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AD-A263 750



USACERL Technical Report FM-93/07
January 1993
Corrosion Mitigation and
Management System

2

Corrosion Assessment of an Army Installation Gas Distribution System Using MicroGPIPER

by
Vicki L. Van Blaricum
Vincent F. Hock
Lewis F. Setliff

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The MicroGPIPER program was used as part of an investigation of the severe corrosion problems which had occurred in the gas distribution piping at Fort Jackson, SC. This report describes the step-by-step process used during the investigation, as well as the results and recommendations presented to the Fort Jackson DEH. GPIPER correctly predicted the severe corrosion problems occurring in the family housing area. The process used at Fort Jackson is applicable to other Army installations that need to assess the corrosion status of their gas distribution systems.

The GPIPER software is designed for use on a DOS-compatible microcomputer with at least 640K of RAM and a hard drive. Software and documentation are available from the U.S. Army Engineering and Housing Support Center, (CEHSC-FU-S) or from USACERL.

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1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE January 1993	3. REPORT TYPE AND DATES COVERED Final	
4. TITLE AND SUBTITLE Corrosion Assessment of an Army Installation Gas Distribution System Using MicroGPIPER		5. FUNDING NUMBERS PF 4A162734 PR AT41 WU MB-C12	
6. AUTHOR(S) Vicki Van Blaricum, Vincent F. Hock, and Lewis F. Setliff			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Construction Engineering Research Laboratories (USACERL) PO Box 9005 Champaign, IL 61826-9005		8. PERFORMING ORGANIZATION REPORT NUMBER TR FM-93/07	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of the Assistant Chief of Engineers ATTN: CEHSC-FU-S Fort Belvoir, VA 22060-5516		10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The MicroGPIPER program has been developed by the U. S. Army Construction Engineering Research Laboratories (USACERL) to assist Army installation Directorates of Engineering and Housing (DEHs) in prioritizing sections of underground natural gas distribution piping for maintenance and repair. The prioritization is generated from data collected from field evaluation of the gas distribution and cathodic protection systems, as well as laboratory evaluation of soil samples. The MicroGPIPER program was used as part of an investigation of the severe corrosion problems which had occurred in the gas distribution piping at Fort Jackson, SC. This report describes the step-by-step process used during the investigation, as well as the results and recommendations presented to the Fort Jackson DEH. GPIPER correctly predicted the severe corrosion problems occurring in the family housing area. The process used at Fort Jackson is applicable to other Army installations that need to assess the status of their gas distribution systems. The GPIPER software is designed for use on DOS-compatible microcomputer with at least 640K of RAM and a hard drive. Software and documentation are available from the U.S. Army Engineering and Housing Support Center (CEHSC-FU-S) or from USACERL.			
14. SUBJECT TERMS microgpiiper Fort Jackson, SC Corrosion Mitigation Management System U.S. Army Directorates of Engineering and Housing gas distribution system		15. NUMBER OF PAGES 38	16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR

FOREWORD

This work was performed for the Office of the Chief of Engineers (OCE) under Project 4A162734AT41, "Military Facilities Engineering Technology"; Work Unit MB-C12, "Corrosion Mitigation and Management Systems." Funding for the field work was provided by the Fort Jackson Directorate of Engineering and Housing. The technical monitor was Mr. Malcolm McLeod, CEHSC-FU-S.

The work was performed by the Engineering and Materials Division (FM), of the Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigators were Ms. Vicki Van Blaricum, Mr. Vincent Hock, and CPT Lewis Setliff. Mr. Malcolm McLeod, CEHSC-FU-S, was instrumental in the field evaluation and analysis. The authors would also like to thank Cadets Kwasi L. Hawks and Kyle J. Marsh of the U. S. Military Academy for their assistance. Dr. Paul A. Howdyshell is Chief, CECER-FM. Dr. Michael J. O'Connor is Chief, CECER-FL.

COL Daniel Waldo, Jr., is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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CORROSION ASSESSMENT OF AN ARMY INSTALLATION GAS DISTRIBUTION SYSTEM USING MICROGPIPER

1 INTRODUCTION

Background

Corrosion of underground steel pipelines used to transport and distribute natural gas on Army installations often leads to property and environmental damage, as well as safety hazards and the loss of valuable resources. However, the corrosion status of these underground pipes is often unknown until a failure occurs. To alleviate this problem, the MicroGPIPER computer program, hereafter called GPIPER (Van Blaricum et al. May 1991), has been developed by USACERL to assist Army installations in prioritizing replacements and renovations of gas distribution systems based upon a prediction of soil-induced corrosion of steel pipe materials. For pipe networks that have cathodic protection (CP), GPIPER can be used to prioritize the maintenance of malfunctioning CP systems. Information about the pipes, the soil in which they are buried, and the existence of a functioning CP system is input into the program. Based upon this information, the corrosion status is predicted, including an approximate year of the first leak and number of leaks per year which can be expected to occur. With this information, installation facility engineers can prioritize the allocation of maintenance dollars and forecast future maintenance needs.

The Directorate of Engineering and Housing (DEH) at Fort Jackson, SC requested USACERL to perform an investigation of the severe corrosion that had been occurring in their natural gas distribution system. Two surveys which were conducted by outside consultants during mid-1991 had uncovered over 400 natural gas leaks at the installation. USACERL and the U.S. Army Engineering and Housing Support Center (USAEHSC) performed a field survey to investigate the problem in August 1991. The GPIPER program was used to assist in the investigation. The same process is applicable to any Army installation.

Objectives

The objectives of this study were (1) to assess selected portions of the underground gas piping system at Fort Jackson with the assistance of the GPIPER program, and (2) to illustrate a typical procedure for implementing the GPIPER program in conjunction with a standard corrosion assessment survey so that maintenance and repair (M&R) alternatives such as installation of CP, repair of leaks, or repair of malfunctioning CP can be prioritized.

Approach

A field study was conducted to collect data about the corrosion problems occurring in the gas distribution system at Fort Jackson. Soil specimens were analyzed in the laboratory. The data obtained was input into GPIPER and predictions were generated. Recommendations were given to the Fort Jackson DEH based on the findings of the survey and analysis.

Mode of Technology Transfer

It is recommended that use of GPIPER be specified in Army Technical Manual (TM) 5-654, *Gas Distribution Systems Operation and Maintenance*. The GPIPER software and documentation are available from USAEHSC (CEHSC-FU-S) or USACERL for implementation at Army installations.

2 THE CORROSION ASSESSMENT PROCESS

The GPIPER data collection procedure closely parallels the procedure used in performing a standard field survey for underground corrosion assessment. The methods set forth in this report clearly illustrate how GPIPER can be implemented in conjunction with such a field survey at very little additional cost to the installation. This chapter describes the steps of the field survey procedure and their performance at Fort Jackson, as well as the analysis of the data using the GPIPER program.

Step 1 -- System Description

The first step in assessing the Fort Jackson gas distribution system was to collect as much existing information as possible. Copies of the utility maps were obtained and reviewed, and information from a survey conducted in 1988 by USAEHSC (USAEHSC 1988) was reviewed. In addition, an on-site meeting was held to obtain the pipe leak history.

