.03	0	4
1959	185	177	8	0.96	1	0.01	0	1	90	83	7	0.92	0	0.00	0	0
1960	145	137	8	0.94	6	0.04	0	6 **	91	87	4	0.96	0	0.00	0	0 **
1961	178	169	9	0.95	2	0.01	0	2	120	110	10	0.92	0	0.00	0	0
1962	104	92	12	0.88	0	0.00	0	0	96	91	5	0.95	0	0.00	0	0
1963	65	58	7	0.89	0	0.00	0	0	98	89	9	0.91	1	0.01	0	1
1964	59	57	2	0.97	0	0.00	0	0	105	100	5	0.95	0	0.00	0	0
1965	60	57	3	0.95	0	0.00	0	0	99	90	9	0.91	0	0.00	0	0
1966	44	40	4	0.91	0	0.00	0	0	139	125	14	0.90	2	0.02	0	2
1967	38	33	5	0.87	0	0.00	0	0	98	89	9	0.91	1	0.01	0	1
1968	23	20	3	0.87	0	0.00	0	0	116	110	6	0.95	1	0.01	0	1
1969	31	23	8	0.74	0	0.00	0	0	90	70	20	0.78	1	0.01	0	1
1970	52	8	44	0.15	3	0.38	17	20 **	125	17	108	0.14	2	0.12	13	15 **
1971	22	3	19	0.14	1	0.33	6	7	80	7	73	0.09	1	0.14	10	11
1972	37	5	32	0.14	0	0.00	0	0	84	7	77	0.08	2	0.29	22	24
1973	76	0	76	0.00	0	0.00	0	0	91	9	82	0.10	0	0.00	0	0
1974	103	4	99	0.04	2	0.50	50	52	118	4	114	0.03	1	0.25	29	30
1975	22	2	20	0.09	0	0.00	0	0	127	22	105	0.17	2	0.09	10	12
1976	65	0	65	0.00	0	0.00	0	0	160	15	145	0.09	0	0.00	0	0
1977	83	1	82	0.01	0	0.00	0	0	87	5	82	0.06	0	0.00	0	0

	WARD 5								WARD 6							
YEAR	TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM LEAD	TOTAL LEAD	TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM LEAD	TOTAL LEAD
1978	53	1	52	0.02	0	0.00	0	0	64	5	59	0.08	0	0.00	0	0
1979	4	1	3	0.25	0	0.00	0	0	21	1	20	0.05	0	0.00	0	0
1980	0	0	0	0.00	0	0.00	0	0 **	0	0	0	0.00	0	0.00	0	0 **
1981	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1982	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1983	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1984	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1985	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1986	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1987	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1988	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1989	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
TOTAL	18369	12196	6173	0.66	1174		1662	2836	17851	9668	8183	0.54	1186		1698	2884

YEAR	WARD 7 TOTAL SERVICES	WARD 7 KNOWN SERVICES	WARD 7 UNKNOWN SERVICES	WARD 7 % KNOWN	WARD 7 LEAD SERVICES	WARD 7 % LEAD	WARD 7 ASSUM: LEAD	WARD 7 TOTAL LEAD	WARD 8 TOTAL SERVICES	WARD 8 KNOWN SERVICES	WARD 8 UNKNOWN SERVICES	WARD 8 % KNOWN	WARD 8 LEAD SERVICES	WARD 8 % LEAD	WARD 8 ASSUM: LEAD	WARD 8 TOTAL LEAD
1900	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1901	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1902	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1903	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1904	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1905	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1906	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1907	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1908	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1909	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1910	0	0	0	0.00	0	0.00	0	0 **	0	0	0	0.00	0	0.00	0	0 **
1911	78	21	57	0.27	2	0.10	5	7	72	16	56	0.22	1	0.06	4	5
1912	6	0	6	0.00	0	0.00	0	0	35	6	29	0.17	0	0.00	0	0
1913	6	0	6	0.00	0	0.00	0	0	26	4	22	0.15	0	0.00	0	0
1914	31	2	29	0.06	1	0.50	15	16	28	3	25	0.11	0	0.00	0	0
1915	18	3	15	0.17	0	0.00	0	0	29	4	25	0.14	0	0.00	0	0
1916	20	2	18	0.10	0	0.00	0	0	29	2	27	0.07	1	0.50	14	15
1917	73	6	67	0.08	2	0.33	22	24	15	2	13	0.13	0	0.00	0	0
1918	86	9	77	0.10	3	0.33	26	29	5	0	5	0.00	0	0.00	0	0
1919	45	12	33	0.27	5	0.42	14	19	5	2	3	0.40	1	0.50	2	3
1920	37	5	32	0.14	2	0.40	13	15 **	11	1	10	0.09	0	0.00	0	0 **
1921	65	9	56	0.14	0	0.00	0	0	15	1	14	0.07	0	0.00	0	0
1922	47	11	36	0.23	5	0.45	16	21	16	6	10	0.38	4	0.67	7	11
1923	49	14	35	0.29	6	0.43	15	21	18	3	15	0.17	1	0.33	5	6
1924	55	13	42	0.24	5	0.38	16	21	53	9	44	0.17	4	0.44	20	24
1925	90	35	55	0.39	6	0.17	9	15	40	19	21	0.48	2	0.11	2	4
1926	148	103	45	0.70	5	0.05	2	7	41	31	10	0.76	6	0.19	2	8
1927	155	111	44	0.72	13	0.12	5	18	33	30	3	0.91	11	0.37	1	12
1928	194	180	14	0.93	42	0.23	3	45	69	66	3	0.96	11	0.17	1	12
1929	223	216	7	0.97	32	0.15	1	33	42	41	1	0.98	9	0.22	0	9
1930	265	256	9	0.97	44	0.17	2	46 **	34	33	1	0.97	11	0.33	0	11 **
1931	229	226	3	0.99	72	0.32	1	73	41	41	0	1.00	12	0.29	0	12
1932	128	124	4	0.97	31	0.25	1	32	54	52	2	0.96	9	0.17	0	9
1933	69	69	0	1.00	20	0.29	0	20	15	15	0	1.00	2	0.13	0	2
1934	115	115	0	1.00	9	0.08	0	9	31	31	0	1.00	1	0.03	0	1
1935	175	172	3	0.98	3	0.02	0	3	68	66	2	0.97	2	0.03	0	2
1936	229	228	1	1.00	1	0.00	0	1	84	82	2	0.98	0	0.00	0	0
1937	302	298	4	0.99	2	0.01	0	2	96	95	1	0.99	0	0.00	0	0
1938	425	423	2	1.00	4	0.01	0	4	42	40	2	0.95	0	0.00	0	0

