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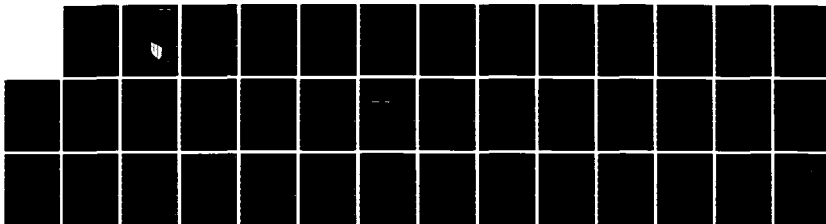
DEMONSTRATION OF THE PIPE CORROSION MANAGEMENT SYSTEM
(PIPER)(U) CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY)
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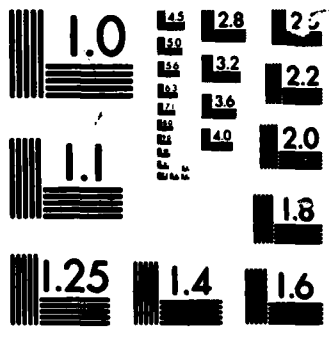
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TECHNICAL REPORT M-86/08

April 1986

Corrosion Mitigation and Management System

AD-A166 807

Demonstration of the Pipe Corrosion Management System (PIPER)

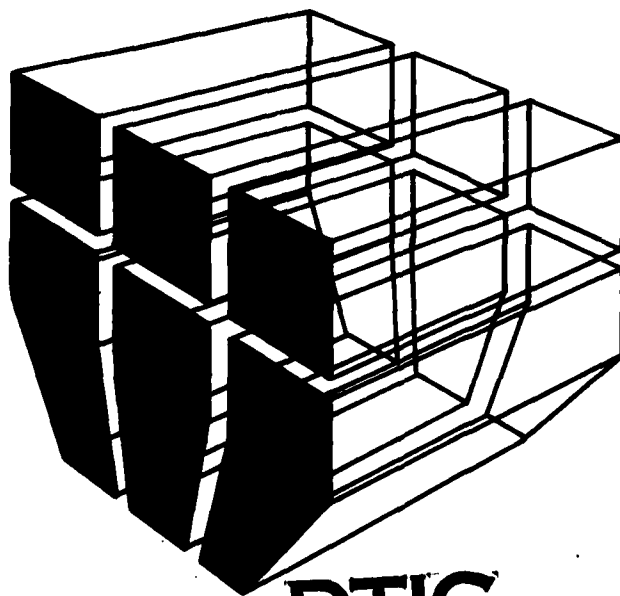
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by
A. Kumar
W. Riggs
M. Blyth

The U.S. Army Construction Engineering Research Laboratory (USA-CERL) has developed a pipe corrosion management system, called PIPER, as part of the Corrosion Mitigation and Management System (CM²S). PIPER is a predictive technique based on state-of-the-art mathematical models. USA-CERL developed the program in conjunction with work on some new nondestructive corrosion assessment methods for buried pipes. The program can predict how many leaks a pipe will have in a given year and then "suggest" the most cost-effective solution for correcting the problem. In this way, PIPER ensures the best distribution of dollars spent on replacement and repair of corroded underground pipes. PIPER includes both manual and computerized methods. The computerized part of the system is user-oriented for easy field use.

PIPER has been fielded at two military installations. Results are promising and will be considered in future developmental work with PIPER.

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↗ underground pipes. PIPER includes both manual and computerized methods. The computerized part of the system is user-oriented for easy field use.

PIPER has been fielded at two military installations. Results are promising and will be considered in future developmental work with PIPER.

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FOREWORD

This study was conducted for the Assistant Chief of Engineers, Office of the Chief of Engineers (OCE), under Project 4A162731AT41, "Military Facilities Engineering Technology"; Task C, "Operation and Maintenance Strategy"; Work Unit 141, "Corrosion Mitigation and Management System." Partial funding was provided by Headquarters, Naval Facilities Engineering Command through work order N0002583WR1107W dated 3 August 1983. The OCE Technical Monitors were L. Keller and B. Wasserman, DAEN-ZCF-U.

The work was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. Robert Quattrone is Chief, EM.

COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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DEMONSTRATION OF THE PIPE CORROSION MANAGEMENT SYSTEM (PIPER)

1 INTRODUCTION

Background

The U.S. Army Construction Engineering Research Laboratory (USA-CERL) has completed preliminary work on concepts for a computerized Pipe Corrosion Management System (PIPER), designed for use by Army installations.¹ As Figure 1 shows, PIPER is a maintenance decision-making tool for assigning priorities to corrosion-related maintenance and repair of underground pipes. It provides fast data storage and retrieval, inventories an installation's pipe network, computes the corrosion status index (CSI), predicts present and future corrosion status based on soil properties, predicts leaks, and gives an economic analysis of maintenance options for budget planning. All output can be formatted into user-defined reports. PIPER is part of the Army's Corrosion Mitigation and Management System (CM²S).

The PIPER data base is custom-designed on a commercially available Boeing Computer Services computer data base manager called "System 2000" (registered trademark of the Intel Corporation).^{*} Data are stored in a tree structure that enables the user to retrieve information based on its connection with other data in the data base. The data can be stored and retrieved through interface programs. PIPER software could be modified to operate on the Vertical Installation on Automatic Baseline (VIALE) system, an Army-wide automatic data processing (ADP) technology. This development would make PIPER available to more users in the field and would allow all future program development to be written directly onto the system.

When soil properties (pH and resistivity) are entered into the system, PIPER predicts the years in which leaks will occur and the number of cumulative leaks over time; the cumulative data are based on an exponential growth curve. (To review PIPER's typical

output, see Figures 11 through 14 in Technical Report [TR] M-337.)

PIPER also can produce an economic analysis when inflation and interest rates are input. Alternative maintenance strategies can be evaluated and "what if" questions can be answered (Figure 15 in TR M-337). Other user-oriented reports, such as annual work plans and budget optimization schedules, can be formatted.

Computerization is not absolutely necessary; a manual system can achieve some of the same systematic management objectives. However, PIPER's computerized version has many advantages as listed above and in TR M-337. Its disadvantages are the costs of initial investment, training, and implementation.

Objectives

The objectives of this study were to (1) continue investigating methods of nondestructive, underground-pipeline corrosion assessment and (2) demonstrate the computerized version of PIPER and obtain data documenting the system's potential for Army-wide use.

Approach

In continuing the investigation on corrosion assessment methods, USA-CERL began developing the alternating current (a.c.) impedance technique, which exploits similarities between an electrical circuit and a buried pipeline. Meanwhile, sites suitable for demonstrating PIPER's current version were determined. The system was fielded at two installations, and data were evaluated.

Mode of Technology Transfer

It is recommended that information gathered in this work be incorporated into Air Force Technical Manual 5-811-4, *Electrical Design-Corrosion Control* and disseminated as an Engineer Technical Note.

2 NONDESTRUCTIVE PIPELINE CORROSION ASSESSMENT: A.C. IMPEDANCE TECHNIQUE

Methods Used in Current PIPER Version

From the variety of corrosion assessment methods being used or developed in the pipeline industry, USA-CERL considered three possibilities: (1) pipe dig-up for visual inspection, (2) electrical assessment techniques, and (3) estimation using mathematical models.

¹A. Kumar, E. Meronyk, and E. Segar, *Development of Concepts for Corrosion Assessment and Evaluation of Underground Pipelines*, Technical Report M-337/ADA140633 (U.S. Army Construction Engineering Research Laboratory, 1983).

^{*}PIPER also can be operated on the Control Data Corporation's (CDC) Cyber network.

Although pipe dig-up with inspection is a highly accurate assessment method, it is also expensive. (Costs range from \$300 to \$1,000 per dig-up, depending on the number of separate inspections.) As alternatives to visual inspection, USA-CERL has been investigating two nondestructive methods that are based on electrical polarization; both the polarization decay technique and the more recent a.c. impedance method are still under development, but show good potential for use with PIPER. Corrosion estimation using mathematical models represents another alternative to inspection. However, the speed and economy of estimation is at the expense of decreased assessment accuracy. For this reason, the PIPER program uses estimation coupled with periodic visual inspection. This dual assessment method maximizes accuracy and minimizes cost.

Future PIPER versions will use electrical assessment instead of inspection, yielding a nondestructive, more economical pipeline management system. The electrical polarization decay technique described in TR M-337 is achieved with direct current (d.c.) (Figure 1 in that report). A newer polarization method being developed uses a.c.

The A.C. Impedance Concept

The terms "resistance" and "impedance" both imply an obstruction to current or electron flow. When the current is d.c., only resistors have this effect. In contrast, with a.c., circuit elements such as capacitors and inductors also can influence electron flow. These elements affect the magnitude of an a.c. waveform along with its time-dependent characteristics or phase.²

Figure 2 represents typical plots of a voltage sine wave (E) applied across a given circuit and the resultant a.c. waveform (I). Note that the two traces differ in amplitude as well as in phase (I leads E). The capacitor in the circuit (in this case, the pipeline corrosion product) is said to "impede" the current flow—thus the term "a.c. impedance." In general, parameters characterizing corrosion behavior can be determined by measuring the frequency dependence of the complex impedance, Z.³ ("Frequency" is defined as the number of alternating cycles through which the voltage goes in 1 sec. By varying the applied frequency, different

responses can be obtained.) When both waveforms are displayed at once on an oscilloscope, a form called a "Lissajous figure" appears (Figure 3). This figure shows that Delta E, Delta I, and Delta I' are readily obtainable. Mathematically:

$$|Z| = \Delta E / \Delta I \quad [\text{Eq 1}]$$

$$\sin \theta = \Delta I' / \Delta I \quad [\text{Eq 2}]$$

$$R = |Z| \cos \theta \quad [\text{Eq 3}]$$

$$-X = |Z| \sin \theta \quad [\text{Eq 4}]$$

R is then plotted on the horizontal axis and -X on the vertical axis. The circuit is tested at several frequencies, and the plot shown in Figure 4 is obtained. This "Cole-Cole" plot allows determination of the purely resistive circuit elements, the polarization resistance, and hence, the capacitance, C. Capacitance is an indicator of the amount of corrosion, with greater amounts of corrosion having larger C values.

Field Testing

The a.c. impedance method must undergo much more development before it will be ready to implement in the field. However, the earlier polarization decay technique is at a higher stage of development and has been field tested. At present, it needs refinement to improve reliability and more experimentation to correct other problems discovered in field testing.