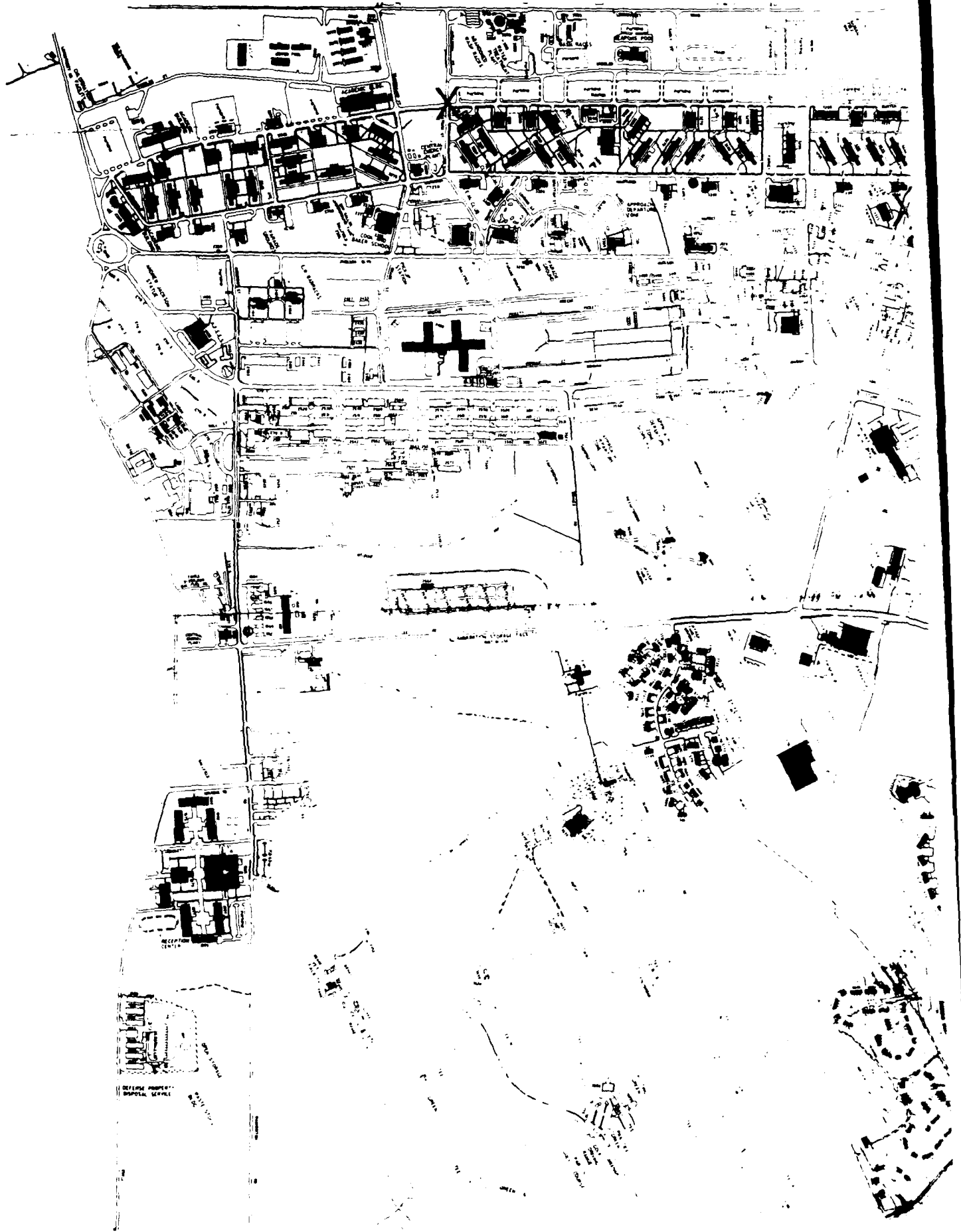
According to the information collected, Fort Jackson's original gas distribution system was installed in 1940. The piping system consisted of bare steel mains and both coal-tar coated and galvanized steel distribution lines. Only a small amount of this piping still exists in the vicinity of Tank Hill, the elevated area near the intersection of Pickens and Marion avenues where the reservoir is located (see the site map in Figure 1). In 1967 and 1968, the majority of the existing base was constructed, including the present gas distribution system. All of the piping installed at this time was carbon steel with a coal-tar coating.

In the 1980s, several projects were initiated to repair leaks or provide new services. In 1983, new service lines were extended to the Enlisted Men's (EM) barracks on Tank Hill. These lines are carbon steel with an extruded polyethylene coating. In 1984, 60 percent of the riser pipes in the family housing area were replaced with polyethylene-coated carbon steel. (The family housing area is the area bounded by Semmes, Lee, Hartsville, and Chestnut roads.) The risers had failed due to corrosion below and just above grade. The replacement pipe coating extends 12 in.* above grade. During 1986, the South Carolina Electric and Gas Company (SCE&G) transferred ownership of all existing SCE&G piping and transmission systems beyond their main point of delivery (located at the traffic circle on Jackson Boulevard near Building 2000) to the Fort Jackson DEH. A large-scale project to replace a corroded main and distribution laterals along Sumter Avenue also occurred in 1986. The laterals were replaced with nonmetallic piping. According to the information collected, most of the gas distribution system is coated but not cathodically protected.

Step 2 -- Leak History Determination

The second step in performing the study was to gather information on the leak history of the system. A complete leak repair history for the Fort Jackson gas distribution system was not available. The data that was available consisted of two gas leak survey reports prepared by private consultants. The May 1991 survey reported a total of 18 leaks, of which 1 was a Grade I, 13 were Grade II, and 4 were Grade

* 1 ft = 0.3048 m.



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Figure 1. Fort Jackson Site Map.



Fort Jackson Site M

- = Leak Location
- X = Excavation Loc

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Fort Jackson Site Map

• = Leak Location

X = Excavation Location

323

III (Health Consultants Incorporated 1991). Grade classifications help to prioritize leaks for repair. According to draft Army TM 5-654:^{*}

- A Grade I leak is "a leak that represents an existing or probable hazard to person or property due to location or the volume of the leak, and requires immediate repair or continuous action until the conditions are no longer hazardous."
- A Grade II leak is "a leak with a relatively large volume, which is recognized as being non-hazardous at the time of detection, but justifies scheduled repair based on probable future hazard."
- A Grade III leak is "a leak that is nonhazardous at the time of detection (usually a low volume leak) and can be reasonably expected to remain nonhazardous."

Specific actions required and examples of each of the three grades of leaks are given in the referenced draft TM, which was sent to the field as an attachment to Technical Note (TN) 5-654-02. All of the leaks reported in the May 1991 survey occurred underground on the mains or service lines and were presumably caused by soil-side corrosion.

The July 1991 survey (Southern Cross Corporation 1991) reported a total of 417 leaks, of which 40 were Grade I, 50 were Grade II, and 327 were Grade III. Of the leaks found in this survey, approximately 58 were caused by soil-side corrosion of the mains or service lines. The remaining leaks were primarily caused by faulty valves and fittings which were not in contact with the soil (i.e., they were aboveground, in valve pits, etc.) It is significant to note that 35 of the 40 Grade I leaks were in the group caused by soil-side corrosion. The locations of the leaks caused by soil-side corrosion that were found in the two surveys are plotted on the map in Figure 1.

The leaks were repaired by the Fort Jackson DEH as required.

Step 3 – On-Site Bell Hole Inspections and Soil Sampling

The third step in the evaluation was to collect soil, coating, and pipe condition data. The GPIPER prediction model requires information on soil chemistry at the pipeline depth, as well as pipe material and coating. Based upon the leak history and the other information collected, locations were selected for soil sampling, bell hole inspections (for evaluation of the pipe and coating condition), and Wenner 4-pin measurements (American Society for Testing and Materials Standard G57) to determine average soil resistivities. Funding and time constraints precluded a large sampling effort, so representative areas were chosen. The sites chosen are shown on the map in Figure 1.

The condition of the coated pipes observed ranged from excellent (coating intact, no leaks) to failed. A leak was occurring at the intersection of Forest and Jackson streets at the time of the inspection. In addition, a leak had recently occurred at the Building 5957 excavation site. The pipes in the family housing area were in very poor condition, as evidenced by the map of leak locations in Figure 1. The pipes in the family housing area showed significant damage to the pipe coating, as well as soil-side corrosion (Figures 2 and 3). Leaks were not observed at the other excavation sites (Sumter and Cheatham and Building 4323), although two or three isolated leaks had occurred in the areas represented by these excava-

^{*} Draft Technical Manual (TM) 5-654, *Gas Distribution Systems Operation and Maintenance*, was transmitted to the field as an attachment to Technical Note (TN) 5-654-02 (January 1991), p 90.

