R-94-12

HISTORICAL PERFORMANCE OF BURIED WATER PIPE LINES

September 1994

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Technical Service Center
Research and Laboratory Services Division
Materials Engineering Branch

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1994	Final

4. TITLE AND SUBTITLE
Historical Performance of
Buried Water Pipe Lines

5. FUNDING NUMBERS
PR

6. AUTHOR(S)
Kurt F. von Fay and Michael T. Peabody

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Bureau of Reclamation
Technical Service Center
Denver CO 80225

8. PERFORMING ORGANIZATION REPORT NUMBER
R-94-12

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Bureau of Reclamation
Denver Federal Center
PO Box 25007
Denver CO 80225-0007

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DIBR

11. SUPPLEMENTARY NOTES
Microfiche and hard copy available at the Technical Service Center, Denver, Colorado

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Available from the National Technical Information Service,
Operations Division, 5285 Port Royal Road,
Springfield, Virginia 22161

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Responses from pipe inventory questionnaires distributed to Bureau of Reclamation water users and American Water Works Association utilities were analyzed. The resulting report summarizes user pipe performance opinions and assesses failure/repair rates. Prestressed concrete pipe is contrasted with other buried water-pipe alternatives including asbestos-cement, ductile iron, fiberglass, polyethylene, pretensioned concrete cylinder, polyvinyl chloride, reinforced concrete, and steel.

14. SUBJECT TERMS--buried pipe/ pipeline/ corrosion/ prestressed concrete/ precast/ pipe failure/ cathodic protection/ defective wire/ hydrogen embrittlement/ Jordan Aqueduct Reach 3 embedded cylinder prestressed concrete pipe/

15. NUMBER OF PAGES
37

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UL	UL	UL	UL

R-94-12

HISTORICAL PERFORMANCE OF BURIED WATER PIPE LINES

by

Kurt F. von Fay
Michael T. Peabody

Materials Engineering Branch
Research and Laboratory Services Division
Denver Office
Denver, Colorado

September 1994

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

Acknowledgment is due Roman Fresquez, Eric Jones, Richard Pepin, Kurt Mitchell, and Steve Reo for their assistance compiling the data, and for conducting the follow-up phone interviews.

Recognition is due Harry Uyeda for his work developing the original questionnaire, and for his review of the original manuscript for this report. Recognition is also due Joel Catlin, AWWARF Project Manager, for his valuable technical input and for assembling and mailing the AWWARF questionnaires and compiling the responses.

U.S. Department of the Interior
Mission Statement

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

CONTENTS

TABLES

Table

FIGURES

Figure

APPENDIXES

Appendix

INTRODUCTION

In 1990, Reclamation (Bureau of Reclamation) embarked on a program to determine the historical performance of buried water pipe lines. As a first step in that program, a questionnaire was developed and mailed to agencies and municipalities that used Reclamation-constructed water pipe lines, and to Reclamation regional and project offices for pipe lines still owned and/or operated by Reclamation.

In mid-1992, Reclamation joined forces with the AWWARF (American Water Works Association Research Foundation) to include members of the AWWA (American Water Works Association) in the survey. The original Reclamation questionnaire was modified and then mailed by AWWARF to selected AWWA utilities. Later, the AWWARF questionnaire was mailed to additional agencies not included in the first AWWARF mailing.

After a preliminary examination of the questionnaire information, a follow-up survey was conducted by phone to gather additional data. The information was needed to clarify some of the responses from the initial survey, as well as to obtain additional information to perform analysis of pipe failure rates incorporating pipe age information.

This report presents information about the questionnaires and results from examination of questionnaire responses to questions about pipe performance and failure rates. The appendix contains a glossary of pipe types included in this study.

CONCLUSIONS

Questionnaires were mailed to 839 water system managers, asking for information about types of pipes in their water systems, historical performance, and pipe type preferences, among other things. A total of 276 questionnaires were returned. Some of the returned questionnaires could not be used because some respondents omitted critical information or some returned the questionnaire without any responses.

Of the returned questionnaires, 162 were used to compile data on opinions of best performance by pipe type and size. Those same questionnaires were used as the basis of a follow-up phone survey.

The follow-up phone survey was conducted to gather additional information or clarification about length, age, and number of failures for all pipe lines in a system, whether or not the pipe line had experienced failures. That information was used to calculate failures per mile–year. The data were analyzed separately, grouped by AWWARF data and Reclamation data, as well as together for a combined analysis.

Failure was defined by the survey as requiring some type of action after installation to correct a pipe deficiency—namely repair, replacement, or both repair and replacement of the affected units. The term failure rate was therefore synonymous with repair/replacement rate.

The majority of information presented in the questionnaire responses pertained to pipe lines 48 inches or less in diameter, indicating that water managers are most familiar with those sizes. Also, availability of pipe types in different size ranges ultimately affects opinions about performance. For instance, AC (asbestos-cement) pipe is only available up to 42 inches in diameter, so it would not be selected as a good performer for pipe sizes larger than 48 inches.

For water transmission lines less than 24 inches in diameter, water system managers seem to prefer PVC (polyvinyl chloride) pipe, followed by AC and DI (ductile iron) pipe. The combined failure rates reported for these pipe types fell below the combined average failure rates for all pipe types.

For water transmission lines greater than 24 inches in diameter, opinions about best performing pipe type were mixed. Overall, a slight preference for PT (pretensioned concrete cylinder) pipe seemed apparent. AWWA members seemed to prefer DI pipe from 24 to 48 inches in diameter, and had no clear preference of pipe type for pipe larger than 48 inches. Again, the combined failure rates reported for these pipe types fell below the combined average failure rates for all pipe types.

For pipe types larger than 48 inches in diameter, RC (reinforced concrete pressure pipe) was the preferred option, even though it exhibited failure rates above the combined average. The availability of pipe sizes greater than 72 inches, however, is generally limited to pipe types ECP (embedded cylinder prestressed concrete), NCP (noncylinder prestressed concrete), FP (fiberglass) (no data), RC, RCCP, RPM (reinforced plastic mortar), and ST (steel). Of this group, only RCCP and ST pipe exhibited combined failure rates lower than the combined average failure rates. ST pipe, however, exceeded the combined average failure rate in two of the three cases considered. The Reclamation questionnaire did not separate RC and RCCP categories as did the AWWARF questionnaire. The Reclamation responses for RC pipe therefore could have included information for RC and RCCP in the RC category to a very limited degree (only 2 documented installations since 1964).

When Reclamation and AWWARF data were analyzed separately for failure rates, the Reclamation data showed that pipe types CI, ECP, NCP, PE (polyethylene), and RC exceeded the Reclamation average failure rates, whereas pipe types AC, DI, PT, PVC, and ST were below the Reclamation average failure rates. RPM pipe exceeded the Reclamation average failure rate in one of the three cases considered. Reclamation respondents reported no data for pipe types LCP (lined cylinder prestressed concrete) and FP. For the AWWARF data, pipe types CI and DI exceeded the AWWA average failure rate, whereas pipe types AC, ECP, LCP, PT, PVC, RC, RCCP, and ST fell below the AWWA average failure rate. AWWA respondents reported no data for pipe types FP, NCP, PE, and RPM.

The combined failure rate data indicated that pipe types CI, ECP (in 2 of 3 cases), NCP, PE, RC, RPM, and ST (in 2 of 3 cases) exceeded the combined average failure rates. Pipe types AC, DI, LCP, PT, PVC, and RCCP fell below the combined average failure rates. The cases considered included combined failure rate calculations for (1) all projected repairs to ECP and NCP, (2) major projected repairs to ECP and NCP, and (3) actual repairs to ECP and NCP. Projections for ECP and NCP repairs were based on extensive data collected by Reclamation specific to the Central Arizona Project, Hayden-Rhodes Aqueduct siphons.

For the most part, when examining pipe preference data with failure rates, water system managers indicated a preference for pipe types that had lower than average failure rates.

Readers should note that the lengths and number of pipe lines sampled for PE, RPM, and NCP pipe types were much lower than lengths and number of pipe lines sampled for the other pipe types included in the analysis. Also, no data were reported for pipe type FP, although RPM pipe is generally considered one type of FP.

RECLAMATION PIPE LINE QUESTIONNAIRE

Figure 1 shows the questionnaire mailed to Reclamation offices and users of Reclamation-constructed water delivery systems. Each questionnaire was mailed with an instruction sheet asking respondents to consider all buried lines 4 inches or larger in diameter and 2,000 feet or more in length. Some respondents provided information on water lines smaller in diameter or shorter in length than specified, but the data were still included if possible.

Questionnaire

1. Owner _____ Telephone No. (___) _____

   Address _____

2. What types (and corresponding sizes and quantities) of buried pipe do you have in your system?

Pipe Type	Size Range (inch-inch)	Length (feet)	Years Installed
Asbestos-cement (AC)			
Gray cast iron (CI)			
Ductile iron (DI)			
Embedded cylinder prestressed (ECP)			
Lined cylinder prestressed (LCP)			
Non-cylinder prestressed (NCP)			
Pretensioned concrete (PT)			
Polyvinylchloride (PVC)			
Polyethylene (PE)			
Reinforced concrete (RC)			
Reinforced plastic mortar (RPM)			
Steel(S)			
Others (identify)			
_____			
_____			
_____			

Figure 1. - Reclamation questionnaire consisting of 12 questions regarding various types of manufactured water pipe.

3. Summarize pipe failures in the table below:

Pipe Leak Summary

COMPLETE ONLY FOR LINES ON WHICH LEAK/S HAVE BEEN EXPERIENCED.