YEAR	WARD 7 TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM LEAD	TOTAL LEAD		WARD 8 TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM LEAD	TOTAL LEAD	
1939	655	654	1	1.00	5	0.01	0	5		152	151	1	0.99	1	0.01	0	1	
1940	720	713	7	0.99	1	0.00	0	1	**	154	153	1	0.99	0	0.00	0	0	**
1941	1030	1029	1	1.00	2	0.00	0	2		413	402	11	0.97	1	0.00	0	1	
1942	439	433	6	0.99	102	0.24	1	103		251	243	8	0.97	49	0.20	2	51	
1943	291	166	125	0.57	79	0.48	59	138		180	164	16	0.91	119	0.73	12	131	
1944	362	362	0	1.00	215	0.59	0	215		132	115	17	0.87	59	0.51	9	68	
1945	930	888	42	0.95	103	0.12	5	108		149	146	3	0.98	23	0.16	0	23	
1946	614	586	28	0.95	24	0.04	1	25		350	349	1	1.00	88	0.25	0	88	
1947	658	648	10	0.98	3	0.00	0	3		370	367	3	0.99	0	0.00	0	0	
1948	411	406	5	0.99	0	0.00	0	0		278	274	4	0.99	1	0.00	0	1	
1949	315	315	0	1.00	0	0.00	0	0		143	134	9	0.94	0	0.00	0	0	
1950	570	566	4	0.99	0	0.00	0	0	**	253	245	8	0.97	0	0.00	0	0	**
1951	472	470	2	1.00	0	0.00	0	0		243	236	7	0.97	0	0.00	0	0	
1952	511	507	4	0.99	0	0.00	0	0		383	382	1	1.00	0	0.00	0	0	
1953	498	494	4	0.99	0	0.00	0	0		206	192	14	0.93	0	0.00	0	0	
1954	357	345	12	0.97	0	0.00	0	0		94	86	8	0.91	1	0.01	0	1	
1955	393	390	3	0.99	1	0.00	0	1		30	30	0	1.00	0	0.00	0	0	
1956	160	156	4	0.98	0	0.00	0	0		13	11	2	0.85	0	0.00	0	0	
1957	118	115	3	0.97	0	0.00	0	0		7	6	1	0.86	0	0.00	0	0	
1958	182	175	7	0.96	0	0.00	0	0		26	22	4	0.85	0	0.00	0	0	
1959	128	114	14	0.89	0	0.00	0	0		43	41	2	0.95	0	0.00	0	0	
1960	86	84	2	0.98	0	0.00	0	0	**	25	25	0	1.00	0	0.00	0	0	**
1961	108	101	7	0.94	0	0.00	0	0		24	23	1	0.96	0	0.00	0	0	
1962	144	143	1	0.99	0	0.00	0	0		32	29	3	0.91	0	0.00	0	0	
1963	181	172	9	0.95	1	0.01	0	1		57	56	1	0.98	0	0.00	0	0	
1964	230	222	8	0.97	0	0.00	0	0		43	39	4	0.91	0	0.00	0	0	
1965	219	218	1	1.00	0	0.00	0	0		47	40	7	0.85	0	0.00	0	0	
1966	198	179	19	0.90	0	0.00	0	0		59	55	4	0.93	0	0.00	0	0	
1967	90	88	2	0.98	0	0.00	0	0		32	23	9	0.72	0	0.00	0	0	
1968	91	89	2	0.98	0	0.00	0	0		42	41	1	0.98	0	0.00	0	0	
1969	84	47	37	0.56	0	0.00	0	0		6	4	2	0.67	0	0.00	0	0	
1970	70	24	46	0.34	1	0.04	2	3	**	16	0	16	0.00	0	0.00	0	0	
1971	50	3	47	0.06	1	0.33	16	17		11	0	11	0.00	0	0.00	0	0	**
1972	39	8	31	0.21	0	0.00	0	0		10	1	9	0.10	0	0.00	0	0	
1973	42	1	41	0.02	0	0.00	0	0		4	0	4	0.00	0	0.00	0	0	
1974	31	0	31	0.00	0	0.00	0	0		17	0	17	0.00	0	0.00	0	0	
1975	36	2	34	0.06	1	0.50	17	18		19	3	16	0.16	0	0.00	0	0	
1976	55	0	55	0.00	0	0.00	0	0		80	27	53	0.34	0	0.00	0	0	
1977	33	0	33	0.00	0	0.00	0	0		49	0	49	0.00	0	0.00	0	0	

	WARD 7								WARD 8							
YEAR	TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM LEAD	TOTAL LEAD	TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM LEAD	TOTAL LEAD
1978	17	2	15	0.12	0	0.00	0	0	29	0	29	0.00	0	0.00	0	0
1979	23	1	22	0.04	0	0.00	0	0	30	0	30	0.00	0	0.00	0	0
1980	0	0	0	0.00	0	0.00	0	0 **	0	0	0	0.00	0	0.00	0	0 **
1981	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1982	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1983	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1984	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1985	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1986	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1987	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1988	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1989	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
TOTAL	15004	13579	1425	0.91	854		268	1122	5549	4816	733	0.87	430		79	509