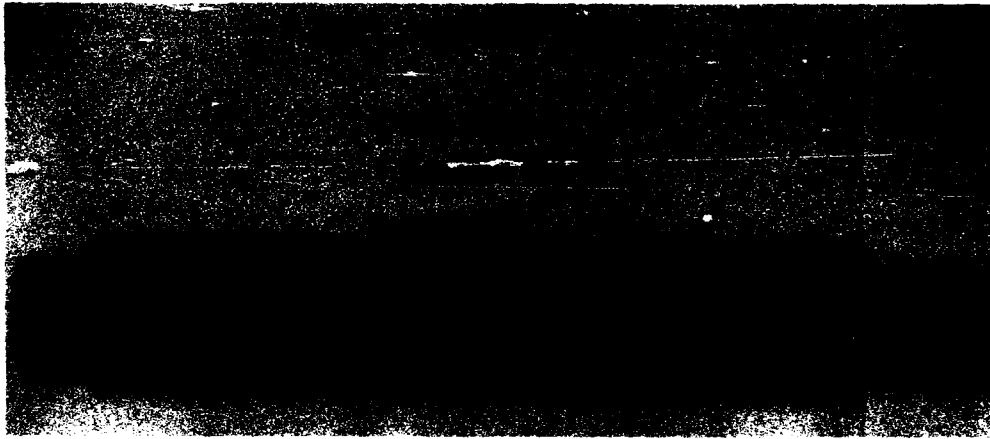


Figure 2. Leaking Lateral From Family Housing (Bldg. 5757) Showing Corrosion and Damaged Coating.

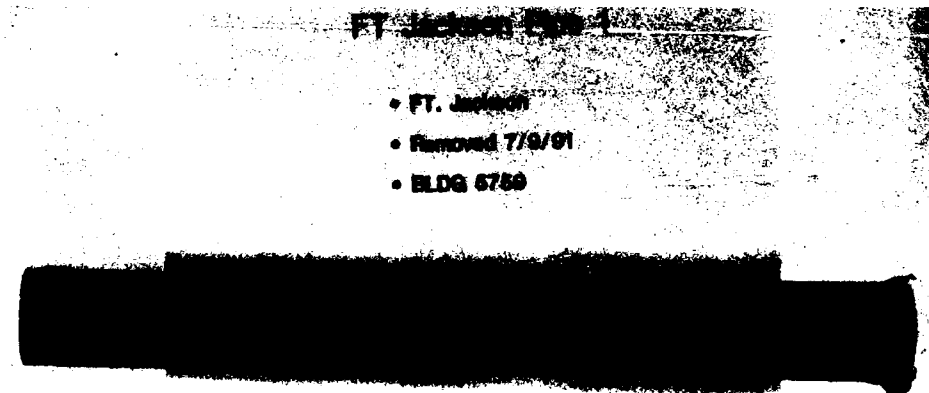


Figure 3. Leaking Lateral From Family Housing (Bldg. 5759) Showing Scraped Coating and Presence of Corrosion.

tion sites. A soil sample was collected at each excavation site. Three samples were collected at the Forest and Jackson site: one exactly at the point of the leak on the 1.25 in. lateral, one several feet away from the point of the leak on the lateral, and one adjacent to the nearby cathodically protected 8 in. main.

Average soil resistivities were measured at the selected locations using the Wenner 4-pin technique. A 5 ft pin spacing was used, so the values measured indicate the average soil resistivity between the soil surface and a 5 ft depth. The results are shown in Table 1.

One important observation during the bell hole inspections was the presence of distinct layers, or strata, of differing characteristics in the soil at all of the excavations. This was also found in the 1988 survey conducted by USAEHSC. The USAEHSC survey reported that at an excavation near Building 1545, the soil strata consisted of 24 in. of clay fill, 6 in. of original top soil, multiple layers of blue, gray, and red clay mixed with sand for approximately 5 ft, with a gumbo clay below the water table. The water table was at approximately 6 ft at this location in 1988. USAEHSC reported that the soil resistivities within this excavation varied from 100,000 ohm-cm in the sandy clay region to 9000 ohm-cm below the water table. Three other random excavations revealed similar soil conditions. Such variations in soil resistivity may lead to accelerated corrosion in the areas where the resistivity is lower.

Step 4 – Cathodic Protection Evaluation

The next step in the assessment was to determine the existence of effective CP. Pipes that are properly cathodically protected and maintained should not corrode. The existence of effective CP can be evaluated by collecting pipe-to-soil potentials. Locations were selected for measuring pipe-to-soil potentials. In addition, dielectric flanges and unions were tested to determine whether the gas piping system was electrically isolated from other piping systems. Results are presented in Table 2.

The pipe-to-soil potentials were evaluated according to the National Association of Corrosion Engineers' criteria of cathodic protection (National Association of Corrosion Engineers 1992). The evaluation showed that, of the lines tested, only the 8 in. line at Forest and Jackson, the supply line at Imboden and Burt, and the supply and distribution lines at Imboden and Bailey were cathodically protected. None of the lines in the family housing area were found to be protected. The criterion used was a negative (cathodic) potential of at least 850 mV with the cathodic protection applied.

It was found that many of the lines tested were not electrically isolated from other piping due to failed or missing dielectric unions. In fact, the potential readings strongly indicate that some of the lines may be electrically connected to copper, which is cathodic to steel. Steel pipes that are connected to copper pipes can be expected to corrode at an accelerated rate.

Table 1
Results of Wenner 4-Pin Soil Resistivity Tests*

Location	Soil Resistivity (ohm-cm)
Sumter and Cheatham	40,215
Forest and Jackson	19,150
Bldg. 4323	90,005
Bldg. 5957	37,342

*Tests were conducted with a 5 ft pin spacing.

Table 2

Pipe-to-Soil Potential Measurements*

Location	Pipe-to-Soil Potential	Dielectric
Hill and Magruder		
Street side	-444	
Building side	-437	
Credit Union Test Station		
Top wire	-502	
Bottom wire	-310	
Hospital	-310	
Forest and Jackson		
8 in. line	-1502	
1-1/4 in. line	-639	
1-1/4 in. lateral	-637	
Imboden and Burt		
Distribution side	-435	Good
Supply side	-1047	
Imboden and Bailey		
Distribution side	-1010	
Supply side	-1070	
School	-469	Bad
Commissary Way/Credit Union		
	-477	
Commissary	-191	Bad
Regulator Bldg. 3771	-349	Good
Bldg. 3751	-128	
Bldg. 4323	-417	
Family Housing		
Bldg. 5717		Bad
Bldg. 5719	-165	Bad
Bldg. 5721	-232	Bad
Bldg. 5729	-353	Bad
Bldg. 5957	-134	

* Measurements are in millivolts (mV) with respect to a copper-copper sulfate (Cu/CuSO₄) reference cell.

Step 5 – Laboratory Analysis

The six soil samples collected at Fort Jackson during the site survey were analyzed at USACERL's Environmental Chemistry Laboratory. The results are given in Table 3.

Table 3

Results of Laboratory Analysis of Soil Samples

Location	pH	Moisture (%)	Sulfate (ppm)	Chloride (ppm)	Sulfide (mg/kg)	Resistivity (ohm-cm)
Bldg. 5957	5.6	9.88	12.1	27.9	3.6	6006
Forest and Jackson (1-1/4 in. line. several feet from leak)	5.49	4.18	0.7	70.5	<0.99	3053
Forest and Jackson (at leak)	4.22	4.77	192.9	61170	1.2	87
Forest and Jackson, 8 in. line	5.95	15.25	7.7	22.9	<0.86	14493
Sumter and Cheatham	6.67	15.37	2.2	35.9	<0.91	7067
Bldg. 4323	5.35	12.81	92.5	35.9	<0.77	5155

Soil Resistivity

One of the most important factors affecting corrosion activity along an underground pipeline is the resistivity of the electrolyte (soil). Corrosiveness of the environment is generally an inverse function of resistivity. Low resistivity favors the flow of current and increases the probability of corrosion; corrosion may not be a problem in very high resistivity electrolytes. The effect of soil resistivity on the anticipated corrosion activity for steel can be predicted using information given in Table 4. These data, however, should not be used as an absolute criterion for corrosivity. Often, severe corrosion damage occurs in soils having relatively high resistivities. This is especially true in heterogeneous soils (e.g., an environment consisting of lumps of clay mixed with sand).