Pipeline name	Pipe[1] type	Size (in)	Head or pressure range (ft)	(lb/in^2)	Joint[2] type/s	Service (yrs)	Leaks (No.)	Cause[3]	Action[4] Required

Legend

1 AC - Asbestos cement
CI - Gray cast iron
DI - Ductile iron
ECP - Embedded cylinder prestressed
LCP - Lined cylinder prestressed
NCP - Noncylinder prestressed
PT - Pretensioned cylinder
PVC - Polyvinylchloride
RC - Reinforced concrete
S - Steel
Others (identify in accord with response for question 2)

2 BS - Bell and spigot
MC - Mechanical couplings
W - Welded
O - Other

3 C - Corrosion
Ex - External damage
FM - Fish mouth
IN - Installation damage
O - Other
? - Undetermined

4 RR - Repair
RE - Replace

Figure 1. - Reclamation questionnaire consisting of 12 questions regarding various types of manufactured water pipe (continued).

4. What maintenance measures have been required to retain pipe system serviceability?

_____
_____
_____
_____
_____
_____
_____

5. Are copies of installation specifications available? ☐ yes ☐ no

6. Are failure reports available? ☐ yes ☐ no

7. Are cost reports (to repair failures) available? ☐ yes ☐ no

8. Do you have a computer database of your water system that contains data relevant to this survey? ☐ yes ☐ no

9. If yes, can we get a copy? ☐ yes ☐ no

10. In your opinion, which type of pipe has provided the most trouble free service?

24- to 48-inch inside diameter _____

48- to 72-inch inside diameter _____

over 72-inch inside diameter _____

11. May we publish this information? ☐ yes ☐ no

Only with the following provisions:_____
_____
_____
_____
_____
_____
_____

12. Person to be contacted if additional information is desired:

Name _____ Telephone No. (__)_____

Figure 1. - Reclamation questionnaire consisting of 12 questions regarding various types of manufactured water pipe (continued).

The questionnaires covered three main areas:

1. The first area concerned owner information and other ancillary data (questions 1, and 4 through 12).
2. The second area asked for information about the types and lengths of buried water pipes in the system (question 2).
3. The third area asked for data about pipe leaks and failures (question 3).

The questionnaire asked respondents to provide information on the 12 pipe types listed. Although space was provided for information on other types of pipe as well, the response was so limited that an attempt was not made to compile those data separately.

A follow-up survey was conducted by phone to obtain additional information needed for failure rate calculations. Only organizations that had properly responded to the initial questionnaire were contacted. Time constraints prevented contacting all respondents. Information on length, age, and number of failures for all pipe lines in a system (whether or not the pipe lines had experienced failures) was gathered.

AWWARF PIPE LINE QUESTIONNAIRE

Figure 2 shows the questionnaire mailed to AWWA members. The AWWA member names, addresses, and mailings were supplied by AWWARF. Although the AWWARF questionnaire was essentially the same as that mailed to Reclamation users, it was modified somewhat to account for the type of pipe and pipe designations with which AWWA members were familiar. In addition, the mailing included a glossary to clearly identify pipe types (see appendix).

Two mailings were performed by AWWARF: the first was from a list supplied by AWWARF, and the second was a follow-up mailing to water users from lists provided by AWWARF members. Each questionnaire was mailed with an instruction sheet asking the respondents to limit their responses to all water pipe lines that were 24 inches or larger in diameter and 1/2 mile or more in length. As with the Reclamation questionnaire, some respondents provided information on pipe lines that were smaller in diameter or shorter in length than requested; however, the information was included if possible.

The AWWARF questionnaire listed several more pipe types than the Reclamation questionnaire. In the AWWARF questionnaire, the steel pipe and ductile iron pipe classifications were divided into several subclassifications. When the compilation was performed, however, all responses in the subclassifications were lumped into their main classifications because the respondents seldom provided data for pipes in the subclassifications, and when they did, it was generally for a subclassification that was not listed.

As with the Reclamation questionnaire, a follow-up survey was conducted by phone to clarify information provided from the initial questionnaire (in limited cases) and to obtain additional information needed for failure rate calculations. Only organizations that had properly responded to the initial questionnaire were contacted. Time constraints prevented contacting all respondents. Information on length, age, and number of failures for all pipe lines (whether or not the pipe lines had experienced failures) was gathered.

Pipe Performance Survey

1. Owner _____ Telephone No. (___) _____
   Address _____

2. Summarize pipe information in the table below.

Pipe Type*	Size Range (Inch-Inch)	Length (feet)	Year(s) Installed	Year(s) In Service	Design Standard/Year	Anticipated Life	Cost per Mile	
							Installation	Maintenance**
AC (AWWA C402)								
RC (AWWA C302)								
RCCP (AWWA C300)								
PT (AWWA C303)								
NCP (No Standard)								
LCP (AWWA C301)								
ECP (AWWA C301)								
RPM (AWWA C950)								
FP (AWWA C950)								
PVC (AWWA C905)								
PB (AWWA C906)								
St (AWWA C-200)								
St w/C-203 Coating								
St w/C-205 Coating								
St wC-210 Coating								
St w/C-213 Coating								
St w/C-214 Coating								
St w/C-215 Coating								
St w/Other Coating-ID								
DI (AWWA C150)								
DI w/C105 Coating								
DI w/ no coating								
DI w/ Other Coating-ID								
Other Pipe (List)								

*See the glossary for an explanation of pipe types.
**Enter total amount of maintenance and repair expenses per mile.

Figure 2. - AWWARF questionnaire consisting of 10 questions regarding various types of manufactured water pipe.

3. Summarize pipe failures in the table below.

Pipeline Name	Pipe Type[1]	Size (inch)	Pressure[2] (lb/in²)	Joint Type[3]	Years in Service	Number of Failures	Cause[4]	Action Required[5]

[1] Identify in accord with previous table.
[2] 1 ft head (water) = .433 lb/in²

[3] BS - Bell and Spigot
MC - Mechanical couplings
W - Welded
O - Other (identify)

[4] C - Corrosion
Ex - External damage
FM - Fish mouth
IN - Installation damage
O - Other (identify)
? - Undetermined

[5] RR - Repair
RE - Replace
RRE - Repair and Replace

Figure 2. - AWWARF questionnaire consisting of 10 questions regarding various types of manufactured water pipe (continued).

4. What maintenance measures have been required to retain pipe system serviceability?

5. Are copies of installation specifications available? ☐ yes ☐ no

6. Are leak reports available? ☐ yes ☐ no

7. Are cost reports (to repair leaks) available? ☐ yes ☐ no

8. For each of the following size ranges, indicate which type of pipe has provided the most trouble free service?

less than 12-inch inside diameter _____

12- to 24-inch inside diameter _____

25- to 48-inch inside diameter _____

over 48-inch inside diameter _____

9. May we publish this information? ☐ yes ☐ no

Only with the following provisions: _____

10. Person to be contacted if additional information is desired:

Name _____ Telephone No. (___) _____

Figure 2. - AWWARF questionnaire consisting of 10 questions regarding various types of manufactured water pipe (continued).

COMPILATION OF QUESTIONNAIRE RESPONSES

Data compilation was performed on the questionnaire responses. Table 1 shows a total of 462 questionnaires were mailed to Reclamation water users, and 377 questionnaires were mailed to AWWA members. Of those, 162 Reclamation questionnaires and 114 AWWA questionnaires were returned. Ninety-seven Reclamation questionnaires and 65 AWWA questionnaires contained sufficient information to be included in the analysis. Those questionnaires also served as the basis for the follow-up phone surveys.

Table 1. - Questionnaire totals.

	Reclamation	AWWA
Questionnaires Mailed	462	377
Questionnaires Returned	162	114
Questionnaires Used	97	65

As noted, not all of the returned questionnaires were used, primarily because critical information was omitted. For instance, some respondents supplied data about lengths of various pipe types in their system, but did not indicate whether or not leaks or failures had occurred associated with any pipe types. Also, some respondents sent ample data about their water pipe systems that were not in the indicated format and/or not classified by the pipe types shown in the questionnaire. Some questionnaires were returned with no information.

For the failure rate calculations, involving information gathered by phone, data from 36 Reclamation and 29 AWWA responses were used in the calculations. Those responses were selected because they contained the information needed for the calculations.

Tables 2 and 3 show questionnaire responses to the question asking water system managers their opinion of which pipe type for the indicated size ranges performed the best. Numbers in the table show the total number of times a particular pipe type was chosen as the best performer. Some respondents indicated which size they thought performed the best; they did not consider pipe type, so their responses were not included. For this part of the analysis, 97 Reclamation and 65 AWWA responses were used.

The results of queried opinions showed that for pipes less than 24 inches in diameter, Reclamation respondents preferred PVC pipe, followed by AC and DI pipe.

For pipe sizes above 24 inches in diameter, opinions about best performing pipe type were mixed for both Reclamation and AWWA respondents. The AWWA members seem to prefer DI pipe from 24 to 48 inches in diameter, and had no clear preference of pipe type for pipe larger than 48 inches in diameter. Reclamation water system managers seem to prefer PT pipe from 25 to 48 inches in diameter and RC pipe for sizes greater than 48 inches.

Table 2. - Opinion of pipe performance (Reclamation).

Pipe Type	less than 12 inch	12 to 24 inch	25 to 48 inch	over 48 inch
AC	9	11	3	
CI				
DI	4	5		
ECP		1	1	3
LCP		1	4	4
NCP				
PE	1			
PT	1	1	8	2
PVC	27	21	3	
RC		2		8
RPM			1	
ST		3	5	4

Table 3. - Opinion of pipe performance (AWWA).

Pipe Type	24 to 48 inch	49 to 72 inch	over 72 inch
AC			
CI	2		
DI	9		
ECP		2	1
FP			
LCP	4	2	1
NCP			
PE			
PT	3	1	1
PVC			
RC	1	1	1
RCCP	3	2	1
RPM			
ST	2	1	

As shown in tables 4, 5, and 7, the survey sample size is greatest for pipe lines less than 48 inches in diameter, indicating that many water managers oversee lines smaller than that. As with the AWWA respondents, Reclamation water managers appear to have more experience with pipe lines less than 48 inches in diameter.