YEAR	WARD NOT INDICATED: TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM: LEAD	TOTAL LEAD	TOTAL FOR THE DISTRICT: TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM: LEAD	TOTAL LEAD
1900	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1901	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1902	0	0	0	0.00	0	0.00	0	0	1	0	1	0.00	0	0.00	0	0
1903	0	0	0	0.00	0	0.00	0	0	11	3	8	0.27	0	0.00	0	0
1904	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1905	0	0	0	0.00	0	0.00	0	0	1	1	0	1.00	0	0.00	0	0
1906	0	0	0	0.00	0	0.00	0	0	1	0	1	0.00	0	0.00	0	0
1907	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1908	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1909	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1910	0	0	0	0.00	0	0.00	0	0 **	0	0	0	0.00	0	0.00	0	0
1911	260	9	251	0.03	1	0.11	28	29	21245	5012	16233	0.24	1396	0.28	4521	5917
1912	51	1	50	0.02	1	1.00	50	51	707	60	647	0.08	22	0.37	237	259
1913	87	2	85	0.02	2	1.00	85	87	1426	149	1277	0.10	19	0.13	163	182
1914	92	2	90	0.02	0	0.00	0	0	1292	122	1170	0.09	22	0.18	211	233
1915	59	0	59	0.00	0	0.00	0	0	1405	176	1229	0.13	27	0.15	189	216
1916	61	0	61	0.00	0	0.00	0	0	1332	187	1145	0.14	29	0.16	178	207
1917	61	1	60	0.02	0	0.00	0	0	800	140	660	0.18	29	0.21	137	166
1918	74	1	73	0.01	1	1.00	73	74	776	127	649	0.16	23	0.18	118	141
1919	44	1	43	0.02	0	0.00	0	0	1191	353	838	0.30	85	0.24	202	287
1920	33	0	33	0.00	0	0.00	0	0 **	973	267	706	0.27	70	0.26	185	255
1921	46	3	43	0.07	1	0.33	14	15	1522	506	1016	0.33	123	0.24	247	370
1922	69	7	62	0.10	2	0.29	18	20	2675	875	1800	0.33	269	0.31	553	822
1923	59	2	57	0.03	0	0.00	0	0	2834	1078	1756	0.38	319	0.30	520	839
1924	73	2	71	0.03	0	0.00	0	0	3232	1186	2046	0.37	333	0.28	574	907
1925	29	7	22	0.24	0	0.00	0	0	4649	2351	2298	0.51	386	0.16	377	763
1926	52	21	31	0.40	0	0.00	0	0	3842	2774	1068	0.72	324	0.12	125	449
1927	30	13	17	0.43	4	0.31	5	9	2373	1985	388	0.84	586	0.30	115	701
1928	40	21	19	0.53	13	0.62	12	25	1858	1742	116	0.94	778	0.45	52	830
1929	70	47	23	0.67	36	0.77	18	54	1872	1748	124	0.93	785	0.45	56	841
1930	35	15	20	0.43	5	0.33	7	12 **	1648	1558	90	0.95	478	0.31	28	506
1931	36	20	16	0.56	6	0.30	5	11	2036	1944	92	0.95	682	0.35	32	714
1932	33	12	21	0.36	3	0.25	5	8	1258	1176	82	0.93	325	0.28	23	348
1933	31	15	16	0.48	5	0.33	5	10	774	721	53	0.93	134	0.19	10	144
1934	60	22	38	0.37	3	0.14	5	8	953	894	59	0.94	90	0.10	6	96
1935	46	19	27	0.41	0	0.00	0	0	2233	2161	72	0.97	89	0.04	3	92
1936	47	31	16	0.66	1	0.03	1	2	2756	2672	84	0.97	39	0.01	1	40
1937	55	40	15	0.73	1	0.03	0	1	2664	2599	65	0.98	36	0.01	1	37
1938	38	19	19	0.50	0	0.00	0	0	2401	2342	59	0.98	19	0.01	0	19