3 DEMONSTRATION OF PIPER

The current computerized version of PIPER (visual inspection coupled with estimation) was fielded at two installations (Fort Riley, KS, and the Naval Supply Depot, Guam) to test whether the system could manage and concisely summarize large data sets. PIPER is a bilevel program designed to provide summary condition reports of whole installations as well as alternative maintenance/replacement evaluations for pipe sections (identified in the condition reports as "failed" or "very poor"; CSI $\leq$ 29). These functions are termed Network Level and Project Level analysis, respectively.

Important components of the Network Level analysis are the: network inventory, frequency report, rank report, projected budget needs, and inspection schedule. In essence, the network inventory is PIPER's data base. Any input parameters stored in the data base

² *Basics of AC Impedance Measurements* (E&G Princeton Applied Research, 1984).

³ J. R. Scully and K. J. Bundy, "The Use of Electrochemical Techniques for Measurement of Pipe Steel Corrosion Rates in Soil Environments," presented at the Corrosion Conference '83 (NACE, 1983).

can be recalled in a "specify" report. As the name suggests, whatever parameters requested will appear on the report.

The frequency report is a histogram that summarizes the condition of an installation's pipes. Headquarters engineers can use this report to compare one installation with another. This report also is a decision-making tool that helps the engineer determine if a single section or many pipe sections should be repaired/replaced. For instance, if an installation's piping is in generally poor condition, it might be better to replace it rather than make repairs.

The prioritization scheme, or rank report, lists pipe sections in ascending order of condition (i.e., worst to best). Since *all* pipes must have *no* leaks, the CSI needs to be at least 30 for all pipes in the network. All pipes with CSI below 30 should be replaced. If the replacement budget is limited and the pipes cannot be replaced, stepped replacement, using budget optimization, is the answer.

Many parameters can be stored for each section of pipe (see Figure 10 in TR M-337). Indeed, the PIPER data base can contain more information about piping systems than is normally available at most facilities. Therefore, only a limited number of parameters were documented for the initial implementation at the field sites (information such as leak records and actual year of first leak usually was not available, but could be entered later). USA-CERL personnel visited each facility, obtained blueprints of the piping systems, gathered soil samples from various locations at the facility, consulted with engineering and maintenance staff, and obtained as much information as possible for inputting into the PIPER data base. Contracts were then awarded to integrate this information, partition the blueprints into a logical sequence of pipe identifications and section numbers, and enter the data into the computer data base. (The partitioning and labeling of piping networks was the greatest challenge since standards for labeling sections and proper partitioning procedures have not yet been established.) The contractors also were required to test output via the various reporting methods.

Fort Riley, KS

The entire gas piping system at Fort Riley, KS, was studied. The 78 gas pipes were segmented logically into 535 sections. To calculate the CSI for each section, the following data were gathered: soil resistivity, soil pH, pipe coating material, wall thickness, and year installed; Figure 5 shows this information in the

form of a specify report. Although the year of first leak data (if applicable) would have made the predicted CSI more accurate, this information was unavailable so the CSI was calculated without it. Figures 6 and 7 are the frequency and rank reports generated.

PIPER helped locate trouble spots in the Fort Riley piping network. As a result, new steel pipes combined with cathodic protection systems were installed in FY85. USA-CERL will continue monitoring the Fort Riley piping system. A future version of PIPER will include a cathodic protection monitor, and this feature will be tested at Fort Riley when it is completed.

Naval Supply Depot (NSD) Guam

The structures considered at NSD Guam were:

1. Sasa Valley Tank Farm and related piping
2. Tenjo Vista Tank Farm and related piping
3. Pipelines to the Naval Air Station (NAS).

The structures were built at various times since 1952. The Sasa Valley-to-NAS pipelines were completed in 1977. Tanks in the Sasa Valley system were completed as follows:

1. Tanks U-1 through U-16—1952/53
2. Tanks U-17 and U-18—1957
3. Tanks U-19 and U-20—1959

Tanks U-28 through U-31 in Vista Tank System were constructed in 1963, and tanks U-33 through U-35 were completed in 1970.

The various structures had the following metal thicknesses:

- Pipelines—0.365 in.
- Tanks U-1 through U-31—0.313 in.
- Tanks U-33* through U-35—0.375 in.

Pipe-to-soil potentials were taken at various locations and are listed in Table 1. Soil samples were taken and forwarded to USA-CERL for analysis. Table 2 shows the results.

*There is no tank U-32.

Table 1
Pipe-to-Soil Potentials, NSD Guam

Location	Pipe/Soil (V vs Cu-CuSO ₄)
Sasa Valley-to-NAS Pipelines*	
CP test station 21 at NAS	-0.61
CP test station at Mongmons Road	-1.04
CP test station 14 at Toto Road	-1.00
CP test station 13 at Sinajania Road	-1.13
CP test station 9 below Sinajania Road	-1.20
CP test station 3 at Nimitz Hill	-1.00
Sasa Valley Tank Farm System**	
Pipelines at Echo Pier valve pit	-0.62
Pipelines at causeway rectifier	-0.80***
Pipelines at booster pumphouse, Marine Drive	-0.67
Top of tank U-5	-0.50
Top of tank U-20	-0.58
Tenjo Vista tank farm system†	
Pipeline at CP test station north of rectifier	-0.56
Pipeline at Tenjo Vista rectifier	-0.43
Top of tank U-28	-0.39
Test coupon for tank U-28	-0.33
Top of tank U-35	-0.25
Test coupon for tank U-35	-0.31

*Nimitz Hill rectifier output: 2 amps at 4.5 V.

**Causeway rectifier not activated; installed new August 1961.

***Receiving some current from the GORCO (Guam Oil and Refining Company) cathodic protection system at this location because the two systems are electrically continuous.

†Tenjo Vista rectifier on Marine Drive output: 0 amp at 11 V.

Table 2
Soil Sample Locations and Results

Location	pH	Resistivity
Nimitz Hill rectifier	6.81	1010
CP test station 9	8.45	1475
NAS pumphouse	8.61	1510
Booster pumphouse	7.88	1160
Causeway rectifier	8.87	6750
Tank U-35	7.70	710
Tank U-28	8.70	1110
Tank U-5	8.06	775
Tank U-20	7.48	730

Using the soil data, material thicknesses, and years installed, PIPER made corrosion predictions. With no cathodic protection, the year of first leak for each structure should be:

1. Nimitz Hill rectifier (Sasa-to-NAS pipelines)—2003

2. CP test station 9 for Sasa-to-NAS pipelines, below Sanajania road—2013

3. NAS pumphouse (Sasa-to-NAS pipelines)—2014

4. Pipelines at booster pumphouse off Marine Drive—1986

5. Causeway/Sasa rectifier (pipelines)—2038

6. U-35—1999

7. U-28—1992

8. U-5—1977

9. U-20—1983

(Results are generalized for tanks surrounding the ones listed since soil data and tank thicknesses are the same.)

Figures 8 through 25 show year to first leak, CSI-versus-year-graphs, and cumulative leak tables. The reason for variations in these reports is that the soils at NSD Guam vary markedly, from a 710-ohm-m resistivity and 7.7 pH at U-35 to a 6750-ohm-m resistivity and 8.9 pH at the causeway rectifier.

Cathodic protection had been installed, but is in a state of disrepair at NSD Guam. Previous reports indicate this status has existed for many years.⁴ The PIPER analysis shows that better cathodic protection with state-of-the-art design must be installed at NSD Guam since the soils are so corrosive. The future version of PIPER that will include cathodic protection system monitoring may be implemented at NSD Guam when it is finished. Although it is impossible to determine the extent of the NSD Guam structures' corrosion (since cathodic protection has been

intermittent), leaks have been reported along the pipelines in the Sasa Valley Tank Farm.

It should be noted that the year-to-first-leak prediction would be affected by improved cathodic protection. Under optimal conditions, when cathodic protection is used, underground materials do not corrode.

4 ECONOMIC ANALYSIS

Factors affecting the repair/replace decision for corroded pipes include costs associated with the various alternatives, safety in residential and industrial areas, esthetic improvements, and ease of maintenance. Of these factors, economics are the most easily analyzed mathematically and, therefore, PIPER uses this parameter in evaluating repair and replacement alternatives.

PIPER has a set of economic analysis subroutines that simplifies and clarifies the budgetary process. The set consists of three programs: ECON, ECON1, and BUDOPT.

Factors in Repair/Replace Decisions

An economic analysis of repair and replacement must consider the following factors:⁵

- Total replacement cost
- Cathodic protection systems' cost
- Main-to-curb replacement cost in distribution systems
- Cost of gas lost while replacing pipe
- Cost incurred to restore service after replacement
- Pipe's salvage value
- Cost of reanoding at various intervals
- Cathodic protection monitoring cost
- Cost of gas lost due to leakage

⁴NSD Guam Marianas Islands, *Cathodic Protection Evaluation* (Corrosion Engineering Research Co., Concord, CA, November 1979); R. T. Engleman, *Cathodic Protection Survey, September 1971, U.S. Naval Activities, Guam, Marianas Islands* (U.S. Navy Pacific Division, Naval Facilities Engineering Command, December 1971).

⁵*Procedure for Evaluating Pipeline Replacements* (East Ohio Gas Company, 1979).

- Projected number of leaks needing repair in a given period
- Cost of examining pipeline condition (test holes)
- Cost associated with a typical repair.

Some of these costs occur only once, whereas others, such as cathodic protection monitoring, are cyclic. The three economic reports in PIPER can accommodate both types.

Several alternatives usually must be evaluated under the total replacement costs category. Should the replacement piping be coated and wrapped steel, or should it be polyethylene? If coated and wrapped steel is considered, which of the available coating systems should be used? Should the polyethylene piping be direct-buried or "sliplined" ("sliplining" refers to slipping a new plastic pipe through an old steel piping system)? Most often, the total cost associated with installing each alternative will be available in approximate dollar amounts (bids from previous contracts). A rough rule of thumb for direct-buried steel and plastic pipe is:

Direct-buried steel = diameter (in.) $\times$ \$8/in. $\times$ pipeline length

Direct-buried plastic = 69 percent of steel cost for 4 in. lines; 104 percent of steel cost for 6-in. lines.