It is interesting to note that the soil resistivities measured in the field at Fort Jackson are significantly higher than those measured in the laboratory at the pipeline depth. As stated earlier, the Wenner 4-pin technique used to measure resistivities in the field gives an average resistivity to a depth equal to the spacing of the pins. As previously reported, the soil at Fort Jackson consists of strata, each

Table 4

Anticipated Corrosion Activity for Steel Exposed to Soils of Varying Resistivity

Soil Resistivity Range, ohm-cm	Corrosion Activity
0 - 2000	Severe
2000 - 10,000	Moderate
10,000 - 30,000	Mild
> 30,000	Slight

of which has a different soil resistivity. According to Table 4, the laboratory-measured resistivity of the Fort Jackson soils at the pipeline depth indicates that moderate to severe corrosion should be expected. The field-measured average resistivities indicate that mild to slight corrosion activity would be expected, but moderate to severe corrosion was actually observed. Thus, because of the differences in resistivity, it is particularly important to use the data taken at the pipeline depth to obtain a proper analysis.

pH

pH is a measure of an environment's hydrogen-ion activity. By definition,

$$\text{pH} = -\log [a(\text{H}^+)] \quad [\text{Eq 1}]$$

where $a(\text{H}^+)$ is the hydrogen-ion activity (concentration, for dilute solutions, in gram-ions/liter). Neutral environments have a pH of 7, alkaline environments have a pH greater than 7, and acids have a pH less than 7. In general, the corrosion rate increases as the pH decreases below a pH of 7. Thus, the acidic soil at Fort Jackson would be expected to support corrosion activity. Table 3 shows that all sampled locations at Fort Jackson have acidic soil. The most acidic soil (lowest pH) is at the leak at Forest and Jackson.

Soluble Salts

The effect of soluble salts such as NaCl generally tends to increase the corrosion rate by decreasing the resistivity of the soil (i.e., increasing the conductivity of the soil). The presence of salts such as CaSO_4 can lead to accelerated corrosion of steel by the production of sulfate reducing bacteria. At Fort Jackson, note that the soil chloride and sulfate contents are also high at the Forest and Jackson leak site.

Moisture

In addition to the mineral content, moisture greatly affects a soil's resistivity. Resistivity decreases with an increase in moisture content up to a point near saturation. The soil at Fort Jackson does not have an extremely high moisture content. All sampling locations had moisture contents below 10 percent. In the GPIPER corrosion prediction model, moisture does not affect the predicted time to first leak unless it is above 28 percent.

Step 6 – GPIPER Analysis

Description of Program

The GPIPER maintenance management system contains a corrosion prediction model that uses soil chemistry data and data about a pipe (such as material and coating) to forecast the year-by-year condition and the year of first leak resulting from soil-side corrosion for the pipe. It also projects the number of leaks per mile of pipe that can be expected to occur during each year after the first leak. This information is extremely useful for forecasting maintenance needs and for determining when it will no longer be cost-effective to continue repairing leaks. Of course, the model cannot be expected to predict failures due to unusual circumstances such as mechanical damage to the pipe coating or corrosion due to stray current (such as that from a mass transit system or an adjacent cathodically protected structure).

The GPIPER models, years-to-first-leak and number of leaks per mile (Van Blaricum et al. 1992), describe the average behavior that can be expected of a pipe under the conditions given by the data. In the GPIPER years-to-first-leak model, the age at which a pipe will experience its first leak is a variable that follows a normal (Gaussian) distribution. This variable has a standard error estimate of 5.5 years.

The model for number of leaks per mile follows an exponential curve based on soil resistivity. This model has been well established by the gas industry. GPIPER calculates a Corrosion Status Index (CSI) from the values predicted by the two models. The CSI is a representation of the condition of the pipe on a scale of 0 to 100. A CSI of 100 denotes a new pipe; a CSI of 0 denotes a completely failed pipe; a CSI of 30 denotes a pipe with one leak.

GPIPER presents predicted condition and leak information in the CSI report. This report plots the predicted CSI versus time for the life of the pipe. The second page of the CSI report contains a table which lists the predicted CSI, number of leaks per mile, and cumulative number of leaks per mile for each year of the pipe's life.

The program is designed for use on a DOS-compatible microcomputer with at least 640K of RAM and a hard drive.

Fort Jackson Analysis

The GPIPER computer program was used to predict the soil-side corrosion behavior of the pipes in contact with the soil at the six sampling points at Fort Jackson. Information on the pipe and soil at each sampling point was entered into the GPIPER program. Data specification reports generated by the GPIPER program which list the complete input data are shown in Appendix A. A sample data input screen is shown in Figure 4. According to the field data, the pipe at only one of the sampling locations (pipe section FOR&JACKSN 3) is cathodically protected.

Appendix B contains CSI reports generated for the pipes at each of the soil sampling locations. The GPIPER predictions correlated quite well with the findings of the field survey. GPIPER correctly predicted the severe soil-induced corrosion problems that had been occurring in the family housing area, as well as the leak at Forest and Jackson streets. For example, the plot that was generated from the information taken at Building 5957 (family housing) is shown in Figure 5. GPIPER predicted that pipes under the soil conditions found at Building 5957 should be expected to begin leaking in 1987, and that by 1991, there should be roughly seven leaks per mile of pipe (cumulative). In addition, GPIPER predicted that a leak should have occurred at Forest and Jackson (pipe section FOR&JACKSN 2) streets in 1984. Given the severity of the leak that was observed at that location, it is likely that the leak began long before it was discovered in 1991.

The CSI report for the cathodically protected main at Forest and Jackson (pipe section FOR&JACKSN 3) shown in Figure 6, illustrates clearly that with the use of a properly maintained CP system (straight line comprised of X's on the plot), the CSI should remain at 100 (excellent condition) indefinitely. The other curve on the plot shows what will happen without cathodic protection.

The pipes installed in 1986 (represented by the Building 4323 and Sumter and Cheatham sampling locations) are not expected to fail because of soil-side corrosion until approximately 2009. It is important to understand that GPIPER can only predict average behavior under given conditions. Unusual circumstances such as those at Fort Jackson must also be taken into account: because of the inhomogeneous soil conditions and the lack of electrical isolation in some locations, isolated leaks can be expected to occur before 2009. This is supported by the findings of the leak survey.

A priority ranking report, which ranks pipe sections from those that most urgently need repair to those that least urgently need repair, is shown in Figure 7.

Database Online: JACKSON	Underground Gas Piping MODIFY PIPE DATA Ft. Jackson Data	Micro GPIPER Version EMS 2.1 1992
Pipe Identification _____ BLDG 595Z Section Identification _____ 1 Section Length (ft.) _____ 1.00 Pipe Use _____ GAS DISTRIBUTION From _____ CHESTNUT & PARKER To _____ Pipe Material _____ CARBON STEEL Coating Material _____ WRAP COAL TAR Type of Joints _____ Installation Name _____ Date Installed _____ 1968.01.01 Date Rehabilitated _____ Date of First Leak _____ 1991.05.14 Type of First Leak _____ Location First Leak _____	Building Category _____ 1 Mission Priority (1 - 9) _____ 1 Outside Diameter (in.) _____ 6.0000 Wall Thickness (in.) _____ 0.2800 Operating Pressure (psi) _____ 1.00 Depth of Burial (ft.) _____ 1.00 pH of Soil _____ 5.60 Chlorides of Soil (mg/kg) _____ 27.9 Sulfides of Soil (mg/kg) _____ 3.6 Resistivity of Soil (Ω -cm) _____ 6006 Moisture of Soil (%) _____ 9.8 Cathodic Protection (Y/F) _____ F Pipe to Soil Potential _____ -0.134 As-Built Records (Y/F) _____ I	
Comment1 ASSUMED SCH. 40 PIPE. PRESSURE UNKNOWN. Comment2 SOIL SAMPLE NO. 800494 Date of Comments _____		
F1 F2 Keys F3 F4 F5 F6 F7 F8 F9 F10 Done		

Figure 4. Sample GPIPER Data Entry Screen.