	WARD NOT INDICATED								TOTAL FOR THE DISTRICT							
YEAR	TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM: LEAD	TOTAL LEAD	TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM: LEAD	TOTAL LEAD
1939	66	33	33	0.50	0	0.00	0	0	3155	3079	76	0.98	21	0.01	1	22
1940	77	48	29	0.62	0	0.00	0	0 **	3261	3185	76	0.98	10	0.00	0	10
1941	54	25	29	0.46	0	0.00	0	0	3840	3731	109	0.97	12	0.00	0	12
1942	37	7	30	0.19	2	0.29	9	11	1364	1271	93	0.93	210	0.17	15	225
1943	99	47	52	0.47	33	0.70	37	70	908	702	206	0.77	329	0.47	97	426
1944	70	14	56	0.20	8	0.57	32	40	723	636	87	0.88	361	0.57	49	410
1945	36	20	16	0.56	4	0.20	3	7	1439	1367	72	0.95	170	0.12	9	179
1946	69	49	20	0.71	2	0.04	1	3	1658	1582	76	0.95	185	0.12	9	194
1947	306	40	266	0.13	2	0.05	13	15	2710	2208	502	0.81	13	0.01	3	16
1948	43	17	26	0.40	0	0.00	0	0	1961	1890	71	0.96	1	0.00	0	1
1949	157	109	48	0.69	5	0.05	2	7	1823	1699	124	0.93	15	0.01	1	16
1950	140	105	35	0.75	1	0.01	0	1 **	2539	2425	114	0.96	3	0.00	0	3
1951	74	59	15	0.80	0	0.00	0	0	2411	2320	91	0.96	2	0.00	0	2
1952	54	43	11	0.80	4	0.09	1	5	2159	2095	64	0.97	5	0.00	0	5
1953	70	46	24	0.66	0	0.00	0	0	1592	1477	115	0.93	4	0.00	0	4
1954	80	63	17	0.79	4	0.06	1	5	1460	1361	99	0.93	9	0.01	1	10
1955	192	124	68	0.65	3	0.02	2	5	1958	1796	162	0.92	18	0.01	2	20
1956	180	122	58	0.68	0	0.00	0	0	975	847	128	0.87	2	0.00	0	2
1957	42	33	9	0.79	0	0.00	0	0	741	647	94	0.87	0	0.00	0	0
1958	121	105	16	0.87	0	0.00	0	0	1155	1055	100	0.91	10	0.01	1	11
1959	198	162	36	0.82	1	0.01	0	1	1328	1191	137	0.90	15	0.01	2	17
1960	151	133	18	0.88	2	0.02	0	2 **	966	887	79	0.92	10	0.01	1	11
1961	111	90	21	0.81	0	0.00	0	0	918	816	102	0.89	6	0.01	1	7
1962	85	69	16	0.81	0	0.00	0	0	838	725	113	0.87	3	0.00	0	3
1963	179	160	19	0.89	2	0.01	0	2	926	807	119	0.87	5	0.01	1	6
1964	146	133	13	0.91	0	0.00	0	0	1021	886	135	0.87	3	0.00	0	3
1965	104	82	22	0.79	0	0.00	0	0	930	823	107	0.88	2	0.00	0	2
1966	144	120	24	0.83	0	0.00	0	0	953	830	123	0.87	5	0.01	1	6
1967	95	81	14	0.85	0	0.00	0	0	788	703	85	0.89	4	0.01	0	4
1968	112	99	13	0.88	0	0.00	0	0	691	612	79	0.89	1	0.00	0	1
1969	103	84	19	0.82	1	0.01	0	1	606	405	201	0.67	2	0.00	1	3
1970	120	1	119	0.01	0	0.00	0	0 **	578	63	515	0.11	7	0.11	57	64
1971	116	2	114	0.02	1	0.50	57	58	522	33	489	0.06	4	0.12	59	63
1972	111	2	109	0.02	0	0.00	0	0	499	31	468	0.06	3	0.10	45	48
1973	201	13	188	0.06	4	0.31	58	62	832	50	782	0.06	8	0.16	125	133
1974	154	17	137	0.11	2	0.12	16	18	703	41	662	0.06	6	0.15	97	103
1975	101	2	99	0.02	0	0.00	0	0	515	34	481	0.07	3	0.09	42	45
1976	77	2	75	0.03	0	0.00	0	0	648	64	584	0.10	0	0.00	0	0
1977	82	4	78	0.05	1	0.25	20	21	654	35	619	0.05	3	0.09	53	56

YEAR	WARD NOT INDICATED TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM: LEAD	TOTAL LEAD	TOTAL FOR THE DISTRICT TOTAL SERVICES	KNOWN SERVICES	UNKNOWN SERVICES	% KNOWN	LEAD SERVICES	% LEAD	ASSUM: LEAD	TOTAL LEAD
1978	9	0	9	0.00	0	0.00	0	0	396	31	365	0.08	0	0.00	0	0
1979	5	0	5	0.00	0	0.00	0	0	179	7	172	0.04	0	0.00	0	0
1980	1	0	1	0.00	0	0.00	0	0 **	1	0	1	0.00	0	0.00	0	0
1981	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1982	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1983	0	0	0	0.00	0	0.00	0	0	1	0	1	0.00	0	0.00	0	0
1984	2	0	2	0.00	0	0.00	0	0	3	0	3	0.00	0	0.00	0	0
1985	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1986	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1987	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1988	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
1989	0	0	0	0.00	0	0.00	0	0	0	0	0	0.00	0	0.00	0	0
TOTAL	6045	2698	3347	0.45	167		583	750	126069	81356	44713	0.65	8987		9538	18525

APPENDIX F

WATER SAMPLING INSTRUCTIONS

DPW - WASUA

WATER SAMPLING INSTRUCTIONS

Step 1 Fill the bottle labeled "A" with cold water from the kitchen faucet.

Step 2 Fill the bottle labeled "B" with cold water from the kitchen faucet.

Step 3 Fill the one gallon container with cold water from the kitchen faucet, then pour this water down the drain.

Step 4 Fill the bottle labeled "C" with cold water from the kitchen faucet.

Step 5 Fill and empty the one gallon container with cold water from the kitchen faucet two times.

Step 6 Fill the bottle labeled "D" with cold water from the kitchen faucet.

Step 7 Place the four sample bottles outside of your home's front door where a District representative can pick them up during the day.

Thank you very much for your kind assistance!

APPENDIX G

WATER SAMPLING QUESTIONNAIRE

WATER SAMPLING QUESTIONNAIRE

ADDRESS ____

____

DATE SAMPLES WERE TAKEN ________________________

HOW LONG WAS THE WATER OFF BEFORE SAMPLING ? ______

HOW OLD IS THE HOUSE ? ____________

HAS ANY PLUMBING WORK BEEN DONE IN THE HOUSE WITHIN THE LAST 2 YEARS ? IF YES, PLEASE DESCRIBE BRIEFLY.

____

____

____

WERE ANY PROBLEMS ENCOUNTERED WHILE TAKING THE WATER SAMPLES ? IF YES, PLEASE DESCRIBE BRIEFLY.

____

____

____

APPENDIX H

TAP FILE DATABASE USER'S GUIDE

SECTION 3

TAP FILE DATABASE

3.1 INTRODUCTION

The Tap File Database was developed using a variety of data sources. The main source of data was the Tap File located at the Bryant Street Pumping Station. Other data sources were used to fill in gaps in the Tap File, and to update the data based on recent service line replacement activities.

One of the main purposes of the Tap File Database was to develop a computerized database to analyze trends of lead service line installation. For this purpose, two fields are most significant. The field PIPEMATL records the material of the District's portion of the service line. The field CUSTSERV records the service line material on the customer's side.