Table 4. - Number of pipe lines by pipe type and size in the survey (Reclamation).

Pipe Type	less than 12 inch	12 to 24 inch	25 to 48 inch	49 to 72 inch	over 72 inch
AC	9	7			
CI	4				
DI		1			
ECP		1	1	4	4
LCP*					
NCP		2			4
PE	1				
PT		1	9	1	
PVC	10	8			
RC		5	5	2	3
RPM		1	2		
ST	1	6	7	2	1

*No data reported for this pipe type.

Table 5. - Number of pipe lines by pipe type and size in the survey (AWWA).

Pipe Type	24 to 48 inch	49 to 72 inch	over 72 inch
AC	1		
CI	20		
DI	46		
ECP	7	4	3
FP*			
LCP	52	2	
NCP*			
PE*			
PT	16	4	3
PVC	1		
RC	5	1	
RCCP	11		1
RPM*			
ST	25	7	

*No data reported for this pipe type.

Table 6. - Availability of pipe by pipe size and head.

Pipe Type	Availability by Size (inches)	Head (feet)
AC	4 to 42	25 to 800
CI	3 to 54	—
DI	3 to 59	up to 1000
ECP	24 and up	25 and up
FP	8 to 144	25 to 550
LCP	16 to 48 and larger	25 to 500
NCP	up to 252	—
PE	4 to 63	95 to 575
PT	10 to 72 and larger	25 to 700
PVC	4 to 48	25 to 700
RC	12 to 144 and larger	25 to 150
RCCP	24 to 144 and larger	25 to 600
RPM	8 to 144 and larger	up to 500
ST	1/2 to 252 and larger	25 to 1300 and higher

Table 7 data show that 85 percent of the respondents managed pipe lines less than 48 inches in diameter; 9 percent managed pipe lines 49 to 72 inches in diameter; and the remaining 6 percent managed pipe lines greater than 72 inches in diameter. The table also presents sample size information, both by pipe line sample numbers and pipe line lengths, categorized by pipe type. The number of pipe lines providing information for pipe types PE, NCP, and RPM was less than 10; all the information on PE pipe came from one pipe line. Also, these three pipe types were represented by only one percent of the total length of all pipe types. Furthermore, table 7 shows that pipe types LCP, ST, DI, and PT contain information from the largest number of pipe lines, and pipe types LCP, ST, AC, PT, and RC make up the majority of pipe line lengths.

The availability of different pipe types in the various sizes is shown in table 6. Availability of pipe types affect choices for use, ultimately affecting opinions about which type of pipe perform best. Head class and cover are also important design parameters that affect pipe selection, particularly when large diameter pipe is involved.

Tables 8 and 9 show pipe type by total length, percent of total length of each pipe type versus total length of all pipe lines, total number of failures, and number of failures per mile–year. Figures 3 and 4 are graphical representations of the failure rates shown in tables 8 and 9.

Failure was indicated as requiring some type of action after installation to correct a pipe deficiency – namely repair, replacement, or both repair and replacement of the affected units. Indicated causes of failure included corrosion, external damage, fish mouth, installation damage, other, and/or undetermined. The term failure rate is therefore synonymous with repair/replacement rate.

Table 7. - Total number and length of pipe lines by pipe type and size in the survey.

Pipe Type	Number of Pipe Lines					Pipe Line Lengths	
	48 inches or less	49 to 72 inches	over 72 inches	Combined Total	% of Combined Total	Combined Total (ft.)	% of Combined Total
AC	17			17	5	1,086,858	13
CI	24			24	8	306,400	4
DI	47			47	15	683,711	8
ECP	9	8	7	24	8	329,792	4
FP*							
LCP	52	2		54	17	1,481,124	18
NCP	2		4	6	2	80,637	1
PE	1			1	.3	125,000	1
PT	26	5	3	34	11	987,153	12
PVC	19			19	6	670,496	8
RC	15	3	3	21	7	856,005	10
RCCP	11		1	12	4	190,407	2
RPM	3			3	1	77,767	1
ST	39	9	1	49	16	1,500,218	18
Total	265	27	19	311	100	8,375,568	100
% of Total	85	9	6	100	100	100	100

*No data reported for this pipe type.

Table 8. - Pipe performance (Reclamation).

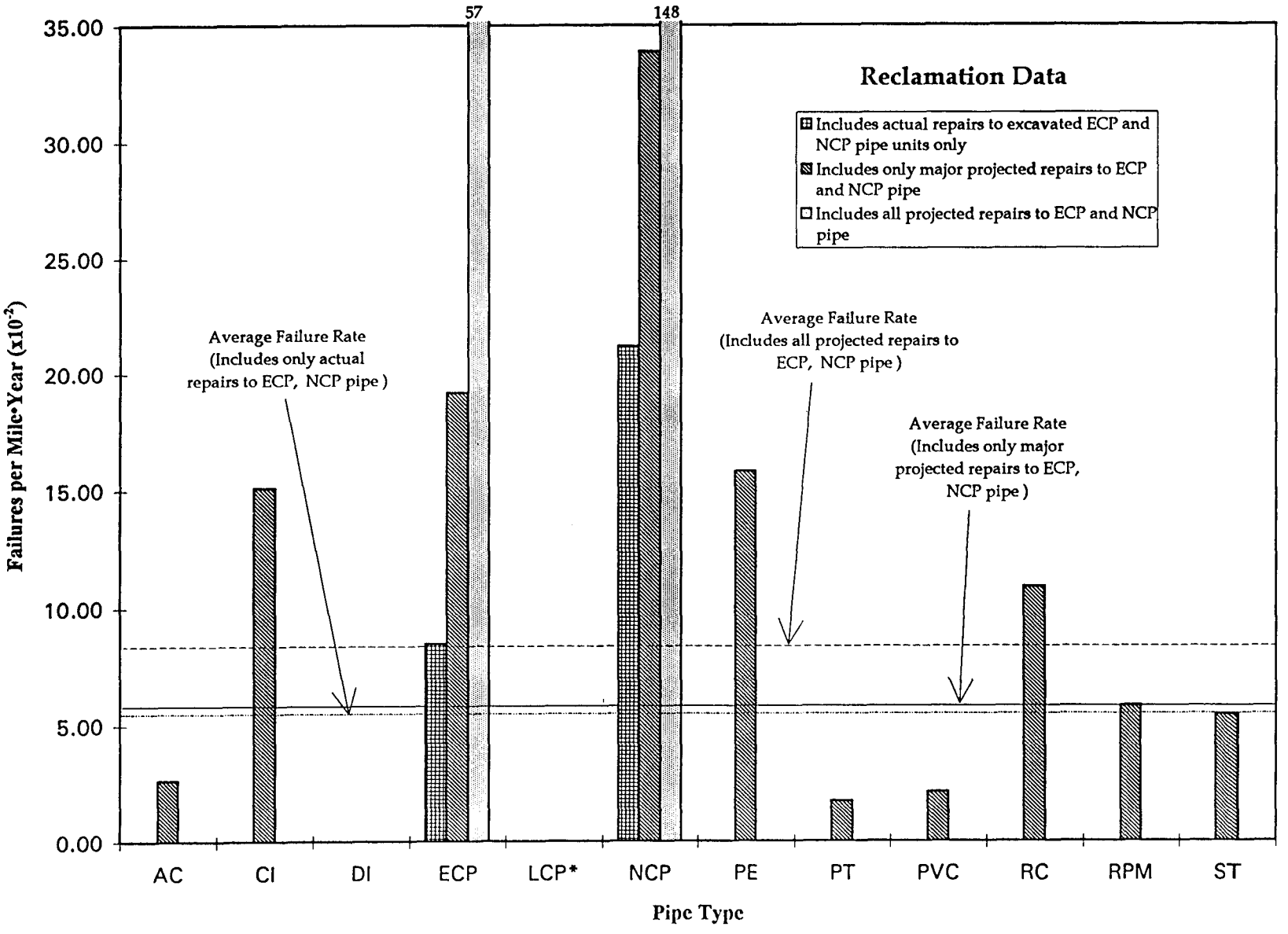
Pipe Type	Length, ft	Percent of Total Length	Failures	Failures per Mile Year ($x10^{-2}$)
AC	1,074,858	29	170	2.64
CI	64,829	2	57	15.10
DI	15,794	0	0	0.00
ECP	96,735	3	22**/50†/148‡	8.48**/19.30†/57.0‡
LCP*				
NCP	80,637	2	70**/112†/489‡	21.2**/33.90†/148‡
PE	125,000	3	75	15.80
PT	311,190	8	20	1.75
PVC	662,163	18	41	2.14
RC	554,425	15	287	10.90
RPM	77,767	2	8	5.82
ST	626,844	17	277	5.45
Average Failure Rate: 5.46**/5.83†/8.36‡				

* No data reported for this pipe type.
** Includes actual repairs to excavated pipe units only
† Includes only projected repairs of complete prestressing replacement for part or all of a pipe unit.
‡ Includes all projected repairs.

Table 9. - Pipe performance (AWWA).

Pipe Type	Length, ft	Percent of Total Length	Failures	Failures per Mile Year ($x10^{-2}$)
AC	12,000	0	0	0.00
CI	241,571	5	126	4.69
DI	667,917	14	23	1.79
ECP	233,057	5	5	0.65
FP*				
LCP	1,481,124	32	21	0.30
NCP*				
PE*				
PT	675,963	14	11	0.43
PVC	8,333	0	0	0.00
RC	301,580	6	2	0.01
RCCP	190,407	4	0	0.00
RPM*				
ST	873,374	19	24	0.64
Average Failure Rate: .97				

*No data reported for this pipe type.



*No data reported for this pipe type

Figure 3. - Failure rate by pipe type.

