RAW, DOMESTIC, AND INDUSTRIAL WATER PIPELINE LEAK-DETECTION METHOD STUDY

Task 20
of the
Zero-Offsite Water-Discharge Study

Prepared For:

EG&G ROCKY FLATS, INC.
Facilities Engineering
Plant Civil-Structural Engineering
P.O. Box 464
Golden, CO 80402-0464

BOA Contract BA72429PB
Purchase Order No. BA76637GS

Prepared By:

ADVANCED SCIENCES, INC.
405 Urban Street, Suite 401
Lakewood, CO 80228

Draft: February 28, 1991
Draft Final: March 21, 1991
Final: March 26, 1991

ASI PROJECT No. 208.0120

DISCLAIMER

This report was prepared as a result of work sponsored by a contractor to an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any contractor or subcontractor, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness or any information, apparatus, product, or process disclosed, or represents that its use would not infringe upon privately owned rights. Reference herein to any specific commercial product, process, or service, any trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

TABLE OF CONTENTS

LIST OF TABLES

TABLE OF CONTENTS
(continued)

LIST OF FIGURES

APPENDIX

RAW, DOMESTIC, AND INDUSTRIAL WATER PIPELINE LEAK-DETECTION METHOD STUDY

Rocky Flats Plant

EXECUTIVE SUMMARY

The Raw, Domestic, and Industrial Water Pipeline Leak-Detection Method Study is one of several studies being conducted for and in the development of a Zero-Offsite Water-Discharge Plan for the Rocky Flats Plant (RFP) in response to Item C.7 of the Agreement in Principle between the Colorado Department of Health (CDH) and the U.S. Department of Energy (DOE)(DOE and State of Colorado, 1989). Item C.7 describes the Source Reduction and Zero Discharges Study: Conduct a study of all available methods to eliminate Rocky Flats discharges to the environment including surface waters and ground water. This review should include a source reduction review" (DOE, 1989).

The amount of water leaking from on-site pipelines may ultimately discharge to the sanitary or storm sewers by means of infiltration and percolation processes. The additional water which may be added to these sewers as a result of leakage of other pipeline systems requires treatment at either the sanitary treatment plant or the on-site terminal ponds prior to off-site release. A reduction of the effluent water volumes requiring treatment may be affected by reducing possible leakage from other on-site pipeline systems. Leakage may also impact local groundwater levels and increase the potential for off-site migration of contaminant plumes, soil instabilities, and increased amounts of groundwater which may require remediation.

Other studies subordinate to the Zero-Offsite Water-Discharge Study that are related to this study include: Task 1 - Sanitary Sewer Infiltration/Inflow and Exfiltration Study, Task 2 - Storm Sewer Infiltration/Inflow and Exfiltration Study, and Tasks 11 and 13 - Treated Sewage/Process Wastewater Recycle Study. Conclusions from these studies reflect the necessity for the quantification of water potentially lost through leaks in the pipeline systems at the RFP.

Alternatives presented in the Treated Sewage/Process Wastewater Recycle Study - Tasks 11 and 13, included a scenario which assessed the use of the existing raw water distribution system as the domestic water distribution system. More importantly, this scenario also proposed that the existing domestic water distribution system be converted to the raw water distribution system. Should leakage occur in the proposed raw water distribution system, sanitary treatment plant (STP) effluent could be released to the environment. However, the preferred alternative from Tasks 11 and 13 was to maintain the existing domestic water and industrial water (plant raw water) pipelines as they currently exist at the RFP. Therefore, leak testing does not appear to be justified at this time and this study addresses only the leak testing methods which could be used, if necessary, to perform leak testing on all or parts of the RFP water pipelines.

Specifically, this report reviews methods related to the testing of raw, domestic, and industrial water pipelines for leak potential. This study assesses possible methods which can be employed at the RFP to detect leaks in selected pipelines and assess potential volume losses due to any leaks. For the purpose of this study, raw water is untreated water, purchased from the Denver Water Board, that is transported from Ralston and/or Gross Reservoirs. Domestic water is raw water that has been treated through the water treatment facility (Building 124) at the RFP. Industrial water is untreated raw water that is used in RFP plant processes. Industrial water is also known by the term Plant Raw Water.

Pipelines at the RFP can be identified by three water supply (influent) systems and three water discharge (effluent) systems. Influent systems are raw water pipelines, domestic water pipelines, and industrial water (plant raw water) pipelines. Effluent systems are the sanitary sewers (addressed in Task 1), storm sewers (addressed in Task 2), and process wastewater (addressed in Tasks 11 and 13). A preferred leak-detection method in the influent systems has been addressed in this task. The potential water lost to leaks in the influent water pipelines will influence the evaluation of the issues addressed in Tasks 1, 2, 11, and 13. Specific relationships and influences among these tasks will be addressed in the Consolidation Plan which will be written as a final step in preparing a Zero-Offsite Water-Discharge Plan for the RFP.

The estimated total length of all influent pipes that may be leak-tested as a result of this study is approximately 130,000 lineal feet. Of this total, approximately 30,000 lineal feet comprise the raw water pipeline, 68,000 lineal feet the domestic water pipeline, and 28,000 lineal feet the industrial water (plant raw water) pipeline. Influent pipelines at the RFP are of differing diameters and material composition. Three leak-detection methods were assessed: injected nitrous oxide, water-balance calculations, and leak-noise correlator. These three methods are compared in the table below.

LEAK-DETECTION METHOD COMPARISON SUMMARY

CRITERIA	INJECTED NITROUS OXIDE	WATER-BALANCE CALCULATIONS	LEAK-NOISE CORRELATOR
NON-INVASIVE?	POSSIBLY, may need to disturb surface	POSSIBLY, may need to install meters	YES
THREAT TO HUMAN HEALTH AND THE ENVIRONMENT?	POSSIBLY, may need to disturb IHSSs	NO	NO
POSSIBLE DISTURBANCE OF IHSSs?	YES	NO	NO
DETECTS LEAK LOCATION?	NO, may surface some distance from leak	NO, locates leak between meters	YES, locates leak to one lineal foot
DETECTS LEAK MAGNITUDE?	NO	YES, if accurately metered	YES, can estimate to less than 5 gpm for each leak
COST	$200/mile	$1,200/mile	$300/mile

As a result of this study, the recommended influent pipeline leak-test method is use of a leak-noise correlator. The computer-enhanced equipment associated with this method uses acoustic amplification to identify discrepancies in computed and anticipated travel times of a signal from a transmitter to a receiver. The equipment is state-of-the-art and generates data which can be evaluated to identify leak locations to the nearest foot and estimate the quantity of water lost from leaks. This method is completely non-invasive and would be of minimal imposition to RFP operation. An evaluation matrix reflecting consideration of eight specific considerations and weighting factors supports the selection of this alternative. The matrix is presented in section 4.0 of this report.

RAW, DOMESTIC, AND INDUSTRIAL WATER
PIPELINE LEAK-DETECTION METHOD STUDY

Rocky Flats Plant Site

1.0 INTRODUCTION

The Raw, Domestic, and Industrial Water Pipeline Leak-Detection Method Study is one of several studies being conducted for, and in the development of, a Zero-Offsite Water-Discharge Plan for Rocky Flats Plant (RFP) in response to Item C.7 of the Agreement in Principle (AIP) between the Colorado Department of Health (CDH) and the U.S. Department of Energy (DOE) (DOE and State of Colorado, 1989). The CDH/DOE Agreement Item C.7 states "Source Reduction and Zero Discharge Study: Conduct a study of all available methods to eliminate Rocky Flats discharges to the environment including surface waters and ground water. This review should include a source reduction review" (DOE, 1989).

This study provides an evaluation of pipeline leak-testing methods applicable to the RFP influent water pipeline systems. The purpose of the pipeline leak study is to assess the technology available to detect leaks in the raw, domestic, and industrial water pipelines. It was anticipated that a quantitative assessment of the amount of water being lost from these pipelines would be included in this study; however, due to schedule constraints, the quantitative assessment could not be accommodated. Additionally, the conclusions of the Treated Sewage/Process Wastewater Recycle Study (Tasks 11 and 13 of the Zero-Offsite Water-Discharge Study (ASI, 1991)) suggested a water management alternative for which quantifying water lost through leaks is not a critical issue.

The amount of water leaking from on-site influent pipelines may ultimately discharge to the sanitary or storm sewers by means of infiltration and percolation processes. The amount of water being lost may also impact local groundwater levels and increase the potential for offsite migration of contaminant plumes, sewer infiltration, and soil instabilities and increased amounts of groundwater which may require remediation.

Effluent water pipelines at the RFP include the sanitary sewer system, the storm sewer system and the process waste system. Leakage in the sanitary sewer and storm sewer systems was addressed in detail in Task 1 (Sanitary Sewer Infiltration/Inflow and Exfiltration Study (ASI, 1990b)) and Task 2 (Storm Sewer Infiltration/Inflow and Exfiltration Study (ASI, 1990a)) of the Zero-Offsite Water-Discharge Study, respectively. Leakage through the process wastewater system is not within the scope of this Zero-Offsite Water-Discharge Study.

The purpose of the sanitary and storm sewer infiltration/inflow and exfiltration studies was to identify and describe sanitary and storm water infiltration from groundwater, inflow from storm runoff, and exfiltration to the groundwater. Ultimately, a better understanding of the potential for contaminant transport by surface water will be gained from these studies.

Preliminary results of the storm-sewer infiltration/inflow and exfiltration study suggest an small but unaccountable volume of water flows continuously from some unknown source. A potential source of some of the flow is water lost through leaks in RFP water supply pipelines. This volume of water was judged to be small in comparison to the total annual volume of water discharging form the storm-sewer system (ASI, 1990b). A conclusion of Tasks 2 and 3 was that it would not be cost effective to locate the source of the unaccounted for water in the sanitary sewer system.

The Treated Sewage/Process Wastewater Recycle Study (Tasks 11 and 13) addressed the potential for reuse (recycling) of sanitary treatment plant (STP) effluent and the required treatment process train to achieve a level of water quality suitable for selected water demand centers at the RFP (ASI, 1991). The water management alternatives presented in that study involved the industrial water (plant raw water) and domestic water pipelines. For this reason, the characterization of the competence of the raw, domestic, and industrial (plant raw) water pipelines, through the identification of potential leaks, would be useful in determining optimal water management.

The preferred alternative from Tasks 11 and 13 was to maintain the existing domestic and industrial (plant raw) water pipelines as the currently exist at the RFP. Therefore, leak testing does not appear to be justified at this time and this study addresses only the leak testing methods which could be used, if necessary, to perform leak testing on all or part of the RFP water pipelines.

2.0 PIPELINE SYSTEMS

Three water-supply pipeline systems for the RFP have been identified for evaluation during this study. These water pipeline systems consist of raw water, domestic water, and industrial water (plant raw water). Raw water is derived for plant use from Ralston Reservoir and Gross Reservoir and is conveyed in the South Boulder Diversion Canal. A pipeline carries raw water from the South Boulder Diversion Canal to the raw-water reservoir. This water is purchased from the Denver Water Board (ASI, 1991). Purchased raw water is the primary source of water for the plant, with recycled water a secondary source for selected uses. Purchased raw water is temporarily stored in the raw-water reservoir located in the west buffer zone at the RFP, although, the raw water system can allow water to bypass this temporary storage. From the raw-water reservoir, water is transferred throughout the RFP for specific plant uses. Approximately 60 percent of the raw water is transferred to the Building 124 Water Treatment Plant (based upon calendar year 1989 (ASI, 1990c)). The water treatment plant is designed to treat one million gallons of raw water per day and results in domestic water for use at the RFP. Domestic water is used for all direct human uses, and to a lesser extent, as process make-up water. The remaining 40 percent of the raw water is used for industrial purposes in RFP processes, cooling towers and landscaping (Figure 1).

2.1 RAW WATER

Raw water is supplied to the RFP directly from the Denver Water Board's (DWB) Ralston and Gross Reservoirs, located west of the RFP. The raw water pipeline supplying the RFP from the Ralston Reservoir dam pump station is approximately 30,000 feet long. The raw-water pipeline supplying the RFP from the South Boulder Diversion Canal is approximately 4,000 feet long. Approximately 120 million gallons of raw water entered the RFP in 1989 via the raw-water pipeline (ASI, 1991). Raw water travels from Ralston Reservoir or the South Boulder Diversion Canal through the raw-water pipeline to the raw-water reservoir located in the west buffer zone at the RFP. Water from the South Boulder Diversion Canal is the primary raw water source due to the shorter distance and the fact that water flows by gravity. When water is unavailable from the South Boulder Diversion Canal, water is pumped the greater distance from Ralston Reservoir. The raw-water pipeline continues from the raw-water reservoir to the water treatment plant (Building 124) as shown on Figures 1 and 2. Prior to entering the water treatment plant, some of the water is diverted to the industrial water (plant raw water) pipeline. Raw water not destined for the water treatment plant is termed industrial water because it is to be used specifically for industrial purposes within RFP. The division between the raw water pipeline and industrial water pipeline is arbitrary.

2.2 DOMESTIC WATER

Raw water has been treated at the RFP since 1952 (ASI, 1990c). As-built design drawings from 1987 indicate approximately 68,000 lineal feet of domestic water pipeline consisting of various pipe materials (Figure 3). The approximate length of domestic pipeline by material composition is summarized in Table 1. The quantity of water entering the domestic water pipeline system has not been well documented. A water balance study was completed as part of the Treated Sewage/Process Wastewater Recycle Study (Tasks 11 and 13) to estimate the volume of water in the industrial water and domestic water systems in calendar year 1989 (ASI, 1991). The study resulted in identifying approximately 72 million gallons per year of water transferred through the water treatment plant. Approximately 68 million gallons were estimated as a result of metering, leaving approximately 4 million gallons exiting the treatment plant through unmetered pipelines in 1989.

TABLE 1

APPROXIMATE PIPELINE LENGTHS AND COMPOSITION

(Lengths in feet)

PIPELINE \ COMPOSITION	STAINLESS STEEL	PVC	COPPER	CAST IRON	TOTAL
RAW	N/A	N/A	N/A	34,000	34,000
DOMESTIC	2,700	1,100	2,050	62,550	68,400
INDUSTRIAL (PLANT RAW WATER)	N/A	N/A	N/A	28,100	28,100
TOTAL	2,700	1,100	2,050	124,650	130,500

2.3 INDUSTRIAL WATER (PLANT RAW WATER)

Raw water not destined for the water treatment plant (Building 124) is applied to industrial uses at the RFP (Figure 2). Pipe lengths and material composition for the industrial water system are presented in Table 1. Most of this industrial water (90%) is destined for cooling tower operations (based upon the 1989 water balance performed for the Treated Sewage/Process Wastewater Recycle Study (ASI, 1991)). Water is recirculated through the cooling towers until the total dissolved solids (TDS) concentration exceeds 1000 mg/l and is then replenished. Approximately 9 percent of the industrial water is directed to the steam plant (Building 443 on Figure 2) and makes up a small percentage of water used in the boiler system of that building. The remaining 1 percent of industrial water is used during summer months for lawn irrigation near Buildings 130 and 850 (ASI, 1991).

3.0 TEST METHODS

Several potential leak-testing methods have been identified for evaluation in this study. Leak detection can be categorized as either invasive or non-invasive. Invasive leak testing includes procedures in which the pipeline system is in some way modified, as in the physical alteration of the pipe or its appurtenances. A leak-detection method could also be considered invasive if it entails disturbing any Individual Hazardous Substance Sites (IHSSs) at the RFP. Invasive leak testing is generally not acceptable at the RFP because of the potential for disruption of plant processes or non-compliance with existing regulations and policies. Accordingly, non-invasive methods have been investigated for use in testing the pipelines transporting raw, domestic, and industrial water. Three methods recognized for potential use at the RFP are: Injected Nitrous Oxide; Water Balance Calculations; and Leak-Noise Correlator.

3.1 INJECTED NITROUS OXIDE

To ascertain potential pipeline leaks, gaseous nitrous oxide can be introduced under pressure to the domestic and industrial pipeline systems from existing pipe apertures. The gaseous nitrous oxide will pass through the leaks and appear at the ground surface. An infrared analyzer to detect nitrous oxide can observe the elevated concentrations of the gas at the ground surface in the general location of the leak.

There are several benefits to the use of this method for subsurface leak detection. First, as per identified criteria, this method is non-invasive in undeveloped areas. In areas that are paved or otherwise developed, the necessary alteration of the ground surface to allow the nitrous oxide to surface renders the method invasive. The viability of this method is in part dependent upon the specific characteristics of the surface above the pipeline. The nitrous oxide is injected where water enters the pipeline and becomes miscibly combined with the water. Nitrous oxide is noncorrosive and the concentration of nitrous oxide in the water would not be potentially harmful to human health or the environment. Second, the method can be utilized over significant lengths of pipeline with a minimum of points of introduction. Finally, using accurate monitoring devices and a known ratio of injected gas to water in the pipeline, small volume leaks can be reliably identified.

Constraints to this method include the following. The soil and bedding between the buried pipeline and the surface must be unobstructive to allow the nitrous oxide to rise from the leak to the ground surface above the point of the leak. For this reason, the use of this method through paved areas, developed areas, areas of compacted soil, or geotextiles is not efficient. If the gas is unable to rise through the ground it may travel laterally and surface only where the materials are of sufficient permeability. The location of the leak or leaks along the pipeline would be misrepresented and, therefore, cannot be accurately determined. Second, in areas where the ground surface materials are natural, a furrow is dug to permit an accurate evaluation of leak location. For large-scale pipelines, the digging of furrows along the entire length becomes inefficient and/or infeasible. Lastly, it is likely for the pipelines addressed in this study cross IHSSs. Regulatory issues involving IHSSs dissuade the use of a leak-detection method that involves disturbing IHSSs.

In the mid 1970s, a leak-detection study was implemented on the raw-water pipeline between Ralston Reservoir and the RFP raw-water reservoir to identify and repair leaks in the system. The leak-detection method was injected nitrous oxide (C. Rose, Utilities, retired, pers. commun. February 25, 1991). Nitrous oxide was introduced into the pump at Ralston Reservoir at a pressure exceeding the water pressure in the pipe. A furrow above the pipe at ground surface was dug along the known path of the pipeline to scarify compacted soil and allow the gas to collect unrestricted. An operator with a monitoring device was able to identify and locate leaks along the pipeline. This method was found to be sensitive to most leaks, including drip leaks, along the pipeline.

The study yielded the identification of numerous small leaks. The ground surface above the pipeline was staked wherever the monitoring equipment detected nitrous oxide. The ground was excavated at the stakes and most of the detects revealed very small magnitude leaks at the leaded joints. These small leaks were not repaired. Leaks of the magnitude of approximately 50 gallons per day (based on visual observation) were identified in approximately four locations and were repaired (C. Rose, Utilities, retired, pers. commun. March 20, 1991). A statement of services from the company who performed this leak-detection method in the mid 1970s is included in Appendix A-1.

The estimated cost for this method is based upon the scope of work provided by the International Leak Detection Services, Inc. for the mid 1970s study (Appendix A-1). It is not currently known whether this company still exists and provides this service. No Denver area leak-detection companies were identified that currently use this method and current cost estimates could not be ascertained. The mid 1970s study took a two-person crew approximately two days of field work to complete approximately five miles of pipeline. At a rate of $255 per day for equipment and operator and $100 per day for the plow vehicle, a total of $710 for the task. The unit cost of this method can be estimated at approximately $140 per mile of pipeline at 1975 dollars. Assuming an inflation rate of 1.5, that rate would be equivalent to about $200 per mile in 1991 dollars.