3.2 DESCRIPTION OF THE TAP FILE DATABASE FIELDS

This subsection describes the various sources of data that were used to compile the Tap File Database. The following data sources were used:

- Tap File
- Meter File
- Maintenance File
- Planning Commission File
- Lead Service Replacement Program File
- Meter Relocation Program File
- Street Replacement Program File
- Project Locator Data File

Table 3-1 lists each data source, its location, the form in which the data were found, and how each source was used in creating the Tap File Database. Figure 3-1 shows the schematic interaction of the various data files in relation to the final Tap File Database.

The database was set up on IBM-compatible personal computers using dBASE IV software. Table 3-2 shows the final structure of the Tap File Database record.

3.2.1 Tap File

The major source of information was the Tap File, which is a collection of index cards stored in the Bureau of Water Measurement and Billing (BWMB) offices at the Bryant Street Pumping Station. The database created from the Tap File records formed the base on which all of the other information sources were compiled.

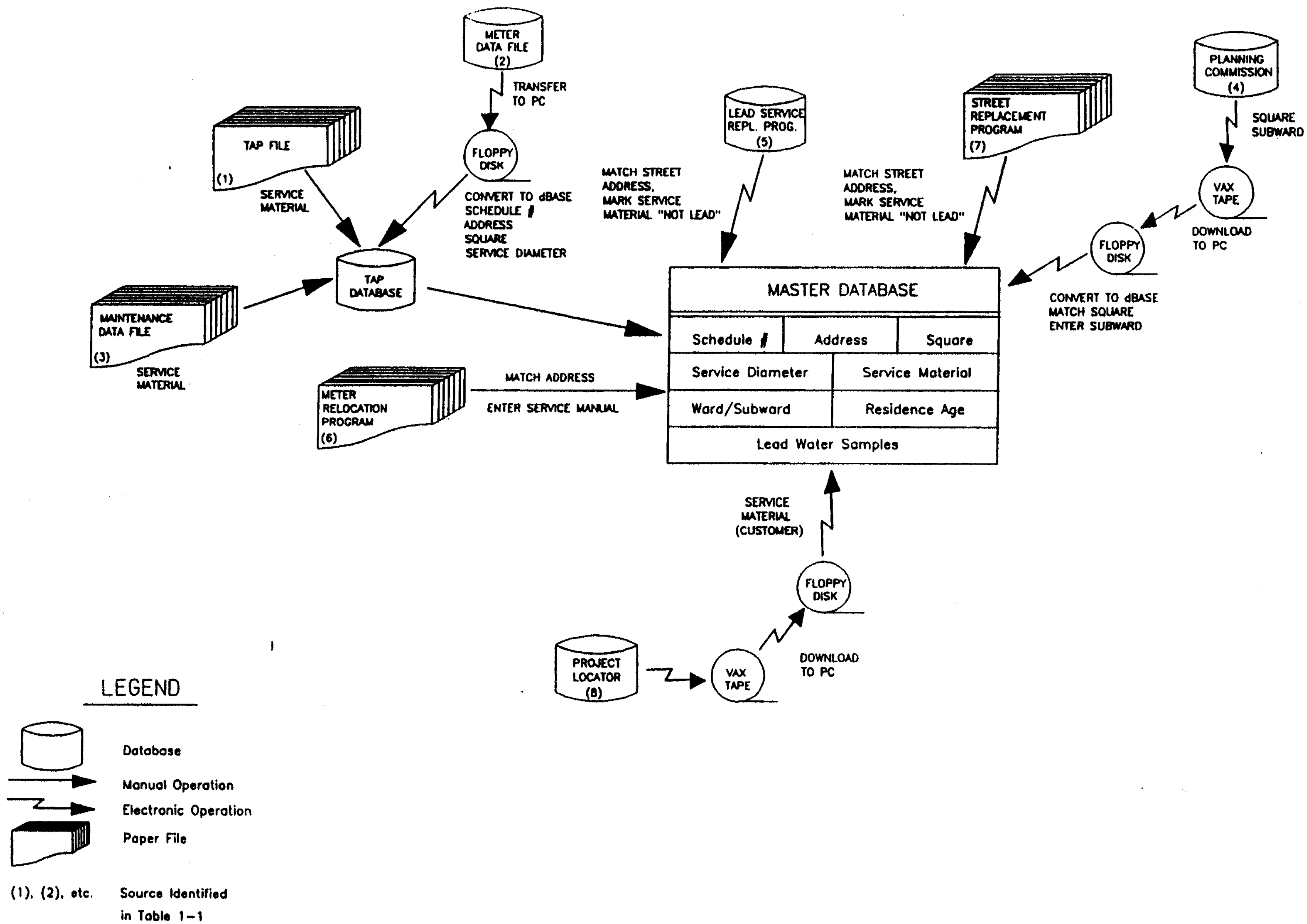


FIGURE 3-1 SCHEMATIC OF INTERACTION OF VARIOUS DATABASES

The Tap File contains cards that are submitted every time a water main is tapped for a new water service connection. All residential taps were supposedly recorded in this file, ordered by schedule number, which is a sequential, unique number assigned to every tap. Approximately 188,000 schedule numbers have been issued by the District. The Tap Cards typically contained the following information:

- Schedule number.
- Address.
- Square.
- Lot.
- Date of connection.
- Property owner and plumber names.
- Size of service line.
- Location of curb-cock.
- Location and size of main.

3.2.2 Meter File

The Tap File did not contain the cards for the first 67,000 taps. Obtaining this information was imperative because these locations are the oldest in the District (pre-1915), and are the most likely to have had originally installed lead service lines. BWMB maintains a Meter File that contains the information that BWMB calls up on its computer screens for billing and customer service purposes.

The Meter File information consisted of selected fields from the master database that the Office of Information Systems maintains on its mainframe computer. Data were extracted for all active residential addresses throughout the District. These data contained the following information for schedule numbers 000000 through 999999:

- Schedule number.
- House number.
- Street name.
- Quadrant.
- Square.

The data from the Meter File were input on the project computers at BWMB. Since the Meter File does not contain all of the necessary information, data entry personnel were instructed to look up each address in the Maintenance File and attempt to fill in the missing data (see Subsection 3.2.3).