Before choosing either steel or plastic piping, the costs peculiar to each material must be compared in addition to the material and installation costs. For example, in evaluating direct-buried plastic pipe, training and accidental damage expenses must be considered (workers inexperienced with plastic pipe will need training in installation and maintenance). In addition, fluid losses and repair costs associated with accidental damage must be estimated. Since the piping is installed just 3 ft underground, it is prone to accidental puncture from excavation or construction. In addition, renters at base housing may damage the piping through carelessness or vandalism.

Costs associated with cathodic protection implementation have been estimated at 3 to 5 percent of the cost for installing a new steel pipeline. Reanoding costs are critically contingent on successful care of the cathodic protection system. If care is taken to avoid electrical shorts and interference, typical replacement of the system will be 15 yr (actually, there will be a short remaining life at the end of the 15-yr period, but

replacement should be underway at that time to ensure protection from corrosion). Replacement costs should be the same 3 to 5 percent, adjusted for inflation. If electrical shorts or interferences are allowed to occur, anode life expectancy drops quickly (to as low as 5 yr or less). For this reason, adequate monitoring is essential.

Cathodic protection monitoring costs are difficult to obtain. Probably the most reliable way for an Army facility to ensure continued success of its installed cathodic protection systems is to award a contract for periodic inspection; contracting ensures accurate, timely cathodic protection surveys. A semiannual survey usually costs only a few thousand dollars. The contractors should be professional corrosion engineers who can assess the system status quickly and make recommendations for repair.

Example Analysis

To demonstrate how the reports in PIPER work, the following parameters are used in an example analysis:

- 6-in. line
- Initial cost of steel pipeline—\$2 million
- Cathodic protection installation costs—5 percent
- Cathodic protection monitoring costs: \$5000/yr, adjusted for inflation
- Salvage value of steel pipe—\$50,000
- Salvage value of plastic pipe—\$0
- Projected number of leaks for repair—will use PIPER's CSI prediction report, with resistivity equal to 5000 ohm-cm, pH 6, and the first year under consideration being year 20 of the pipeline's life
- Cost for each repair—\$3000 (includes detection, gas lost, light-up services, etc., adjusted for inflation in subsequent years).

The alternatives to be analyzed are:

1. Replace the existing pipeline with new steel pipeline
2. Replace the existing pipeline with new plastic pipeline

3. Continue to repair the existing pipeline.

(Numbers 1, 2, and 3 correspond to A, B, and C in the economic reports.)

The annual inflation rate is considered to be 6 percent and the interest rate is 0 percent (since military facilities use existing monies and do not pay interest).

Figure 26 is the first half of the CSI prediction report. As indicated, the expected year of first leak is 1982. Figure 27 is the graph table that accompanies the CSI prediction report in Figure 26 and shows that, by 1995, 82 cumulative leaks are predicted. Two leaks are projected for year 20 (1984).

Figure 28 shows the first economic analysis report, ECON. Here, the program has asked the user for (1) costs associated with each of several alternatives for each fiscal year of the analysis period and (2) the salvage value of each alternative at the end of the analysis period. The alternatives are analyzed for present worth based on user-specified inflation and interest rates. The user is left to determine the best present worth of the various alternatives.

The second report is ECON1, which is much more detailed and asks the user for initial and recurring costs. The user specifies differing cyclical costs, initial cost, inflation, and interest rates. (Figures 29 through 31 show which costs are yearly, which occur only once, and others, such as the cost of reanoding, that occur every 15 yr.) ECON1 can handle all of these situations. The output for each alternative is initial cost, present value, Equivalent Uniform Annual Cost (EUAC), and EUAC per area (EUAC/A). As Figures 29 through 31 show, the EUAC/A is greatest for continued repair, much less for replacement with steel pipe (five times), and least for replacement with plastic pipe.

Data from ECON1 are input into the subroutine BUDOPT, which selects the preferred alternative(s) for a given number of locations based on a benefit-to-cost ratio. The alternatives can be weighted with respect to importance and other variables. For example, a pipeline that serves a strategic function, such as refueling, might receive the highest priority, whereas a pipeline to an abandoned barracks would receive very low priority. Projects will be selected until a given budget is exceeded (Figure 32). Thus, BUDOPT is a tool with which to optimize facility monies.

For this example, the results of ECON, ECON1, and BUDOPT indicate replacement with plastic pipe is

the best available alternative if weighting factors are the same (identical benefit was used for each alternative).

5 FUTURE DEVELOPMENTS FOR PIPER

Most military facilities incorporate cathodic protection into their piping networks. However, the major problem in protecting underground structures is not designing and installing the necessary equipment, but rather maintaining it in working order. Potential problem sources are common: lawn mowers or earth-moving equipment damaging the system, plumbers eliminating dielectric unions, electricians grounding different systems onto the protected lines, birds building nests in rectifiers, rodents chewing holes in lines, and many others.

To help facilities with maintenance, USA-CERL is developing a Cathodic Protection Monitoring System as part of PIPER. This system will prompt the user for input (i.e., rectifier readings and test station readings) that she or he has gathered. It will then analyze the data, determine if problems exist, flag existing problems, and suggest "most probable cause" for the problem (e.g., "check for short circuit at Building A," or "anode ground bed resistance too high—check anode wires"). In addition, low-maintenance cathodic protection hardware will be developed.

Another proposed enhancement to PIPER will be graphic representation of piping systems, color-keyed to operating pressures. In addition, a microcomputer version of PIPER is being developed. When it becomes operational, "micro" PIPER will operate more economically than the CDC network version. The savings will stem from the difference in computer time costs between microcomputers and the commercial network. For noncomputational tasks such as inputting data, microcomputers are less expensive and no more time-consuming than minicomputers.

At present, PIPER evaluates gas piping systems exclusively. Future work will extend PIPER's applicability to water, sewage, and exhaust pipes as well as boilers and chillers. Using data and mathematical models compiled by private industry, CSIs pertaining to these pipes will be developed. Thus, a future version of PIPER will apply to all types of external and internal pipes.

6 CONCLUSIONS

In continuing the search for nondestructive corrosion assessment techniques, USA-CERL has investigated a new electrical concept for checking underground pipelines. This "a.c. impedance" method is under development for use with the corrosion mitigation and management system PIPER.

The current computerized version of PIPER has been demonstrated at two military facilities Fort Riley, KS, and NSD Guam. Results indicate PIPER is successful in managing large amounts of data and in generating concise frequency and rank reports. The system helped identify failed piping at Fort Riley and correctly predicted leaks in NSD Guam's Sasa Valley pipelines (no cathodic protection assumed).

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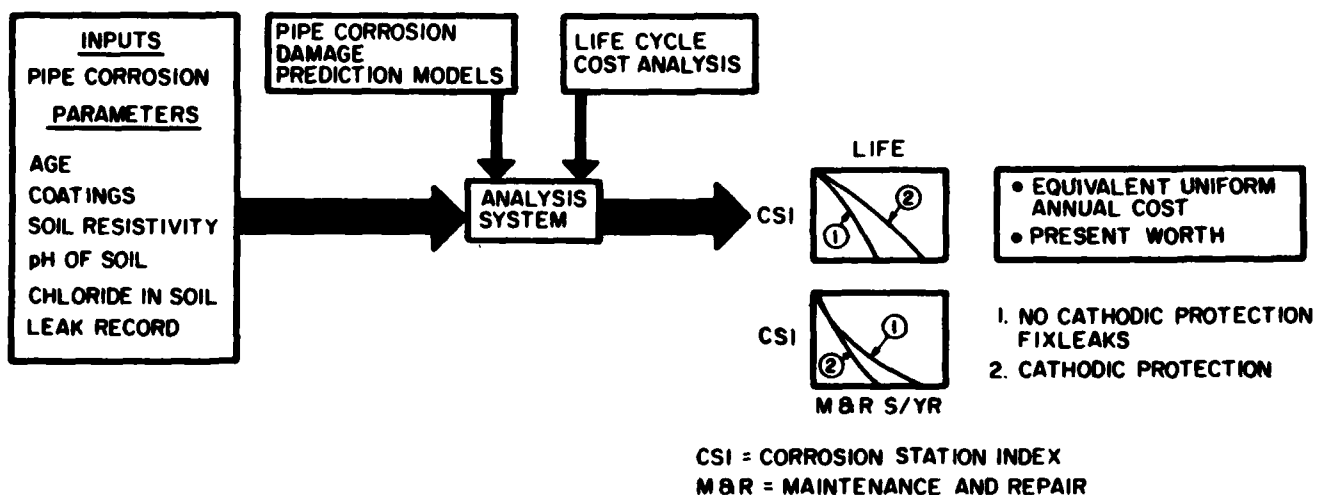


Figure 1. Pipe Corrosion Mitigation and Management System (PIPER).

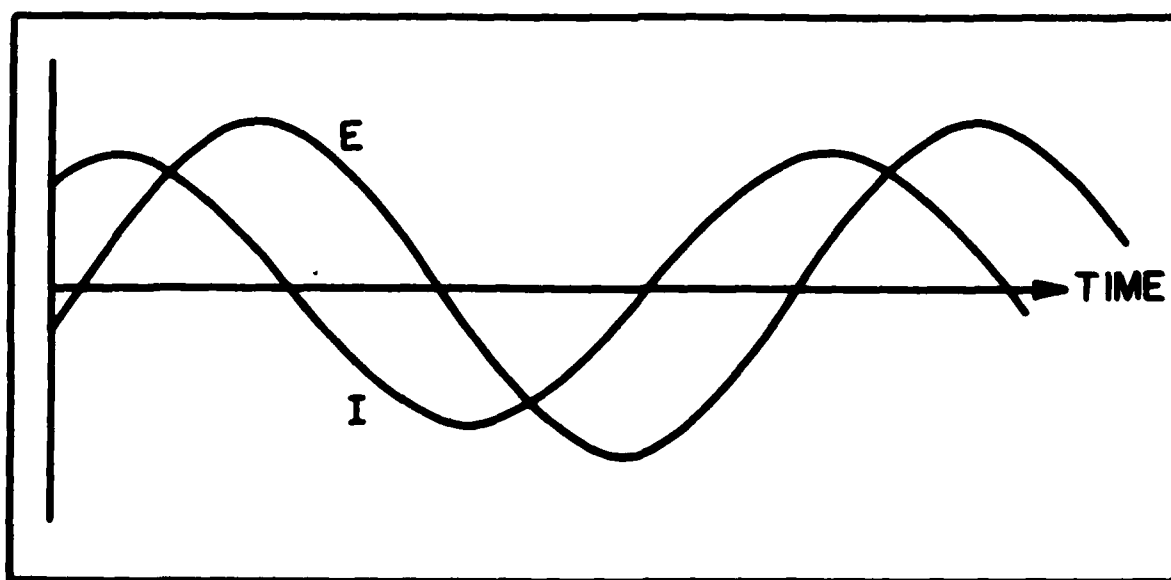


Figure 2. Electrical waveforms for a.c. impedance.