3.2 WATER BALANCE CALCULATIONS

The quantity of water supplied to the RFP is a measurable volume and is divided into the categories of water addressed in this study. Water is applied to a number of functions by category and used throughout the RFP. Metering devices can define water flow in specific pipeline zones. The basic water balance equation for the RFP water system is:

$$\text{water supply} = \text{water demand} + \text{water lost}$$

Water supply has been identified as domestic water and industrial water (plant raw water), both of which are derived from raw water. A portion of the domestic water is directed through backflow preventors to be used in RFP processes and is termed process water but is not a distinct water supply. Supply water can be metered as it enters and exits the water treatment plant (Building 124). Meters can be installed to continuously ascertain flow to various RFP demand centers. The difference between the readings from the supply and demand meters is water lost, primarily to leaks.

Water balance calculations require the accurate metering of all pipelines. Meters isolate portions of the systems and, through complex iterations, can provide the volume of water lost in pipeline sections but not specific locations. Water demand is not constant at the RFP and, consequently, adds a further level of complexity to the calculations.

Benefits to the use of water balance calculations are that they are non-invasive, provided meters are currently attached to system, and they provide a method of tracking water flow problems. Disadvantages of applying this method to the water pipeline systems addressed in this study are that there are currently no metering systems installed at the RFP extensive enough to provide the data necessary for the accurate use of this method, and to install such meters would be invasive. The water balance calculations performed as part of the Treated Sewage/Process Wastewater Study (Tasks 11 and 13) were hindered by the lack of extensive and accurate data; therefore, back-calculations, forcing totals, and informed guesses were necessary in the water balance calculations (ASI, 1991). Additionally, once a section of pipe is determined to have a leak, the location of that leak (or leaks) within that section would be unknown. Additional leak testing using a more sophisticated method would be required or the entire length would need to be excavated to identify the leak location. An implemented program of extensive metering, accurate meter calibration, and meter maintenance would provide records of water demand, volume of potential leaks, and information for water conservation.

Assuming there were sufficient metering to accurately quantify leaks, and based upon the time required for the water balance calculation for the Treated Sewage/Process Wastewater Study (Tasks 11 and 13), an estimate can be made of the cost of performing leak detection with this method. Assuming an engineer at a rate of $60 per hour and 500 hours for evaluation, this method would cost approximately $1,200 per mile of pipe for the approximate 25 miles (130,500 feet) of water pipeline at the RFP.

3.3 LEAK-NOISE CORRELATOR

The current state-of-the-art method of water pipeline leak detection is the use of a leak-noise correlator. Water leaking through a pipe generates a noise detectable by sophisticated computer-enhanced equipment. The principle is that noise from a leak, heard at two known points, can be compared at those two points so a noise source location correlation may be measured. The measured correlation identifies the distance from both points to the site of greatest noise which is the leak. In this manner, several leaks along the same section of pipe can be discerned.

Two microphones are attached to convenient positions of a pipeline to isolate a section. Convenient positions along a pipeline would be areas of exposure, for instance at valves or in a pumphouse. Radio transmitters send electronic signals to a computer processor that correlates the time required for the leak noise to reach each microphone. Specifically, the radio transmitters amplify and send noise (vibrations) to the correlator which transfers the information to an oscilloscope for interpretation. Accelerometers are used on metallic pipe contacts to relay the vibrations through the pipe itself. Hydrophones are used on non-metallic pipes to send the vibrations through the fluid contained in the pipeline. The computer can accept variable sound velocity data as required by the pipe size, material, age, burial, compaction, corrosion, and other pertinent data. By knowing the speed of sound for the type and size of pipe, the distance between both microphones, and the travel time for the noise to reach each microphone, a precise location of the noise caused by leakage can be determined.

Advantages to this system are that, aside from being non-invasive, the system is proven, accurate, and quick. The pipeline system can remain on-line as a small crew with computers located in a van can promptly and systematically evaluate the pipeline system. The lengths of pipe isolated for this method can be up to 2,400 lineal feet and the surrounding material and surficial material are of no consequence. A typical crew can test three to five miles of pipe in one day. This method has been regularly used by municipalities (e.g. City of Denver) and large industrial plants (e.g. Coors Brewery), for its accuracy and efficiency (D. Anderson, Utility Technical Services, Inc., pers. commun., March 20, 1991) .

A disadvantage to this system is that it is affected by extraneous noise, such as from plant processes or vehicular traffic, that can cause vibrations in the pipeline. Extraneous noise can interfere with the evaluation of the study. Methods of circumventing the extraneous noise are to perform the leak detection monitoring at times of low plant operations (nights, weekends) or through cooperative efforts to curtail operations in isolated sections of the RFP during monitoring in that area. Pipeline information is required to be entered into the computer system to best evaluate the location and magnitude of a leak. The specific physical information of the pipeline (e.g. pipe size, composition, age, burial, etc..) required for this method is more detailed than for other methods identified.

The estimated cost for this method is based on information provided by Donohue Engineers, Architects, Scientists and Utility Technical Services, Inc. who performs noise leak correlator detection. The statement of services for these consulting companies who perform leak-noise correlation services are included in Appendix A-2. For time and equipment, the cost is approximately $300 per mile. This estimate is generalized and in no way should be considered binding.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Based upon the leak-detection methods investigated as a result of this study, the leak-noise correlator method of pipeline leak detection has been evaluated as being preferred for the specified water pipelines at the RFP. Table 3 summarizes specific criteria used in selecting the preferred method. The leak method can be implemented quickly and is relatively unobtrusive to plant operations. Results of the method are sufficiently accurate to locate a leak to within one lineal foot of pipeline. This degree of accuracy minimizes the efforts to repair leaks after their locations are identified. Furthermore, this method can provide reasonable estimates of water lost at individual leaks prior to any ground breaking to expose the leak. The estimates of leakage rates can be provided in the ranges of less than 5 gallons per minute (gpm), between 5 and 20 gpm, or greater than 20 gpm.

It is assumed that prior to implementing any method of leak detection analysis, a survey of the existing pipelines would be required. For the recommended leak-detection system, information such as the pipeline locations, lengths, diameters, and composition are required. As-built drawings exist for raw, industrial (plant raw), and domestic water that provide much of the information required.

TABLE 2

LEAK-DETECTION METHOD COMPARISON SUMMARY

CRITERIA	INJECTED NITROUS OXIDE	WATER-BALANCE CALCULATIONS	LEAK-NOISE CORRELATOR
NON-INVASIVE?	POSSIBLY, may need to disturb surface	POSSIBLY, may need to install meters	YES
THREAT TO HUMAN HEALTH AND THE ENVIRONMENT?	POSSIBLY, may need to disturb IHSSs	NO	NO
POSSIBLE DISTURBANCE OF IHSSs?	YES	NO	NO
DETECTS LEAK LOCATION?	NO, may surface some distance from leak	NO, locates leak between meters	YES, locates leak to one lineal foot
DETECTS LEAK MAGNITUDE?	NO	YES, if accurately metered	YES, can estimate to less than 5 gpm for each leak
COST	$200/mile	$1,200/mile	$300/mile

TABLE 3
EVALUATION MATRIX

EVALUATION FACTORS*	WEIGHTING FACTOR	ALT 1 (INJECTED NITROUS OXIDE)		ALT 2 (WATER-BALANCE CALCULATIONS)		ALT 3 (LEAK-NOISE CORRELATOR)	
		S	W	S	W	S	W
INVASIVENESS	8	2	16	3	24	5	40
IHSS DISTURBANCE	8	2	16	4	32	4	32
COST	5	4	20	1	5	3	15
TIME	5	3	15	1	5	3	15
ACCURACY	6	3	18	3	18	5	30
LEAK MAGNITUDE DETECTION	7	2	14	3	21	5	35
LEAK LOCATION DETECTION	7	3	21	3	21	5	35
TECHNICAL FEASIBILITY	5	2	10	2	10	5	25
TOTALS			130		136		227
RANK			**3**		**2**		**1**

S = SCORE; W = WEIGHTING FACTOR X SCORE

* Defined on the following pages

The evaluation matrix presented in Table 3 is based on the factors described below. The weighting factors were derived objectively on their relative importance for the use of a leak-detection method. The weighting factors are on a scale of one (least significance) to 10 (greatest significance). The scores of each leak-detection method reflect the relative desirability of the leak-detection method. A score of one is least desirable and a score of five is most desirable. The leak-detection method with the highest overall score is the desired method.

- Invasiveness - A criteria of leak-detection method selection was that the method should be non-invasive to the pipelines at the RFP. Alternative 3 represents an advantage in being completely non-invasive to pipelines and the materials surrounding the pipelines. Alternative 1 would necessitate injecting gas into the water in the pipelines and disturbing the material above the pipelines. Alternative 2 would not be invasive if there were sufficient meters to calculate a water balance. Meters would have to be installed for this method to be accurate and the installation of meters would be invasive.

- IHSS Disturbance - Due to regulatory concerns, disturbance of IHSSs would be undesirable. Alternatives 2 and 3 could be performed without entering an IHSS. Alternative 1 requires the path of all pipelines to be followed at the ground surface, and the ground surface above pipelines that pass through any IHSSs would be disturbed.

- Cost - Costs were estimated per mile of pipeline for comparison. Alternative 2 is estimated to require the largest amount of time and a significantly higher cost. Alternatives 1 and 3 are similar in both time and cost; Alternative 1 was projected to be slightly less expensive. These cost estimates were derived in different manners and relative ranking of this category may change if additional information is obtained.

- Time - Alternatives 1 and 3 could each progress at approximately 2 to 4 miles of pipeline in a day. Alternative 2 would require a much greater number of labor hours to acquire the necessary information to perform the calculations.

- Accuracy - The overall accuracy of the methods was compared taking into account time, cost, and results of the survey. Generally, accuracy pertains to the reliability of the data generated from the different methods. Alternatives 1 and 2 are limited in their accuracy. Alternative 1 can be inaccurate if the nitrous oxide rises in a location other than above the leak. The accuracy of Alternative 2 is dependent upon the accuracy of the metering and the reliability of the readings. For this method to be accurate, there must be a sufficient number of meters situated strategically throughout the pipeline systems. Alternative 3 is considered most accurate because of the sophisticated equipment that reduces the error potential.

- Leak Magnitude Detection - The leak-detection investigation is effective if the volume of water being lost through leaks is estimated. Leak magnitude cannot be estimated from Alternative 1. Alternative 2 can quantify the magnitude of the leak if the metering is accurate. The volume of water lost through leaks can be estimated with the use of Alternative 3.

- Leak Location Detection - The location of a leak along the pipeline can be identified accurately using Alternative 3. Alternative 1 has the potential of accurately locating a leak if the gas rises directly above the leak without traveling along the pipeline. Alternative 2 can identify the location of a leak within a section of pipe between meters but not specifically along a given pipe length.

- Technical Feasibility - The technical feasibility of Alternatives 1 and 2 may restrict these options. None of the leak-detection companies in the Denver area provide injected nitrous oxide services. Currently, metering at RFP on the water supply pipelines is not sufficient to provide accurate data for Alternative 2. Alternative 3 is the state-of-the-art method and services are provided by several companies in the Denver area and elsewhere.

5.0 ACKNOWLEDGEMENTS

This study was conducted by Advanced Sciences, Inc. (ASI) under the general supervision of Mr. Michael G. Waltermire, P.E. Project Manager, ASI. This report was written by Ms. Ann K. Sieben, ASI Engineer. Technical assistance was provided by Dr. James R. Kunkel, P.E., ASI and Mr. C.R. Rose, consultant to EG&G CWAD. Mr. Nick Massaro, ASI Staff Member assisted in the preparation of this report. EG&G responsive reviews of this report included:

R.A. Applehans, EG&G - FE/PSCE
D. Sassone, EG&G - SH
J.R. McKeown, FE/PCSE

This report was prepared and submitted in partial fulfillment of the Zero-Offsite Water-Discharge Study being conducted by ASI on behalf of EG&G Rocky Flats, Inc. EG&G's Project Engineer for this study was Mr. R.A. Applehans of EG&G's Facilities Engineering, Plant Civil-Structural Engineering (FE/PCSE).

6.0 REFERENCES

Advanced Sciences, Inc. (ASI), 1991, Treated Sewage/Process Wastewater Recycle Study Rocky Flats Plant Site, Tasks 11 & 13 of the Zero-Offsite Water-Discharge Study: Project Nos. 208.0111 and 208.0113, January 8, 40 p., 14 figures, 3 appendices.

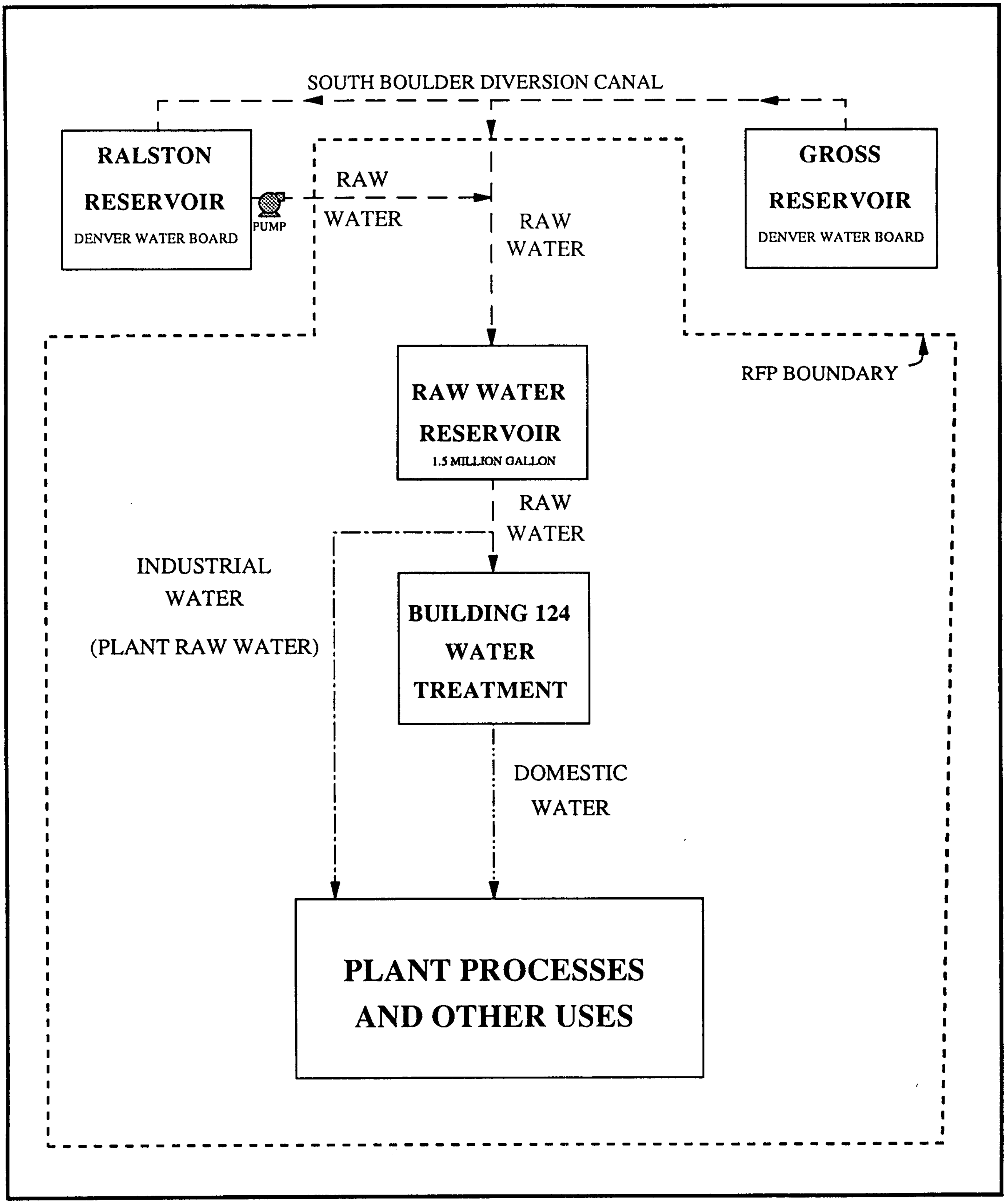
Advanced Sciences, Inc. (ASI), 1990a, Interim Report, Sanitary Sewer Infiltration/Inflow and Exfiltration Study, Task 1 of the Zero-Offsite Water-Discharge Study: Prepared for EG&G Rocky Flats, Inc. Project No. 208.0101, December 18, 47 p. 9 tables, 24 figures, 5 appendices.

Advanced Sciences, Inc. (ASI), 1990b, Interim Report, Non-Point Source Assessment and Storm-Sewer Infiltration/Inflow and Exfiltration Study, Rocky Flats Plant Site, Tasks 2 and 3 of the Zero-Offsite Water-Discharge Study: Prepared for EG&G Rocky Flats, Inc. Project Nos. 208.0102 and 208.0103 , December 8, 53 p, 10 tables, 15 figures, 8 appendices.

Advanced Sciences, Inc. (ASI), 1990c, Scope of Work for Water Treatment Compliance (Building 124), Draft Completion Report, p.8 June.

U.S. Department of Energy (DOE) and State of Colorado, 1989, Agreement in Principle Between the United States Department of Energy and the State of Colorado: June 28, 25p.