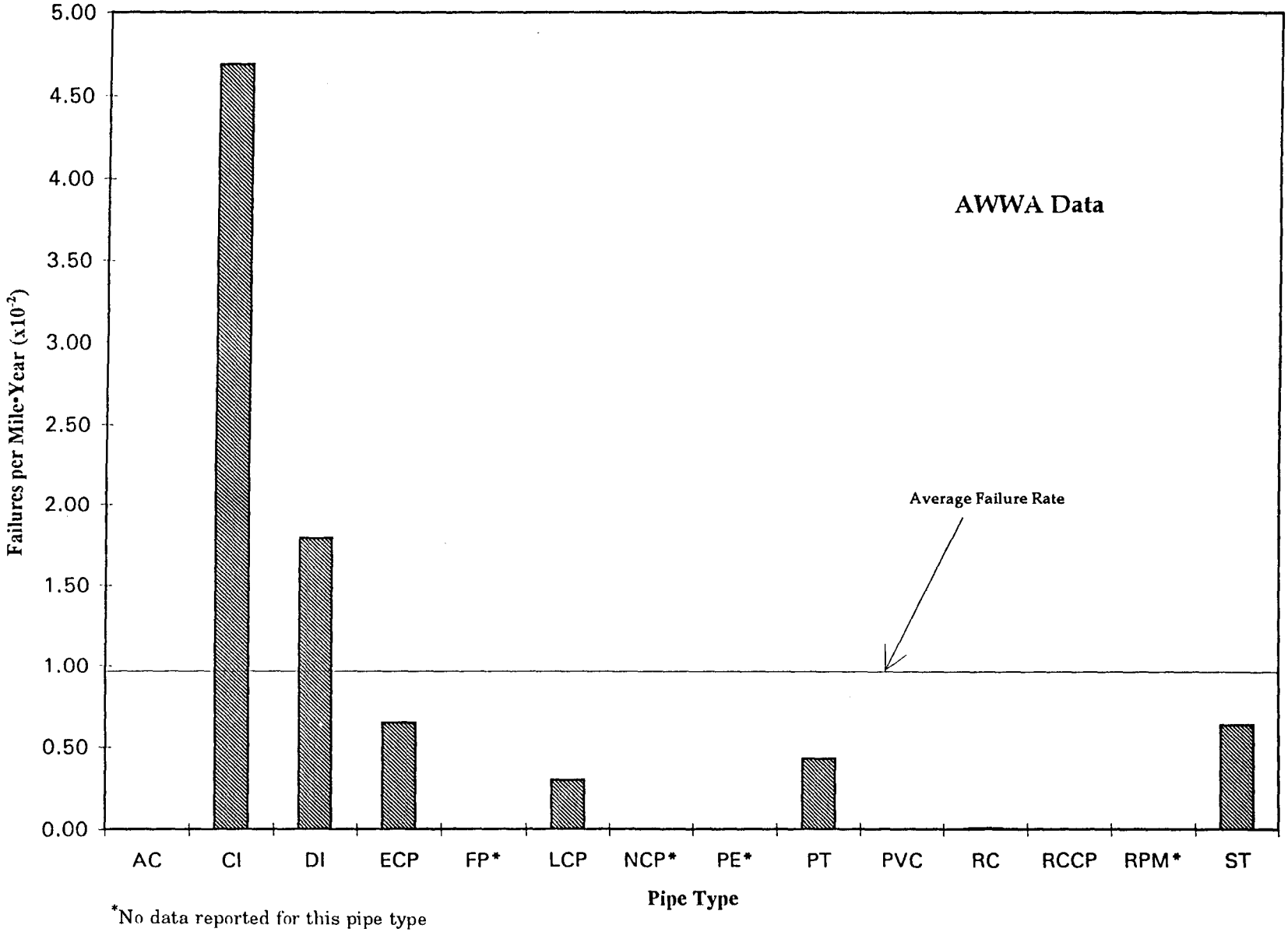


Figure 4. - Failure rate by pipe type.

Failure rates were calculated using a weighted average age of pipe to account for pipe lines that were older and therefore likely to have experienced more failures. Age for a pipe line was weighted by feet of pipe for a given pipe type within a size range. The number of failures was then divided by the weighted average age and length of the pipe line to yield failures per mile–year. Data used for the calculations is in appendix B.

Failure is difficult to quantify on a per pipe unit basis when repair or replacement of an entire pipe line is required. For the Reclamation survey, the ECP and NCP pipe categories include projections of severe distress for six 252-inch-diameter CAP (Central Arizona Project) siphons. In other words, based on the findings from representative excavations, 161 pipe units out of 1562 total units were projected to be so severely distressed that complete prestressing replacement was required for all or a portion of a pipe unit. Twenty-three of the 223 excavated units were found in this condition.

If all the repairs to the excavated units are considered, as suggested by the survey concept of failure, it is projected that 636 pipe units would require some type of repair. In fact, 91 units of the 223 excavated units required some type of repair. Combined average failure rates for all pipe types were therefore calculated using (1) all projected repairs to ECP and NCP, (2) major projected repairs to ECP and NCP, and (3) actual repairs to ECP and NCP.

Although the projected repairs are specific to the 252-inch-diameter ECP and NCP Central Arizona Project pipe, it should be noted that the Reclamation figures in the tables are conservative because the Jordan Aqueduct Reach 3 (66-inch diameter) failure is treated as a single failure, even though the entire 2.3 miles of the pipe line were lined with steel.

Survey data show that for Reclamation water systems, NCP, ECP, CI, PE, and RC pipe had failure rates above the Reclamation average failure rates. RPM pipe exceeded the Reclamation average failure rate in one of the three cases considered. Survey data from the AWWA members showed that CI had the highest failure rate, and both CI and DI failure rates were above the AWWA average.

Tables 10, 11, 12, and 13 present the failure data shown in tables 8 and 9 by pipe type and size of pipe. Table 14 shows the combined failure rates for both Reclamation and AWWA data. Figure 5 is a graphical representation of the data in table 14.

The combined failure rate data (table 14) shows that the failure rates for pipe types CI, ECP (in 2 of 3 cases), NCP, PE, RC, RPM, and ST (in 2 of 3 cases) exceeded the combined average failure rate. Failure rates for pipe types AC, DI, LCP, PT, PVC, and RCCP fell below the combined average failure rates. It should be emphasized that these results were based on a relatively small sample size for pipe types PE, RPM, and NCP. No data were provided on FP pipe, although RPM pipe is generally considered one type of FP.

It is interesting to note that Reclamation water users preferred (table 2) PVC, AC, and DI for pipe sizes less than 24 inches; PT for pipe sizes ranging from 24 to 48 inches; and RC for sizes greater than 48 inches. With the exception of RC pipe, these pipe types exhibited lower than average failure rates (tables 8, 10, and 11). The availability of pipe sizes greater than 72 inches is generally limited to pipe types ECP, NCP, FP (no data), RC, RCCP, RPM, and ST. Of this group, only RCCP and ST pipe exhibited a combined failure rate lower than the combined average failure rate. ST pipe, however, exceeded the combined average failure rate in two of the three cases considered. Also, the Reclamation questionnaire did not separate

RC and RCCP categories as did the AWWARF questionnaire. The Reclamation responses for RC pipe therefore included information for RC and RCCP in the RC category to a very limited degree (only 2 documented installations since 1964).

Table 10. - Failures by size (Reclamation).

Pipe Type	less than 12 inch	12 to 24 inch	25 to 48 inch	49 to 72 inch	over 72 inch
AC	98	72			
CI	57				
DI		0			
ECP		0	0	1	21**/49†/147‡
LCP*					
NCP		0	0		70**/112†/489‡
PE	75				
PT		3	16	1	
PVC	39	2			
RC		207	24	55	1
RPM		2	6		
ST	2	252	15	8	0

* No data reported for this pipe type
** Includes actual repairs to excavated units only.
† Includes only projected repairs of complete prestressing replacement for part or all of a pipe unit.
‡ Includes all projected repairs.

Table 11. - Failure rate by size (Reclamation, failures per mile-year [$x10^{-2}$]).

Pipe Type	less than 12 inch	12 to 24 inch	25 to 48 inch	49 to 72 inch	over 72 inch
AC	2.35	3.18			
CI	15.10				
DI		0.00			
ECP		0.00	0.00	8.10	26.6**/62.00†/186.0‡
LCP*					
NCP		0.00	0.00		161**/258.0†/1,130‡
PE	15.80				
PT		2.98	1.69	1.04	
PVC	2.21	1.32			
RC		16.40	1.91	92.9	1.89
RPM		2.19	12.90		
ST	4.62	5.23	7.38	4.10	0.00
Average Failure Rate:		5.46**/5.83†/8.36‡			

* No data reported for this pipe type
** Includes actual repairs to excavated units only
† Includes only projected repairs of complete prestressing replacement for part or all of a pipe unit.
‡ Includes all projected repairs.

Table 12. - Failures by size (AWWA).

Pipe Type	24 to 48 inch	49 to 72 inch	over 72 inch
AC	0		
CI	126		
DI	23		
ECP	1	4	0
FP*			
LCP	19	2	
NCP*			
PE*			
PT	11	0	0
PVC	0		
RC	2	0	
RCCP	0		0
RPM			
ST	22	2	

*No data reported for this pipe type

Table 13. - Failure rate by size (AWWA, failures per mile-year [$x10^{-2}$]).