PIPE IDENTIFICATION	: BLDG. 5957	SECTION NUMBER:	1
SOIL RESISTIVITY	: 6006.00	SOIL pH	: 5.60
COATING MATERIAL	: WRAP COAL TAR	WALL THICKNESS:	0.2800
YEAR INSTALLED	: 1968	PIPE SIZE (OD):	6.0
PREDICTED FIRST LEAK (CSI<=30):	1987	ACTUAL FIRST LEAK:	1991.05.14

Adjusted Formula : Max.Pit Depth = 0.0454 * (time ^ 0.58)
Pit Depth (in inches) and Time (in years)

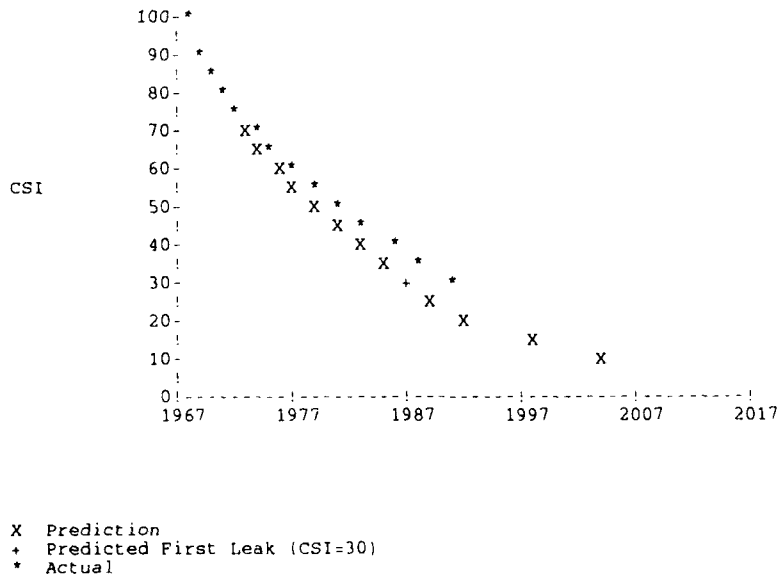


Figure 5. Corrosion Status Index (CSI) Report for Bldg. 5957 (Family Housing).

PIPE IDENTIFICATION : BLDG. 5957

SECTION NUMBER: 1

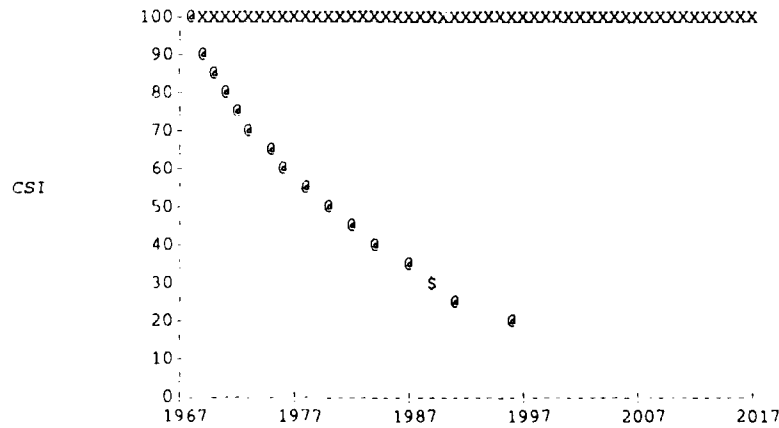
GRAPH TABLE

CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1968	100	0	0
1969	87	0	0
1970	81	0	0
1971	76	0	0
1972	72	0	0
1973	68	0	0
1974	64	0	0
1975	61	0	0
1976	58	0	0
1977	55	0	0
1978	52	0	0
1979	49	0	0
1980	46	0	0
1981	44	0	0
1982	41	0	0
1983	39	0	0
1984	37	0	0
1985	34	0	0
1986	32	0	0
1987	30	1	1
1988	26	1	2
1989	23	2	4
1990	23	1	5
1991	21	2	7
1992	20	2	9
1993	19	3	12
1994	18	2	14
1995	17	4	18
1996	16	3	21
1997	16	4	25
1998	15	5	30
1999	14	5	35
2000	13	6	41
2001	13	7	48
2002	12	7	55
2003	12	8	63
2004	11	9	72
2005	10	11	83

Figure 5 (cont'd).

CSI PREDICTION REPORT
Filename: JACKSON
REPORT DATE: 1992.08.05 08:25:10
GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION : FORandJACKSN SECTION NUMBER: 3
SOIL RESISTIVITY : 1449.00 SOIL pH : 5.95
COATING MATERIAL : WRAP COAL TAR WALL THICKNESS: 0.3220
YEAR INSTALLED : 1968 PIPE SIZE (OD): 8.0
PREDICTED FIRST LEAK (CSI<=30): 1989 ACTUAL FIRST LEAK: No leak.
CATHODIC PROTECTION w/ PIPE-to-SOIL POTENTIAL <= -0.85 VOLTS



X Prediction
e Prediction (in event of Cathodic Protection Failure)
S Predicted First Leak (CSI=30, in event of Cathodic Protection Failure)

Figure 6. CSI Report for Cathodically Protected Main at Forest and Jackson.

CSI PREDICTION REPORT
 Filename: JACKSON
 REPORT DATE: 1992.09.05 08:25:10
 GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION : F0RandJACKSN SECTION NUMBER: 3

GRAPH TABLE
 EVENT OF CATHODIC PROTECTION FAILURE:

CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1968	100	0	0
1969	88	0	0
1970	82	0	0
1971	77	0	0
1972	73	0	0
1973	70	0	0
1974	66	0	0
1975	63	0	0
1976	60	0	0
1977	57	0	0
1978	54	0	0
1979	52	0	0
1980	49	0	0
1981	47	0	0
1982	45	0	0
1983	42	0	0
1984	40	0	0
1985	38	0	0
1986	36	0	0
1987	34	0	0
1988	32	0	0
1989	30	1	1
1990	26	1	2
1991	25	1	3
1992	23	1	4
1993	23	1	5
1994	22	1	6
1995	21	1	7
1996	20	1	8
1997	20	1	9
1998	20	1	10
1999	19	1	11
2000	19	1	12
2001	18	1	13
2002	18	1	14
2003	18	1	15
2004	17	1	16
2005	17	1	17
2006	17	1	18
2007	17	1	19

Figure 6 (cont'd).

PRIORITY RANKING REPORT
 Filename: JACKSON
 REPORT DATE: 1992.08.05 08:28:00
 GPIPER (v. EMS 2.1)

RANK	PIPE ID	SEC. #	CSI	OPER. PRES.	MISSION PRIORITY
1	FOR and JACKSN	2	9	1.000	1
2	FOR and JACKSN	1	12	1.000	1
3	BLDG. 5957	1	20	1.000	1
4	BLDG4323	1	68	125.000	1
5	SUMP and CHEAT	1	69	125.000	1
6	FOR and JACKSN	3	100	1.000	1

Figure 7. Priority Ranking Report.

3 DISCUSSION OF FIELD INVESTIGATION AND GPIPER ANALYSIS

Findings

1. The GPIPER predictions, supported by the findings of the field survey, show that the pipes installed in 1968 are in a critical stage. They are expected to be leaking, and the number of leaks is accelerating, particularly in the areas with lower soil resistivities. Thus, preventive action is required immediately for these sections of the piping network. GPIPER predicted that leaks would be expected to begin occurring in the 1968-installed pipes in the areas with lower soil resistivities in approximately 1984, and in the areas with higher soil resistivities in approximately 1988. Surveys conducted by the DEH in 1991 validated the GPIPER predictions of multiple leaks in the 1968-installed pipes. In addition, the metallic gas lines installed in the mid-1980s are predicted to begin failing in about 15 years if preventive action is not taken.

2. On-site evaluations revealed several factors in addition to the corrosive soil that contributed to the corrosion activity at Fort Jackson. These influencing factors consist of failed or missing dielectric unions, variations in soil resistivity, coating damage in places, and a lack of CP.

3. Some sections of the existing 8- and 10-in. gas main piping were found to be cathodically protected using sacrificial anodes. Some sections were not protected. Piping in the family housing area was not protected, and the pipes and coating were found to be in poor condition.

Recommendations Pertaining to Fort Jackson

1. Install CP on the unprotected 8- and 10-in. mains, which appear to be in good condition. Perform current requirement and design testing to determine the optimum type of CP on the unprotected mains. Existing CP indicates that magnesium anodes can be used. Additional GPIPER analyses using the procedures described in this report can be used to prioritize sections of the mains for installation of CP, as well as the criticality of CP maintenance after it is installed.