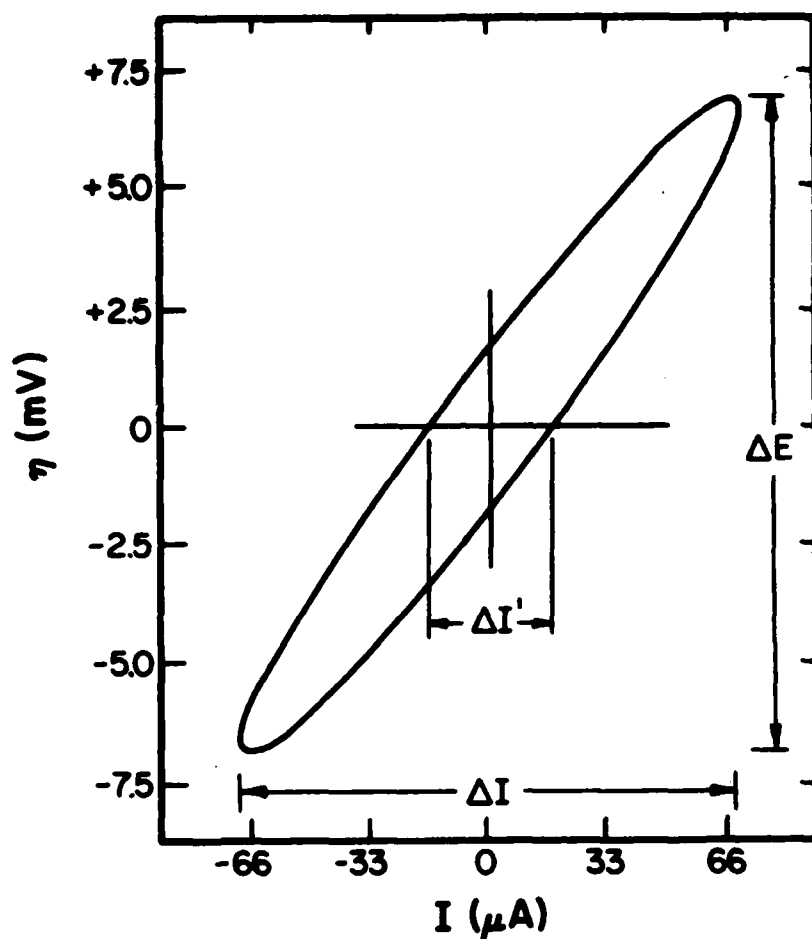


Figure 3. Impedance measurement (a.c.) Lissajous figure.

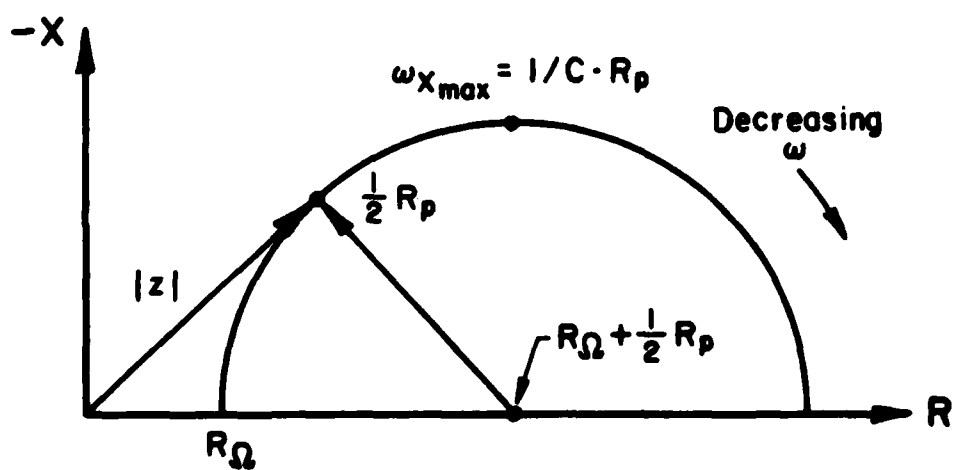


Figure 4. Cole-Cole plot.

SPECIFY REPORT
85/11/27.

PIPE ID	SEC#	FROM	TO	SCIL PH	LSI

• CSTRFM-BANK	0	NRMY & EWELL	5291	7.70	11
•	1	NRMY & BNW RD	ALL 3"	7.70	55
•	2	BNKLN	POST OFF	7.70	60
•	3	NRMY	5202	7.70	57
•	4	NRMY & BNW RD	PX	7.70	46
• CSTRFM-FIR	0	1ST % & NRMY	1ST % & FIRE	7.70	70
•	1	1ST % & FIRE	5000	7.70	71
• CSTRFM-JRM	0	1ST % & S KING	1ST % & TTL	7.70	25
•	1	1ST % & JRMI W	1ST % & JRMI E	7.70	27
•	2	1ST % & JRMI E	4020	7.70	35
• CSTRFM-NW	0	NRMY & 6641	NRMY & 6491	7.70	41
•	1	NRMY & PX RD	6909	7.70	77
•	2	6909	6914	7.70	91
•	3	NRMY & MSS RD	6620	7.70	18
•	4	NRMY & HPTN	6344	7.70	15
•	5	NRMY & 6491	NRMY & 5291	7.70	38
• CSTRFM-SE	0	1ST % & TTL	1P & L AT WTR STR TN	7.70	47
•	1	1ST % & TTL	KP & L AT WTR STR TN	7.70	29
• CUSTER A	0	1ST% & FIRE	1ST% & SEW	7.70	71
•	1	1ST % & SEW	BLDG 8130A	7.70	30
•	2	8130A	8130B	7.70	17
•	3	APEN & CNR	8100	7.70	96
•	4	APEN & CNR	4" W	7.70	100
• CUSTER B	0	1ST % & SEWAGE	1ST DIV & DRM.2	7.70	89
•	1	APEN & CNR.5	BLDG 8063-7 FEED	7.70	81
•	2	8063-7 FEED	8063-7	7.70	66
•	3	APEN & CNR .7	7960	7.70	84
• CUSTER C	0	APEN&DRM.2	APEN&BRWN	7.70	81
•	1	APEN&DRM.2	NRMY&DRM.2	7.70	68
•	2	DRM.2A	BLDG 7856	7.70	30
•	3	DRM.2B	BLDG 7858	7.70	44
•	4	APEN & DRM.3	7940 FEED	7.70	77
•	5	7940 FEED	BLDG 7940	7.70	62
•	6	APEN & BRWN	BLDG 7920	7.70	88
• CUSTER D	0	NRMY & DRM.2	NRMY & HLE.B	7.70	81
•	1	NRMY & BRWN	APEN & BRWN	7.70	62
•	2	BRWN E	CIRCLE	7.70	62
•	3	CIRCLE	CIRCLE	7.70	62
•	4	BRWN W	ALL 2"W	7.70	30
•	5	BRWN W	ALL 1"	7.70	20
•	6	NRMY & BRWN.2	BLDG 7866	7.70	44
•	7	NRMY & HLE	BLDG 7865	7.70	38
• CUSTER E	0	APEN & BRWN	APEN & GRV.2	7.70	86
•	1	APEN & HLE.B	BLDG 7900	7.70	75

Figure 5. Fort Riley specify report.

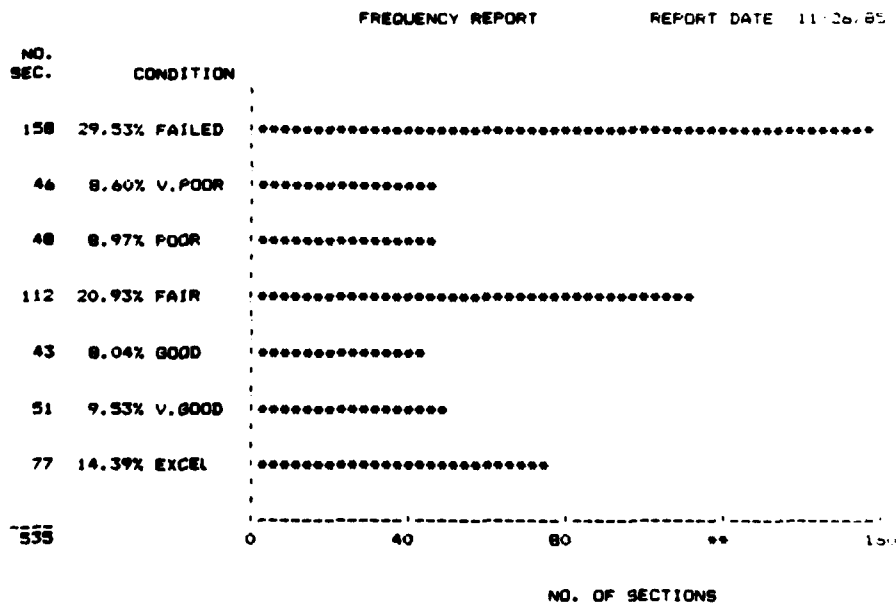


Figure 6. Fort Riley frequency report.