Pipe Type	24 to 48 inch	49 to 72 inch	over 72 inch
AC	0.00		
CI	4.69		
DI	1.79		
ECP	0.26	1.37	0.00
FP*			
LCP	0.28	2.78	
NCP*			
PE*			
PT	0.85	0.00	0.00
PVC	0.00		
RC	0.28		
RCCP	0.00		0.00
RPM			
ST	0.61	1.23	
Average Failure Rate: .97			

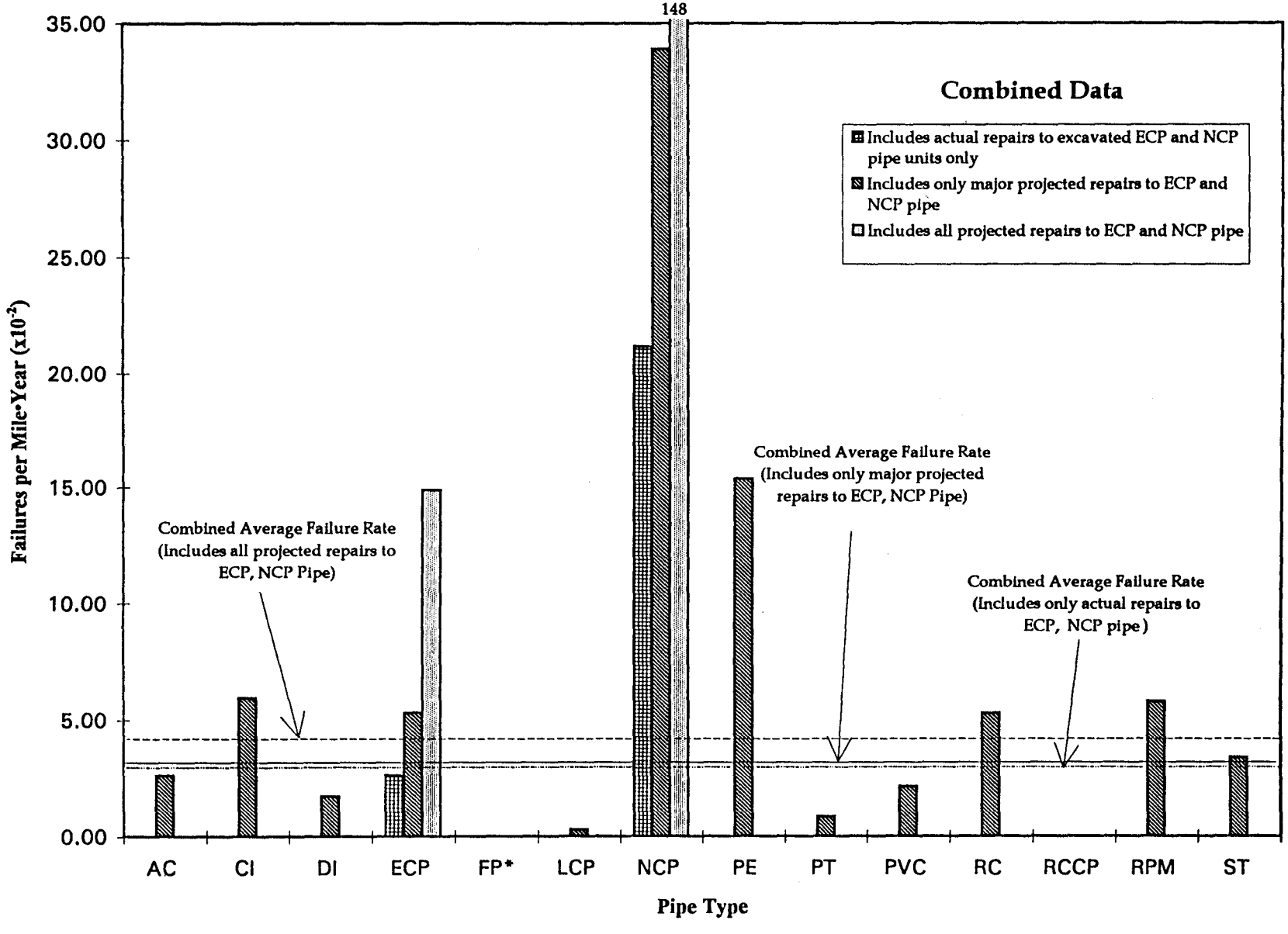
*No data reported for this pipe type

Table 14. - Combined failure rate (AWWA and Reclamation, failures per mile-year [$x10^{-2}$]) by pipe type.

Pipe Type	Failure Rate
AC	2.63
CI	5.97
DI	1.75
ECP	2.63**/5.32†/14.9‡
FP*	
LCP	0.30
NCP	21.2**/33.9†/148‡
PE	15.8
PT	0.84
PVC	2.14
RC	5.30
RCCP	0.00
RPM	5.82
ST	3.40
Combined Average Failure Rate	3.05**/3.22†/4.40‡

* No data reported for this pipe type
** Includes repairs to excavated pipe units only
† Includes only projected repairs of complete prestressing replacement for part or all of a pipe unit.
‡ Includes all projected repairs.

AWWA member respondents showed a preference for DI pipe (table 3). Although its failure rate was higher than the AWWA average failure rate, the combined DI pipe failure rates were lower than the combined average failure rate (tables 9, 12, 13, and 14).



*No data reported for this pipe type

Figure 5. - Combined failure rate by pipe type.

APPENDIX A

GLOSSARY FOR PIPE TYPES

AC - Asbestos-cement. This type of rigid transmission pipe consists of a mixture of portland cement and asbestos fibers.

DI - Ductile Iron Pipe. This type of pipe, which has considerable rigidity in the small diameters but is flexible in the larger diameters, is manufactured by introducing a charge of molten iron in a rapidly spinning mold. The centrifugal force caused by the spinning process forms the molten iron into a cylinder of uniform thickness that is determined by the volume of the molten charge. After cooling and annealing, a thin cement-mortar lining is applied to the inside of the pipe.

ECP - Embedded Cylinder Prestressed Concrete Pipe. This type of rigid pipe consists of a welded steel cylinder with steel joint rings attached to each end and embedded in a concrete core. The high-tensile wire reinforcement is helically wound under measured tension in one or more layers around the outside of the concrete core containing the cylinder. The high-tensile wire is protected by a cement mortar placed by an impact method.

FP - Fiberglass Pipe (Reinforced Thermosetting Resin Pipe). This type of flexible pipe is composed of continuous fiberglass filaments in a polyester resin matrix. The glass strands are wound on a rotating mandrel in a helical fashion until the required wall thickness is obtained. The helical angle, which varies among manufacturers, provides longitudinal as well as circumferential strength.

LCP - Lined Cylinder Prestressed Concrete Pipe. This type of pipe consists of a welded steel cylinder with steel joint rings attached to each end. Then, the cylinder is centrifugally lined with dense concrete to constitute the core. The high-tensile wire is helically wound under controlled tension directly on the steel cylinder. The wrapped core is then covered by a cement mortar coating applied by a mechanical impact method.

NCP - Noncylinder Prestressed Concrete Pipe. This type of pipe consists of a concrete core which may include embedded prestressed longitudinal reinforcement. The high-tensile wire reinforcement is helically wound under controlled tension around the outside of the concrete core. The high-tensile wire is protected by a cement mortar coating applied by impact.

PE - Polyethylene. This type of pipe is made from materials having standard PE code designations.

PT - Pretensioned Concrete Cylinder Pipe. This type of flexible pipe is a composite design; the basic element of the pipe is a welded steel cylinder with steel joint rings welded to its ends. The cylinder is lined with centrifugally placed cement mortar or concrete. Then, continuous reinforcing rod is helically wound, under controlled tension, around the lined cylinder, and a mortar coating is placed by means of high-velocity impaction. In Saudi Arabia, this type of pipe is called Concrete Cylinder Pipe.

PVC - Polyvinyl Chloride Pipe. PVC plastic is a thermo-plastic that can be repeatedly softened to a plastic state by the application of heat and hardened to a solid state by cooling. This type of flexible pipe is manufactured by extruding the heated, molten plastic through a forming die to obtain a cylindrical shape of the proper diameter and wall thickness. The pipe is immediately cooled and then is cut to the proper length.

RC - Reinforced Concrete Pressure Pipe. This type of rigid pipe is commonly called "bar" pipe and consists of reinforcing cages placed in the concrete shell to resist bursting pressures and external earth loads.

RCCP - Reinforced Concrete Cylinder Pressure Pipe. This type of rigid pipe was developed to handle higher internal heads than reinforced concrete pressure pipe. This pipe consists of a steel cylinder welded to end rings and surrounded by reinforcing cages embedded in a concrete shell.

RPM - Reinforced Plastic Mortar Pipe (Fiberglass Pipe). This type of flexible pipe is manufactured of polyester plastic resin reinforced with continuous fiberglass filaments. Sand is incorporated into the pipe wall at various stages of manufacture as an inexpensive filler material to build up the pipe wall to its required thickness. The continuous fiberglass strands are wound on a rotating mandrel in a circumferential fashion and separate longitudinally oriented fibers are added to provide the necessary longitudinal strength.

ST - Steel Pipe. Flexible steel pipe can be manufactured in practically any size and for any pressure rating. The pipe is manufactured by rolling sheet steel (either flat plate or continuous roll) into a cylindrical shape and welding the edges of the sheet together. The inside of the pipe can be lined with cement mortar, coal-tar epoxy, or fusion epoxy. The outside of the pipe is coated with either cement-mortar or coal-tar enamel. Polyethylene tape coating systems are also allowed for steel pipe.