2. Install CP on the distribution piping located in the 3000, 5000, 6000, and 7000 family housing areas and the 10000 series area. Perform a current requirements test and a more detailed pipe to soil potential survey to determine the most cost effective type of CP system. Additional GPIPER analyses using the procedures set forth in this report can be used to prioritize sections of the mains for installation of CP, as well as criticality of CP maintenance after it is installed.

3. Initiate a program of CP testing and maintenance to keep existing and future CP active. This should include not only the gas distribution system, but also underground storage tanks (USTs), water storage tanks, and any other cathodically protected utility systems. Repair test stations on the cathodically protected lines and install additional test stations where necessary. USACERL's CP Diagnostic computer program (Van Blaricum et al. September 1991) could be implemented to make CP operation and maintenance easier.

4. Initiate a program for testing and installation of dielectric unions. Train maintenance personnel in the importance of corrosion control, cathodic protection, and dielectric unions.

5. Continue installation of plastic piping with new construction. CP should also be installed as soon as possible on existing and future metallic risers and other components (c.g., valves) which are part of any nonmetallic gas piping system.

6. Continue the program of annual gas leak surveys.

4 SUMMARY

A typical procedure for implementing the GPIPER program at an Army installation in conjunction with a corrosion survey to assist in the prioritization of gas piping repair has been illustrated. The procedure includes the following steps: (1) collecting system background information, (2) collecting leak history information, (3) performing bell hole inspections in the field to obtain soil samples and pipe and coating condition information, (4) assessing the cathodic protection system by measuring pipe-to-soil potentials, (5) performing laboratory analysis of the soil samples, and (6) GPIPER analysis.

An assessment of the gas distribution system at Fort Jackson, SC was performed with the assistance of the GPIPER program. As predicted by GPIPER, the pipes installed in 1967-1968 which were coated and not cathodically protected had begun to fail at a high rate due to soil-side corrosion. The field survey uncovered additional problems that had contributed to the accelerated failures in some of the other areas of the installation: failed or missing dielectric unions, variations in soil resistivity, coating damage in places, and a lack of CP. It was recommended that Fort Jackson install CP on unprotected metallic piping. Since it is unlikely that funding will be available to install CP on all sections of the gas distribution at the same time, GPIPER will be a valuable tool for prioritizing sections for CP installation as well as prioritizing the criticality of CP system maintenance and repair after it is installed.

REFERENCES

- "Control of External Corrosion on Underground or Submerged Metallic Piping Systems," Recommended Practice RP0169-92 (National Association of Corrosion Engineers, Houston, TX, April 1992).
- Corrosion Reduction Survey Report: Fort Jackson, SC*, Report Number E-87144 (U. S. Army Engineering and Housing Support Center [USAEHSC], May 1988).
- Gas Distribution Systems Operation and Maintenance*, Draft Technical Manual (TM) 5-654 as transmitted to the field by Technical Note 5-654-02 (USAEHSC, January 1991).
- Report of Leakage Control Survey for DEH Supply Division, Fort Jackson, South Carolina* (Heath Consultants Incorporated, Nashville, TN, May 1991).
- Report of Leakage Survey* (Southern Cross Corporation, July 1991).
- "Standard Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method," Standard G57 (American Society for Testing and Materials, 1992).
- Van Blaricum, V.L., Guglomo, R.C., Page, C.D., and Kumar, A., *MicroGPIPER Implementation Guide*, Technical Report FM-92/04/ADA256755 (U.S. Army Construction Engineering Research Laboratories [USACERL], 1992).
- Van Blaricum, V.L., Guglomo, R.C., Page, C.D., and Kumar, A., *MicroGPIPER User's Manual*, ADP Report M-92/10/ADA251459 (USACERL, May 1991).
- Van Blaricum, V.L., Page, C.D., Reinke, K., and Kumar, A., *Cathodic Protection Diagnostic Computer Program for Sacrificial and Impressed Current Systems: Overview and User's Manual*, ADP Report M-91/24/ADA243663 (USACERL, September 1991).

APPENDIX A: Input Data for GPIPER Analysis

This appendix contains two Data Specification report printouts generated by the GPIPER program which list the input data for the GPIPER analysis at Fort Jackson. In these reports:

- Outside diameter and wall thickness are given in inches
- Soil chloride contents are given in parts per million (ppm)
- Soil sulfides are given in milligrams per kilogram (mg/kg)
- Soil resistivity is given in ohm-centimeters
- Soil moisture is given in percent (%)
- In the "CATHODIC PROTECTION" column, ".T." indicates that the pipe section is cathodically protected, and .F. indicates that it is not
- Pipe-to-soil potentials are given in volts.

Page 1

SPECIFY REPORT
 Filename: C:\EMS\DATA\JACKSON
 REPORT DATE: 1992.08.05 08:56:30
 GPIPER (v. EMS 2.1)

PIPE SECTION ID	LOCATION	PIPE MATERIAL	COATING MATERIAL	DATE INSTALLED	OUTSIDE DIAMETER	WALL THICK
BLDG. 59571	CHESTNUT & PARKER	CARBON STEEL	WRAP COAL TAR	1968.01.01	6.0000	0.2800
BLDG. 4323 1	BLDG. 4323	CARBON STEEL	WRAP COAL TAR	1968.01.01	10.0000	0.3650
FOR&JACSN1	FOREST & JACKSON	CARBON STEEL	WRAP COAL TAR	1968.01.01	1.2500	0.1400
FOR&JACSN2	FRST & JACKSON LEAK	CARBON STEEL	WRAP COAL TAR	1968.01.01	1.2500	0.1400
FOR&JACSN3	FOREST & JACKSON	CARBON STEEL	WRAP COAL TAR	1968.01.01	8.0000	0.3220
SUMP&CHEAT1	SUMPTER & CHEATUM	CARBON STEEL	WRAP COAL TAR	1986.01.01	10.0000	0.3650

Page 1

SPECIFY REPORT
 Filename: C:\EMS\DATA\JACKSON
 REPORT DATE: 1992.08.05 08:55:30
 GPIPER (v. EMS 2.1)

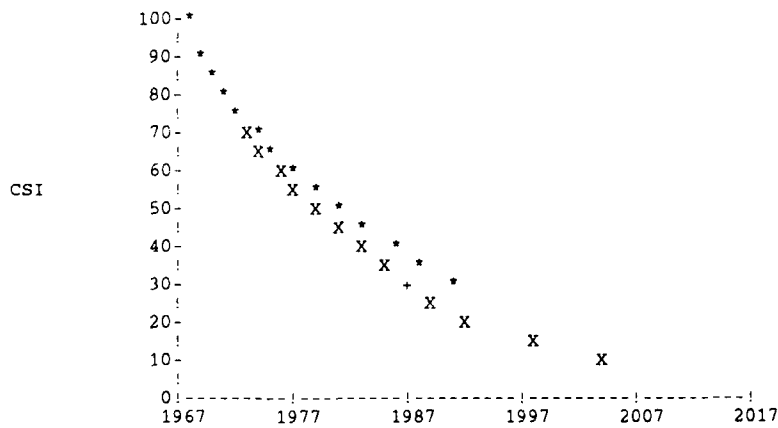
PIPE SECTION ID	pH (SOIL)	CHLORIDES (SOIL)	SULFIDES (SOIL)	RESISTIVITY (SOIL)	MOISTURE (SOIL)	CATHODIC PROTECTION	PIPESOIL POTENTIAL
BLDG. 59571	5.60	27.9	3.6	6006	9.8	.F.	-0.134
BLDG4323 1	5.35	35.9	0.7	5155	12.8	.F.	-0.417
FOR&JACSN1	5.49	70.5	0.9	3053	4.1	.F.	-0.637
FOR&JACSN2	4.22	61170.0	1.2	87	4.7	.F.	-0.639
FOR&JACSN3	5.95	22.9	0.8	14493	15.2	.T.	-1.502
SUMP&CHEAT1	6.67	35.9	0.9	7067	15.3	.F.	-0.639