FIGURES

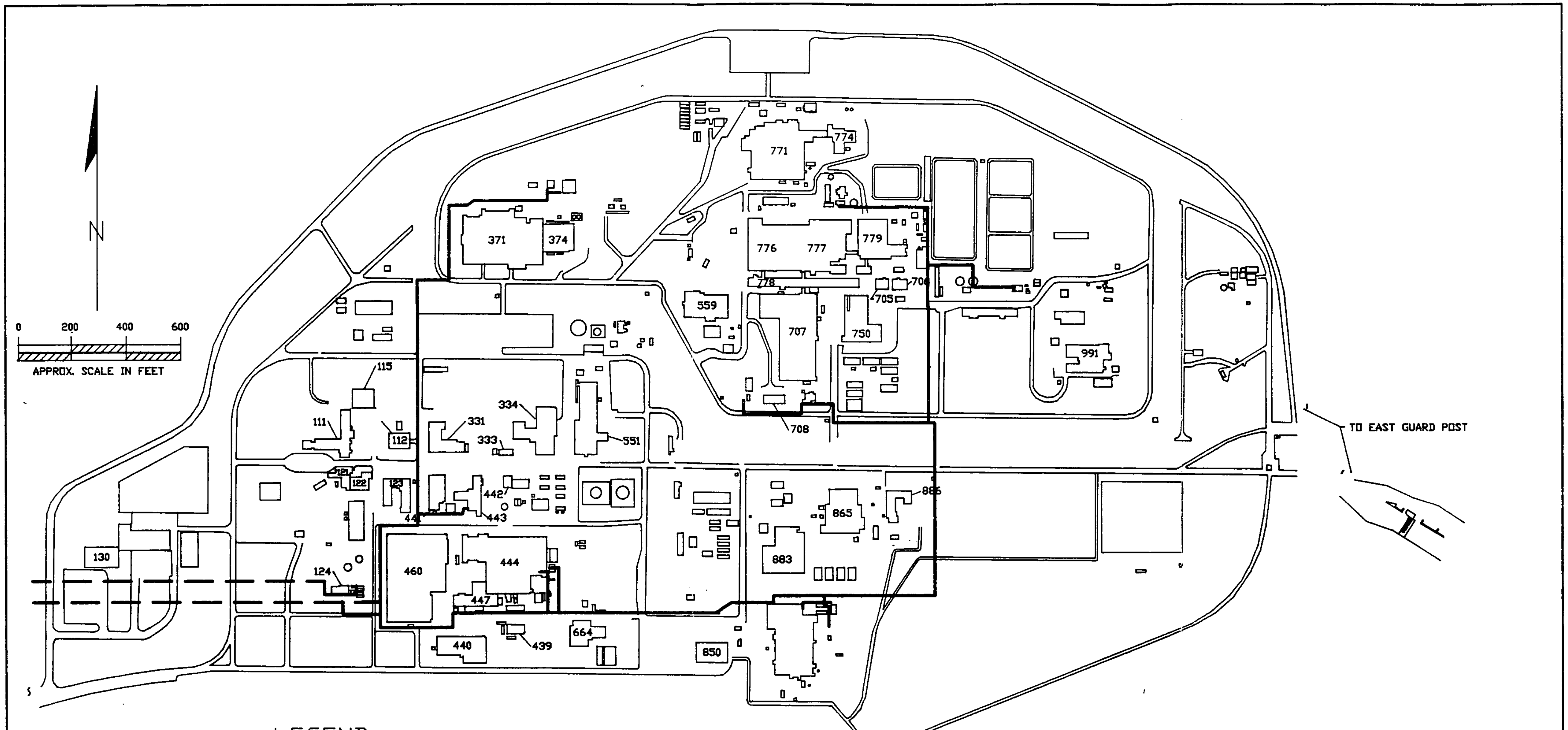


RFP WATER SUPPLY DISTRIBUTION

RAW, DOMESTIC, AND INDUSTRIAL WATER
PIPELINE LEAK DETECTION METHOD STUDY
ZERO-OFFSITE WATER-DISCHARGE STUDY

PROJECT No. 208.0120

FIGURE 1



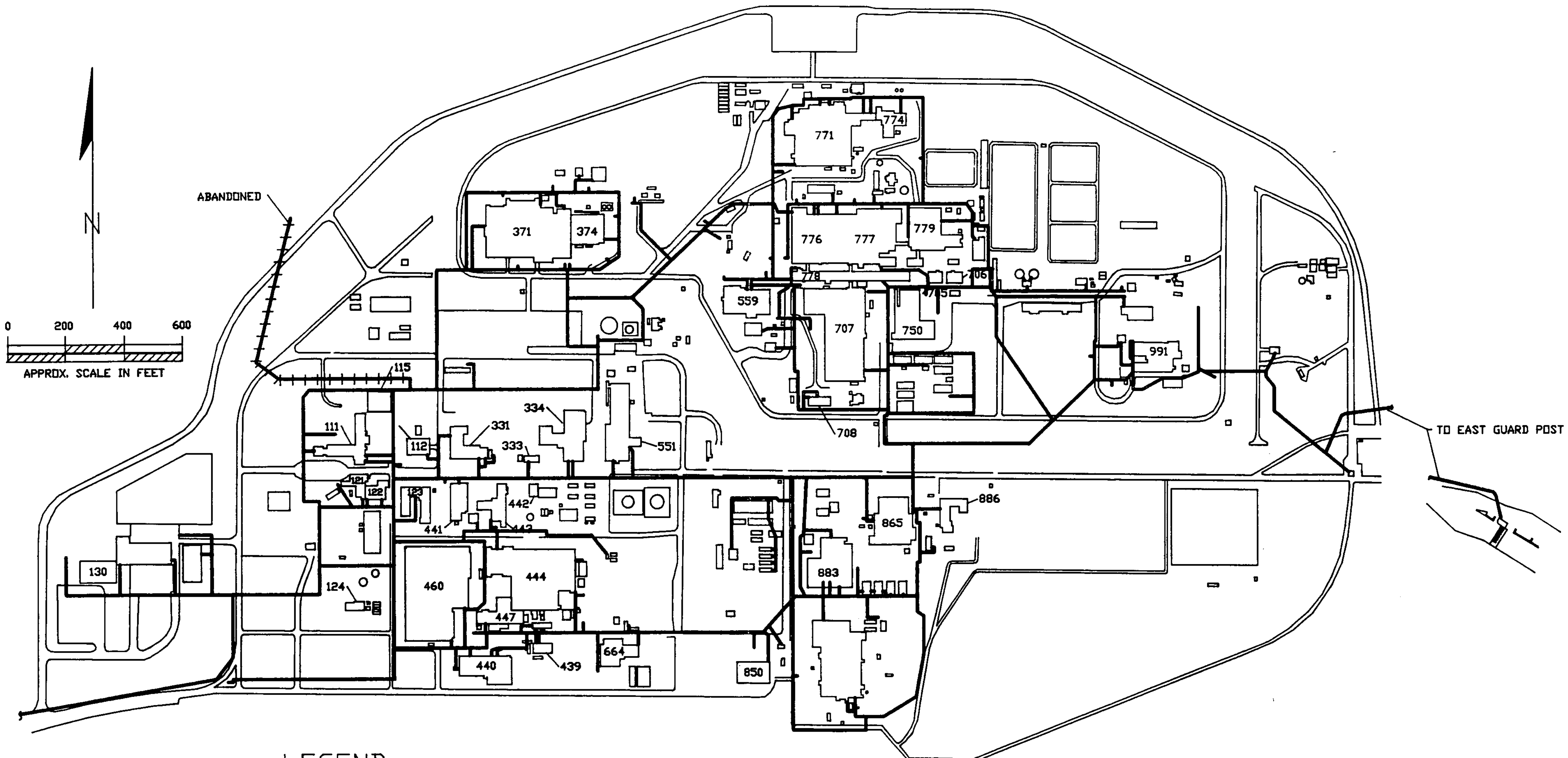
LEGEND

INDUSTRIAL WATER (PLANT RAW WATER) PIPELINE

RAW WATER

EXISTING PLANT INDUSTRIAL WATER (PLANT RAW WATER) SYSTEM	
RAW, DOMESTIC, AND INDUSTRIAL WATER PIPELINE LEAK-DETECTION METHOD STUDY	
ZERO-OFFSITE WATER-DISCHARGE STUDY	
PROJECT: 208.0120	FIGURE 2
DATE: MAR 1991	

RFPICW



LEGEND

DOMESTIC COLD WATER PIPELINE

EXISTING PLANT DOMESTIC COLD WATER SYSTEM

RAW, DOMESTIC, AND INDUSTRIAL WATER PIPELINE LEAK-DETECTION METHOD STUDY

ZERO-OFFSITE WATER-DISCHARGE STUDY

ASI	PROJECT: 208.0120	FIGURE 3
	DATE: MAR 1991	

RFPICV

A

A-1

INTERNATIONAL LEAK DETECTION SERVICES, INC.

INTERNATIONAL LEAK DETECTION SERVICES, INC.

5109 GULFTON DRIVE

HOUSTON, TEXAS 77036

TELEPHONE (713) 667-8463

PIPELINE AND COMMUNICATION CABLE LEAK DETECTION

THE NITROUS OXIDE METHOD

ROBERT A. LANE	HAROLD W. DECKER	CLAUDE W. BRANDON
President	Vice President	Secretary/Treasurer
8941 Croes Drive	6110 Bridlington	6111 Bridlington
Houston, Texas 77055	Houston, Texas 77045	Houston, Texas 77045
HO 4-1770	PA 9-0923	PA 3-4706

TABLE OF CONTENTS

Reprints

Deason, Dave "Black Mesa's River Of Coal Spans Arizona's Navajo Land" Pipe Line Industry, August, 1969

Bozeman, H. C. "N_2O Proves Good Leak Detector in Hydrostatic Testing Program" The Oil and Gas Journal, October, 1962.

THE INTERNATIONAL LEAK DETECTION SYSTEM

PRINCIPLE OF OPERATION

TRACER INJECTION:

Nitrous Oxide (N_2O) is used as the tracer gas. It is injected into the pipeline with water (about 1 lb. of N_2O per 1000 gallons of water).

TRACER ACCUMULATION:

At a leak, Nitrous Oxide breaks out of its solution in water. At atmospheric pressure, Nitrous Oxide is a gas. As a gas, it rises to the surface of the back-fill. Being heavier than air, Nitrous Oxide will not rise in air. Thus, the Nitrous Oxide will accumulate in the upper crust of the back-fill.

Normally, 24 hours of "soak" time is sufficient to accumulate a detectable quantity of tracer.

TRACER DETECTION:

An infrared analyzer is used to locate the presence of the Nitrous Oxide that has accumulated from the leak. The infrared analyzer is mounted on a vehicle to survey the line.

CHARACTERISTICS OF NITROUS OXIDE

DESCRIPTION:

Nitrous Oxide is a unique gas. It is man made and not found in nature. (other commercial uses are as an anesthetic - laughing gas - and as a propellant in aerosol packed foods) It is nontoxic, noncorrosive and nonflammable.

Nitrous Oxide is about 1.5 times as heavy as air. It is water soluble.

DETECTION PROPERTIES

The infrared absorption of a compound is a characteristic of the type and arrangement of the atoms composing the molecule. The frequency of wave length at which infrared energy absorption occurs is determined by the mass of the atoms and the strength of the bond joining them. Dissimilar compounds absorb in widely different spectral regions, and similar compounds have similar spectral regions.

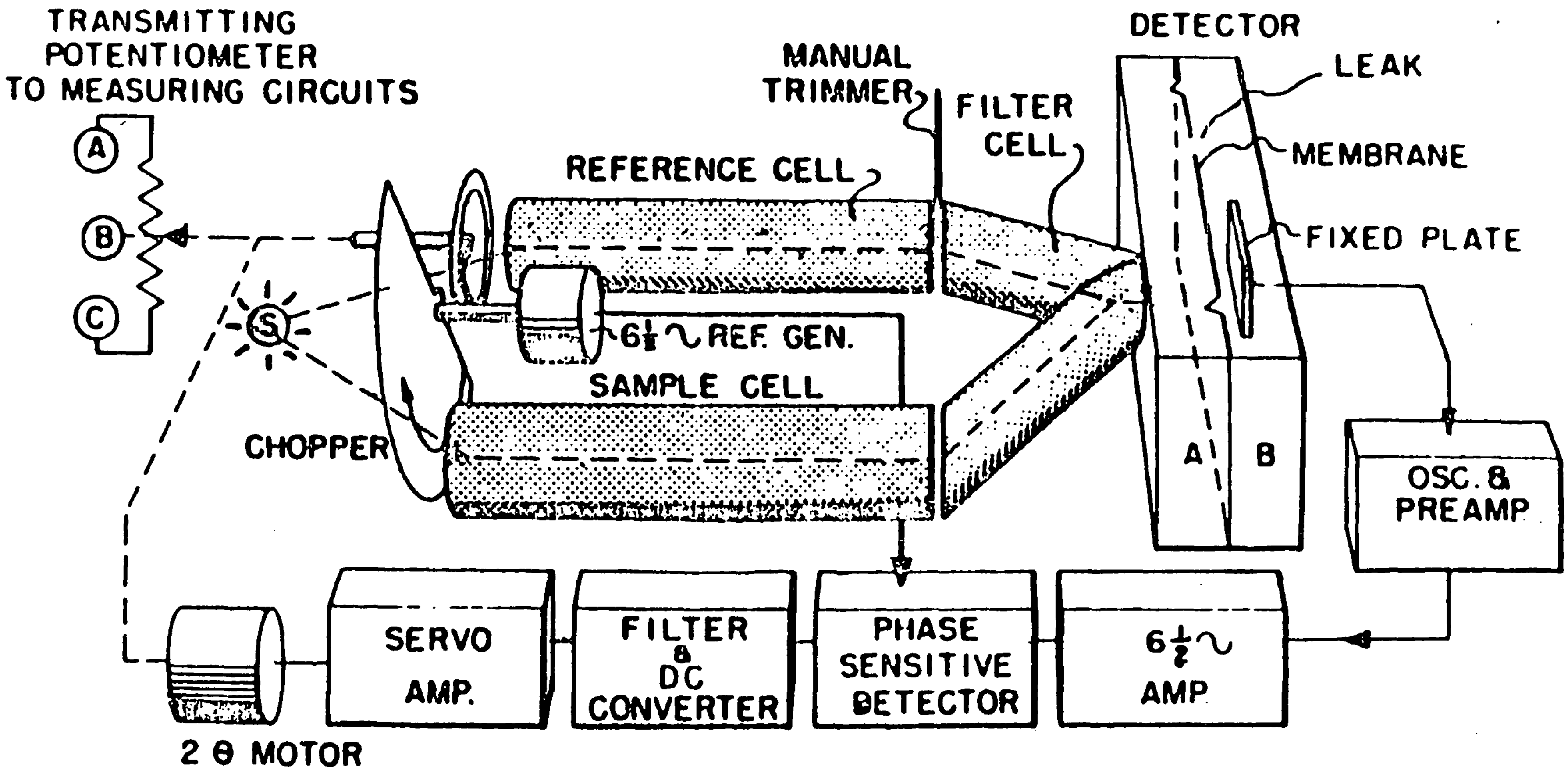
Nitrous Oxide infrared absorbence characteristics are such that there is a peak absorption band at 4.5 microns wave length. This particular frequency is uniquely free from infrared energy absorbence by other compounds. This allows a single frequency infrared analyzer to be highly selective to Nitrous Oxide (at the 4.5 micron wave length).

NITROUS OXIDE DETECTOR

An infrared analyzer (illustrated following page 3) basically consists of a heat energy source of a specific wave length, and an intrared energy (heat) detector. Between the source and the detector is installed a hollow tube which is sealed by special lenses on both ends. The 4.5 micron infrared source emits energy through the sample tube to the heat detector.

When gases not containing Nitrous Oxide are flowed through the sample cell (by pressure or a vacuum system), maximum energy is transmitted to the infrared detector. If gas containing Nitrous Oxide is circulated through the sample cell, the Nitrous Oxide will absorb a portion of the infrared energy being transmitted to the detector, and a change in energy level is monitored by the detector. The indicates the presence of Nitrous Oxide.

The infrared detector is connected to a series of special electronic circuits and amplifiers. The output of the Nitrous Oxide detector is displayed on a meter. An audible alarm and chart recorder are commonly added to the Nitrous Oxide detector to facilitate operation and to provide a permanent record.



Schematic of infrared analyzer. Twin beams of infrared radiation pass through identical cells -- one a sample cell, the other a reference cell. If gas in sample cell contains nitrous oxide, it absorbs more heat, and imbalance of pressure on membrane that separates the two, sends signal.

<u>THE USE OF NITROUS OXIDE AS A TRACER GAS FOR LEAK LOCATION</u>

Nitrous Oxide has been used as a tracer gas to detect leaks in more than 2,000 miles of major pipelines and in 8,000 miles of pressurized cable installed at missile bases and in telephone systems. For the most part, the lines and cable have been buried, and the detection of the leaks was effected through 2 to 15 feet of overburden.

Leaks which in the past eluded inspection teams because of their small size or deep burial, have been discovered easily and quickly by personnel of International Leak Detection Service using routine test procedures set up for cross-country lines. The most common test procedure is to blend Nitrous Oxide into the hydrostatic test water. When the test water excapes from the pipe via a leak, it releases traces of Nitrous Oxide gas into the soil. The gas works its way toward the surface following the line of least resistance. Sometimes this path is a crack, crevice or post hole; but, most often, where the soil is somewhat homogenous, the Nitrous Oxide gas will follow the normal angle of repose of the soil forming a corona at the surface centered around the leak.

Because the Nitrous Oxide is heavier than air (Sp. Gr.--1.53) it tends to linger in the soil, making it easy for the sub-soil "sniffer" or probe to pick up traces as it draws a constant sample from a depth of 5 to 8 inches below the surface of the ground.

The heart of the detection unit is a portable infrared analyzer mounted in the test vehicle which works the sub-soiler through the back-fill at the rate of about two miles per hour. When the indicator-recorder shows any response whatever to the gas sample passing through the analyzer, it invariably signals a leak -- for Nitrous Oxide does not appear in nature, and the only possible mechanism to explain its presence in the back-fill of a pipeline is a leak.

The field operator's response to the Nitrous Oxide contact is to stop the vehicle and start an intense sampling pattern in the area to pinpoint the leak. Often, there is no visible trace of moisture at the surface of the ground to indicate the hydrostatic test leak.

The most recent history of a Nitrous Oxide test program was Black Mesa's Coal Slurry Line in Arizona. On this line, International Leak Detection Service was called in early in the test program and located fifteen leaks, varying in size from 180 gallons per minute down to a size that appeared as a bead of sweat on the line. The average depth of the line at the location of the leaks was approximately five feet. The effectiveness of the Nitrous Oxide leak detection system is pointed out by the fact that of the fifteen leaks located by this method, none showed any moisture near the surface of the ground and very little along the pipe in the area of the leak.

By permission of Pipe Line Industry magazine, we have included an article from their August issue which gives a good background of the obstacles and accomplishments surrounding the construction of the Black Mesa Coal Slurry Line. This article was printed prior to the testing of the line.

Black Mesa's 'River of Coal' Spans Arizona's Navajo Land

Designed for a 660-ton-per-hour flow rate, the 273-mile, 18-inch pipe line is the world's largest and longest slurry system yet to be built

Dave Deason
Associate Editor-Construction
Pipe Line Industry

From the top of Black Mesa, deep in the heart of northern Arizona's Land of the Navajo, the world's largest and longest slurry pipe line to be constructed to date will carry coal to the Mohave Power Project generating station at the southern tip of Nevada, 273 miles distant (Fig. 1).

The system will use 18-inch, LX-52 pipe for 260 miles from Station 1 on Black Mesa, westward to where the line drops from about a 5,750-foot elevation at Cottonwood Pass to 400 feet at the crossing of the Colorado River to terminate at the power plant near the Davis Dam. Over the final 13 miles from Cottonwood Pass, the pipe line will reduce to 12 inches for control of static head pressures induced by gravity flow factors.