APPENDIX B

SURVEY FAILURE RATE DATA

Bureau of Reclamation Survey Failure Rate Data

Pipe Type	*Size Range (in)*	*Years in Service*	*Number of Failures*	*Length (ft)*	*Length X Age*	*Failures per Mile•Year*
AC	less than 12	12	0	8,000	96,000	
AC	less than 12	30	0	4,400	132,000	
AC	less than 12	35	30	200,000	7,000,000	
AC	less than 12	35	30	200,000	7,000,000	
AC	less than 12	35	30	200,000	7,000,000	
AC	less than 12	30	6	19,645	589,350	
AC	less than 12	12	0	3,700	44,400	
AC	less than 12	30	0	1,100	33,000	
AC	less than 12	25	2	3,320	83,000	
AC	**less than 12 Total**		98	640,165	21,977,750	
AC	**less than 12 Average Age and Failure Rate**				34	2.35E-02
AC	12 to 24	34	50	285,120	9,694,080	
AC	12 to 24	20	0	2,400	48,000	
AC	12 to 24	24	2	49,530	1,188,720	
AC	12 to 24	12	18	68,940	827,280	
AC	12 to 24	2	1	6,403	12,806	
AC	12 to 24	16	0	2,600	41,600	
AC	12 to 24	8	1	19,700	157,600	
AC	**12 to 24 Total**		72	434,693	11,970,086	
AC	**12 to 24 Average Age and Failure Rate**				28	3.18E-02
AC Total			170	1,074,858	33,947,836	
AC Average Age and Failure Rate					32	2.64E-02
CI	less than 12	29	0	50,481	1,463,949	
CI	less than 12	45	17	4,800	216,000	
CI	less than 12	35	40	5,180	181,300	
CI	less than 12	30	0	4,368	131,040	
CI Total			57	64,829	1,992,289	
CI Average Age and Failure Rate					31	1.51E-01
DI	12 to 24	11	0	15,794	173,734	
DI Total			0	15,794	173,734	
DI Average Age and Failure Rate					11	0.00E+00
Note: ECP and NCP values include projected repairs of prestressing for part or all of a pipe unit. See end of table for other cases						
ECP	12 to 24	30	0	29,540	886,200	
ECP	**12 to 24 Total**		0	29,540	886,200	
ECP	**12 to 24 Average Age and Failure Rate**				30	0.00E+00
ECP	25 to 48	3	0	382	1,146	
ECP	**25 to 48 Total**		0	382	1,146	
ECP	**25 to 48 Average Age and Failure Rate**				3	0.00E+00
ECP	49 to 72	3	0	3,775	11,325	
ECP	49 to 72	3	0	5,808	17,424	
ECP	49 to 72	3	0	528	1,584	
ECP	49 to 72	3	1	11,616	34,848	
ECP	**49 to 72 Total**		1	21,727	65,181	
ECP	**49 to 72 Average Age and Failure Rate**				3	8.10E-02
ECP	over 72	5	0	22,176	110,880	
ECP	over 72	14	0	8,588	120,232	
ECP	over 72	13	42	8,998	116,974	
ECP	over 72	13	7	5,324	69,212	
ECP	**over 72 Total**		49	45,086	417,298	
ECP	**over 72 Average Age and Failure Rate**				9	6.20E-01
ECP Total			50	96,735	1,369,825	
ECP Average Age and Failure Rate					14	1.93E-01

Pipe Type	Size Range (in)	Years in Service	Number of Failures	Length (ft)	Length X Age	Failures per Mile•Year
NCP	12 to 24	25	0	7,919	197,975	
NCP	12 to 24 Total		0	7,919	197,975	
NCP	12 to 24 Average Age and Failure Rate				25	0.00E+00
NCP	25 to 48	25	0	52,676	1,316,900	
NCP	25 to 48 Total		0	52,676	1,316,900	
NCP	25 to 48 Average Age and Failure Rate				25	0.00E+00
NCP	over 72	13	28	770	10,010	
NCP	over 72	13	28	5,544	72,072	
NCP	over 72	13	42	3,168	41,184	
NCP	over 72	10	14	10,560	105,600	
NCP	over 72 Total		112	20,042	228,866	
NCP	over 72 Average Age and Failure Rate				11	2.58E+00
NCP Total			112	80,637	1,743,741	
NCP Average Age and Failure Rate					22	3.39E-01
PE	less than 12	20	75	125,000	2,500,000	
PE Total			75	125,000	2,500,000	
PE Average Age and Failure Rate					20	1.58E-01
PT	12 to 24	25	3	21,230	530,750	
PT	12 to 24 Total		3	21,230	530,750	
PT	12 to 24 Average Age and Failure Rate				25	2.98E-02
PT	25 to 48	25	6	8,090	202,250	
PT	25 to 48	30	4	60,850	1,825,500	
PT	25 to 48	15	1	12,398	185,970	
PT	25 to 48	14	1	81,877	1,146,278	
PT	25 to 48	25	4	3,960	99,000	
PT	25 to 48	4	0	13,910	55,640	
PT	25 to 48	10	0	13,504	135,040	
PT	25 to 48	20	0	67,056	1,341,120	
PT	25 to 48	1	0	1,515	1,515	
PT	25 to 48 Total		16	263,160	4,992,313	
PT	25 to 48 Average Age and Failure Rate				19	1.69E-02
PT	49 to 72	19	1	26,800	509,200	
PT	49 to 72 Total		1	26,800	509,200	
PT	49 to 72 Average Age and Failure Rate				19	1.04E-02
PT Total			20	311,190	6,032,263	
PT Average Age and Failure Rate					19	1.75E-02
PVC	less than 12	1	0	4,000	4,000	
PVC	less than 12	8	2	55,000	440,000	
PVC	less than 12	30	1	6,300	189,000	
PVC	less than 12	25	30	300,000	7,500,000	
PVC	less than 12	5	0	4,500	22,500	
PVC	less than 12	4	0	10,000	40,000	
PVC	less than 12	7	5	125,000	875,000	
PVC	less than 12	5	0	4,000	20,000	
PVC	less than 12	6	1	24,285	145,710	
PVC	less than 12	8	0	10,560	84,480	
PVC	less than 12 Total		39	543,645	9,320,690	
PVC	less than 12 Average Age and Failure Rate				17	2.21E-02
PVC	12 to 24	11	0	36,960	406,560	
PVC	12 to 24	5	0	12,000	60,000	
PVC	12 to 24	14	2	2,640	36,960	
PVC	12 to 24	2	0	23,500	47,000	
PVC	12 to 24	1	0	4,260	4,260	
PVC	12 to 24	7	0	30,058	210,406	

Pipe Type	Size Range (in)	Years in Service	Number of Failures	Length (ft)	Length X Age	Failures per Mile•Year
PVC	12 to 24	3	0	3,400	10,200	
PVC	12 to 24	4	0	5,700	22,800	
PVC	12 to 24 Total		2	118,518	798,186	
PVC	12 to 24 Average Age and Failure Rate				7	1.32E-02
PVC Total			41	662,163	10,118,876	
PVC Average Age and Failure Rate					15	2.14E-02
RC	12 to 24	26	173	161,040	4,187,040	
RC	12 to 24	30	22	56,520	1,695,600	
RC	12 to 24	18	0	6,144	110,592	
RC	12 to 24	25	0	12,900	322,500	
RC	12 to 24	25	12	13,200	330,000	
RC	12 to 24 Total		207	249,804	6,645,732	
RC	12 to 24 Average Age and Failure Rate				27	1.64E-01
RC	25 to 48	12	2	72,470	869,640	
RC	25 to 48	5	1	30,040	150,200	
RC	25 to 48	25	0	2,000	50,000	
RC	25 to 48	30	21	172,950	5,188,500	
RC	25 to 48	37	0	10,000	370,000	
RC	25 to 48 Total		24	287,460	6,628,340	
RC	25 to 48 Average Age and Failure Rate				23	1.91E-02
RC	49 to 72	55	55	3,259	179,245	
RC	49 to 72	37	0	3,600	133,200	
RC	49 to 72 Total		55	6,859	312,445	
RC	49 to 72 Average Age and Failure Rate				46	9.29E-01
RC	over 72	7	0	4,800	33,600	
RC	over 72	37	0	1,230	45,510	
RC	over 72	47	1	4,272	200,784	
RC	over 72 Total		1	10,302	279,894	
RC	over 72 Average Age and Failure Rate				27	1.89E-02
RC Total			287	554,425	13,866,411	
RC Average Age and Failure Rate					25	1.09E-01
RPM	12 to 24	12	2	40,122	481,464	
RPM	12 to 24 Total		2	40,122	481,464	
RPM	12 to 24 Average Age and Failure Rate				12	2.19E-02
RPM	25 to 48	6	3	36,182	217,092	
RPM	25 to 48	19	3	1,463	27,797	
RPM	25 to 48 Total		6	37,645	244,889	
RPM	25 to 48 Average Age and Failure Rate				7	1.29E-01
RPM Total			8	77,767	726,353	
RPM Average Age and Failure Rate					9	5.82E-02
S	less than 12	20	2	11,440	228,800	
S	less than 12 Total		2	11,440	228,800	
S	less than 12 Average Age and Failure Rate				20	4.62E-02
S	12 to 24	55	200	400,000	22,000,000	
S	12 to 24	38	52	76,560	2,909,280	
S	12 to 24	5	0	13,175	65,875	
S	12 to 24	24	0	15,840	380,160	
S	12 to 24	35	0	2,300	80,500	
S	12 to 24	11	0	623	6,853	
S	12 to 24 Total		252	508,498	25,442,668	
S	12 to 24 Average Age and Failure Rate				50	5.23E-02
S	25 to 48	30	15	300	9,000	
S	25 to 48	20	0	500	10,000	
S	25 to 48	10	0	26,192	261,920	