APPENDIX B: Corrosion Status Index (CSI) Reports

Page 1

CSI PREDICTION REPORT
 Filename: JACKSON
 REPORT DATE: 1992.08.05 11:28:20
 GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION :	BLDG. 5957	SECTION NUMBER:	1
SOIL RESISTIVITY:	6000.00	SOIL pH:	0.2800
COATING MATERIAL:	WRAP COAL TAR	WALL THICKNESS:	0.2800
YEAR INSTALLED:	1968	PIPE SIZE (OD):	6.0
PREDICTED FIRST LEAD (CSI<=30):	1987	ACTUAL FIRST LEAK:	1991.05.14
Adjusted Formula:	Max.Pit Depth = 0.0454 * (time ^ 0.58)		
Pit Depth (in inches) & Time (in years)			



X Prediction
 + Predicted First Leak (CSI=30)
 * Actual

CSI PREDICTION REPORT
 Filename: JACKSON
 REPORT DATE: 1992.08.05 11:28:20
 GPIPER (v. EMS 2.1)

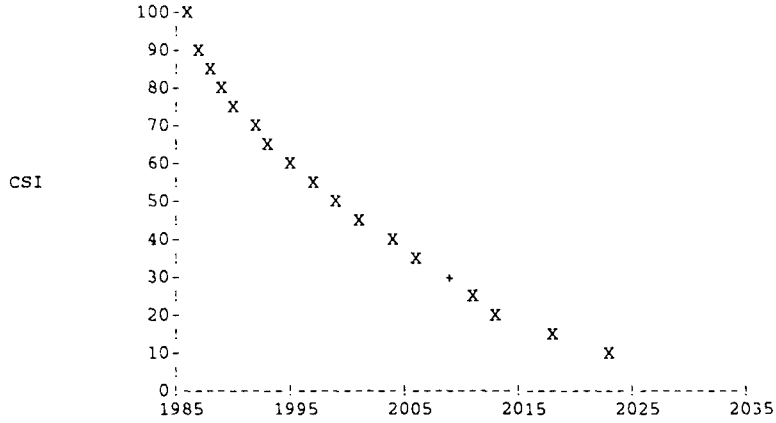
PIPE IDENTIFICATION : BLDG. 5957 SECTION NUMBER: 1

GRAPH TABLE

CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
-----	-----	-----	-----
1968	100	0	0
1969	87	0	0
1970	81	0	0
1971	76	0	0
1972	72	0	0
1973	68	0	0
1974	64	0	0
1975	61	0	0
1976	58	0	0
1977	55	0	0
1978	52	0	0
1979	49	0	0
1980	46	0	0
1981	44	0	0
1982	41	0	0
1983	39	0	0
1984	37	0	0
1985	34	0	0
1986	32	0	0
1987	30	1	1
1988	26	1	2
1989	23	2	4
1990	23	1	5
1991	21	2	7
1992	20	2	9
1993	19	3	12
1994	18	2	14
1995	17	4	18
1996	16	3	21
1997	16	4	25
1998	15	5	30
1999	14	5	35
2000	13	6	41
2001	13	7	48
2002	12	7	55
2003	12	8	63
2004	11	9	72
2005	10	11	83

CSI PREDICTION REPORT
Filename: JACKSON
REPORT DATE: 1992.08.05 08:24:10
GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION : BLDG4323 SECTION NUMBER: 1
SOIL RESISTIVITY : 5155.0C SOIL pH : 5.35
COATING MATERIAL : WRAP COAL TAR WALL THICKNESS: 0.3650
YEAR INSTALLED : 1986 PIPE SIZE (OD): 10.0
PREDICTED FIRST LEAK (CSI<=30): 2009 ACTUAL FIRST LEAK: No leak.



X Prediction
+ Predicted First Leak (CSI=30)

CSI PREDICTION REPORT
 Filename: JACKSON
 REPORT DATE: 1992.08.05 08:24:10
 GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION : BLDG4323 SECTION NUMBER: 1

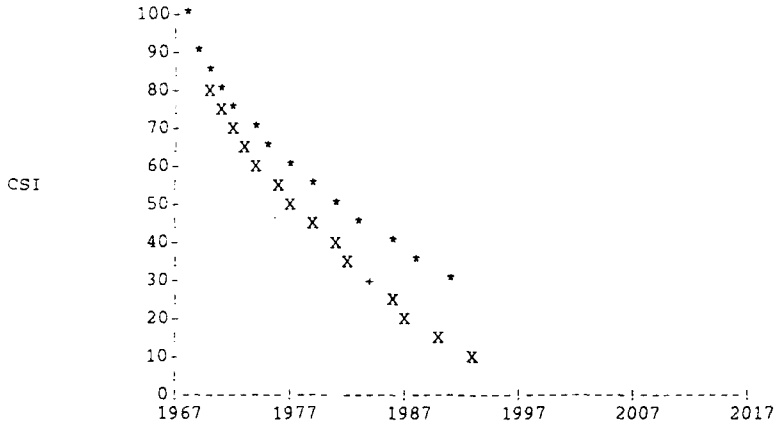
GRAPH TABLE

CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
-----	-----	-----	-----
1986	100	0	0
1987	89	0	0
1988	83	0	0
1989	79	0	0
1990	75	0	0
1991	71	0	0
1992	68	0	0
1993	65	0	0
1994	62	0	0
1995	59	0	0
1996	57	0	0
1997	54	0	0
1998	52	0	0
1999	50	0	0
2000	48	0	0
2001	45	0	0
2002	43	0	0
2003	41	0	0
2004	39	0	0
2005	37	0	0
2006	35	0	0
2007	34	0	0
2008	32	0	0
2009	30	1	1
2010	26	1	2
2011	23	2	4
2012	22	2	6
2013	20	3	9
2014	19	2	11
2015	18	4	15
2016	16	5	20
2017	16	5	25
2018	15	6	31
2019	14	8	39
2020	13	10	49
2021	12	11	60
2022	11	13	73
2023	10	15	88

CSI PREDICTION REPORT
 Filename: JACKSON
 REPORT DATE: 1992.08.05 11:29:10
 GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION : FOR&JACKSN SECTION NUMBER: 1
 SOIL RESISTIVITY : 3053.00 SOIL pH : 5.49
 COATING MATERIAL : WRAP COAL TAR WALL THICKNESS: 0.1400
 YEAR INSTALLED : 1968 PIPE SIZE (OD): 1.3
 PREDICTED FIRST LEAK (CSI<=30): 1984 ACTUAL FIRST LEAK: 1991.08.01

Adjusted Formula : Max.Pit Depth = 0.0227 * (time ^ 0.58)
 Pit Depth (in inches) and Time (in years)



X Prediction
 + Predicted First Leak (CSI=30)
 * Actual

CSI PREDICTION REPORT
 Filename: JACKSON
 REPORT DATE: 1992.08.05 11:29:10
 GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION : FOR&JACKSN SECTION NUMBER: 1

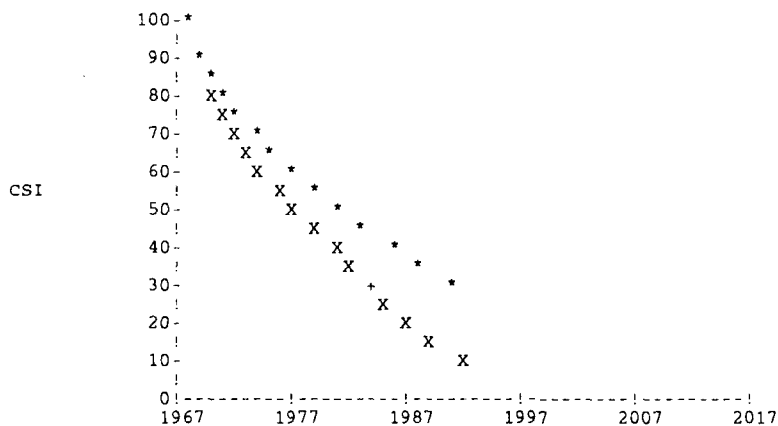
GRAPH TABLE

CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1968	100	0	0
1969	86	0	0
1970	79	0	0
1971	73	0	0
1972	69	0	0
1973	64	0	0
1974	60	0	0
1975	57	0	0
1976	53	0	0
1977	50	0	0
1978	47	0	0
1979	44	0	0
1980	41	0	0
1981	38	0	0
1982	35	0	0
1983	33	0	0
1984	30	1	1
1985	26	1	2
1986	23	3	5
1987	20	3	8
1988	18	5	13
1989	17	6	19
1990	15	9	28
1991	13	12	40
1992	12	17	57
1993	10	23	80