The pipe line and preparation plant is owned and will be operated by Black Mesa Pipeline, Inc., a subsidiary of Southern Pacific Pipe Lines, Inc. The pipe line is being constructed

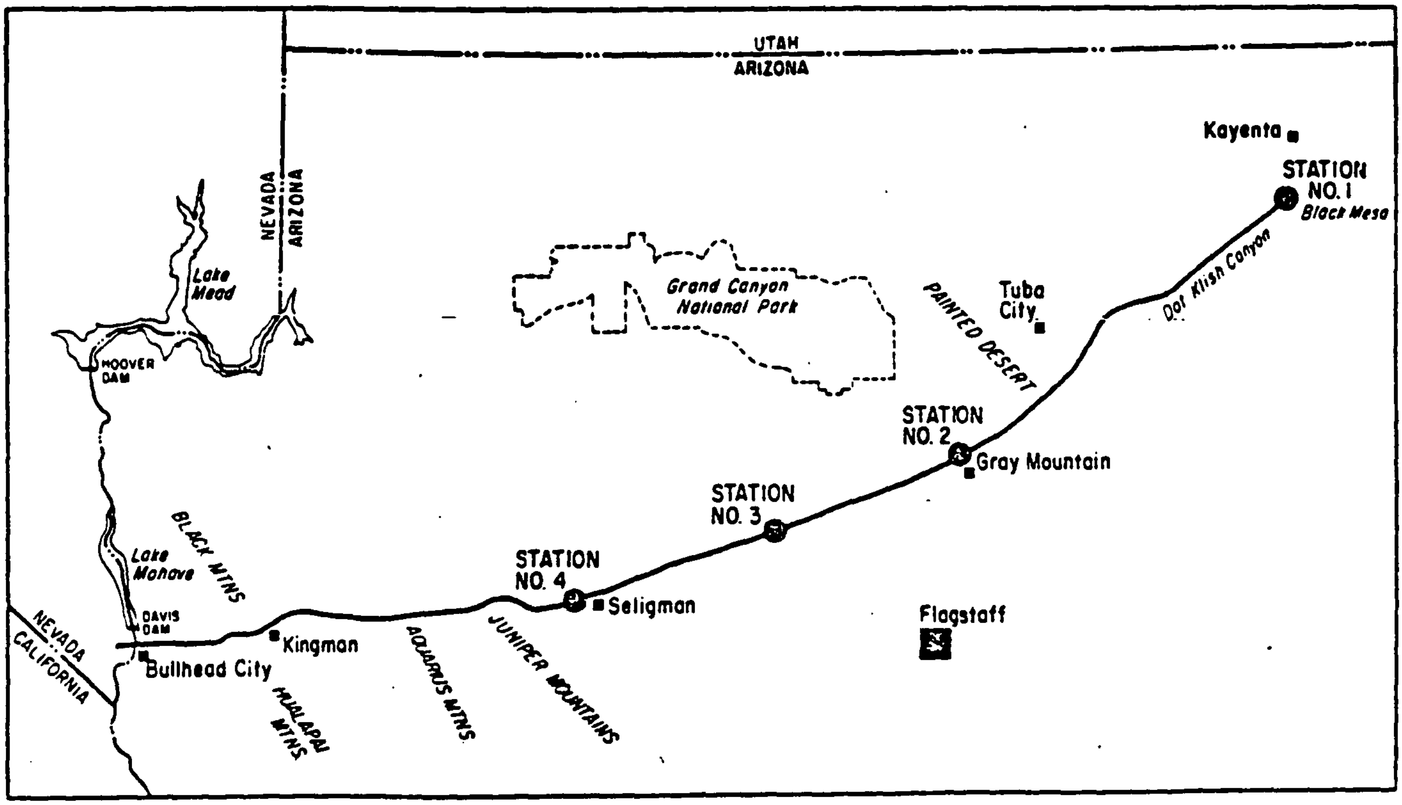
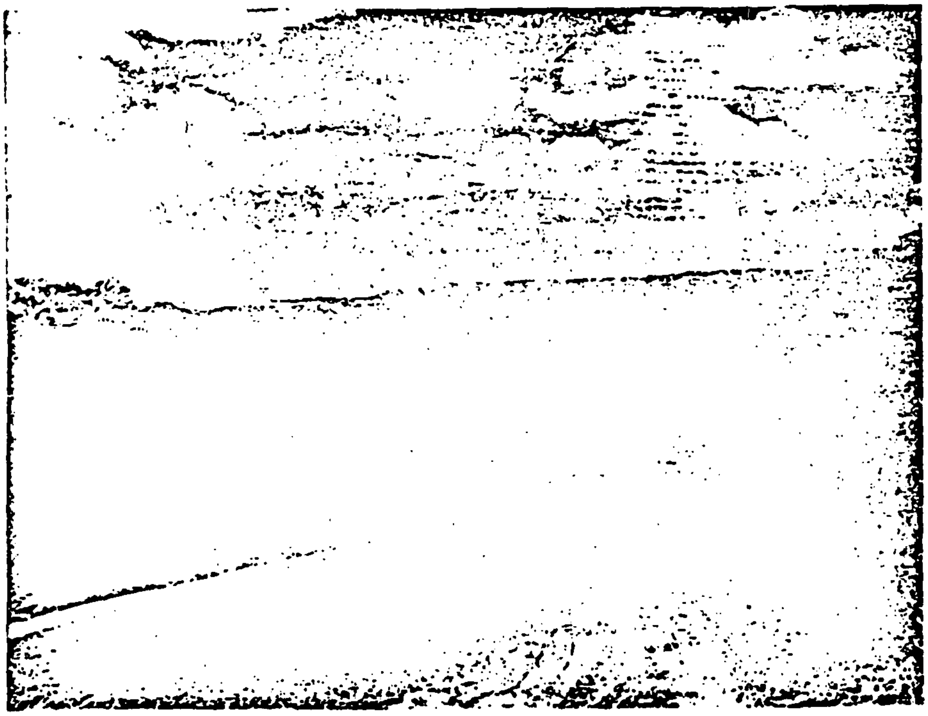


Fig. 1—Route map and pump station locations for the Black Mesa coal slurry pipe line across northern Arizona.



SUBSURFACE WATER on the floor of Dot Klish Canyon at the eastern end of Black Mesa pipe line ROW fills the ditch in each of 44 crossings of dry stream bed.

by R. H. Fulton of Lubbock, Texas. Engineering Management, Inc., is charged with all design and engineering functions plus management of construction and materials purchase.

Fulton began clearing and ditching along the ROW in April and pipe laying from the Black Mesa end in mid-June. Pipe for the system was purchased from Kaiser's Napa, Calif., mill and U.S. Steel at McKeesport, Pa.

Fulton double joints the Kaiser pipe at yards at Flagstaff, Ash Fork and Kingman, Ariz. USS pipe is delivered in 65-foot joints and is trucked directly from the railhead to the ROW.

CREW HOUSING PROBLEM

Housing for the spread crews is not available except at Flagstaff, 150 miles from the Kayenta end of the pipe line. Daily, busses take the men to and from the ROW, but a second fleet of four-wheel-drive busses is required to take them up onto Black Mesa and down along the ditch. A single road with 16 and 18 percent grades snakes to the mesa top. From there, it's about 30 miles down the ROW to the next usable trail back out to the highway. Both routes had to be improved before even the four-wheel-drive vehicles could use them.

The Black Mesa pipe line will cost about $35 million. On completion, it will transport coal at a 660-ton-per-hour rate to the generating plant. There, about 85 percent of the water will be removed by centrifuge, the coal re-pulverized and fed into the furnaces. The excess water from the slurry will be channelled into settling basins and subsequently used for coolant in the generating plant.

Over its planned, 35-year service life, the Black Mesa pipe line will deliver at least 117 million tons of coal. The line starts on Hopi and Navajo tribal lands in northern Arizona at a point central to large strip mines operated by Peabody Coal Co. (See PLI, March 1969, Page 77.)

OPERATIONAL PROCEDURES

High-capacity trucks will deliver the coal from the mines to the slurry preparation plant atop the 6,500-foot-high Black Mesa near the town of Kayenta. At the plant, the coal will be reduced to a powder by the pipe line company and mixed approximately 50-50 with water. It is then pumped into one of three tanks. While one tank is being filled, another stands ready and the third discharges into the pipe line.

Four pumping stations, equipped with 13 Wilson-Snyder 1,700-SP duplex piston pumps, will push the slurry through the line. The stations are located at the Black Mesa starting point, Gray Mountain, Williams and Seligman, Ariz. The Gray Mountain station, which has the greatest elevation hurdle to overcome, will mount four pumps and the others will have three. Pumps are electrically powered and the three outlying stations will be manned during the day while Station 1, which will have control over the entire system, will be manned around the clock.

The slurry will move through the pipe line at approximately 4 mph, or 4,500 gpm. Flow speed must be carefully regulated—too fast will produce abrasive corrosion and settling will result if the rate is slowed.

Re-slurrying can be accomplished following short-period shutdown. But, in case of a prolonged shutdown, the pipe line will have to be water-flushed before re-introduction of the slurry.

Dravo Corp. is constructing Station 1 and the coal preparation plant at Black Mesa and Alex Robertson has the contract for Stations 2, 3 and 4.

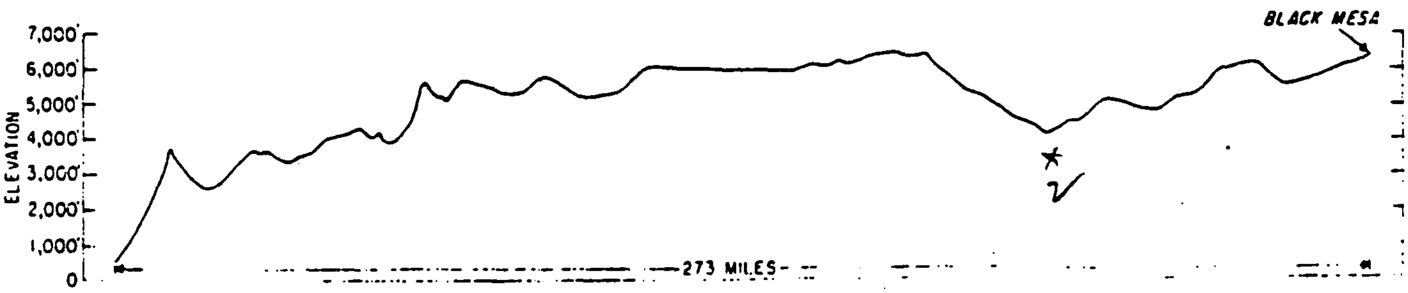


Fig. 2—Profile of the extreme elevation changes for the Black Mesa pipe line. Across the 273-mile ROW, the route has an average 16 percent downhill gradient.

REMOTE REGION

Perhaps nowhere this side of the moon could a more rugged and remote area be selected across which to construct a pipe line. Within only a few hundred yards of its start on top of Black Mesa, the ROW drops 1,000 feet to the floor of Dot Klish Canyon, a dry wash in which a dusty stream bed meanders from side-to-side for some 20 miles. At the canyon mouth the pipe line plunges nearly 1,000 feet again to span a 40-mile-wide desert region of blowsand and then cross the Little Colorado River gorge. It then enters a corner of the Painted Desert which is followed by some 30 miles of solid rock overlain with perhaps 18 inches of stony soil.

West of the Little Colorado River the ROW crosses the highway just north of the Gray Mountain trading post at an elevation of 4,250 feet. It then climbs to 6,600 feet to cross Mesa Butte and remains near that elevation for the next 160 miles. Over the following 100 miles the pipe line will be all downhill, crossing Cottonwood Pass at 5,750 feet and then plunge 3,000 feet to cross the Colorado River at an elevation of 400 feet, lowest point on the entire system.

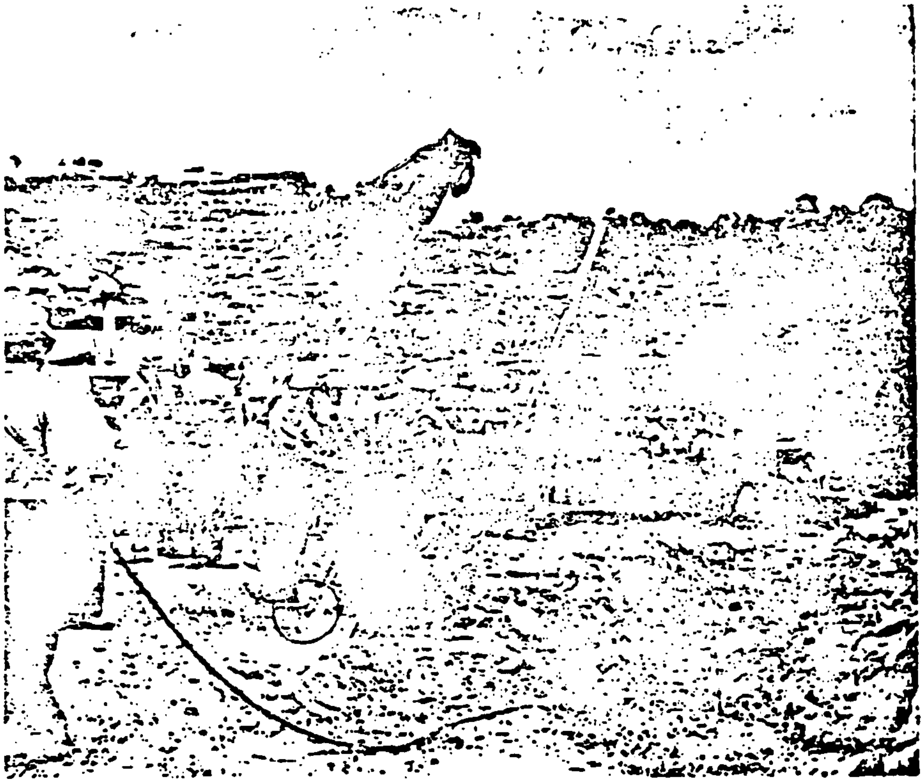
FREQUENT DEEP CUTS

Between the major elevation changes and maintaining an average 16 percent downhill gradient, the route leads up, down and over hundreds of minor buttes into deep gorges and arroyos and through dozens of cuts, most of which had to be blasted out of hard shale and basalt rock (Fig. 2).

Cuts from 20 to 50-foot depths were common. One ran to 70 feet at the crossing of the Little Colorado River. At Milepost 20, the route of the pipe line was actually shifted a couple of hundred-feet so that the contractor could blast off the side of a butte and use a dozer to push the spoil to one side instead of having to haul it out. An Air-Trac and a truck-mounted single-bit, 5-inch drill bored 50-feet deep holes into solid rock to make the cut. After the shot, some 32,000 cubic yards of stone were moved off the ROW to a depth of 59 feet.

PIPE SPECIFICATIONS

Most of the line pipe is heavy walled, but in some areas joint walls were quite thin. Changes were made to adjust for wear factors induced by hydraulics and gradient variations. Ex-



USING A CRC-CROSE internal lineup clamp and Scamp tack rig to apply the stringer bead, welding crews assemble the joints for the Black Mesa coal slurry pipe line across northern Arizona. Line begins on Navajo and Hopi Indian lands where the region is wild, extremely remote and largely composed of hard shale rock.

BENDING ENGINEERS PLOT the sags and side bends for the Black Mesa pipe line as it courses through the Dot Klish Canyon in northern Arizona's Land of the Navajo. Deep cuts, averaging around 50 feet through solid rock were commonplace as the ROW led for some 20 miles westward on the canyon floor.

CLEANING OUT SHOTHOLES on the route of the Black Mesa pipe line, crews use one of a pair of Ingersoll Rand Pipeline Twin drills as the ROW crosses a 30-mile region of solid rock south of Gray Mountain in northern Arizona.

cept for the Grade B pipe used in river crossings, all was LX-52 in wall thicknesses of: 0.500, 0.469, 0.406, 0.375, 0.344, 0.312, 0.281, 0.250 and 0.219. For the 12-inch seamless pipe, wall thicknesses include: 0.625, 0.594 and 0.531. At the river crossings, Grade B 0.500 wall, 18-inch pipe was used at the Little Colorado and 0.750 wall, 14-inch pipe at the Colorado. At both crossings, the line was buried in an underwater trench as the bottom was largely composed of gravel and there was small danger of external corrosion due to sand scouring.

Somastic and concrete coating was applied to the line as it passed beneath the rivers. H. C. Price was the contractor at the Colorado and American Pipe & Construction Co. at the Little Colorado.

Elsewhere along the system the line was coated and wrapped over the ditch with Kendall's cold primer topped with 20-mil Polyken tape.

CONSTRUCTION METHODS

Welding was done using a Cat-mounted CRC-Crose Scamp rig delivering 50V at 200 amps and with Fleet 5 rods for the stringer bead. Lineup was made using a Crose internal clamp. The firing line, manned by welders with individually owned pickup-mounted rigs, applied the hot pass, filler and capwelds with medium voltage at about 185 amps and burning Shieldarc 85 rods.

Throughout the system the bottom of the ditch is padded with sandbags; and after lowering-in, the line is backfilled with dirt to cover the pipe to a depth of 30 inches. Much of the dirt fill has to be imported as the native soil is rocky and would damage the coating and wrapping. Where "import" is required, the fill is deep enough to provide protection and then topped with the native material.

Inspection of weld joints is made by the Richardson X-Ray Service.

Along the ROW the pipe line will make four railroad, eight highway and two river crossings. As of early July, the pipeliners were stretched out over a 115-mile-long spread.

HYDROSTATIC TESTING

The system is hydrostatically tested to a 95 percent maximum and 79.2 percent minimum yield strength. Water for testing is drawn from five Peabody Coal Co. wells at Black Mesa. Throughout the entire ROW, no other dependable water supply is available. Testing is done as sections are completed. Ultimately on completion, the whole line will be water-filled, requiring about 900,000 barrels of water to perform the tests.

Passing near Gray Mountain and the site of Station 2, the ditching crew is in the midst of a long area of solid rock with an overburden of about 18 inches of stony soil. Backhoes expose the subsurface rock and the trench is cut by explosives. A pair of Ingersoll-Rand Pipeline Twin and one quad drill cuts hole for the dynamite and ammonium nitrate charges.

SUBSURFACE WATER PROBLEM

Although the entire country across which the Black Mesa pipe line runs is arid and dry as a tinderbox, water has caused construction difficulties on the beginning mileage.

In the Dot Klish Canyon, the line crosses an intermittent stream bed 44 times. At each crossing and less than 2 feet beneath the ground surface an underground water flow fills the ditch. Removed by pumps and emptied onto the canyon floor, it has formed a flowing stream to the obvious joy of some dessicated-looking cattle who have homesteaded the gorge.

Flashflooding, common during July and August, poses another threat to construction within the canyon.

PREHISTORIC RUINS DISCOVERED

Remote though the area is, and today but sparsely peopled by the Navajo in his lonely hogan, the route of the Black Mesa pipe line lies within a region occupied by man for centuries.

Archaeologists from Prescott College touring the ROW have discovered at least four ancient Indian pithouse communities exposed by the ditching machine. The major find, situated at Milepost 32, is extensive and consists of two separate villages. Topmost of these dates from about 950 A.D. while below it, the other was built and occupied around 530 A.D. by a tribe known as the Anasazi (the Old People). Each of the sites exposed on the ROW was excavated by the archaeological team and artifacts removed and preserved for study.

Continuing the role of the Indian in today's technology, Black Mesa Pipeline, Inc., will draw as many employes as is possible from the native Hopi and Navajo tribes, owners of the land across which much of the pipe line extends. ■

THE HISTORY AND IMPORTANCE OF NITROUS OXIDE LEAK DETECTION

The Nitrous Oxide (N_2O) method was developed by Mr. Vernon Scott some 10 years ago and several important projects were undertaken at that time. One of the more important projects was the communications cabling of the United States Air Force Minuteman Missile Program which was completed in 1964. Included is an article from the October 22, 1962 issue of The Oil and Gas Journal describing the first major pipeline project using the Nitrous Oxide method. This leak detection was carried out on Pacific Gas Transmission Company's pipeline from the United States-Canadian border to the California-Oregon line.