Pipe Type	Size Range (in)	Years in Service	Number of Failures	Length (ft)	Length X Age	Failures per Mile•Year
S	25 to 48	3	0	26,192	78,576	
S	25 to 48	12	0	33,885	406,620	
S	25 to 48	26	0	3,000	78,000	
S	25 to 48	30	0	7,650	229,500	
S	25 to 48 Total		15	97,719	1,073,616	
S	25 to 48 Average Age and Failure Rate				11	7.38E-02
S	49 to 72	37	8	100	3,700	
S	49 to 72	14	0	7,087	99,218	
S	49 to 72 Total		8	7,187	102,918	
S	49 to 72 Average Age and Failure Rate				14	4.10E-01
S	over 72	6	0	2,000	12,000	
S	over 72 Total		0	2,000	12,000	
S	over 72 Average Age and Failure Rate				6	0.00E+00
S Total			277	626,844	26,860,002	
S Average Age and Failure Rate					43	5.45E-02
Note: ECP and NCP values below include all projected repairs for part or all of a pipe unit						
ECP	12 to 24	30	0	29,540	886,200	
ECP	12 to 24 Total		0	29,540	886,200	
ECP	12 to 24 Average Age and Failure Rate				30	0.00E+00
ECP	25 to 48	3	0	382	1,146	
ECP	25 to 48 Total		0	382	1,146	
ECP	25 to 48 Average Age and Failure Rate				3	0.00E+00
ECP	49 to 72	3	0	3,775	11,325	
ECP	49 to 72	3	0	5,808	17,424	
ECP	49 to 72	3	0	528	1,584	
ECP	49 to 72	3	1	11,616	34,848	
ECP	49 to 72 Total		1	21,727	65,181	
ECP	49 to 72 Average Age and Failure Rate				3	8.10E-02
ECP	over 72	5	0	22,176	110,880	
ECP	over 72	14	0	8,588	120,232	
ECP	over 72	13	119	8,998	116,974	
ECP	over 72	13	28	5,324	69,212	
ECP	over 72 Total		147	45,086	417,298	
ECP	over 72 Average Age and Failure Rate				9	1.86E+00
ECP Total			148	96,735	1,369,825	
ECP Average Age and Failure Rate					14	5.70E-01
NCP	12 to 24	25	0	7,919	197,975	
NCP	12 to 24 Total		0	7,919	197,975	
NCP	12 to 24 Average Age and Failure Rate				25	0.00E+00
NCP	25 to 48	25	0	52,676	1,316,900	
NCP	25 to 48 Total		0	52,676	1,316,900	
NCP	25 to 48 Average Age and Failure Rate				25	0.00E+00
NCP	over 72	13	56	770	10,010	
NCP	over 72	13	181	5,544	72,072	
NCP	over 72	13	112	3,168	41,184	
NCP	over 72	10	140	10,560	105,600	
NCP	over 72 Total		489	20,042	228,866	
NCP	over 72 Average Age and Failure Rate				11	1.13E+01
NCP Total			489	80,637	1,743,741	
NCP Average Age and Failure Rate					22	1.48E+00
Note: ECP and NCP values below include actual repairs for part or all of a pipe unit						
ECP	12 to 24	30	0	29,540	886,200	
ECP	12 to 24 Total		0	29,540	886,200	
ECP	12 to 24 Average Age and Failure Rate				30	0.00E+00

Pipe Type	Size Range (in)	Years in Service	Number of Failures	Length (ft)	Length X Age	Failures per Mile•Year
ECP	25 to 48	3	0	382	1,146	
ECP	25 to 48 Total		0	382	1,146	
ECP	25 to 48 Average Age and Failure Rate				3	0.00E+00
ECP	49 to 72	3	0	3,775	11,325	
ECP	49 to 72	3	0	5,808	17,424	
ECP	49 to 72	3	0	528	1,584	
ECP	49 to 72	3	1	11,616	34,848	
ECP	49 to 72 Total		1	21,727	65,181	
ECP	49 to 72 Average Age and Failure Rate				3	8.10E-02
ECP	over 72	5	0	22,176	110,880	
ECP	over 72	14	0	8,588	120,232	
ECP	over 72	13	10	8,998	116,974	
ECP	over 72	13	11	5,324	69,212	
ECP	over 72 Total		21	45,086	417,298	
ECP	over 72 Average Age and Failure Rate				9	2.66E-01
ECP Total			22	96,735	1,369,825	
ECP Average Age and Failure Rate					14	8.48E-02
NCP	12 to 24	25	0	7,919	197,975	
NCP	12 to 24 Total		0	7,919	197,975	
NCP	12 to 24 Average Age and Failure Rate				25	0.00E+00
NCP	25 to 48	25	0	52,676	1,316,900	
NCP	25 to 48 Total		0	52,676	1,316,900	
NCP	25 to 48 Average Age and Failure Rate				25	0.00E+00
NCP	over 72	13	8	770	10,010	
NCP	over 72	13	26	5,544	72,072	
NCP	over 72	13	16	3,168	41,184	
NCP	over 72	10	20	10,560	105,600	
NCP	over 72 Total		70	20,042	228,866	
NCP	over 72 Average Age and Failure Rate				11	1.61E+00
NCP Total			70	80,637	1,743,741	
NCP Average Age and Failure Rate					22	2.12E-01

AWWARF Survey Failure Rate Data

Pipe Type	Size Range (in)	Years in Service	Number of Failures	Length (ft)	Length X Age	Failures per Mile•Year
AC	25 to 48	20	0	12,000	240,000	
AC Total			0	12,000	240,000	
AC Average Age and Failure Rate					20	0.00E+00
CI	24 to 48	45	24	1,600	72,000	
CI	24 to 48	30	1	385	11,550	
CI	24 to 48	52	6	8,000	416,000	
CI	24 to 48	31	4	66,700	2,067,700	
CI	24 to 48	25	1	3,822	95,550	
CI	24 to 48	81	2	8,170	661,770	
CI	24 to 48	79	0	5,369	424,151	
CI	24 to 48	38	20	3,000	114,000	
CI	24 to 48	92	5	9,000	828,000	
CI	24 to 48	92	8	5,300	487,600	
CI	24 to 48	58	8	5,300	307,400	
CI	24 to 48	58	0	8,500	493,000	
CI	24 to 48	58	5	5,000	290,000	
CI	24 to 48	39	0	4,000	156,000	
CI	24 to 48	39	20	10,000	390,000	
CI	24 to 48	100	1	10,500	1,050,000	
CI	24 to 48	90	0	40,000	3,600,000	
CI	24 to 48	57	1	20,000	1,140,000	
CI	24 to 48	20	0	9,600	192,000	
CI	24 to 48	80	20	17,325	1,386,000	
CI Total			126	241,571	14,182,721	
CI Average Age and Failure Rate					59	4.69E-02
DI	24 to 48	20	0	30,974	619,480	
DI	24 to 48	3	0	5,280	15,840	
DI	24 to 48	1	0	5,280	5,280	
DI	24 to 48	3	0	13,250	39,750	
DI	24 to 48	20	0	2,000	40,000	
DI	24 to 48	6	0	8,870	53,220	
DI	24 to 48	27	0	1,049	28,323	
DI	24 to 48	25	0	2,430	60,750	
DI	24 to 48	24	0	2,944	70,656	
DI	24 to 48	23	0	2,381	54,763	
DI	24 to 48	20	0	3,406	68,120	
DI	24 to 48	19	12	2,540	48,260	
DI	24 to 48	18	0	2,112	38,016	
DI	24 to 48	17	0	5,124	87,108	
DI	24 to 48	15	0	2,458	36,870	
DI	24 to 48	13	0	2,646	34,398	
DI	24 to 48	8	4	24,307	194,456	
DI	24 to 48	7	0	42,305	296,135	
DI	24 to 48	1	0	7,866	7,866	
DI	24 to 48	1	0	7,956	7,956	
DI	24 to 48	1	0	17,010	17,010	
DI	24 to 48	20	0	4,287	85,740	
DI	24 to 48	19	0	2,765	52,535	
DI	24 to 48	11	1	8,838	97,218	
DI	24 to 48	6	0	3,131	18,786	
DI	24 to 48	20	0	19,401	388,020	
DI	24 to 48	10	0	23,111	231,110	
DI	24 to 48	16	0	4,000	64,000	
DI	24 to 48	4	0	7,000	28,000	

Pipe Type	Size Range (in)	Years in Service	Number of Failures	Length (ft)	Length X Age	Failures per Mile•Year
DI	24 to 48	4	0	7,500	30,000	
DI	24 to 48	4	0	8,500	34,000	
DI	24 to 48	1	0	10,000	10,000	
DI	24 to 48	1	0	5,300	5,300	
DI	24 to 48	25	0	84,968	2,124,200	
DI	24 to 48	5	0	139,002	695,010	
DI	24 to 48	3	1	35,000	105,000	
DI	24 to 48	2	1	4,434	8,868	
DI	24 to 48	14	0	4,634	64,876	
DI	24 to 48	12	0	2,100	25,200	
DI	24 to 48	18	1	4,200	75,600	
DI	24 to 48	5	0	5,500	27,500	
DI	24 to 48	3	0	41,589	124,767	
DI	24 to 48	8	0	3,924	31,392	
DI	24 to 48	3	0	17,690	53,070	
DI	24 to 48	20	3	28,800	576,000	
DI	24 to 48	28	0	55	1,540	
DI Total			23	667,917	6,781,989	
DI Average Age and Failure Rate					10	1.79E-02
ECP	24 to 48	12	0	71,200	854,400	
ECP	24 to 48	33	0	6,400	211,200	
ECP	24 to 48	37	0	6,467	239,279	
ECP	24 to 48	8	0	5,000	40,000	
ECP	24 to 48	28	1	20,000	560,000	
ECP	24 to 48	11	0	6,800	74,800	
ECP	24 to 48	14	0	6,000	84,000	
ECP	**24 to 48 Total**		1	121,867	2,063,679	
ECP	**24 to 48 Average Age and Failure Rate**				17	2.56E-03
ECP	49 to 72	4	0	17,512	61,292	
ECP	49 to 72	28	0	15,640	437,920	
ECP	49 to 72	28	0	16,304	456,512	
ECP	49 to 72	28	4	20,807	582,596	
ECP	**49 to 72 Total**		4	70,263	1,538,320	
ECP	**49 to 72 Average Age and Failure Rate**				22	1.37E-02
ECP	over 72	8	0	3,861	30,888	
ECP	over 72	11	0	18,516	203,676	
ECP	over 72	12	0	18,550	222,600	
ECP	**over 72 Total**		0	40,927	457,164	
ECP	**over 72 Average Age and Failure Rate**				11	0.00E+00
ECP Total			5	233,057	4,059,163	
ECP Average Age and Failure Rate					17	6.50E-03
LCP	24 to 48	28	0	14,200	397,600	
LCP	24 to 48	42	2	60,670	2,548,140	
LCP	24 to 48	28	0	24,805	694,540	
LCP	24 to 48	28	0	4,360	122,080	
LCP	24 to 48	26	0	16,765	435,890	
LCP	24 to 48	24	0	4,355	104,520	
LCP	24 to 48	13	0	9,153	118,989	
LCP	24 to 48	35	0	86,328	3,021,480	
LCP	24 to 48	25	0	50,888	1,272,200	
LCP	24 to 48	6	0	21,014	126,084	
LCP	24 to 48	26	0	100,320	2,608,320	
LCP	24 to 48	25	0	3,624	90,600	
LCP	24 to 48	21	0	11,421	239,841	