PRIORITY RANKING

REPORT DATE: 11/26/85

ORDER	PIPE - ID	SEC #	CSI	PRESSURE
0	CUSTER L	3	0	48.0000
0	CUSTER M	2	0	48.0000
0	CUSTER M	4	0	48.0000
0	CUSTER M	6	0	48.0000
0	CUSTER N	8	0	48.0000
0	CUSTER N	0	0	48.0000
0	CUSTER N	1	0	48.0000
0	FORSYCOLYR	0	0	20.0000
0	FORSYCOLYR	1	0	20.0000
0	FORSYCOLYR	2	0	20.0000
0	FORSYTH E	7	0	20.0000
0	MAIN ARTLB	2	0	30.0000
0	MAIN ARTLB	3	0	30.0000
0	MAIN CMS C	2	0	30.0000
0	MAIN CMS C	3	0	30.0000
0	MAIN CMS C	4	0	30.0000
0	MAIN CMS C	5	0	30.0000
0	MAIN CMS C	6	0	30.0000
0	MAIN CMS C	9	0	30.0000
0	MAIN ENG B	4	0	30.0000
0	MAIN ENG C	9	0	30.0000
0	O'DONNLL	0	0	10.0000
0	WHITSD B	3	0	12.0000
0	WHITSD B	4	0	12.0000
0	WHITSD B	5	0	12.0000
0	WHITSD C	2	0	12.0000
0	WHITSD C	4	0	12.0000
0	WHITSD C	5	0	12.0000
0	WHITSD C	6	0	12.0000
0	WHITSD C	7	0	12.0000
1	FORSYTH A	0	1	20.0000
1	FUNSTON E	3	1	26.0000
1	FUNSTON F	2	1	26.0000
1	FUNSTON F	4	1	26.0000
1	WHITSD D	4	1	12.0000
2	CUSTER L	2	2	48.0000
2	CUSTER L	4	2	48.0000
2	CUSTER M	3	2	48.0000
2	CUSTER M	7	2	48.0000
2	FORSYTH G	1	2	20.0000
2	FORSYTH H	8	2	20.0000
2	WHITSD C	1	2	29.0000
3	FUNSTON C	10	3	26.0000
3	FUNSTON C	2	3	26.0000
3	FUNSTON C	4	3	26.0000
3	FUNSTON C	8	3	26.0000
3	FUNSTON D	11	3	26.0000
3	FUNSTON E	7	3	26.0000
3	FUNSTON E	8	3	26.0000
3	FUNSTON F	5	3	26.0000
3	WHITSD A	4	3	12.0000
3	WHITSD C	3	3	12.0000
4	FUNSTON B	4	4	26.0000
4	FUNSTON B	5	4	26.0000
5	CUSTER L	1	5	48.0000
5	FUNSTON F	1	5	26.0000

Figure 7. Fort Riley rank report.

CSI PREDICTION REPORT
REPORT DATE: 11/26/85

PIPE ID : CPSTA9 SECTION NUMBER: 1
SOIL RESISTIVITY : 1475.00 SOIL PH : 8.45
COATING MATERIAL : YES WALL THICKNESS: .3650
YEAR INSTALLED : 1977
PREDICTED FIRST LEAK: 2013
ACTUAL FIRST LEAK : DATA NOT AVAILABLE

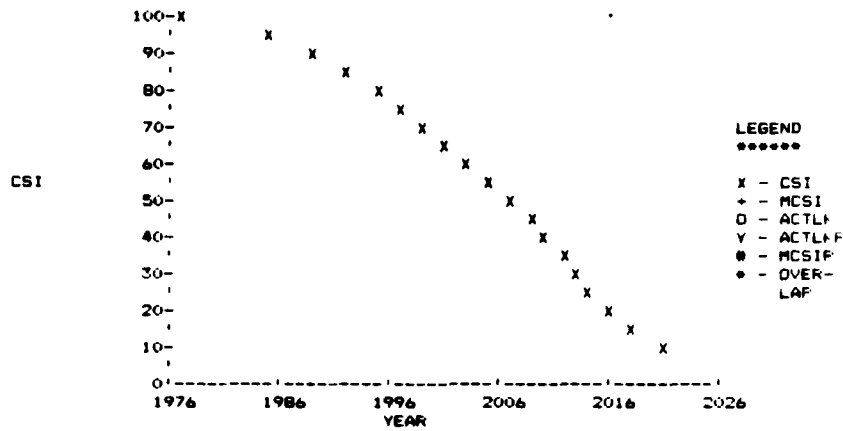


Figure 8. CSI prediction report, CP test station 9.

GRAPH TABLE			
CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1977	100	0	0
1978	100	0	0
1979	100	0	0
1980	99	0	0
1981	98	0	0
1982	98	0	0
1983	97	0	0
1984	96	0	0
1985	95	0	0
1986	94	0	0
1987	92	0	0
1988	91	0	0
1989	89	0	0
1990	88	0	0
1991	86	0	0
1992	85	0	0
1993	83	0	0
1994	81	0	0
1995	79	0	0
1996	77	0	0
1997	75	0	0
1998	72	0	0
1999	70	0	0
2000	68	0	0
2001	65	0	0
2002	63	0	0
2003	60	0	0
2004	57	0	0
2005	55	0	0
2006	52	0	0
2007	49	0	0
2008	46	0	0
2009	43	0	0
2010	40	0	0
2011	37	0	0
2012	33	0	0
2013	30	1	1
2014	25	2	3
2015	23	2	5
2016	20	5	10
2017	17	8	18
2018	15	11	29
2019	13	17	46
2020	11	25	71
2021	9	38	109

Figure 9. Graph table, CP test station 9.

CSI PREDICTION REPORT
REPORT DATE: 11/26/85

PIPE ID : NIMITZ SECTION NUMBER: 1
SOIL RESISTIVITY : 1010.00 SOIL PH : 6.81
COATING MATERIAL : YES WALL THICKNESS: .2650
YEAR INSTALLED : 1977
PREDICTED FIRST LEAK: 2003
ACTUAL FIRST LEAK : DATA NOT AVAILABLE

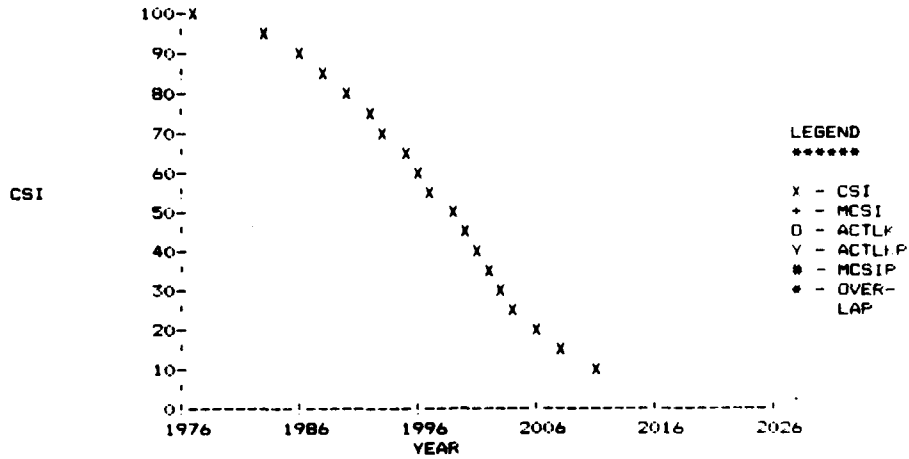


Figure 10. CSI prediction report, Nimitz Hill rectifier.

GRAPH TABLE			
CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1977	100	0	0
1978	100	0	0
1979	99	0	0
1980	98	0	0
1981	97	0	0
1982	96	0	0
1983	94	0	0
1984	93	0	0
1985	91	0	0
1986	89	0	0
1987	87	0	0
1988	84	0	0
1989	82	0	0
1990	79	0	0
1991	76	0	0
1992	73	0	0
1993	70	0	0
1994	66	0	0
1995	63	0	0
1996	59	0	0
1997	55	0	0
1998	52	0	0
1999	48	0	0
2000	43	0	0
2001	39	0	0
2002	35	0	0
2003	30	1	1
2004	25	2	2
2005	23	2	5
2006	20	5	10
2007	17	8	18
2008	15	11	29
2009	13	17	46
2010	11	25	71
2011	9	38	109

Figure 11. Graph table, Nimitz Hill rectifier.

CSI PREDICTION REPORT
REPORT DATE: 11/26/85

PIPE ID : NABPUMP SECTION NUMBER: 1
SOIL RESISTIVITY : 1510.00 SOIL PH : 8.61
COATING MATERIAL : YES WALL THICKNESS: .3650
YEAR INSTALLED : 1977
PREDICTED FIRST LEAK: 2014
ACTUAL FIRST LEAK : DATA NOT AVAILABLE

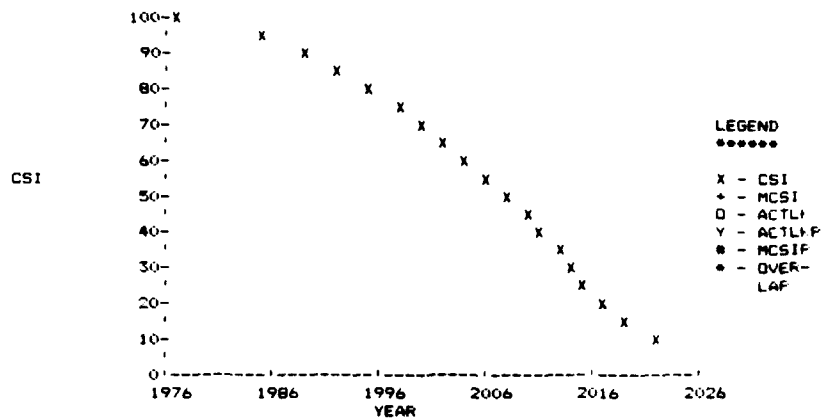


Figure 12. CSI prediction report, NAS pumphouse.

GRAPH TABLE			
CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1977	100	0	0
1978	100	0	0
1979	100	0	0
1980	99	0	0
1981	98	0	0
1982	98	0	0
1983	97	0	0
1984	96	0	0
1985	95	0	0
1986	94	0	0
1987	93	0	0
1988	91	0	0
1989	90	0	0
1990	88	0	0
1991	87	0	0
1992	85	0	0
1993	84	0	0
1994	82	0	0
1995	80	0	0
1996	78	0	0
1997	76	0	0
1998	74	0	0
1999	71	0	0
2000	69	0	0
2001	67	0	0
2002	64	0	0
2003	62	0	0
2004	59	0	0
2005	57	0	0
2006	54	0	0
2007	51	0	0
2008	48	0	0
2009	46	0	0
2010	43	0	0
2011	39	0	0
2012	36	0	0
2013	33	0	0
2014	30	1	1
2015	25	2	3
2016	23	2	5
2017	20	5	10
2018	17	8	18
2019	15	11	29
2020	13	17	46
2021	11	25	71
2022	9	38	109

Figure 13. Graph table, NAS pumphouse.