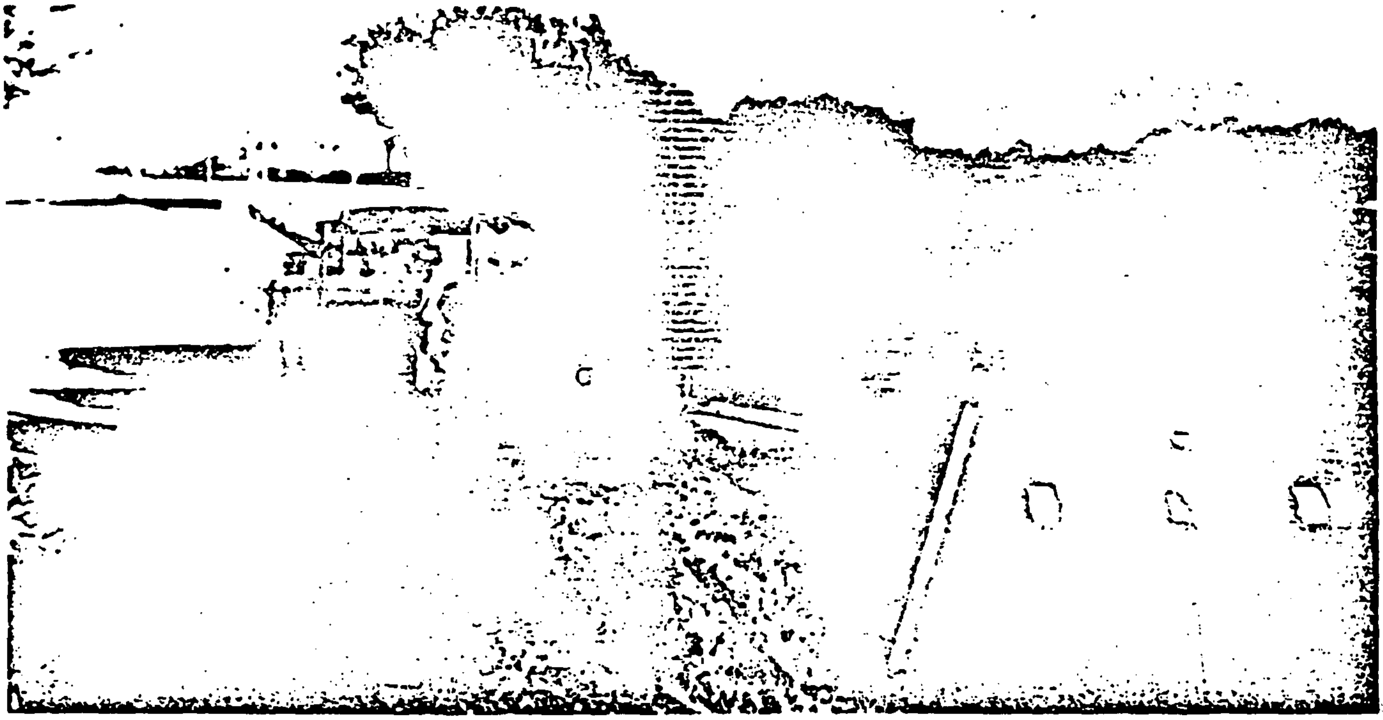
The Nitrous Oxide method was obtained from the Scott Corporation in 1969, by the International Leak Detection Services, Inc. and since that time the old infrared equipment has been remade into the latest solid state instruments incorporating the better features of the outdated equipment.

The results brought about by this solid state equipment is evidenced by the successful leak detection which revealed fifteen leaks on the Black Mesa Coal Slurry Line.

the OIL AND GAS JOURNAL
A REPRINT October 22, 1962

N_2O proves good leak detector in hydrostatic testing program

BY H. C. BOZEMAN
Journal Staff



PRIMING PUMPS take suction from floating suction lines in the river. These pumps feed water to the fill pumps.

N_2O proves good leak detector in hydrostatic testing program

A TRACKED VEHICLE pulls a subsoil sniffer which takes a gas sample below the surface for more accurate location of the leak. Shock-mounted detection equipment is installed on the vehicle. The recorder and control equipment is placed in the driver's cab.

BY H. C. BOZEMAN
Journal Staff

THE BIGGEST hydrostatic testing program and the first to use nitrous oxide commercially was carried out on Pacific Gas Transmission Co.'s pipeline from the U.S.-Canadian border to the California-Oregon line.

This portion of the huge Alberta-California natural-gas pipeline consists of 612 miles of 36-in. pipe.

Nitrous oxide is nontoxic, noncorrosive, and water soluble. It is a synthetic compound, nonexistent in nature, so it can't be confused with natural materials or environment. It diffuses properly, rises to the surface for easy detection, is reasonable in cost, positively detectable by mobile instruments, and available in quantity.[1,2]

The pipeline crosses high and rugged terrain. Despite these obstacles, the test was finished in 3½ months. Completion was 2 weeks ahead of schedule, primarily because of the use of nitrous oxide for leak detection.

Thirteen leaks were found. One split, near a weld in the line, occurred during testing. Average time for locating a leak was about 1 day. Without nitrous oxide, the contractor said, it would have taken much longer to find the leaks since only

ONE OF THE SKID-MOUNTED 550-hp gas-turbine-powered fill pumps (center) is shown on location at the Umatilla River. The complete skid weighs only 8,000 lb. Nitrous oxide cylinders are manifolded together (right). Also, nitrous oxide is available in refrigerated tank trailers.

one showed moisture at the ground level.

The test program was divided into three phases: (3) filling the line with water, (2) pressure testing and leak detection, and (3) dewatering.

Filling. Pressure-testing began after laying operations were complete and the contractors had moved off the job. The filling step consisted of: (1) manifold fabrication, (2) manifold installation, and (3) filling the line with water.

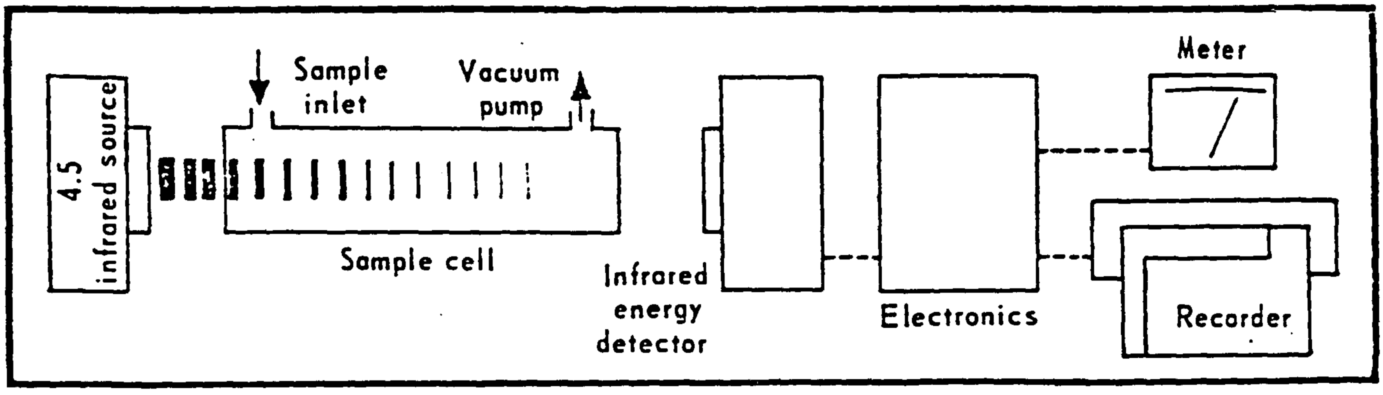
The test criterion was to stress the pipewall to a minimum of 95% of specified yield with an upper limit of 100%. It established the location of test sections because of elevation changes. The line was divided into 119 test sections.

Manifolds were installed at each end of a test section to launch or receive foamed polyurethane filling pigs. Valves in the manifold permitted bleeding air during filling, isolation of section during pressure test, and draining water after testing. Whenever possible main-line block valves were used for test manifolding.

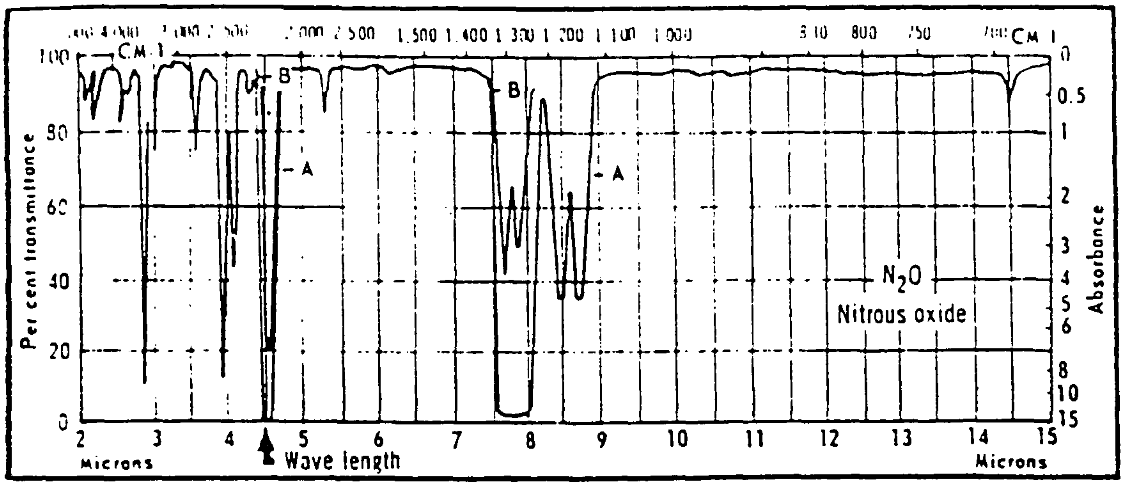
Manifolds leapfrogged. Crews installed the first manifold at the California-Oregon line and then worked northward. As a section was completed, manifolds were leapfrogged ahead.

Water pumping began at the Williamson River, elevation 4,500 ft, near Klamath Falls, Ore., and nitrous oxide was blended into the fill water in trace concentrations. Filling proceeded behind the manifolding crew.

Other water sources were Crooked River, elevation 2,750 ft, near Bend, Ore.; Umatilla River, elevation 560 ft, near Pendleton, Ore.; Spokane River, elevation 2,020 ft, near Spokane, Wash.; and Pend Oreille



SCHEMATIC of the nitrous oxide infrared analyzer. Infrared radiation from two similar Nichrome filaments is filtered to a specific wave length. Beams travel through two parallel gold-plated stainless-steel cells to a detector. Now, if the gas in the sample cell absorbs the infrared radiation less light intensity from this cell will reach the detector than from the reference cell. A chopper alternately blocks light from the reference and sample cell which alternately expands and contracts the gas in the detector cell and causing a condenser microphone membrane to move. Thus, a signal is generated which is amplified and fed to a recorder.



CURVES show the infrared characteristics of nitrous oxide and several other gases in the 2 to 7-μ wavelength region. Nitrous oxide has high speed absorbency at 4.5 and 7.8 (not shown) μ. Methane, butane, and propane have high absorbency in the 7.6 to 8.0-μ region so the nitrous oxide detectors use the 4.5-μ wave length.

River, elevation 2,070 ft, near Sandpoint, Idaho.

Pumps and prime movers were either skid-mounted or placed on semitrailers for easy portability. Fill pumps were two 550-hp gas-turbine-driven five-stage centrifugal pumps, one 1,000-hp gas-turbine driving two pumps for either series or parallel operation, and one 300-hp diesel three-stage pump.

Turbines flexible. The gas turbines proved flexible in operating despite large elevation changes. Each of the five-stage pumps had a maximum capacity of 1,800 gpm at 300-ft discharge head to 1,000 gpm at 1,000-ft discharge head. Diesel-engine-driven pumps primed the fill pumps with river water.

Pumping started on schedule but the Williamson River soon went dry and the pumps were relocated at the Crooked River, 90 miles further up the line. This move raised the pump's required discharge pressure by 1,750 ft.

Water sources were not entirely dependable since many rivers there normally are dry in early autumn. The mountainous, remote location of the pipeline added to the difficulties. Water was purchased from irrigation districts located along the pipeline. On one occasion water from a dam on the Umatilla River above the pumping station was discharged to provide fill water. All pump locations were on or near major highways.

Other problems. Other problems arose during filling. Floating moss on the Crooked River threatened to block the suction of the prime pumps. It was skimmed from the water's surface to prevent its floating into the suction pipes.

Farther north at the Umatilla River, wheat chaff floating on the river plugged the suction lines on the prime pumps one day about 2:00 a.m. Pitchforks were used to clear them and keep them clear.

About 2,000 gpm of water was pumped for about 50 days to meet the contract schedule. Peak pump rate was 6,000 gpm when pumping was in progress at four locations.

Testing and detection. The test sections were blocked off when filled with water. A small reciprocating pump was connected to the test section. Water was pumped into the section until the test pressure was reached and the pump was then disconnected.

Dead-weight pressure readings were taken hourly for 24 hours. The specification called for the pressure at the end of the test period to equal that at the beginning. When a section showed loss of pressure the leak had to be located. A mobile truck checked the area around all valves and fittings. At the same time a tracked vehicle with a subsoil sampler traversed the line to pinpoint any leak in the pipe.

Almost all leaks were around main-line installations on screw fittings, flanges, and small valves. The deepest was 14 ft below the surface and average depth was 4 ft. Two leaks were found before test pressure was applied.

All sections were pressure tested as well as every pup cut from the pipelines. Caps were welded on each end of the pup and they were tested at the same pressure as the rest of the line.

Manifolds were removed after the test was satisfactory and the pups were rewelded into the pipeline. Completed welds were X-rayed.

Dewatering began as the tests were completed to specification on each section. It was planned to minimize right-of-way damage.

Natural low points on the pipeline were picked for dewatering. About 60% of the water drained by gravity.

Final dewatering and drying began when natural gas was introduced at a tie-in to an El Paso Natural Gas Co. line near Spokane. The line was dewatered northward to a point near the U.S.-Canadian border and southward to Stanfield, Ore. At Stanfield, gas from El Paso's main line pushed the pig trains south to California.

The pipeline was dry and full of natural gas at low pressure when dewatering was completed at the California-Oregon line. The pig trains traversed the pipeline a sufficient number of times to reduce the retained moisture level inside the pipe to specifications. No methanol was used for final drying. The internal coating on the inside of the pipeline made drying much easier, according to the contractor.

Bechtel Corp. was project manager for constructing the pipeline. Thomas Contracting Co. did the pressure testing and Scott Corp. did the leak detection.

References

1. Kaufman, John E., "Use Nitrous Oxide to Spot Pipeline Leaks": The Oil and Gas Journal, Vol. 58, No. 8, p. 100, Feb. 22, 1960.

2. Williams, Ralph, "Nitrous Oxide Traces Pipeline Leaks": The Oil and Gas Journal, Vol. 60, No. 10, p. 108, Mar. 5, 1962.

LEAK DETECTION IN COMMUNICATION CABLE SYSTEMS

With the exception of the Nitrous Oxide (N_2O) injection, the leak detection is carried out identically with that of the pipeline method.

The injection of N_2O into a cable system is accomplished with a mixture of 10% N_2O and 90% dry Nitrogen, making it an ideal pressure gas for the system.

The leaking section is selected and a back pressure regulator is connected at the discharge end of the section and set at a predetermined pressure; for example, 5 PSI. At the injection end, the 10% N_2O bottle is connected and the regulator set at a higher pressure than the discharge end; for example, 15 PSI. The gas flow then begins with the N_2O flowing to the area of least pressure which is the direction of the back pressure regulator. Periodic gas samples are taken at discharge end until desired concentration of N_2O is reached. The back pressure regulator is then removed and the line is allowed to reach maximum pressure for twenty-four hours. The leak location is then accomplished as on a pipeline.

WHY NITROUS OXIDE AS A TRACER?

Consider the characteristics of an ideal tracer material for detecting leaks in pipelines. Generally it should have the following qualities:

1. Nontoxic and noncorrosive to make it safe for both men and pipelines;
2. Water soluble so it can be mixed with hydrostatic test water;
3. Synthetic, not existing in nature, so it cannot be confused with natural materials or environment;
4. Proper diffusion characteristics so it will rise near the surface of the ground for detection, once it escapes from the line;
5. Reasonable cost and readily available in the proper quantities; and
6. Positively detectable by a portable, reliable instrument at a relatively fast survey speed. The instrument system should be such that the element of human interpretation is eliminated.

Nitrous Oxide has all of these "ideal" characteristics. Its response on the infrared spectra at 4.5 microns wave length is virtually unique. Only one other gas -- diazomethane -- could possibly be confused with Nitrous Oxide, and this gas is quite rare and certainly not to be found on a pipeline right-of-way.

DOMESTIC RATE SCHEDULE

Item	Description	Rate
1.	Leak Detection Unit/Operator	$225.00/Day
	(a) One unit and one operator based on 10 hour day	
	(b) Necessary Nitrous Oxide (N_2O) injection equipment	
2.	Nitrous Oxide (to be furnished by customer)	
	If furnished by International	$ .70 lb.
	International can provide customer with necessary information for obtaining which results in savings to customer.	
3.	Transportation to Site	
	All travel expenses of personnel and equipment billed at cost plus 10% or Move-in and Move-out quoted at time of job acceptance.	
4.	Plow-Vehicle and Sub-Soil Unit	
	Is requested to be furnished by customer.	
	If provided by International (Ford tractor and sub-soiler with operator 10 hour day)	$100.00/Day

CUSTOMER SUPPLIES:

1. Description and drawings of line.
2. Vehicle and operator for Right-of-Way traverse.
3. Special access through pavement or flooring where involved.

CUSTOMER SUPPLIES: (Continued)

4. Fence crew or special access personnel and equipment.

5. All permits.

6. Support personnel where necessary when large quantities of bottled gas are handled, or line fill requires around-the-clock operation and if extensive hand probing of Right-of-Way is required.

7. All personnel required may be provided by International Leak Detection Services at additional charge. Normally, one technician and leak instruments are provided by International at the above quoted rates and support personnel are furnished by customer.

FOREIGN RATE SCHEDULE

Item	Description	Rate
1.	Leak detection unit/operator	$400.00/Day
2.	Nitrous Oxide (to be furnished by customer)	
3.	Plow-vehicle and sub-soil unit (to be furnished by customer)	
4.	Transportation to and from Right-of-Way (to be furnished by customer)	
5.	All other rates as quoted on Domestic Rate Schedule.	

A-2

UTILITY TECHNICAL SERVICES, INC.

UTILITY
TECHNICAL
SERVICES, INC.

P.O. Box 3613 • Englewood, Colorado 80155 • 303-773-2808

January 30, 1991

Ann Sieben
A S I
400 Urban
Suite 401
Lakewood, CO 80228

Dear Ms. Sieben:

Thank you for the inquiry to Utilty Technical Services, Inc. We would like to offer the following information for consideration as a qualified contractor for leak detection on your project.

UTILITY TECHNICAL SERVICES, Inc. is a company specializing in unaccounted for water in municipal and private water systems. Established in 1985 the firm has surveyed hundreds of miles of pipeline in the western United States with excellent results.

We have surveyed pipelines of virtually all materials and sizes, and our combined experience and expertise encompass all types of systems under a wide variety of conditions. We have at this time performed over 200 leak surveys covering fifteen of the western states. With four leak noise correlators, UTS and their associates offer prompt, thorough and accurate leak detection. Our effort, conscientious approach, and success is reflected in our excellent reputation.

In the water distribution field since 1973, David Anderson had a background that put him in touch with the needs of the water industry. First, in sales of two of the leading suppliers of waterworks equipment in the midwest and western United States and second as a manufacturing representative for MUELLER CO. Mr. Anderson has also contributed papers to the AWWA which were published in the national handbook "Introduction to Water Distribution Systems". He has helped conduct leak detection seminars for the AWWA, Washington State Department of Social and Health Services, Colorado Rural Water and recently for the National Rural Water Association. This last training seminar was to instruct all 52 of the NRWA circuit riders on the methods of leak detection.

2.Equipment

The equipment used is the METRAVIB noise correlator. This includes the correlator (micro-processor) itself (in a van), radio transmitters, which amplify and send the noise (vibration) signals to the correlator, accelerometers which are used for metallic pipe contact and hydrophones. Hydrophones rely on sound transmission through water and must make contact with the fluid in the pipe. Accelerometers pick up the noise from the pipe wall.

The correlator includes multiple noise frequency filters with a total of 20 ranges which can be combined in numerous arrangements. This allows the technician to scan many overlapping frequency ranges in order to detect leaks, to determine the best range for location and size estimation. The correlator computes and gives the results on an oscillpscope where the operator can make his determining decision. This correlator also allows the input of virtually infinitely variable sound velocity data as required by the pipe size, material, age, bury, compaction, corrosion and combinations thereof. This unique instrument allows the technician to determine actual velocities under your particular field conditions. Its speed and convenience make it a superior instrument which maximizes operator skill and experince as well as system variables. External noises such as pumps or machinery that cause vibration on the pipeline must be offduring the survey.