It should be noted that only 20,400 of the first 67,000 taps were still active. This is not surprising, since most of these residences were located in the center of the District and, as such, were probably torn down and replaced by commercial or government buildings, or by open space (especially the Mall) or new roads.

However, to complete the data collection for the first 67,000 taps (obtained from the Meter File), the following data had to be obtained from the Maintenance File for each address:

- Date of tap installation.
- Service line material.
- Service line diameter.

The database was sorted to match the organization of the Maintenance File. Nevertheless, the volume of information available for any address that had to be sorted greatly diminished productivity. To ensure that the effort was completed on time, the data entry staff were instructed to concentrate only on obtaining the service line material for each address, which was the most important piece of information of the three. The staff were then free to look through all of the service orders for each address as well as the Tap Card, thus increasing the chances of obtaining a definite service material indication.

3.2.4 Planning Commission File

All data analyses were to be performed on the basis of political ward. The District is divided into eight wards, with each ward being divided further into five subwards. The District's Planning Commission provided a database giving the relationship between square and ward for every square in the District.

The Ward-Versus-Square Database enabled each ward field to be filled easily for any record in the Tap File Database, as long as the record contained the proper value in the square field. The merge was highly successful; more than 90 percent of the records now had a ward location. Those records that did not get a ward had Tap Cards that did not have the square specified, which was fairly common in the older Tap File records.

3.2.5 Lead Service Replacement Program

The District's Lead Service Replacement Program, which has been in operation since late 1987, replaces District-owned, noncopper residential service lines (i.e., the portion of the service line that lies between the main and the curb shut-off valve). The Lead Service Replacement Program Database contains the following fields of interest:

- House number.
- Street name.
- Quadrant.
- Material type replaced.
- Date.

The objective in using these data was to match each replaced service line with its corresponding entry in the Tap File Database and mark the service material as being copper. It was desirable to perform this matching and marking function electronically;

The Meter Relocation Program management was advised to modify its program in the following two ways:

- Instruct all crews to excavate down to the service line so that they could determine the type of service line on both the customer and the District sides.

- Have the crews fill out a simple form and return it at the end of the day to a central location.

Program management has implemented these recommendations, which has resulted in the collection of approximately 200 additional identified service lines to date.

3.2.7 Street Replacement Program

The Street Replacement Program is a result of the District's requirement that all noncopper service lines (as well as other utilities) be replaced whenever a street construction contract is awarded. All available street inspector logs that identified the service line material were obtained for project use.

As was found with the Meter Replacement Program information, the Street Replacement Program information is not computerized; moreover, the information is not centrally located. Data were obtained by contacting the inspectors, who then pulled their logs from their personal files.

The format of the information also lends itself to manual entry into the Tap File Database. The time required is minimal because of the consistent nature of the information.

Since each group of addresses represents a replaced street, almost all of the records to be changed are located on one street and, therefore, will appear together in the Tap File Database. The database was sorted to facilitate entry of this information. For each address found, the original service line material was marked to match that indicated on the Street Replacement Sheet, and the service line was marked as having been replaced.

3.2.8 Project Locator Data File

The Project Locator Data File is the end product of an extensive study performed in 1983 to 1984 by the Office of Engineering Services for the BWMB. Project Locator was a house-to-house survey, the objective of which was to improve the quality and accuracy of water billing. As part of this survey the service line material was recorded for the customer's portion of the line for those houses with inside meters.

The service line material information from the Project Locator Database was merged with the Tap File Database by matching the schedule numbers in the two databases. To accommodate the service line material information, a new field was created in the Tap File

SECTION 4

USING THE MENU SYSTEM

A simple menu system was created using the dBASE IV programming language to facilitate using the Tap File Database. The present menu system allows the user to add new records to the database, edit existing records, retrieve data in various forms, and recreate certain basic indexes. The menu system can be updated easily by users familiar with simple dBASE IV commands as new applications are developed for using the database.

4.1 OVERVIEW

The first step in accessing the Tap File Database main menu is to enter into dBASE IV from the DOS environment. The specifics of this step will depend on the setup of the user's particular computer. Upon entering dBASE IV, the user will be presented with the dBASE Assistant, the user-friendly menu system that drives dBASE IV. To access the Tap File Database menu system, the user simply presses the <ESCAPE> key. At the Yes/No prompt that appears next, answer Yes by pressing the "Y" key, or moving the cursor to "Yes" and pressing <RETURN>.

At this point the user is at the dBASE IV dot prompt. From here the user can perform any dBASE IV function by typing in the appropriate commands. To access and work with the Tap File Database, type in DO TAP and <RETURN>. The Tap File Database main menu will appear as shown in Table 4-1.