CSI PREDICTION REPORT
REPORT DATE: 11/26/85

PIPE ID : BOOSTER SECTION NUMBER: 1
SOIL RESISTIVITY : 1160.00 SOIL PH : 7.88
COATING MATERIAL : YES WALL THICKNESS: .3650
YEAR INSTALLED : 1952
PREDICTED FIRST LEAK: 1986
ACTUAL FIRST LEAK : DATA NOT AVAILABLE

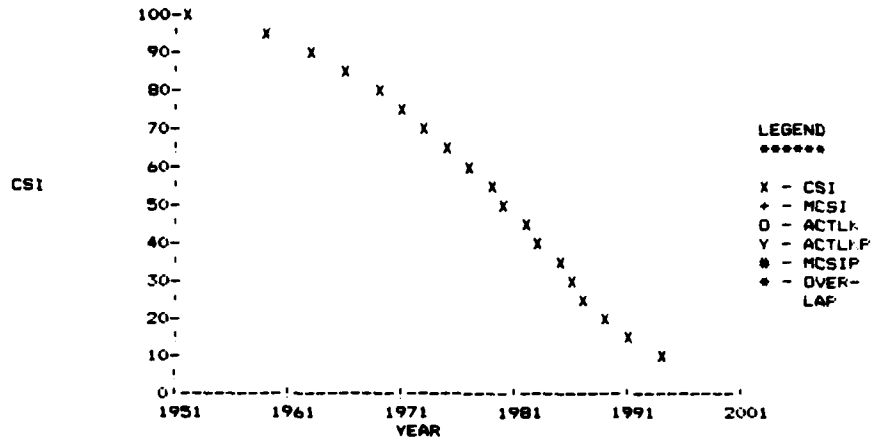


Figure 14. CSI prediction report, booster pumphouse.

GRAPH TABLE			
CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1952	100	0	0
1953	100	0	0
1954	99	0	0
1955	99	0	0
1956	98	0	0
1957	97	0	0
1958	96	0	0
1959	95	0	0
1960	94	0	0
1961	93	0	0
1962	92	0	0
1963	90	0	0
1964	88	0	0
1965	87	0	0
1966	85	0	0
1967	83	0	0
1968	81	0	0
1969	79	0	0
1970	77	0	0
1971	74	0	0
1972	72	0	0
1973	69	0	0
1974	67	0	0
1975	64	0	0
1976	62	0	0
1977	59	0	0
1978	56	0	0
1979	53	0	0
1980	50	0	0
1981	47	0	0
1982	44	0	0
1983	40	0	0
1984	37	0	0
1985	34	0	0
1986	30	1	1
1987	25	2	3
1988	23	2	5
1989	20	5	10
1990	17	8	18
1991	15	11	29
1992	13	17	46
1993	11	25	71
1994	9	38	109

Figure 15. Graph table, booster pumphouse.

CSI PREDICTION REPORT
REPORT DATE: 11/27/85

PIPE ID : CAUSREC SECTION NUMBER: 1
SOIL RESISTIVITY : 6750.00 SOIL PH : 8.87
COATING MATERIAL : YES WALL THICKNESS: .3650
YEAR INSTALLED : 1952
PREDICTED FIRST LEAK: 2038
ACTUAL FIRST LEAK :

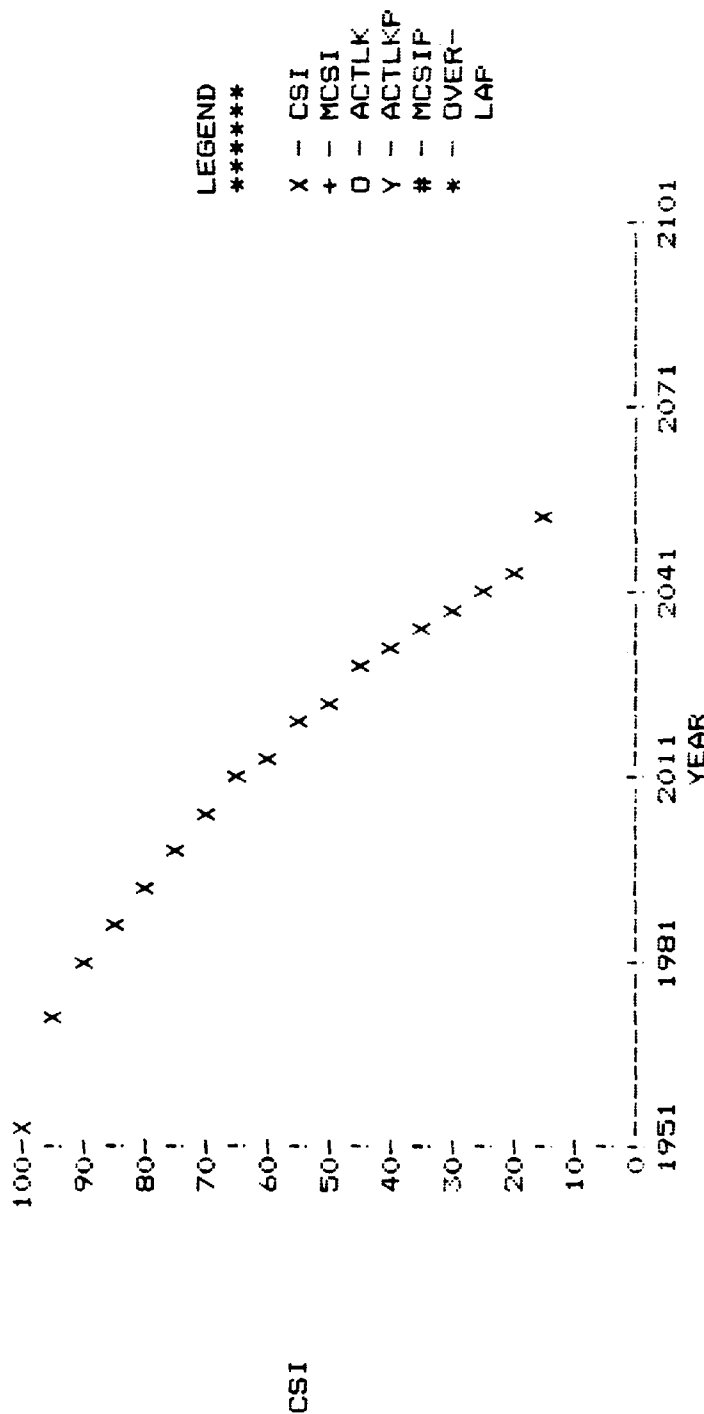


Figure 16. CSI prediction report, causeway rectifier.

GRAPH TABLE

CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1952	100	0	0
1955	100	0	0
1958	99	0	0
1961	99	0	0
1964	98	0	0
1967	97	0	0
1970	95	0	0
1973	94	0	0
1976	92	0	0
1979	91	0	0
1982	89	0	0
1985	87	0	0
1988	84	0	0
1991	82	0	0
1994	80	0	0
1997	77	0	0
2000	74	0	0
2003	72	0	0
2006	69	0	0
2009	66	0	0
2012	62	0	0
2015	59	0	0
2018	56	0	0
2021	52	0	0
2022	51	0	0
2023	50	0	0
2024	48	0	0
2025	47	0	0
2026	46	0	0
2027	45	0	0
2028	43	0	0
2029	42	0	0
2030	41	0	0
2031	40	0	0
2032	38	0	0
2033	37	0	0
2034	36	0	0
2035	34	0	0
2036	33	0	0
2037	31	0	0
2038	30	1	1
2039	26	1	2
2040	24	1	3
2041	23	2	5
2042	22	1	6
2043	21	2	8
2044	20	1	9
2045	19	2	11
2046	18	2	13
2047	18	3	16
2048	17	2	18
2049	16	3	21
2050	16	3	24
2051	15	3	27
2052	15	3	30
2053	14	3	33
2054	14	4	37
2055	13	4	41
2056	13	4	45
2057	13	5	50
2058	12	5	55

Figure 17. Graph table, causeway rectifier.

CSI PREDICTION REPORT
REPORT DATE: 11/26/85

PIPE ID : U5 SECTION NUMBER: 1
SOIL RESISTIVITY : 775.00 SOIL PH : 8.06
COATING MATERIAL : YES WALL THICKNESS: .3130
YEAR INSTALLED : 1952
PREDICTED FIRST LEAK: 1977
ACTUAL FIRST LEAK : DATA NOT AVAILABLE

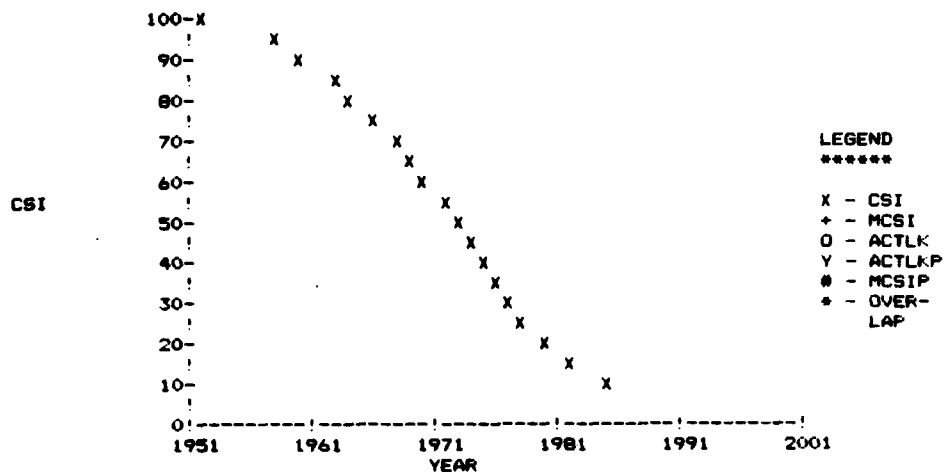


Figure 18. CSI prediction report, tank U-5.

GRAPH TABLE			
CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1952	100	0	0
1953	100	0	0
1954	99	0	0
1955	98	0	0
1956	97	0	0
1957	96	0	0
1958	94	0	0
1959	92	0	0
1960	90	0	0
1961	88	0	0
1962	86	0	0
1963	83	0	0
1964	80	0	0
1965	77	0	0
1966	74	0	0
1967	71	0	0
1968	68	0	0
1969	64	0	0
1970	60	0	0
1971	56	0	0
1972	52	0	0
1973	48	0	0
1974	44	0	0
1975	39	0	0
1976	35	0	0
1977	30	1	1
1978	25	2	3
1979	23	2	5
1980	20	5	10
1981	17	8	18
1982	15	11	29
1983	13	17	46
1984	11	25	71
1985	9	38	109

Figure 19. Graph table, tank U-5.