3. Proposed Methodology

The leak survey begins at one end of the system (or portion of system) to be surveyed, and proceeds section by section until that portion is completed. The sensors are placed at intervals determined in part by the pipe size, material, as well as availability of access and pressure. Generally the set-up length desired on a water distibution system is one city block. Commercial setups vary depending on external noise loads. On non-metallic pipe materials, hydrophones are utilized, enabling us to detect and pinpoint leaks on PVC, AC and large diameter pipelines. These connections must have contact with the water in the pipeline. This is generally accomplished by making a connection at a fire hydrant or meter set.

The key to our method is that all spans of pipeline are scanned for leak noise through the full frequency range and not just at convenient contact points. This is crucial, since we have seen leaks that are not detectable by any other method. With the equipment used, if pipeline access is relatively easy (as in main line valves or fire hydrants at each intersection), the survey can proceed quite rapidly. Minimum survey quantity is two miles per day but four to five miles are common. The equipment will also detect multiple leaks on a single set-up. If necessary, leaks can be detected and pinpointed at much greater distances, up to 2,400 lf in some cases.

Leaks can be pinpointed later, after the entire system is surveyed, or at the time of the survey. If pinpointing is carried out during the survey the district can start excavating and making repairs early. Pinpointing later reduces the chances of chasing down consumption noises. A district employee with support vehicle and familiar with the system is asked to be present during the survey. This person will assist the technician in placing and connecting of any sensors, operating of any valve, shutoff and general public relations.

Records of all set-ups, measurements and leak locations are kept on a daily basis. The leak location form is provided to the district for each leak found. The district provided map is also clearly marked with leak noise locations which are in turn, keyed to the individual leak record sheets.

Our rates vary depending on the piping situation. Leak surveys are generally quoted by the foot with a 25,000 foot minimum. Daily rates are $650.00 for one half day and $1000.00 for a full, day. Jobsites outside metro Denver are an additional .35 per mile and accrued expenses. Work can begin usually within one week of notice.

We hope that this proposal will meet with your approval. If you have any additional questions, please do not hesitate to call.

Sincerely;

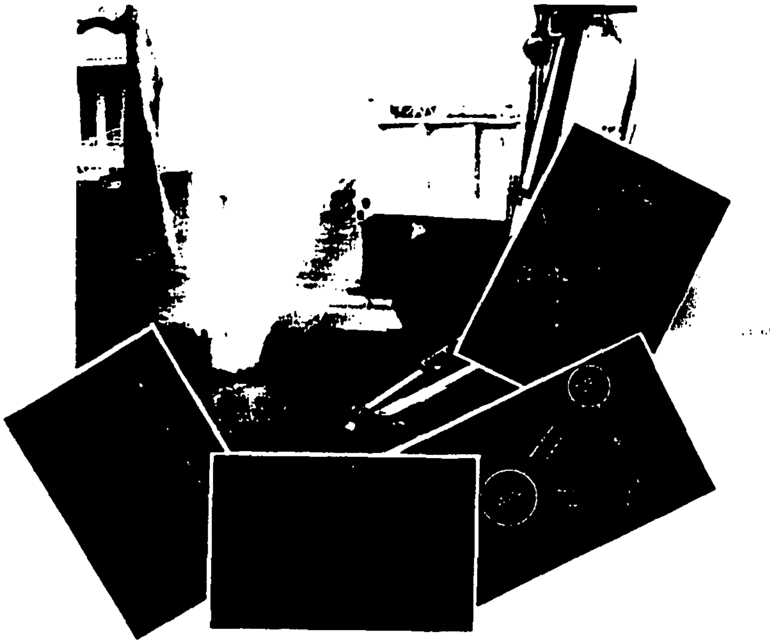
David B. Anderson

A-3

DONOHUE ENGINEERS, ARCHITECTS, SCIENTISTS

Statement of Qualifications

Water Audit/Leak Detection Services



Donohue ENGINEERS ARCHITECTS SCIENTISTS

CONTENTS

■ INTRODUCTION

INTRODUCTION

Estimates by national funding agencies have indicated that nearly $100 billion will be required during the next 20 years to maintain the water systems in the United States. Furthermore, $100 billion more will be needed to construct and expand water systems just to keep pace with new development and growth. The U.S. Department of Interior has indicated that developing and maintaining adequate water systems will be the resource issue of the coming decade.

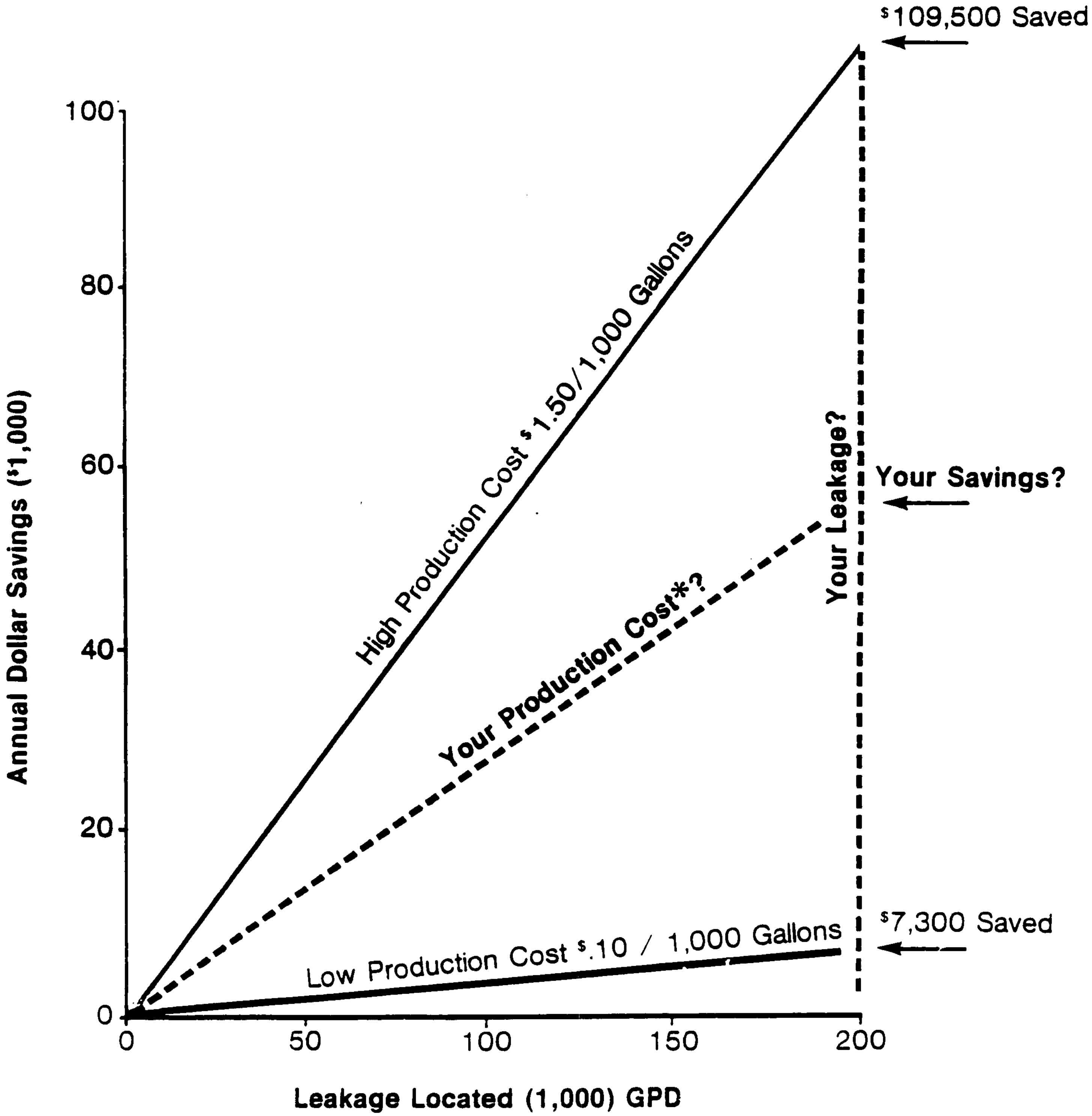
Water lost through a deteriorated pipe network carries a double price tag: 1) depriving the producing utility of revenue, and 2) forcing customers to pay for water they have not and cannot use. Losses, whether product or revenue, have the potential to restrict new development, complicate and frustrate system planning, and cause more emergencies than should normally be addressed. Solving water loss problems can enhance system operations and reduce product and revenue inequities.

The water audit is an important part of solving these problems. Donohue has developed and refined water audit and leak detection techniques which are fully described in this document. Briefly, a water audit consists of a series of investigations designed to give the utility accurate, concise, and practical data concerning its system. A professionally conducted water audit program has a rapid payback, resulting in savings from the recovery and control of unaccounted–for water within the distribution system.

Donohue approaches its water audit projects with a blend of engineering knowledge and practical hands–on experience. We have gained this expertise through countless water system designs, comprehensive planning reports, and management projects. Our hands–on experience consists of comprehensive field investigations in more than 250 communities. We possess the in–house equipment, personnel, and expertise to conduct all forms of field investigations. Many of our past projects are described in this document, accompanied by the name of the appropriate client reference. We strongly urge you to contact these references for their assessment of our performance.

We would welcome the opportunity to discuss our capabilities in greater detail and to assist you with your project. Our dedication to professionalism will result in a quality project that meets time and budget constraints.

Annual Savings From Leakage Repair



*Production Cost = (Chemical + Energy Costs) / 1,000 Gallons

TYPICAL WATER AUDIT ACTIVITIES

TYPICAL WATER AUDIT ACTIVITIES

The term "water audit" describes a series of activities that can stand alone, or that can work in concert with other activities to form a more comprehensive effort. An exciting feature of this approach is its flexibility. We can tailor a series of water audit activities to take advantage of their individual benefits so that the problems are adequately addressed, but with the client's schedule and budget clearly in mind. These individual activities, which are described in this section, include:

- Background Data Review
- Meter Testing
- Leak Detection
- Field Measurements
- System Inventory
- Storage Facility Inspection
- Computer Modeling
- System Design
- Infrastructure Management
- Client Personnel Training

Background Data Review

In some cases, the first step in a successful water audit is to meet with client representatives to determine the proper approach to solving the problem. Donohue brings to this process our experience with previous projects and our ability to assist in defining conditions that might be addressed. By combining the client's knowledge of the system with our engineering capabilities and experienced personnel, an approach can be developed that will solve problems in the most efficient and cost–effective manner. Donohue will provide budget information and assist in developing a schedule to take advantage of climatic conditions that can influence certain field activities. We are also prepared to assist client staff in creating public relations materials and making presentations to citizen or government groups.

Meter Testing

A widely used first step in determining total unaccounted–for water is to test the master water meters for accuracy. These meters measure flow into the community, whether from well sites, points of entry from other suppliers, or the treatment facility. Testing meters under operating conditions provides an accurate assessment of the meter's accuracy and eliminates the potentially large expense of removing and replacing the meter.

Over–registration (recording more water than is actually flowing through the meter) can falsely indicate leakage or other unaccounted–for water that does not exist. Under–registration might mask actual leakage and could cause a false sense of security concerning the system. Meter tests are critical in the case of purchasing water from a wholesale supplier or a contract community and should be checked often to ensure proper invoicing and revenue balance.

Tests are conducted in–place and require only a short time to complete. The tests do not disrupt the system in any way and do not require client personnel to be diverted from other duties.

Leak Detection

The most popular service provided during an audit is the leak detection survey. The purpose of this survey is to identify and mark, in the field and on maps, the precise location of active leaks. We also provide an estimate of leak rate based on the amount of noise detected.

The survey is conducted using several pieces of equipment which intensify the sound made by water escaping from the distribution network. Our approach to leak detection involves two steps which result in thorough coverage of pipes in the survey area and accurate location of leaks for subsequent repair by the utility. A general leak location procedure is followed by pinpoint location. This two–step procedure allows high productivity, superb accuracy, and efficient documentation of findings.

General leak detection involves placing electronic sound amplification equipment directly on the system at hydrants, valves, curb stops, and other exposed components. We can also apply this equipment to water services, meters, and hose bibs. For larger mains, surface listening points might also be used to identify noise from potential leakage. During this general survey, noise from potential leaks is documented on field forms and identifies the probable location, such as on a main between two hydrants. These suspect locations are plotted on utility maps to record areas for subsequent pinpoint location.

Pinpoint leak detection is performed after the general leak detection survey using the most sophisticated equipment available. With this equipment, we can pinpoint leaks to within several feet, well within limits of excavations required to complete repairs. The leak correlator, the most accurate piece of equipment in use today, is employed.

The correlator operates on the principle that noise from a leak, heard at two known points, can be compared at these two points so that a correlation is measured. The measured correlation identifies the distance from both points to the site of greatest noise, the leak. Using this device, we have accurately located leaks to within one foot of their actual location. The correlator is computer driven

and uses the known physical characteristics of the pipe, the distance between known points, and the speed of sound through various pipe materials. Information is transmitted from both listening points either through hardwire or by radio transmitter. The accuracy and speed of the correlator have been demonstrated through many projects.

Detected leaks are judged for potential leak rate. Using the utility's cost data, we are then able to estimate annual savings possible from repairing leaks. In many situations, we identify sufficient leakage to pay for our survey in two years or less. In some situations, we identify leakage with a payback period of six months. The benefits of leak detection include its simplicity, accuracy, and cost–effectiveness. Our leak location success ratio is in excess of 95 percent; that is, 19 of 20 leaks we identify are in the locations we predict.

Field Measurements

District Measurements

Water demand can vary extensively throughout a distribution system. Dividing the network into individual districts often is a practical step in evaluating overall system performance. Typical districts contain 10 to 20 miles of main and are established to contain homogeneous users so that consumption patterns can be measured. Water flow into each district is measured at a single point using a Pitot rod and flow recording instrument. Flows are generally recorded for several days to establish a consumption pattern during typical 24–hour periods.

Based on these 24–hour patterns, the ratio of average flow to minimum flow is determined and forms an initial basis for determining leakage potential in the district. Using actual field measurements yields very accurate data so decisions for future activities are reliable and justified.

Subdistrict Measurements

The purpose behind a subdistrict measurement is to subdivide a district, where potential for leakage has been identified, into smaller areas. Each subdistrict is evaluated for leakage potential and either eliminated from further investigation or scheduled for detailed leak detection.

Subdistricts are performed using the same pitot equipment used for district measurements. They are generally performed in the late evening and early morning hours and contain less than one mile of main. Again, valving off methods are used to isolate areas of the system for measurement.

Subdistricts are generally completed at night between midnight and 5:00 a.m., when it can be assumed that little or no water is being used. Flow measured in the system is assumed to be caused by leakage. This then gives an even smaller area within a distribution system to concentrate leak detection. Investigations in high usage areas determine if high flows are the result of unauthorized use, leakage, or other causes.

Pump Efficiency Tests

Pumps that are inefficient cause two problems: inordinate energy consumption and poor performance. Using specialized equipment, we conduct in–situ tests to determine pump efficiencies as they occur in the system. Bench testing alters conditions, is not totally reliable, and has the further disadvantage of disrupting the network. A true pump operating curve can be determined which reflects actual field conditions, another accurate data set required for a computer model. Tests are conducted in–place and measure flow, pressure, and electrical energy. Tests require little time and do not cause interruptions to the distribution system or require utility participation.

runk Main Gauging

Field measurements of flow conditions in major transmission mains are critical to determining actual performance. Basic parameters evaluated during this activity include flow direction, discharge, and pressure. Field measurements are made over several days to obtain a typical 24-hour data set. In supporting a computer model, field measurements replace theoretical values so that the model closely mirrors the actual system.

Trunk main survey data provide the utility with information as to whether those transmission mains are operating at full capacity. With or without a model, the decision to replace or expand transmission line size will be significantly influenced by these results.

Loss of Head – Friction Factor Determination

A key factor in determining the ability of a water main to carry a desired flow, at a certain minimum drop in pressure, is the coefficient of friction of the internal pipe walls. Frequently, a friction factor is estimated for purposes of an engineering study based on industry averages for pipes of certain age and materials. A far more precise method of determining the friction factors is through field measurements. Measurements are made at two points along an isolated main to determine actual flow diameter inside the pipe, the discharge through that pipe, and corresponding pressures at that discharge level. These measurements are converted to a friction factor which represents actual pipe characteristics rather than estimates of those characteristics.

Other field measurements and investigations include:

- Fire Flows
- Pressure Testing
- Valve Exercise Program
- Corrosion Evaluations

System Inventory

During each of our field operation activities, we note the conditions of the distribution system so that map discrepancies can be corrected. High–quality records are the single most important group of information a utility can possess since nearly all operations flow from these documents. As routine procedure, we note the location of all components operated during our activities. We document the condition of valves, hydrants, curb stops, and other components and also list any problems such as damage, missing parts, or inaccessibility.

An inventory of the system is a physical reconnaissance designed to precisely locate and assess the operational status of distribution network components. The resolution of discrepancies between actual field locations and design or planning reports provides accurate modeling and, more importantly, gives precise locations of components for access during emergency periods. System inventory is an important part of maintaining accurate and current records.

Storage Facility Inspection

Every water storage tank, standpipe, or reservoir should be carefully inspected prior to repair and/or repainting and at any time when leakage or some other deterioration is observed. The AWWA recommends all water tanks should be thoroughly inspected at intervals of not more than five years.

Computer Modeling

The purpose of a computer model is to allow designers and operators to evaluate results of improvements or modifications before they are carried out. Computer modeling allows our engineers to rapidly and accurately observe the consequences of alternative actions, a vital process in determining the most cost–effective solution to distribution system problems.

Our in–house VAX 11/780 computers provide the necessary speed and accuracy to operate the University of Kentucky (Wood model) program. We evaluate the full network including storage facilities, valves, meters, and other components. Items observed during typical modeling runs include total hydraulic capacity, fire flow capability, expansion feasibility, and overall system reliability.

The model, once developed, becomes a tool that can be used continually for evaluating performance and planning future activities. Perhaps the most important factor in establishing a model is the calibration to the actual system. We start the model's development by looking at system maps and other theoretical data. We believe very strongly, however, that field measurements must be obtained to allow the model to accurately reflect actual field conditions. We have the tools necessary to make these measurements and the engineering acumen to determine which measurements to obtain.

Design of System Components

Our engineering expertise in water distribution systems has spanned more than 75 years. We have designed all facets of distribution systems from small extensions to major water treatment facilities and pump stations. Many of our engineers serve as professional representatives for water utilities, and we have completed dozens of comprehensive plans for water systems.

Design has included transmission mains, storage facilities, extensions for residential, commercial, and industrial clients, and new and expanded purification facilities. Our planning and design personnel are augmented by a construction–related services staff of resident engineers who have vast experience in construction techniques and methods. Their expertise assists our planners and designers in developing system plans that can be built economically and that efficiently serve the intended function.

Donohue is a total engineering firm; we possess the personnel, experience, and equipment to handle all facets of water systems. We have built our reputation on high–quality service with a constant view of our clients' needs and desires. We have the water system expertise to successfully perform any project to your satisfaction.

Infrastructure Management

Our infrastructure management (IM) staff includes experts in automated mapping and facilities management, application specialists, engineers, planners, computer scientists, and system analysts/consultants. We also have in–house expertise in various geographic information systems (GIS), including Intergraph, Arc/Info, AutoCAD, DigiCAD, Synercom, and IBM.