CSI PREDICTION REPORT
 Filename: JACKSON
 REPORT DATE: 1992.08.05 08:25:00
 GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION : FORandJACKSN SECTION NUMBER: 2
 SOIL RESISTIVITY : 87.00 SOIL pH : 4.22
 COATING MATERIAL : WRAP COAL TAR WALL THICKNESS: 0.1400
 YEAR INSTALLED : 1968 PIPE SIZE (OD): 1.3
 PREDICTED FIRST LEAK (CSI<=30): 1984 ACTUAL FIRST LEAK: 1991.08.01

Adjusted Formula : Max.Pit Depth = 0.0227 * (time ^ 0.58)
 Pit Depth (in inches) and Time (in years)



X Prediction
 + Predicted First Leak (CSI=30)
 * Actual

CSI PREDICTION REPORT
 Filename: JACKSON
 REPORT DATE: 1992.08.05 08:25:00
 GPIPER (v. EMS 2.1)

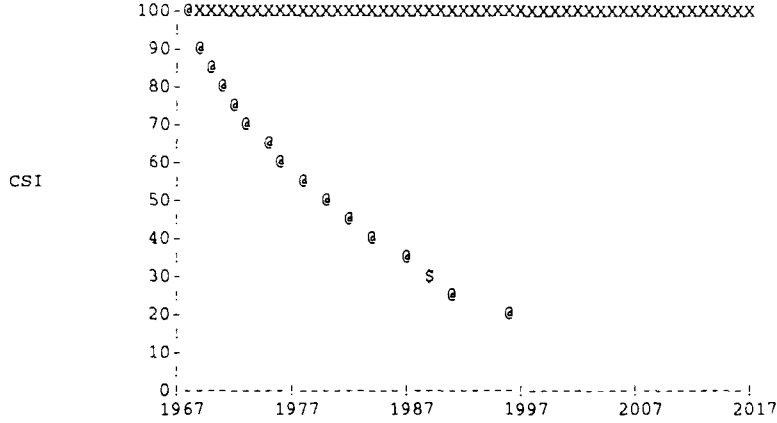
PIPE IDENTIFICATION : FOR&JACKSN SECTION NUMBER: 2

GRAPH TABLE

CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1968	100	0	0
1969	86	0	0
1970	79	0	0
1971	73	0	0
1972	69	0	0
1973	64	0	0
1974	60	0	0
1975	57	0	0
1976	53	0	0
1977	50	0	0
1978	47	0	0
1979	44	0	0
1980	41	0	0
1981	38	0	0
1982	35	0	0
1983	33	0	0
1984	30	1	1
1985	25	2	3
1986	23	2	5
1987	20	5	10
1988	17	8	18
1989	15	11	29
1990	13	17	46
1991	11	25	71
1992	9	38	109

CSI PREDICTION REPORT
Filename: JACKSON
REPORT DATE: 1992.08.05 08:25:10
GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION : FOR&JACKSN SECTION NUMBER: 3
SOIL RESISTIVITY : 14493.00 SOIL pH : 5.95
COATING MATERIAL : WRAP COAL TAR WALL THICKNESS: 0.3220
YEAR INSTALLED : 1968 PIPE SIZE (OD): 8.0
PREDICTED FIRST LEAK (CSI<=30): 1989 ACTUAL FIRST LEAK: No leak.
CATHODIC PROTECTION w/ PIPE-to-SOIL POTENTIAL <= -0.85 VOLTS



X Prediction
@ Prediction (in event of Cathodic Protection Failure)
S Predicted First Leak (CSI=30, in event of Cathodic Protection Failure)

CSI PREDICTION REPORT
 Filename: JACKSON
 REPORT DATE: 1992.08.05 08:25:10
 GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION : FOR&JACKSN SECTION NUMBER: 3

GRAPH TABLE
 (EVENT OF CATHODIC PROTECTION FAILURE)

CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1968	100	0	0
1969	88	0	0
1970	82	0	0
1971	77	0	0
1972	73	0	0
1973	70	0	0
1974	66	0	0
1975	63	0	0
1976	60	0	0
1977	57	0	0
1978	54	0	0
1979	52	0	0
1980	49	0	0
1981	47	0	0
1982	45	0	0
1983	42	0	0
1984	40	0	0
1985	38	0	0
1986	36	0	0
1987	34	0	0
1988	32	0	0
1989	30	1	1
1990	26	1	2
1991	25	1	3
1992	23	1	4
1993	23	1	5
1994	22	1	6
1995	21	1	7
1996	20	1	8
1997	20	1	9
1998	20	1	10
1999	19	1	11
2000	19	1	12
2001	18	1	13
2002	18	1	14
2003	18	1	15
2004	17	1	16
2005	17	1	17
2006	17	1	18
2007	17	1	19

CSI PREDICTION REPORT
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 GPIPER (v. EMS 2.1)

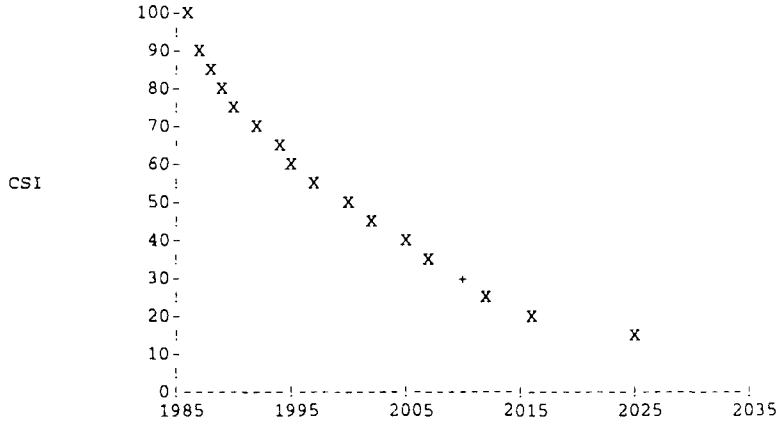
PIPE IDENTIFICATION : FOR&JACKSN SECTION NUMBER: 3

GRAPH TABLE
 (EVENT OF CATHODIC PROTECTION FAILURE)

CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
2008	16	1	20
2009	16	1	21

CSI PREDICTION REPORT
Filename: JACKSON
REPORT DATE: 1992.08.05 08:25:50
GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION : SUMP&CHEAT SECTION NUMBER: 1
SOIL RESISTIVITY : 7067.00 SOIL pH : 6.67
COATING MATERIAL : WRAP COAL TAR WALL THICKNESS: 0.3650
YEAR INSTALLED : 1986 PIPE SIZE (OD): 10.0
PREDICTED FIRST LEAK (CSI<=30): 2010 ACTUAL FIRST LEAK: No leak.



X Prediction
+ Predicted First Leak (CSI=30)

CSI PREDICTION REPORT
 Filename: JACKSON
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 GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION : SUMP&CHEAT SECTION NUMBER: 1

GRAPH TABLE

CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1986	100	0	0
1987	89	0	0
1988	83	0	0
1989	79	0	0
1990	75	0	0
1991	72	0	0
1992	69	0	0
1993	66	0	0
1994	63	0	0
1995	60	0	0
1996	58	0	0
1997	55	0	0
1998	53	0	0
1999	51	0	0
2000	49	0	0
2001	47	0	0
2002	45	0	0
2003	43	0	0
2004	41	0	0
2005	39	0	0
2006	37	0	0
2007	35	0	0
2008	33	0	0
2009	32	0	0
2010	30	1	1
2011	26	1	2
2012	25	1	3
2013	23	1	4
2014	22	2	6
2015	21	1	7
2016	20	2	9
2017	20	1	10
2018	19	2	12
2019	18	2	14
2020	17	2	16
2021	17	2	18
2022	16	2	20
2023	16	2	22
2024	16	3	25
2025	15	2	27

CSI PREDICTION REPORT
 Filename: JACKSON
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 GPIPER (v. EMS 2.1)

PIPE IDENTIFICATION : SUMP&CHEAT SECTION NUMBER: 1

GRAPH TABLE

CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
2026	15	3	30
2027	14	3	33
2028	14	3	36
2029	14	3	39
2030	13	3	42

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