CSI PREDICTION REPORT
REPORT DATE: 11/26/85

PIPE ID : U20 SECTION NUMBER: 1
SOIL RESISTIVITY : 730.00 SOIL PH : 7.48
COATING MATERIAL : YES WALL THICKNESS: .3130
YEAR INSTALLED : 1959
PREDICTED FIRST LEAK: 1983
ACTUAL FIRST LEAK : DATA NOT AVAILABLE

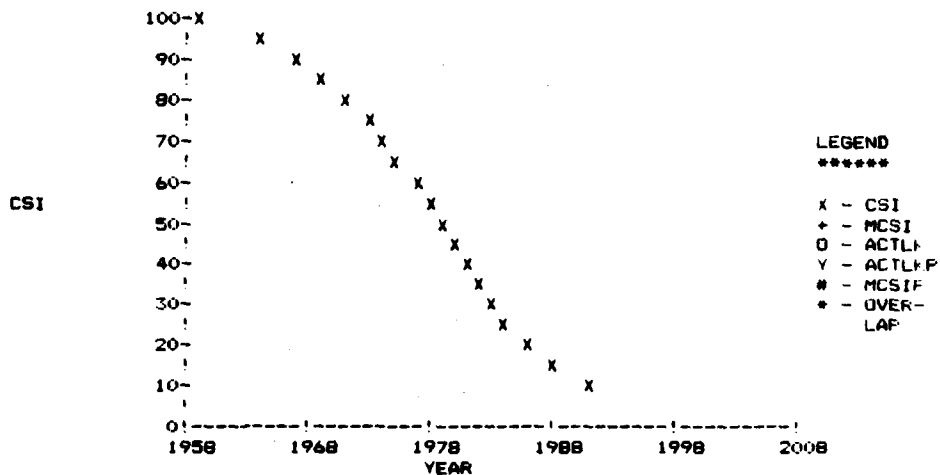


Figure 20. CSI prediction report, tank U-20.

GRAPH TABLE			
CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1959	100	0	0
1960	100	0	0
1961	99	0	0
1962	98	0	0
1963	97	0	0
1964	95	0	0
1965	94	0	0
1966	92	0	0
1967	89	0	0
1968	87	0	0
1969	85	0	0
1970	82	0	0
1971	79	0	0
1972	76	0	0
1973	72	0	0
1974	69	0	0
1975	65	0	0
1976	61	0	0
1977	57	0	0
1978	53	0	0
1979	49	0	0
1980	44	0	0
1981	40	0	0
1982	35	0	0
1983	30	1	1
1984	25	2	3
1985	23	2	5
1986	20	5	10
1987	17	8	18
1988	15	11	29
1989	13	17	46
1990	11	25	71
1991	9	38	109

Figure 21. Graph table, tank U-20.

CSI PREDICTION REPORT
REPORT DATE: 11/26/85

PIPE ID : U28 SECTION NUMBER: 1
SOIL RESISTIVITY : 1110.00 SOIL PH : 8.70
COATING MATERIAL : YES WALL THICKNESS: .3130
YEAR INSTALLED : 1963
PREDICTED FIRST LEAK: 1992
ACTUAL FIRST LEAK : DATA NOT AVAILABLE

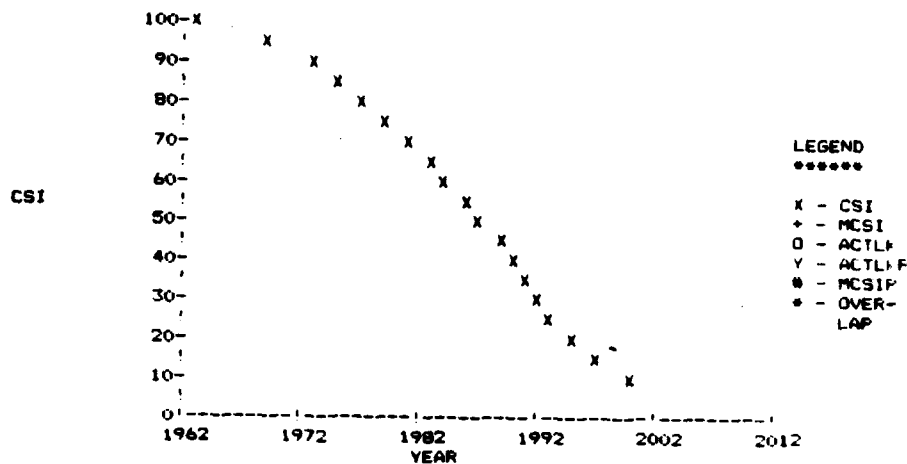


Figure 22. CSI prediction report, tank U-28.

GRAPH TABLE			
CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1963	100	0	0
1964	100	0	0
1965	99	0	0
1966	99	0	0
1967	98	0	0
1968	97	0	0
1969	95	0	0
1970	94	0	0
1971	92	0	0
1972	91	0	0
1973	89	0	0
1974	87	0	0
1975	85	0	0
1976	82	0	0
1977	80	0	0
1978	78	0	0
1979	75	0	0
1980	72	0	0
1981	69	0	0
1982	66	0	0
1983	63	0	0
1984	60	0	0
1985	57	0	0
1986	53	0	0
1987	49	0	0
1988	46	0	0
1989	42	0	0
1990	38	0	0
1991	34	0	0
1992	30	1	1
1993	25	2	3
1994	23	2	5
1995	20	5	10
1996	17	8	18
1997	15	11	29
1998	13	17	46
1999	11	25	71
2000	9	38	109

Figure 23. Graph table, tank U-28.

CSI PREDICTION REPORT
REPORT DATE: 11/26/85

PIPE ID : U35 SECTION NUMBER: 1
SOIL RESISTIVITY : 710.00 SOIL PH : 7.70
COATING MATERIAL : YES WALL THICKNESS: .3750
YEAR INSTALLED : 1970
PREDICTED FIRST LEAK: 1999
ACTUAL FIRST LEAK : DATA NOT AVAILABLE

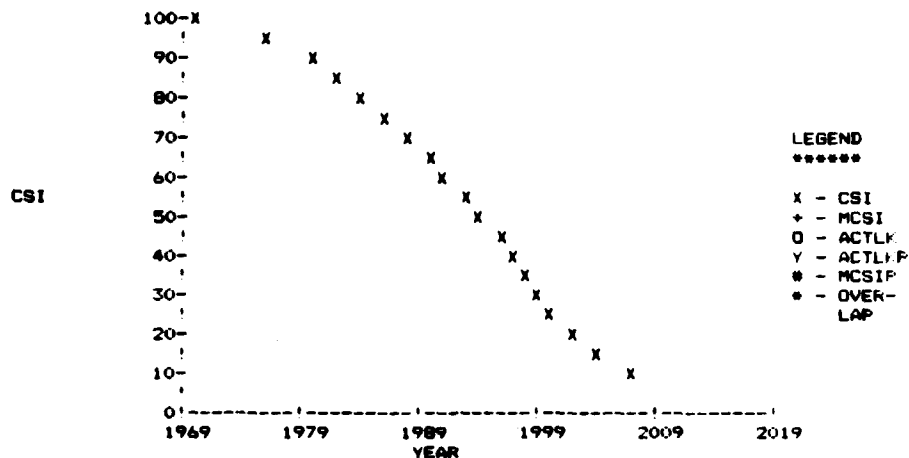


Figure 24. CSI prediction report, tank U-35.

CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1970	100	0	0
1971	100	0	0
1972	99	0	0
1973	99	0	0
1974	98	0	0
1975	97	0	0
1976	95	0	0
1977	94	0	0
1978	92	0	0
1979	91	0	0
1980	89	0	0
1981	87	0	0
1982	85	0	0
1983	82	0	0
1984	80	0	0
1985	78	0	0
1986	75	0	0
1987	72	0	0
1988	69	0	0
1989	66	0	0
1990	63	0	0
1991	60	0	0
1992	57	0	0
1993	53	0	0
1994	49	0	0
1995	46	0	0
1996	42	0	0
1997	38	0	0
1998	34	0	0
1999	30	1	1
2000	25	2	3
2001	23	2	5
2002	20	5	10
2003	17	8	18
2004	15	11	29
2005	13	17	46
2006	11	25	71
2007	9	38	109

Figure 25. Graph table, tank U-35.

CSI PREDICTION REPORT
REPORT DATE: 11/26/85

PIPE ID : FTCLRL SECTION NUMBER: 1
SOIL RESISTIVITY : 5000.00 SOIL PH : 6.00
COATING MATERIAL : COALTAR WALL THICKNESS: .2500
YEAR INSTALLED : 1965
PREDICTED FIRST LEAK: 1982
ACTUAL FIRST LEAK : DATA NOT AVAILABLE

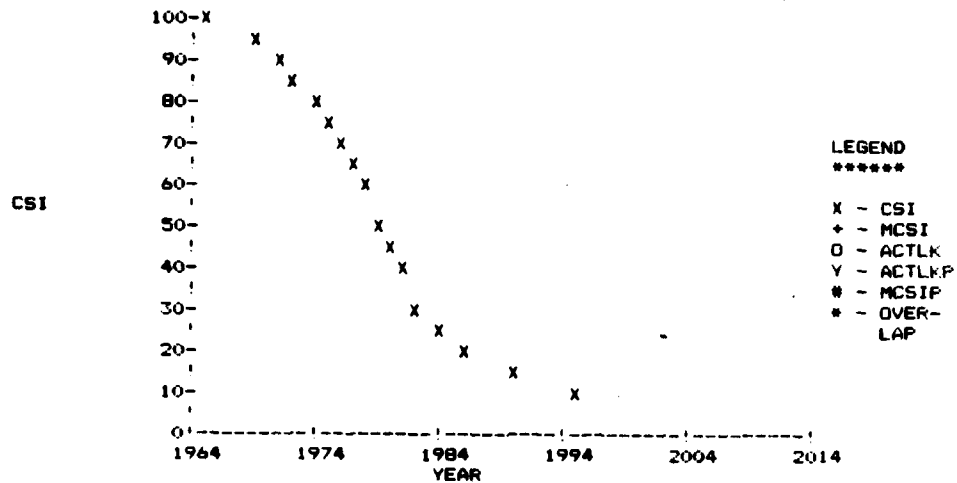


Figure 26. CSI prediction report, economic analysis example.