Whether you're looking for total integration of your infrastructure information or simply a place to start, Donohue can help you maximize your decision making, minimize costs, and improve the services you provide.

Client Personnel Training

Donohue maintains a high level of training throughout all areas of the company including water audit/leak detection personnel. We maintain a full–time corporate training manager who coordinates and assists in training needs. Our personnel have developed a classroom training program which utilizes not only their extensive experience but also slides, exhibits, and case studies conducted over the years. Several of our engineers have prepared and presented professional papers on subjects such as Leak Detection Equipment – What's Right for You; Field Evaluation of Water Systems – Key to Effective Maintenance and Planning; The Role of Water Audits in Water Conservation; and Controlling Unaccounted–For Water. This knowledge, coupled with our extensive library of copyrighted record forms provide an impressive classroom training program.

Field training has been an ongoing process at Donohue since the start of our water audit/leak detection services. Donohue personnel possess both the required expertise in performing meter tests and leak detection and the ability to train client personnel in a well–organized manner. Typically, training begins by having the client observe several tests while our personnel explain the procedures being conducted. Once client staff members have developed the necessary knowledge, they conduct the tests themselves with the assistance of Donohue engineers/technicians. We will take the client through the necessary procedures until thorough understanding of all facets of field measurements and leak detection are obtained.

Our experience with a variety of leak detection and field measurement equipment allows us to select the type of equipment best suited to each utility. In the course of our investigations we have employed sonic leak location equipment such as geophones, aquaphones, and a variety of electronic amplification devices. We have had extensive experience in the operation of three distinct types of leak correlators made by Fluid Conservation System, Metravib, and Fuji. Our engineers and technicians have the knowledge to instruct utility personnel in the use of each type of equipment used.

■ EQUIPMENT

EQUIPMENT

Specialized equipment is required to effectively and efficiently perform water audit functions. We have made a significant investment, not only in equipment itself, but in training our personnel, so that we can provide high-quality service at reasonable prices. And we not only know how to operate these tools, but when to use them as well. Our experience allows us to be efficient by using the correct tools for each activity. Major pieces of our equipment are described below.

Computer-Enhanced Correlator

The most sophisticated piece of equipment in the leak detection field today is the computer-enhanced correlator. This device locates the source of sounds to a high degree of accuracy, although not by locating the greatest sound intensity. Operation of this equipment is based on the premise that for a known size and type of water main, the speed of sound along this pipe can be accurately determined.

In a typical operation, general leak location activities (using tools described above) have identified a potential leak in a portion of water main, perhaps between two hydrants. The correlator is used to pinpoint the exact location of this leak. The operation would then follow an approach such as that described below.

Highly sensitive microphones would be placed on both hydrants straddling or bracketing the leak. Radio transmitters send electronic signals to the computer processor that compares or correlates the time required for the leak noise to reach each microphone. By knowing the speed of sound for the type and size of pipe, the distance between both microphones, and the travel time for the noise to reach each microphone, a precise location of the sound can be determined. The computer processes the information and displays the sound's location on an oscilloscope. The operator then checks the sound's location using an electronic amplifier to confirm the existence and location of the leak.

We have used several different model correlators during the last several years and have had excellent success — in excess of 95 percent accuracy. We continue to be impressed with the correlator's accuracy, durability, and speed. It is a rugged unit made for the harsh environment in which it operates. Its most important feature is accuracy both in identifying the existence and the location of leaks.

Electronic Amplifiers

Electronic amplification equipment operates on the same principle as mechanical, except that sounds are enhanced electronically and directed to a headset worn by the operator. These devices amplify all sounds to a greater degree than mechanical devices, and are more accurate as a result.

Beyond better amplification, the electronic devices allow some of the ambient or background noise to be filtered out, permitting greater accuracy in listening for leak noise. Ambient noise results from vehicle and pedestrian traffic, industrial operations, and other sources. While the human ear cannot fully filter out these background sounds, the electronic amplifiers can, and the result is a more accurate, more rapid procedure to listen for potential leakage.

Donohue possesses two different brands of electronic amplifiers. These devices are used extensively during the general leak detection survey described in the previous section. While speed and accuracy are the true primary features of this unit, its ability to subdue background noise also reduces operator fatigue, resulting in greater productivity.

Mechanical Amplifiers

Geophones have been in use for many years. They are simple devices which amplify sound mechanically and might be thought of as large stethoscopes. The device has ear pieces and a contact disk. The disk is placed directly on the system (valve, hydrants, etc.), and any sound is amplified by a metal diaphragm directly to the operator's ears. We typically use these on a limited basis only, since they are not as effective as other equipment.

Additional Equipment

In support of other water system activities, Donohue employs a variety of equipment such as manometers, flow recorders, and calibration equipment used to perform pump efficiency tests. We own and operate equipment to perform fire flow tests and can rely upon our in–house equipment as well as leased equipment to adequately supply our crews with the proper type and amount of tools for any particular job. Hand tools commonly used include valve keys and calipers that help determine the actual inside diameter of pipes in the field.

All of Donohue's equipment is operated and maintained to manufacturers' recommendations. Our performance testing procedures involve using the best quality tools and having the equipment operated by trained, seasoned professionals. Operator training and periodic refresher training is a continuing part of our overall water system investigation activities.

■ PROJECT EXPERIENCE

PROJECT EXPERIENCE

Donohue has completed well over 250 water audits throughout the United States. Projects have ranged in size from small leak detection efforts completed in a matter of days to comprehensive water audits spanning many months. We have performed specialty projects such as evaluating a meter testing program for a large utility; putting an entire distribution system on computer–aided drafting systems; and evaluating several major city distribution networks in order to establish a long–range program of operation and management techniques.

The following pages describe some of our recent projects. Along with these are reference and contact information. We urge you to call on these clients for an appraisal of our efforts and performance. We think you will be impressed.

Water System Audit – Washington, D.C.

Donohue performed a comprehensive audit of a large portion of Washington, D.C.'s water system. Their annual program includes flow measurements of 60–80 districts, further measurements at 200–250 subdistricts, and leak detection for 150–200 miles of water main. The project identified leakage which cost more than $77,000 per year.

Because of our performance, we were awarded a contract amendment to evaluate the District's meter test facility and procedures. In an effort to control meter inaccuracies, we made a detailed evaluation of the meter test facility including physical layout, number of meters tested, size of meters tested, record keeping procedures, productivity, and staff sizing and training requirements.

As part of the annual program, we also conducted 60–70 in–place tests on large water meters to verify their accuracy. These tests often indicated significant inaccuracies which translate directly into lost revenues through artificially lower invoices.

Reference: James Dennis
Assistant Division Manager
202–767–7614

Leak Detection Survey (Phase I) – City of Portland, Oregon

Donohue Performed a leak detection survey over approximately 625 miles of main within the City of Portland. This included the West Central District, Southwest District, part of the South District, and Rose City.

Electronic listening equipment and state–of–the–art computer–assisted correlation equipment were used to locate the leakage. Two hundred sixty–two leaks were located during this survey, totaling over 1.7 million gallons per day of leakage. At the City's cost for water, repairs will save over one–half million dollars per year, a payback period of less than two months to recover the survey cost.

Reference: Dennis Kessler
Bureau of Water Works
(503) 796–7473

Leak Detection Program – Massachusetts Water Resources Authority

Donohue is currently under contract with the Massachusetts Water Resources Authority (MWRA) to perform leak detection services throughout the various communities in the greater Boston area. The MWRA supplies water to 46 cities and towns through approximately 130 miles of large aqueducts, 260 miles of large diameter distribution pipelines, and approximately 6,700 miles of water mains. The leak detection program consisted of master meter testing, district and total consumption measurements, and leak detection.

Results have already shown over three million gallons per day of leakage. This project is anticipated to last through the Summer of 1990.

Reference: David A. Liston
Program Manager
(617) 242–7110

Water Audit/Leak Detection Survey – Duluth, Minnesota

The water distribution system for the City of Duluth contains approximately 370 miles of main. The water audit consisted of nine master meter tests, ten large consumer meter tests, and eight district flow measurements. Two of the master meters and four of the large consumer meters were found to be inaccurate. A high potential for leaks was identified in four of the eight districts, and a leak detection survey was undertaken in these areas.

The leak detection survey identified 1,786,000 gallons per day of leakage. Annual savings of approximately $63,000 will be realized by the City of Duluth following repair of the leakage.

Reference: Mr. R. W. Monson
Water Division Manager
(218) 723–3381

Water Audit – Harrisburg International Airport, Pennsylvania

The water audit for HIA consisted of large consumption meter tests, leak detection, water distribution mapping update, inspection and evaluation of four elevated storage facilities, and a short–term and long–range maintenance plan.

Deterioration was identified on all four water towers and a cost–effective rehabilitation program was initiated. 176,000 gallons per day of leakage on 24 miles of main was identified at an annual cost to the airport of approximately $51,000. Five of the ten large consumption meters were identified as inaccurate and a repair, replacement, and meter installation program was developed. The long–range maintenance plan included tanks, meters, fire protection, and distribution which was developed through the year 2000.

Reference: Mr. Francis Strouse
Airport Engineer Supervisor
(717) 948–3968

Water Audit/Leak Detection Program – Elgin, Illinois

The City of Elgin has had an ongoing water audit/leak detection program of their entire system, consisting of 231 miles of water main. Donohue's scope of recent services included 76 miles of leak detection in 1983, seven district measurements in 1984, and a leak detection survey covering 88 miles of main and 144 miles of main in 1985 and 1986, respectively. Also, concluded in 1988 was a water distribution system analysis involving computer modeling.

Total leakage identified during these surveys was 1,239,000 gallons per day, representing almost 15 percent of the City's estimated pumpage of 8,500,000 gallons per day. The 1986 leak detection survey alone identified 555,000 gallons per day of leakage and it was estimated that an annual savings of $85,000 would result from repair of the leakage. Leak detection has been performed over a portion of the system more than once, indicating that leakage is a continuing problem. This is a normal occurrence for all water systems as they become older.

Reference: Mr. Ralph L. Ridley
Engineering Supervisor
(312) 695–6500

Comprehensive Water Audit – Cherokee Water and Sanitation District – Colorado Springs, Colorado

This project involved a comprehensive water audit, including district measurements, leak detection, and master meter tests. Results indicated that one master meter acted erratically depending upon the operation of different pumps. Leak detection identified approximately 31,000 gallons per day, a relatively small total and indicative of a well–maintained system. Most leakage was observed to result from an open hose bib, that, while metered, represents unneeded treatment and pumping costs. Another leak was at a hydrant and was quickly repaired by district personnel.

The district's distribution network is in good condition as monitored by district measurements and confirmed by the minor leaks identified. Recommendations were to repair the minor leaks that were identified and to address the meter acting erratically so that proper records are available. Several valve problems were identified including one pressure reducer that was not allowing water to flow into an area of the district. Overall, the operational capabilities were to have been reviewed so that the network operated as designed and at an economical cost.

Reference: Mr. F. Stuart Loosley
Manager
303–597–5080

Leak Detection Survey – Daytona Beach, Florida

This leakage control survey consisted of master meter testing, district flow measurements, a leak investigation survey, water accounting (audit), development of criteria for water main improvements, and long–range leakage control planning.

Master meters were tested at two water treatment plants and supply points to a neighboring community. Six of nine meters tested were found to be outside acceptable limits of accuracy. The inaccuracies were found in both raw and treated water meters. In addition, flow measurements were made over a 24–hour period in two districts. Measurements helped to determine leakage potential and demand characteristics.

Leakage investigations were conducted using both mechanical and electronic sound–intensifying equipment. A total of 182,500 gallons per day of leakage was detected, of which nearly half was found on private property and is classified as house waste. Remaining leakage originated from distributed mains, service laterals, valves, and hydrants. Corrosion appeared to be the primary cause of leakage in the water mains and service laterals. Estimated annual savings following repair of the leakage was $12,500, representing a payback period of 2.4 years. Extrapolation of the savings to the remaining 200 miles of water main in the system yielded an estimated potential annual savings of $200,000 following leakage repair.

Reference: Richard Dembinsky, P.E.
Water and Wastewater Engineer
904–258–3174

Leak Detection Program – Beaver Dam, Wisconsin

The City of Beaver Dam's total pumpage for 1985 was 749,156,000 gallons, of which only 70.2 percent was accounted–for by metered sales, prompting the City to undertake a leak detection program. Donohue conducted a leak detection survey in 1986 throughout the entire system, consisting of 67 miles of water main.

Eighteen leaks were located during the survey, contributing a total of 190,000 gallons per day of leakage, which cost $46,500 per year. The majority of the leakage located (55 percent) occurred on service connections. We recommended that the cause of service breaks in Beaver Dam be investigated. Review of service repair records would indicate common causes to locate those areas of the system which require service replacement.

Reference: Mr. Ray Thiel
Water Department Superintendent
(414) 885–5541

Leak Detection Program – Meriden, Connecticut

Donohue was selected to conduct a leak detection program for all 217 miles of water main in this northeastern city. In response to a drought which had caused the city to deplete its reservoirs and as an on–going system maintenance project, leak detection was performed throughout the system. Mechanical listening equipment and state–of–the–art computer–assisted correlation equipment were used to rapidly and precisely locate approximately 700,000 gallons per day of leakage. At the city's cost for water, repairs will save $58,000 per year, a payback period of less than six months to recover the survey costs. More important, however, a precious natural resource will be retained in the city's reservoir supply system, available for public use.

Reference: David P. Lohman
Superintendent of Operations
203–237–1944

Leak Detection Program – Cloquet, Minnesota

The average daily pumpage for the City of Cloquet in 1985 was 1.9 million gallons of which 52 percent was not accounted for. For a community of only 5,000 people, that resulted in a significant amount of lost revenue. In August of 1986, Donohue performed a leak detection survey over the entire system in Cloquet, Minnesota, consisting of 46 miles of water main.

The survey located 19 leaks ranging from 1,000 to 200,000 gallons per day for a total of 720,000 gallons per day of leakage. Repair of the leaks resulted in a reduction of daily pumpage by almost 47 percent and a savings in wastewater treatment fees. Water mains in Cloquet are installed just above sanitary sewers and it was estimated that 224,000 gallons per day of potable water was entering the sewer system and conveyed to the treatment facility. Results indicated an estimated annual savings of $16,400 in water and an additional $22,400 in reduced wastewater treatment after repairs.

Reference: Mr. James Prusak
Director of Public Works
(218) 879–6758

Leak Detection Survey – Big Bear, California

Donohue conducted a leak detection survey on Big Bear's entire system, consisting of 56 miles of water main. The survey identified 160,000 gallons per day of leakage, worth nearly $10,000 per year. The survey was conducted by listening on all system components such as hydrants, valves, meters, and stop valves using electronic sound–enhancing equipment and our computer–driven leak correlator. These pieces of equipment permit rapid and highly accurate leak locations, often to within one or two feet of the precise location (as verified by subsequent excavation and repair activities).

Ancillary benefits to the survey included map discrepancy resolution and defective component identification. Because of our "hands–on" operation of much of the system, we were able to find and list those components in need of repair or attention. This process gives the community additional information concerning overall system maintenance requirements.

Reference: Mr. Gary S. Keller
Utilities Superintendent
714–585–2565

Water System Inventory, Leak Detection, and Computer Modeling – Des Plaines, Illinois

This project was divided into three phases. Phase I included location, operation, and data collection on all system valves and hydrants. A weekly list was submitted to the city identifying defective valves and hydrants needing repair. After completing this inventory, district measurements and leak detection were conducted. During Phase II, we used the field data collected during Phase I to create a base map showing right–of–way, street names, and the water system. Phase III involved developing a computer model of the distribution system and analyzing the improvements needed to meet present and future demands. As part of this analysis, trunk main gauging, loss of head tests, and fire flow tests were conducted to determine the capacity, condition, and use of the existing transmission mains.

Approximately 500,000 gallons per day (gpd) of leakage were located and repaired. Hydrants were repaired and buried valves located. Field work verified cross–connections between transmission and distribution mains, verified main sizes, and identified left–handed valves.

The final project report detailed the condition of the system and needed repairs. Other end products were a CADD base map and water system overlay, recommendations for system improvements, and a 20–year capital improvements plan that will help Des Plaines plan an orderly expansion of their system.

Reference: Bruce Shrake, P.E.
City Engineer
312-391-5300

<u>Leakage Control Program – Arlington, Texas</u>

This study was designed to develop a methodology for controlling unaccounted–for water in Arlington. It included developing a standardized method to account for all water usage within the system from raw intake through metered consumption. Measurements were conducted for 24–hour periods in five selected districts throughout the distribution system to evaluate leakage potential. Leak isolation and quantification in each district was achieved through subdistrict measurements and subsequent leak detection activities. A consumer meter sampling program was developed as a means of determining the contribution of these meters to total unaccounted–for water. Results from this sampling program were used to develop recommendations for an on–going meter replacement program. Results of the field analysis and review of system records were the basis for preparing a long–range approach for continued control of unaccounted–for water in the distribution system. City personnel were also given on–the–job training to help prepare them to continue leakage control activities.

Reference: George O. Muller, P.E.
Assistant Director of Utilities
817-275-3271

During the past 18 months, we have completed projects for many other clients, including:

- Joliet, Illinois
- Grinnel, Iowa
- Superior, Wisconsin
- Watertown, Wisconsin
- Hinsdale, Illinois
- Grand Marais, Minnesota
- Taunton, Massachusetts
- Waldorf, Minnesota
- Hartland, Wisconsin
- Falmouth, Massachusetts
- Wayne, Michigan
- Deerfield, Illinois
- Ely, Minnesota
- Pismo Beach, California
- North Miami, Florida
- Duluth, Minnesota
- Ft. Carson, Colorado
- Liberty, Missouri
- Park Ridge, Illinois
- Eldon, Iowa
- Maywood, Illinois
- Topeka, Kansas
- Quinnesec, Michigan
- Morro Bay, California
- Oceanside, California
- Villa Park, Illinois
- Big Bear Lake, California

■ STAFF QUALIFICATIONS

STAFF QUALIFICATIONS

The Donohue staff specializing in water audit projects consists of professional engineers and technicians who have participated in a large number of projects nationwide and who have had extensive experience in all phases of water audit programs. These key individuals are described in this section. Full resumes are available.

Thomas D. Jakubowski, P.E.

BSCE – University of Wisconsin, 1983

Background – Mr. Jakubowski has administrative and technical responsibility for all water audits undertaken by the firm. Specific water audit tasks include client liaison, proposal preparation, cost estimating and contract preparation, staff assignments, and overall quality control. Equipment and personnel scheduling are also under his direct control. Mr. Jakubowski has been personally involved with over 100 water audit/leak detection projects and has first hand experience with all phases of these programs. He has also participated in completing comprehensive plans and design projects related to water system improvements.

Gary K. Coates, P.E.

BSCE – Marquette University, 1957

Background – Mr. Coates is a vice–president of Donohue and is manager of the firm's Milwaukee Division, the office responsible for water audit services. He is directly responsible to the corporate management for all Milwaukee Division projects including water audits. In addition to his present position, Mr. Coates is the former general manager of the Racine Water and Wastewater Utility, an entity serving 100,000 people. Mr. Coates' experience provides Donohue with both corporate and client viewpoints, an important aspect of water audit projects.

Claus Dunkelberg, P.E.

BSCE – Valparaiso University, 1974

Background – Mr. Dunkelberg is a project manager and has participated in a wide variety of water audits, comprehensive plan preparations, and design efforts. He has extensive experience with all facets of water systems including computer modeling and evaluating operation and management procedures. His responsibilities include training efforts and review of project work plans and approaches.