Table 4-1

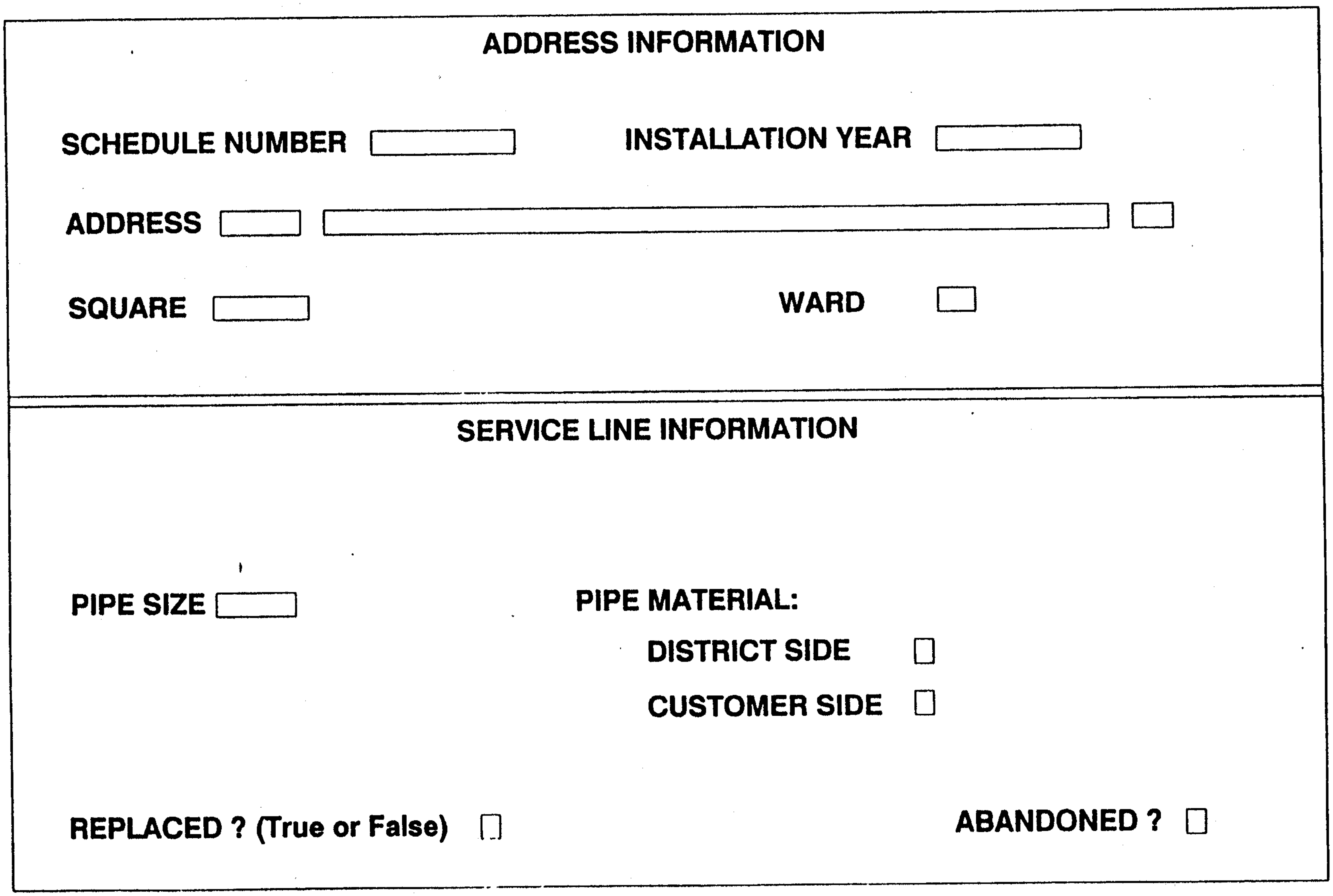
District of Columbia Water and Sewer Utility Administration
Tap File Database Main Menu

---

(1) Input New Records
(2) Edit Existing Records
(3) Listing of Service Line Materials for a Series of Years
(4) Listing of Service Line Materials for Individual Addresses
(5) Count of Service Lines of a Given Material
(6) Summary of Replaced Service Lines by Ward and Year
(7) Summary of Service Line Installations by Ward and Year
(8) Re-Index Database
(9) Quit to Dot Prompt
(X) Quit to DOS

ENTER MENU CHOICE ->

FIGURE 4-1 TAP FILE DATABASE DATA ENTRY SCREEN



As an example, assume the user has responded to these prompts as follows:

- ENTER WARD TO REPORT -> **4**
- ENTER PIPE MATERIAL TO REPORT -> **L**
- ENTER FIRST YEAR TO REPORT -> **1930**
- ENTER LAST YEAR TO REPORT -> **1935**

These responses would generate a report (see Table 4-2) which would appear on the screen.

Table 4-2

Example of Report 3

ADDRESS	QUAD	WARD	INSTALL YEAR	TAP	PIPE MATERIAL RECORD	PROJ	LOCATOR
7125 16TH ST	NW	4A	1931		L		N
7627 16TH ST	NW	4A	1932		L		I
7721 16TH ST	NW	4A	1933		L		I
7755 16TH ST	NW	4A	1933		L		N
4312 17TH ST	NW	4A	1933		L		N
4316 18TH ST	NW	4A	1933		L		N
7801 16TH ST	NW	4A	1934		L		N
7815 16TH ST	NW	4A	1934		L		I
7809 16TH ST	NW	4A	1935		L		I
5610 1ST PL	NW	4B	1935		L		N
5611 1ST PL	NW	4B	1935		L		
5614 1ST PL	NW	4B	1935		L		
5615 1ST PL	NW	4B	1935		L		
5618 1ST PL	NW	4B	1935		L		
5619 1ST PL	NW	4B	1935		L		

Press any key to continue . . .

Menu Choice 4 allows the user to retrieve information about a particular address. The user is prompted to enter the address in three parts as follows:

- ENTER STREET NUMBER TO REPORT ->
- ENTER STREET NAME TO REPORT ->
- ENTER QUADRANT TO REPORT ->
- DO YOU WISH TO PRINT THE RESULTS ? (Y OR N)

Again, the form of the responses is very important. All responses must be in capital letters. The street name must be spelled correctly to match the addresses in the database. This includes

Table 4-4

Example of Report 5

IN 1935 THERE WERE 7 LEAD SERVICE LINES INSTALLED IN WARD 4

Press any key to continue . . .

Menu Choice 6 focuses on the number of lead service lines that have been replaced. The user selects the ward and date range to report on, and the dBASE IV program produces a count of the number of lead service lines in that ward that have been replaced. Table 4-5 is an example of the output produced by the following user responses:

- ENTER WARD TO REPORT -> **4**
- ENTER FIRST YEAR TO REPORT -> **1930**
- ENTER LAST YEAR TO REPORT -> **1935**

Table 4-5

Example of Report 6

ADDRESS	QUAD	WARD	INSTALL YEAR	PIPE MATERIAL	REPLACED?
7755 16TH ST	NW	4A	1933	L	T

Press any key to continue . . .