Pipe Type	Size Range (in)	Years in Service	Number of Failures	Length (ft)	Length X Age	Failures per Mile•Year
LCP	24 to 48	1	0	85,784	85,784	
LCP	24 to 48	31	1	19,591	607,321	
LCP	24 to 48	5	0	26,946	134,730	
LCP	24 to 48	20	1	85,102	1,702,040	
LCP	24 to 48	21	0	8,800	184,800	
LCP	24 to 48	32	0	3,400	108,800	
LCP	24 to 48	31	0	5,314	164,734	
LCP	24 to 48	27	0	11,740	316,980	
LCP	24 to 48	26	0	11,616	302,016	
LCP	24 to 48	24	0	10,191	244,584	
LCP	24 to 48	24	0	8,800	211,200	
LCP	24 to 48	5	0	12,807	64,035	
LCP	24 to 48	33	0	28,600	943,800	
LCP	24 to 48	39	3	47,500	1,852,500	
LCP	24 to 48	20	1	5,000	100,000	
LCP	24 to 48	21	1	31,549	662,529	
LCP	24 to 48	30	0	18,600	558,000	
LCP	24 to 48	36	5	163,700	5,893,200	
LCP	24 to 48	27	0	3,114	84,078	
LCP	24 to 48	24	0	3,000	72,000	
LCP	24 to 48	4	0	51,482	205,928	
LCP	24 to 48	26	0	31,680	823,680	
LCP	24 to 48	35	0	2,250	78,750	
LCP	24 to 48	38	0	52,800	2,006,400	
LCP	24 to 48	21	1	53,162	1,116,402	
LCP	24 to 48	26	0	42,366	1,101,516	
LCP	24 to 48	26	0	23,340	606,840	
LCP	24 to 48	20	0	16,309	326,180	
LCP	24 to 48	3	0	13,665	40,995	
LCP	24 to 48	26	0	14,963	389,038	
LCP	24 to 48	24	0	14,773	354,552	
LCP	24 to 48	15	0	13,277	199,155	
LCP	24 to 48	15	0	15,174	227,610	
LCP	24 to 48	1	0	20,206	20,206	
LCP	24 to 48	27	0	13,936	376,272	
LCP	24 to 48	24	0	13,129	315,096	
LCP	24 to 48	19	1	31,680	601,920	
LCP	24 to 48	36	0	31,200	1,123,200	
LCP	24 to 48	21	3	5,555	116,655	
LCP	24 to 48 Total		19	1,460,004	36,103,810	
LCP	24 to 48 Average Age and Failure Rate				25	2.78E-03
LCP	49 to 72	18	2	21,120	380,160	
LCP	49 to 72 Total		2	21,120	380,160	
LCP	49 to 72 Average Age and Failure Rate				18	2.78E-02
LCP Total			21	1,481,124	36,483,970	
LCP Average Age and Failure Rate					25	3.04E-03
PT	24 to 48	3	0	27,607	82,821	
PT	24 to 48	23	4	6,000	138,000	
PT	24 to 48	37	2	42,240	1,562,880	
PT	24 to 48	28	0	11,769	329,532	
PT	24 to 48	44	2	20,180	887,920	
PT	24 to 48	2	0	38,500	77,000	
PT	24 to 48	24	0	8,330	199,920	
PT	24 to 48	11	0	58,679	645,469	
PT	24 to 48	11	1	14,000	154,000	

Pipe Type	Size Range (in)	Years in Service	Number of Failures	Length (ft)	Length X Age	Failures per Mile•Year
PT	24 to 48	11	1	20,000	220,000	
PT	24 to 48	4	0	9,000	36,000	
PT	24 to 48	20	0	16,000	320,000	
PT	24 to 48	25	0	42,240	1,056,000	
PT	24 to 48	15	1	2,640	39,600	
PT	24 to 48	8	0	2,445	19,560	
PT	24 to 48	28	0	36,760	1,029,280	
PT	**24 to 48 Total**		11	356,390	6,797,982	
PT	**24 to 48 Average Age and Failure Rate**				19	8.54E-03
PT	49 to 72	28	0	20,854	583,912	
PT	49 to 72	8	0	4,160	33,280	
PT	49 to 72	27	0	11,495	310,365	
PT	49 to 72	28	0	16,479	461,412	
PT	**49 to 72 Total**		0	52,988	1,388,969	
PT	**49 to 72 Average Age and Failure Rate**				26	0.00E+00
PT	over 72	20	0	16,742	334,840	
PT	over 72	20	0	240,035	4,800,700	
PT	over 72	17	0	9,808	166,736	
PT	**over 72 Total**		0	266,585	5,302,276	
PT	**over 72 Average Age and Failure Rate**				20	0.00E+00
PT Total			11	675,963	13,489,227	
PT Average Age and Failure Rate					20	4.31E-03
PVC	24 to 48	2	0	8,333	16,666	
PVC Total			0	8,333	16,666	
PVC Average Age and Failure Rate					2	0.00E+00
RC	24 to 48	57	1	23,400	1,333,800	
RC	24 to 48	25	1	11,500	287,500	
RC	24 to 48	53	0	16,420	870,260	
RC	24 to 48	47	0	11,000	517,000	
RC	24 to 48	47	0	17,500	822,500	
RC	**24 to 48 Total**		2	79,820	3,831,060	
RC	**24 to 48 Average Age and Failure Rate**				48	2.76E-03
RC	49 to 72	50	0	221,760	11,088,000	
RC	**49 to 72 Total**		0	221,760	11,088,000	
RC	**49 to 72 Average Age and Failure Rate**				50	0.00E+00
RC Total			2	301,580	14,919,060	
RC Average Age and Failure Rate					49	7.08E-04
RCCP	24 to 48	45	0	32,800	1,476,000	
RCCP	24 to 48	30	0	38,500	1,155,000	
RCCP	24 to 48	10	0	32,962	329,620	
RCCP	24 to 48	25	0	12,907	322,675	
RCCP	24 to 48	20	0	11,190	223,800	
RCCP	24 to 48	29	0	11,160	323,640	
RCCP	24 to 48	19	0	5,500	104,500	
RCCP	24 to 48	20	0	16,050	321,000	
RCCP	24 to 48	7	0	4,248	29,736	
RCCP	24 to 48	30	0	6,900	207,000	
RCCP	24 to 48	22	0	16,330	359,260	
RCCP	**24 to 48 Total**		0	188,547	4,852,231	
RCCP	**24 to 48 Average Age and Failure Rate**				26	0.00E+00
RCCP	over 72	15	0	1,860	27,900	
RCCP	**over 72 Total**		0	1,860	27,900	
RCCP	**over 72 Average Age and Failure Rate**				15	0.00E+00

Pipe Type	Size Range (in)	Years in Service	Number of Failures	Length (ft)	Length X Age	Failures per Mile•Year
RCCP Total			0	190,407	4,880,131	
RCCP Average Age and Failure Rate					26	0.00E+00
ST	24 to 48	5	0	13,500	67,500	
ST	24 to 48	6	0	12,000	72,000	
ST	24 to 48	12	0	8,550	102,600	
ST	24 to 48	6	0	4,000	24,000	
ST	24 to 48	5	0	4,000	20,000	
ST	24 to 48	17	0	95,513	1,623,721	
ST	24 to 48	30	0	86,993	2,609,790	
ST	24 to 48	29	0	2,677	77,633	
ST	24 to 48	26	0	14,725	382,850	
ST	24 to 48	5	0	2,356	11,780	
ST	24 to 48	44	15	10,950	481,800	
ST	24 to 48	9	0	8,000	72,000	
ST	24 to 48	4	0	10,560	42,240	
ST	24 to 48	12	1	8,000	96,000	
ST	24 to 48	20	2	10,450	209,000	
ST	24 to 48	35	0	82,802	2,898,070	
ST	24 to 48	29	0	14,249	413,221	
ST	24 to 48	32	0	420	13,440	
ST	24 to 48	85	1	8,800	748,000	
ST	24 to 48	22	1	640	14,080	
ST	24 to 48	30	2	21,000	630,000	
ST	24 to 48	27	0	298,890	8,070,030	
ST	24 to 48	6	0	37,892	227,352	
ST	24 to 48	7	0	11,410	79,870	
ST	24 to 48	8	0	6,603	52,824	
ST	**24 to 48 Total**		22	774,980	19,039,801	
ST	**24 to 48 Average Age and Failure Rate**				25	6.10E-03
ST	49 to 72	10	1	200	2,000	
ST	49 to 72	5	1	42,000	210,000	
ST	49 to 72	8	0	13,097	104,776	
ST	49 to 72	10	0	12,574	125,740	
ST	49 to 72	9	0	6,016	54,144	
ST	49 to 72	12	0	19,550	234,600	
ST	49 to 72	26	0	4,957	128,882	
ST	**49 to 72 Total**		2	98,394	860,142	
ST	**49 to 72 Average Age and Failure Rate**				9	1.23E-02
ST Total			24	873,374	19,899,943	
ST Average Age and Failure Rate					23	6.37E-03

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public.