GRAPH TABLE			
CSI YEAR	CALCULATED CSI	NUMBER OF LEAKS	TOTAL # LEAKS
1965	100	0	0
1966	99	0	0
1967	98	0	0
1968	96	0	0
1969	94	0	0
1970	92	0	0
1971	88	0	0
1972	85	0	0
1973	81	0	0
1974	77	0	0
1975	72	0	0
1976	67	0	0
1977	62	0	0
1978	56	0	0
1979	50	0	0
1980	44	0	0
1981	37	0	0
1982	30	1	1
1983	26	1	2
1984	23	2	4
1985	22	2	6
1986	20	3	9
1987	19	3	12
1988	17	4	16
1989	16	5	21
1990	15	6	27
1991	14	7	34
1992	13	9	43
1993	12	11	54
1994	11	13	67
1995	10	15	82

Figure 27. Graph table, economic analysis example.

COMPARISON OF M&R ALTERNATIVES
FT CERL
SECTION 1

ANALYSIS PERIOD - 30 YEARS

INFLATION RATE 6.00 PERCENT
INTEREST RATE .00 PERCENT

ALTERNATIVE	DESCRIPTION	NET PRESENT COST
B	REPLACE W/ PLASTIC	2080000.
A	REPLACE W/ STEEL	4633293.
C	CONTINUED REPAIR	60156288.

DETAILED COMPARISON OF M&R ALTERNATIVES

YEAR	* ALT A *	* ALT B *	* ALT C *
	PRES COST	PRES COST	PRES COST
0 (FY85)	210000	210000	2080000
1 (FY86)	5300	5617	0
2 (FY87)	5618	6312	0
3 (FY88)	5955	7092	0
4 (FY89)	6312	7968	0
5 (FY90)	6691	8954	0
6 (FY91)	7092	10060	0
7 (FY92)	7518	11304	0
8 (FY93)	7969	12701	0
9 (FY94)	8447	14271	0
10 (FY95)	8954	16035	0
11 (FY96)	9491	18016	0
12 (FY97)	10060	20242	0
13 (FY98)	10664	22745	0
14 (FY99)	226090	511167	0
15 (FY00)	11982	28715	0
16 (FY01)	12701	32265	0
17 (FY02)	13463	36252	0
18 (FY03)	14271	40734	0
19 (FY04)	15128	45771	0
20 (FY05)	16035	51426	0
21 (FY06)	16997	57782	0
22 (FY07)	18017	64924	0
23 (FY08)	19098	72949	0
24 (FY09)	20244	81966	0
25 (FY10)	21459	92099	0
26 (FY11)	22747	103484	0
27 (FY12)	24112	116276	0
28 (FY13)	25558	130644	0
29 (FY14)	568930	3082683	0
30 (FY15)	0	0	0
TOTAL	1356903	4920467	2080000
SALVAGE	50000	287174	0
PRES WORTH	4633293		2080000

Figure 28. ECON report.

DATE:= 85/11/26.

PROJECTED COST ANALYSIS

(DETAIL)

SECTION ID:=SAMPLE

ALTERNATIVE:= REPLACE W/ STEEL

SECTION AREA(S.Y.):= 250000.0

LIFE OF ALTERNATIVE:= 30 INTEREST RATE:= .0 INFLATION RATE:= 6.0

M&R ACTIVITY	YEAR	COST(\$)	PRESENT VALUE(\$)
INSTALL STEEL PIPE	1985	2000000.00	2000000.00
C.P. INSTALLATION	1985	100000.00	100000.00
TOTAL:=		2100000.00	2100000.00
C.P. MONITORING	1986	5000.00	5300.00
C.P. MONITORING	1987	5000.00	5618.00
C.P. MONITORING	1988	5000.00	5955.08
C.P. MONITORING	1989	5000.00	6312.38
C.P. MONITORING	1990	5000.00	6691.13
C.P. MONITORING	1991	5000.00	7092.60
C.P. MONITORING	1992	5000.00	7518.15
C.P. MONITORING	1993	5000.00	7969.24
C.P. MONITORING	1994	5000.00	8447.39
C.P. MONITORING	1995	5000.00	8954.24
C.P. MONITORING	1996	5000.00	9491.49
C.P. MONITORING	1997	5000.00	10060.98
C.P. MONITORING	1998	5000.00	10664.64
C.P. MONITORING	1999	5000.00	11304.52
C.P. MONITORING	2000	5000.00	11982.79
C.P. MONITORING	2001	5000.00	12701.76
C.P. MONITORING	2002	5000.00	13463.86
C.P. MONITORING	2003	5000.00	14271.70
C.P. MONITORING	2004	5000.00	15128.00
C.P. MONITORING	2005	5000.00	16035.68
C.P. MONITORING	2006	5000.00	16997.82
C.P. MONITORING	2007	5000.00	18017.69
C.P. MONITORING	2008	5000.00	19098.75
C.P. MONITORING	2009	5000.00	20244.67
C.P. MONITORING	2010	5000.00	21459.35
C.P. MONITORING	2011	5000.00	22746.91
C.P. MONITORING	2012	5000.00	24111.73
C.P. MONITORING	2013	5000.00	25558.43
C.P. MONITORING	2014	5000.00	27091.94
RE-ANODING	2014	100000.00	541838.79
TOTAL:=		105000.00	568930.73

INITIAL COST(\$):= 2100000.00

PRESENT VALUE(\$):= 3032129.72

EQUIVALENT UNIFORM ANNUAL COST(\$):= 3032129.72

EUAC PER SQ. YD. (\$):= 12.13

----- END OF REPORT -----

Figure 29. ECON1 report (replace with steel).

DATE:= 85/11/26.

PROJECTED COST ANALYSIS

(DETAIL)

SECTION ID:=SAMPLE

ALTERNATIVE:= REPLACE W/ PLASTIC

SECTION AREA(S.Y.):= 250000.0

LIFE OF ALTERNATIVE:= 30 INTEREST RATE:= .0

INFLATION RATE:= 6.0

M&R ACTIVITY	YEAR	COST(\$)	PRESENT VALUE(\$)
INSTALL PLASTIC PIPE	1985	2080000.00	2080000.00

INITIAL COST(\$):= 2080000.00

PRESENT VALUE(\$):= 2080000.00

EQUIVALENT UNIFORM ANNUAL COST(\$):= 2080000.00

EUAC PER SQ. YD. (\$):= 8.32

----- END OF REPORT -----

Figure 30. ECON1 report (replace with plastic).

DATE:= 85/11/26.

PROJECTED COST ANALYSIS

(DETAIL)

SECTION ID:=SAMPLE

ALTERNATIVE:= CONTINUED REPAIR

SECTION AREA(S.Y.):= 250000.0

LIFE OF ALTERNATIVE:= 30 INTEREST RATE:= .0

INFLATION RATE:= 6.0

M&R ACTIVITY	YEAR	COST(\$)	PRESENT VALUE(\$)
REPAIR	1985	6000.00	6000.00
REPAIR	1986	9000.00	9540.00
REPAIR	1987	90000.00	101124.00
REPAIR	1988	12000.00	14292.19
REPAIR	1989	15000.00	18937.15
REPAIR	1990	18000.00	24088.06
REPAIR	1991	21000.00	29788.90
REPAIR	1992	27000.00	40598.02
REPAIR	1993	35000.00	55784.68
REPAIR	1994	39000.00	65889.68
REPAIR	1995	45000.00	80588.15
REPAIR	1996	54000.00	102508.12
REPAIR	1997	63000.00	126768.38
REPAIR	1998	75000.00	159969.62
REPAIR	1999	90000.00	203481.36
REPAIR	2000	105000.00	251638.61
REPAIR	2001	117000.00	297221.15
REPAIR	2002	141000.00	379680.96
REPAIR	2003	159000.00	453839.93
REPAIR	2004	180000.00	544607.91
REPAIR	2005	231000.00	740848.29
REPAIR	2006	240000.00	815895.26
REPAIR	2007	279000.00	1005386.94
REPAIR	2008	300000.00	1145924.90
REPAIR	2009	300000.00	1214680.39
REPAIR	2010	300000.00	1287561.22
REPAIR	2011	300000.00	1364814.89
REPAIR	2012	300000.00	1446703.78
REPAIR	2013	300000.00	1533506.01
REPAIR	2014	300000.00	1625516.37

INITIAL COST(\$):= 6000.00

PRESENT VALUE(\$):= 15147184.92

EQUIVALENT UNIFORM ANNUAL COST(\$):= 15147184.92

EUAC PER SQ. YD. (\$):= 60.59

----- END OF REPORT -----

Figure 31. ECON1 report (continued repair).

INPUT DATA

LOC	ALT-NO	EUAC/SY	ANNUAL-BENEFIT	INITIAL-COST
1	1	.43	50.00	3258219.00
1	2	.28	50.00	2080000.00
1	3	2.01	50.00	1505264.00

PROJECTS OF SAME TOTAL COST BUT LESS BENEFIT DELETED

LOC	ALT-NO	EUAC/SY	ANNUAL-BENEFIT	INITIAL-COST
NO PROJECT IS DELETED				

AN INCREMENTAL BENEFIT-COST ANALYSIS

LOC	ALT-NO	INC COST	INC BENEFIT	EUAC/SY INC BC-RATIO	ANNUAL-BENEFIT AVG BC-RATIO
1	2	.28	50.00	.28	50.00
			50.00	178.57	.00

PROJECTS DELETED

LOC	ALT-NO	INITIAL-COST	EUAC/SY	ANNUAL BENEFIT	INC COST	INC BENEFIT	INC BC-RATIO
1	1	3258219.00	.43	50.00	.15	.00	.00
1	3	1505264.00	2.01	50.00	1.73	.00	.00

SELECTION OF PROJECTS

ALT-NO	INITIAL-COST	EUAC/SY	ANNUAL BENEFIT	INC COST	BC-RATIO	CUM COST
2	2080000.00	.28	50.00	.28	178.57	2080000.00

THE FOLLOWING BEST SOLUTION IS OBTAINED WHEN THE ONE TO ONE AND
PAIRWISE PROJECT REPLACEMENT ARE NOT POSSIBLE.

THE PREFERRED SOLUTION OF PROJECTS FOR A FIXED BUDGET OF 4000000.00 IS :

ALT-NO	EUAC/SY	ANNUAL-BENEFIT	INITIAL-COST
2	.28	50.00	2080000.00

THE TOTAL INITIAL COST IS	2080000.00
THE TOTAL ANNUAL BENEFIT IS	50.00
THE EXCESS BUDGET IS	1920000.00

Figure 32. BUDOPT report.

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