Menu Choice 7 produces a summary report of service line installations in all wards throughout the District for a given material. This report lists the number of service lines of that material that were installed in each year in each ward. The user is prompted to enter this material and a range of years to report on as follows:

- ENTER FIRST YEAR TO REPORT ->
- ENTER LAST YEAR TO REPORT ->
- ENTER PIPE MATERIAL TO REPORT ->

Table 4-6 gives an example of this report. It was produced by the following responses to the user prompts:

- ENTER FIRST YEAR TO REPORT -> **1930**
- ENTER LAST YEAR TO REPORT -> **1935**
- ENTER PIPE MATERIAL TO REPORT -> **L**

Table 4-8 lists the indexes that are used by the five reports. If a particular report must be generated quickly, the index needed for that report only can be recreated. However, when more time is available all the indexes should be recreated. The schedule number index is the basic index, and is used only when inputting new data or modifying existing records.

Table 4-8

Indexes Used by the Report Programs

Report Number	Index
3	Ward/Date
4	Address
5	Ward/Date
6	Ward/Date
7	Date

Selecting any of Menu Choices 1 through 5 performs a dBASE IV command to index the database. As the indexes already exist, the user will be prompted by dBASE IV that the index file already exists. The user should select to overwrite the existing file, as the menu system is geared to using the existing files. Only if the user decides to abandon the operation should the "Cancel" option be selected.

4.2.4 Exiting the Menu System

The Tap File Database main menu includes two menu choices that allow the user to exit from the menu system. Menu Choice 9 allows the user to return to the dBASE IV dot prompt. Experienced users will use this choice to allow them to work with the Tap File Database outside of the menu environment. Entering an "X" at the menu prompt will exit the user from dBASE IV completely.

SECTION 5

ADDITIONAL DATABASE TOPICS AND APPLICATIONS

The User's Guide gives an overview of the Tap File Database and shows how to edit and query the file. There are additional applications available to users that have not been discussed herein, such as acquiring printed reports, inserting memo fields, and database maintenance and management. These areas tend to be unique to the user's environment and must be developed after gaining experience with the database.

This section describes three additional topics and gives suggestions on possible future user projects. These topics are: maintenance and management techniques, obtaining printed reports, and advanced applications.

5.1 SYSTEM MAINTENANCE AND MANAGEMENT

A database must be maintained for it to be an effective information management tool. New data must be entered into the database in a timely manner, old or incorrect records must be deleted or edited as necessary, and user problems and requests must receive immediate attention. The most effective way to achieve these goals is to assign a Database Administrator (DBA).

The DBA is essential to the success of a database, especially in the early stages of use. The DBA assists users, maintains the database, and responds to requests for new applications. He/she should be experienced in all areas of dBASE IV, with special emphasis on writing reports and custom programmed applications for management information systems. The Tap File Database is not complicated; however, it does require maintenance and attention from a reasonably knowledgeable DBA.

The system maintenance needs of the Tap File Database are no different than any other large database. There are three main types of maintenance: addition of new information, removal of old records, and editing of incorrect information. Although, the various users of the system will be the source of the information, the actual changes to the database must be made by the DBA or his/her designee. This level of control must be maintained to ensure the integrity of the database.

The last area of responsibility for the DBA involves disaster recovery. The DBA must follow a strict backup schedule to minimize the inconvenience caused by computer or human failures. It is suggested that two sets of backup disks be kept and that the database be backed up on one set of disks at least once a week, rotating between sets. This system will limit the data loss to a maximum of 2 weeks. If the database is heavily used and updated, the backup frequency can be increased to twice per week, or even daily if necessary.

TAP FILE DATABASE USER'S GUIDE

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Department of Public Works
Water and Sewer Utility Administration
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Prepared by

Roy F. Weston, P.E., P.C.
955 L'Enfant Plaza, S.W.
Washington, D.C.

TABLE OF CONTENTS

Section	Title	Page
1	**INTRODUCTION**	**1-1**
	1.1 Background	1-1
	1.2 Objectives	1-1
2	**GETTING STARTED**	**2-1**
	2.1 System Requirements	2-1
	2.2 Installing the Database and Software	2-1
3	**TAP FILE DATABASE**	**3-1**
	3.1 Introduction	3-1
	3.2 Description of the Tap File Database Fields	3-1
	3.2.1 Tap File	3-1
	3.2.2 Meter File	3-5
	3.2.3 Maintenance File	3-6
	3.2.4 Planning Commission File	3-7
	3.2.5 Lead Service Replacement Program	3-7
	3.2.6 Meter Replacement Program	3-8
	3.2.7 Street Replacement Program	3-9
	3.2.8 Project Locator Data File	3-9
4	**USING THE MENU SYSTEM**	**4-1**
	4.1 Overview	4-1
	4.2 Menu Options	4-2
	4.2.1 Adding and Editing Records	4-2
	4.2.2 Data Retrieval	4-4
	4.2.3 Database Maintenance	4-8
	4.2.4 Exiting the Menu System	4-9
5	**ADDITIONAL DATABASE TOPICS AND APPLICATIONS**	**5-1**
	5.1 System Maintenance and Management	5-1
	5.2 Printed Reports	5-2
	5.3 Advanced Applications	5-2

WESTON

LIST OF FIGURES

Figure No.	Title	Page
3-1	Schematic of Interaction of Various Databases	3-3
4-1	Tap File Database Data Entry Screen	4-3

WESTON.

LIST OF TABLES

Table No.	Title	Page
3-1	Tap File Database Data Sources	3-2
3-2	Tap File Database Data Structure	3-4
4-1	District of Columbia Water and Sewer Utility Administration Tap File Database Main Menu	4-1
4-2	Example of Report 3	4-5
4-3	Example of Report 4	4-6
4-4	Example of Report 5	4-7
4-5	Example of Report 6	4-7
4-6	Example of Report 7	4-8
4-7	Index Creation Submenu	4-8
4-8	Indexes Used by the Report Programs	4-9