Kenneth J. Kline, P.E.

MSCE – University of Iowa, 1969
BSCE – University of Iowa, 1968

Background – Mr. Kline has extensive experience in all facets of water distribution networks including planning, design, and construction contract administration. He has participated in many water system designs as lead design engineer and in providing quality control and value engineering services. He chairs a local water utility, an activity that furnishes insight into our clients' viewpoints. Mr. Kline is one of our most experienced designers in the water distribution field and has responsibility for reviewing project work plans so that optimum use is made of client resources.

Michael J. Gatzow

BSCE – Michigan Technologies University, 1986

Background – Mr. Gatzow is a project engineer and has been involved in several water audit activities. Duties include client liaison, data collection, report preparation, and conducting all field investigations.

Thomas J. Nejedlo

Background – Mr. Nejedlo is our chief field technician and has performed all water audit activities for the past ten years. In that time, he has participated in more than 75 projects throughout the country. His responsibilities include conducting tests, recordkeeping, and client liaison. Mr. Nejedlo also assists in training additional staff and evaluating and maintaining equipment.

Michael J. Carpenter

BS – University of Wisconsin, 1978

Background – Mr. Carpenter is a field technician with five years of extensive experience in field activities. His responsibilities have included leak detecting/location, district measurements, loss of head test, meter testing, fire flow tests, system mapping, and computer modeling.

Gary S. Fenney

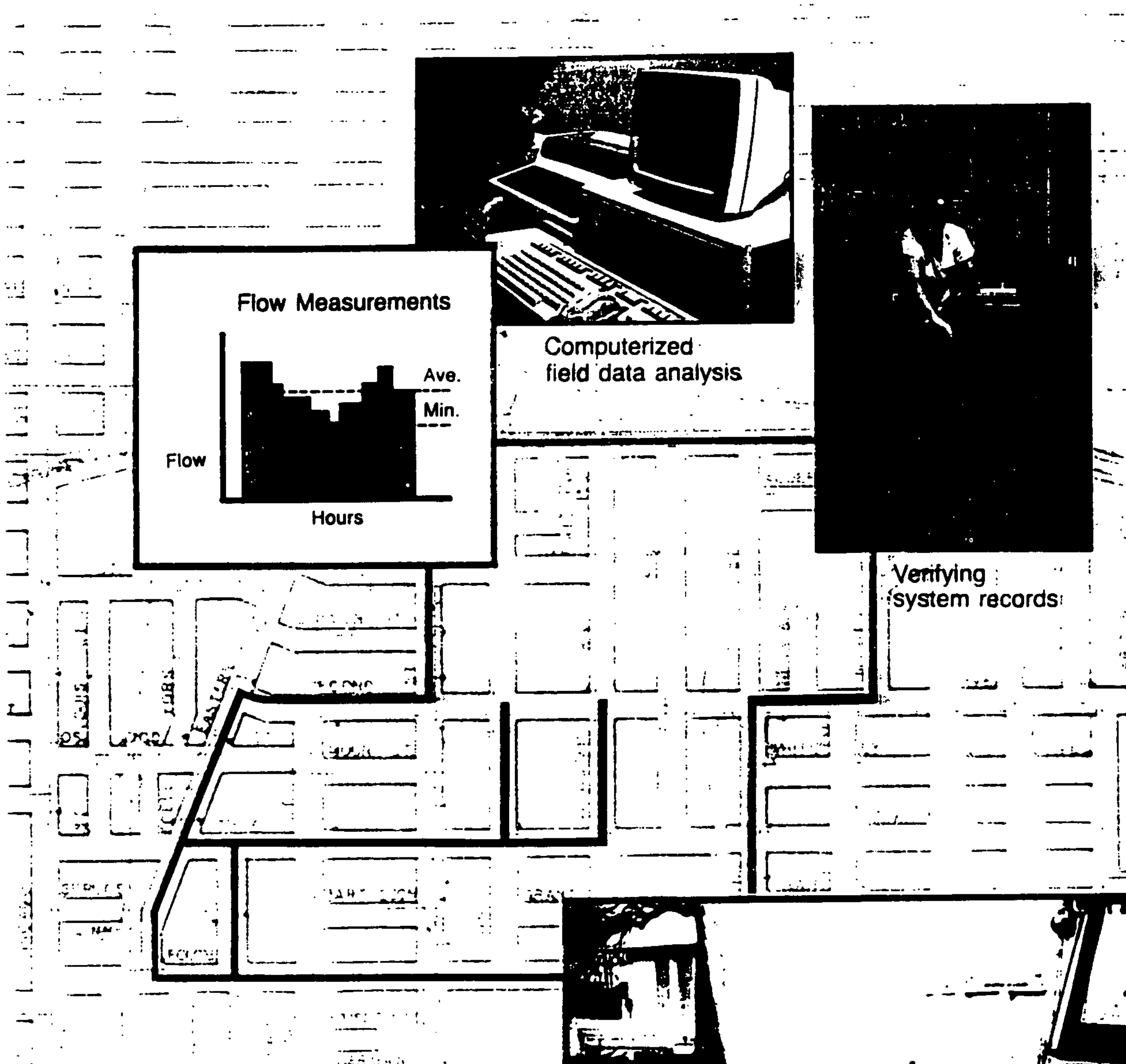
Background – Mr. Fenney is a field technician and has performed field measurements and leak detection on a variety of projects. His responsibilities include performing field investigations, report preparation, and client liaison.

Additional Staff

During the past three years, Donohue has used various staff members to augment our water audit/leak detection staff. We have the ability to draw from a pool of technicians familiar with the techniques and equipment employed in water audit activities.

■ GENERAL INFORMATION

Water Audit/ Leak Detection Services



Computerized field data analysis

Verifying system records

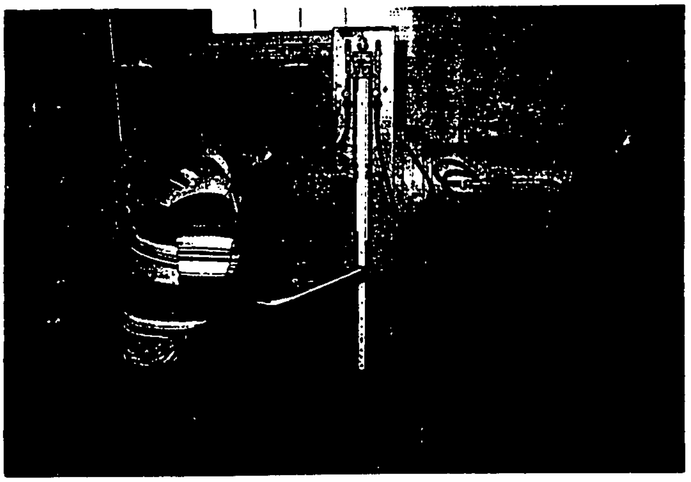
Leak detection

Objectives:

- Improve system accountability.
- Locate and quantify distribution system leakage.
- Determine meter accuracy.
- Update and verify system records/maps.

Results:

- Substantial cost savings following leakage repair.
- Increased revenue from improved meter accuracy.
- Reduction of unaccounted–for water
- Improved system records resulting in higher efficiency
- Accurate input data for computerized system modeling and record keeping



Meter testing

Computer-aided mapping/records

Other related services:
Pump efficiency tests
Loss of head tests
Meter changeout programs
Total water accounting systems
Hydraulic investigations
Trunk main surveys
Client Personnel Training

Typical Annual Savings with Leakage Repair

Community Population	Average Consumption 1,000 gpd	Leakage 1,000 gpd	Production Cost per 1,000 gal.	Annual Savings with Leakage Repair
3,300	550	198	$0.12	$ 8,700.00
580	220	165	$1.10	$ 66,260.00
78,000	10,200	2,022	$0.25	$185,000.00
38,700	4,830	410	$0.69	$104,000.00

Donohue ENGINEERS ARCHITECTS SCIENTISTS

Corporate Office: 4738 North 40th Street
P.O. Box 1067
Sheboygan, Wisconsin 53082-1067
414.458.8711

"Our objective is to find the leak and recommend solutions, whether it's losing 4,000 gallons per day or 400,000," Donohue project manager Thomas Jakubowski commented.

Jakubowksi and a team of water audit specialists analyze hundreds of miles of water distribution systems every year, using a variety of inventory/leak detection activities.

"Water audits and leak detection have come a long way in the last five years," he said. "We're working with equipment that is more sensitive and much more accurate. The most significant change in our methodology has occurred because of the computer-enhanced correlator."

Like more traditional methods, the correlator still "listens" for the sound of the leaks, Jakubowski explained, "but it doesn't rely just on sound intensity." Instead, the correlator operates on the premise that, for a known size, length, and type of water main, the speed of sound along the pipe can be accurately determined.

Highly sensitive microphones are placed on two system components, such as fire hydrants, that bracket the leak. Radio transmitters send electronic signals to the computer processor that compares, or correlates, the time required for the leak noise to reach each microphone. By knowing the speed of sound for the type and size of pipe and the pipe distance between both microphones, a precise location of the sound can be determined.

"The correlator has been used with greater than 95 percent success to pinpoint the exact location of leaks," he said. "We are able to work during the day because the correlator's sound filters make daytime ambient noise, such as traffic, less of a factor. We can evaluate four to six miles each day instead of a mile or so using traditional methods. That allows us to improve the cost-effectiveness of our studies.

"The better and more accurate our equipment is, the more leaks we'll find," he said, "and the shorter the payback period will be for our clients."

Fort Carson, Colorado

"We would be listening for leaks in the system and several tanks would suddenly rumble past, obscuring the sound," Jakubowski recalled. "Heavy traffic consisting of tanks and other heavy military vehicles on maneuvers made it necessary to perform much of the work at night." That was just one of the challenges of surveying the 115-mile water supply system at Fort Carson, Colorado.

The U.S. Army Construction Engineering Research Laboratory (USACERL) retained Donohue to perform leak detection surveys as part of a demonstration program to determine the cost-effectiveness of leak detection technology.

"This study was done as a Facility Technology Applications Test (FTAT)," USACERL environmental engineer Stephen Maloney explained. Maloney and another USACERL environmental engineer, Richard Scholze, served as the principal investigators for this test program.

"We see a lot of new technology, but until we take it into the field, we don't really know how well it will perform for our installations," Scholze added. "USACERL funds the FTAT: the installation doesn't have to take the risk."

Fort Carson Photos: Tom Nennig

Engineering technician Thomas Nejedlo, shown here performing general leak detection, and other Donohue staff traveled throughout the installation to survey the 115-mile water supply system.

"Leak detection is most commonly used on Army installations as an emergency response," Maloney said. "We wanted to show that leak detection, under the right conditions, should be part of our overall water conservation effort. We wanted to indicate that you don't have to wait for your water consumption to suddenly double or triple for the technology to be cost-effective."

USACERL selected Fort Carson as the pilot project because the combination of the installation's high rate and cost of water usage made the cost-benefit potential very high. Over a billion gallons of water costing more than $1 million dollars is purchased annually from Colorado Springs.

"Water has one of the highest costs per unit of any utility we purchase," Fort Carson's energy program manager Stephen Snyder explained. "Any time you have an expenditure that large, you want to keep an eye on it."

Donohue reviewed existing water distribution system maps and other pertinent records and reports. A leak detection survey of the water mains was performed using sonic detection and correlators. Defective system components were inventoried.

Thirty-five leaks were located in the initial 1988 survey, accounting for approximately 435,000 gallons of water per day and costing approximately $178,000 per year. Half of the leaks were found in the wash platforms of the installation's vehicle maintenance areas, but they lost more than 84 percent of the total leakage through worn valves.

"Water is at a premium in southern Colorado, and these leaks were costing us money every minute," Snyder said. "We wanted to get our water system back under control. We knew we had trouble at our maintenance facilities, but the survey helped us quantify our losses and assign priorities for repair. That's important to us because we have a backlog of repairs and limited resources to complete them."

Post personnel had begun making the recommended repairs when a sudden jump in water usage occurred.

"Our Energy Conservation Council monitors gas, electricity, and water use. When our water bill reported an additional 1 million gallons per day, we needed to know why," Snyder said. "It was particularly puzzling because we had made enough repairs to reduce our leakage by at least 100,000 gallons per day but our consumption apparently still went up."

A helicopter survey of the entire installation turned up no visible signs of a major leak.

"Donohue was due to come back in spring 1989," Snyder said. "We asked to move the schedule up, and another leak detection survey was performed in February and March."

More than 84 percent of the unaccounted-for water at Fort Carson was lost through worn or damaged valves, such as this leaking Murdoch valve at the installation's vehicle wash platforms.

The 1989 survey confirmed that, although there were still many repairs left to make on the installation's distribution system, the unaccounted-for water had been reduced.

"It turned out that the Colorado Springs water utility had installed a new meter that wasn't registering properly," Snyder explained. "We received a $250,000 refund. Without Donohue, we couldn't have proven that we hadn't used that extra water.

"The followup survey also allowed us to set priorities for the work needed to eliminate all of the identified water loss," he continued. "The resulting savings would not have been realized if USACERL hadn't picked Fort Carson to test the leak detection technology."

USACERL has begun publishing the results of the Fort Carson test program.

"Fort Carson is a good example of how well a leak detection program works under the right conditions," Scholze said. "They tightened up their system and reduced their water costs. They now place a higher emphasis on preventive maintenance.

"We have hard data that it's worth going over the water distribution systems to look for leaks," he said. "Facilities managers will be a lot more receptive about using this technology because they can see the results and talk to the person who's managing the facility."

Massachusetts Water Resource Authority

"We had consistently been using much more water than we estimated to be our 'safe' limit," David Liston said. Liston is program manager for leak detection and repair for the Waterworks Division of the Massachusetts Water Resource Authority (MWRA).

The 43 user communities, including Boston, that rely on the MWRA for the delivery and distribution of water had used 336 million gallons per day (mgd) in 1987 and 324 mgd in 1988. The MWRA determined the safe yield to be 300 mgd. According to Liston, the water use has exceeded that limit by 20 to 40 mgd since 1969. The combined 477-billion-gallon storage capacity of the Quabbin and Wachusett reservoirs enables the MWRA system to easily withstand brief dry periods, but the higher water use was slowly draining that buffer.

"We were trying to avoid having to develop new sources of water," Liston added. "That's a very expensive prospect. We decided to look first at our consumption, find and fix the leaks in our user communities, perform other conservation activities, and see how much we could bring down our consumption. It's a lot cheaper to cut demand than to find more water."

The MWRA's user communities were responsible for repairing their distribution systems. A representative of the Saugus, Massachusetts, water utility shuts off a valve at a tapping valve saddle. Approximately 50,000 gallons of water per day were lost through this leak.

MWRA Photos: Keith Nelson

Much of the unaccounted-for water in MWRA communities came from small leaks rather than major system failures. Thousands of gallons of water can seep from undetected cracks in water pipe.

Rather than leave the responsibility to its user communities, the MWRA developed and is funding a regional water audit/leak detection program. Four consultants specializing in water distribution systems were hired to survey each community. Donohue is one of those firms. Each community is provided with a detailed report and recommendations for repair and is responsible for those repairs.

"The MWRA assigns a community to us and determines the course of action," Jakubowski explained. "So far, we've investigated 11 communities, and we just received instructions for another."

As of August 1989, a total of 4,474 miles of water main had been surveyed by the four firms with more than 22 mgd of leakage located. Most of those leaks have been repaired. In the communities Donohue surveyed, more than 12.3 mgd of leakage was uncovered in 2,104 miles of main.

"In most cases, we've been finding a lot of leaks rather than a single leak causing the unaccounted-for water," Jakubowski commented. "In the Charlestown district and Boston proper, for example, we found 75 leaks in 114 miles of main. Thirteen water main leaks accounted for 44.6 percent of the total 1,285 mgd leakage."

According to Liston, the MWRA wasn't surprised by the results. "The real problem isn't major leaks, it's the large number of leaks," he said. "There are many factors, but age has a lot to do with it. Boston, especially, is an old system with some pipes that are more than 100 years old."

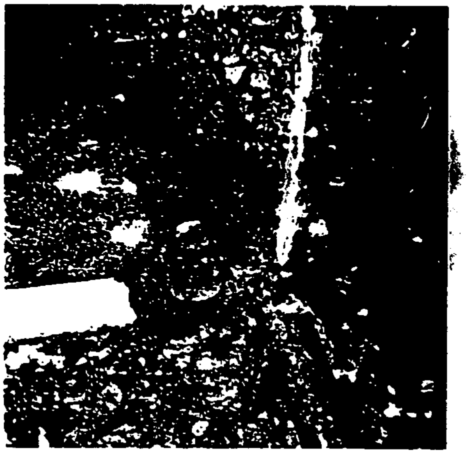
The leak detection and repair program was a major reason for the approximately 40 mgd drop in MWRA system consumption. The MWRA's original goal was the recovery of 25 mgd of previously unaccounted-for water.

"We expect that MWRA water use will average 285 mgd throughout 1989," Liston commented. "This is the first time in the past 20 years that we have been below our system's safe yield."

One project that is definitely on the MWRA agenda is the mandating of leak detection programs every two years.

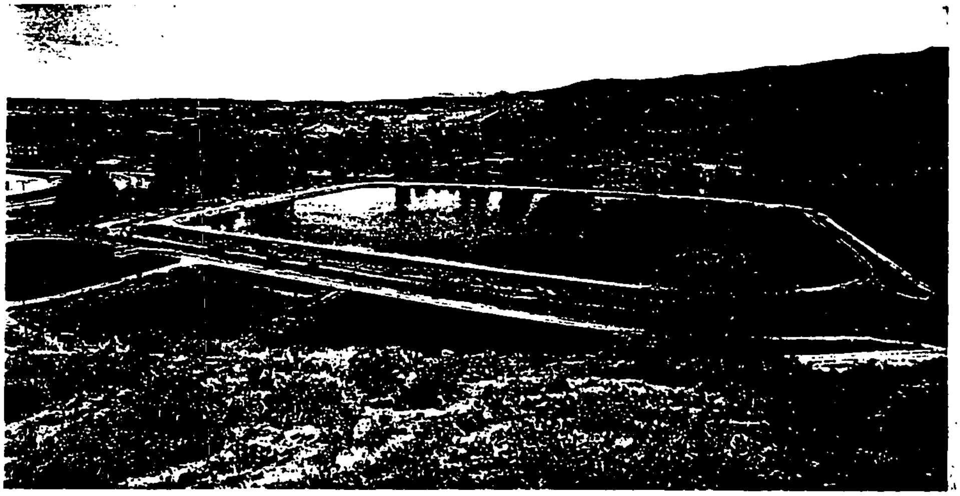
"The MWRA was the catalyst," Liston said. "We got everyone thinking conserve water, find the leaks. Donohue was sent back into some communities to check on the repairs and listen for secondary leaks. We want to make sure we attain the maximum results possible from this program.

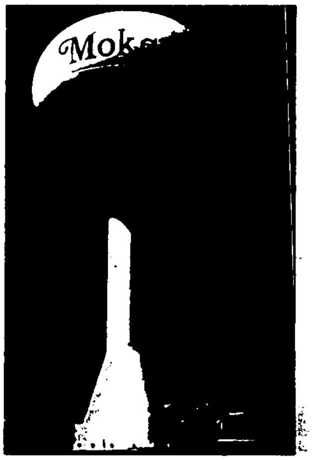
"The MWRA has made the initial investment of time and money. For us, the results lead directly to regulating the maintenance and repair of the distribution systems in this region. There are currently 130 miles of large aqueducts and nearly 7,000 miles of distribution pipelines," Liston concluded. "Our goal is to make sure that these systems are never again in such bad condition." ■

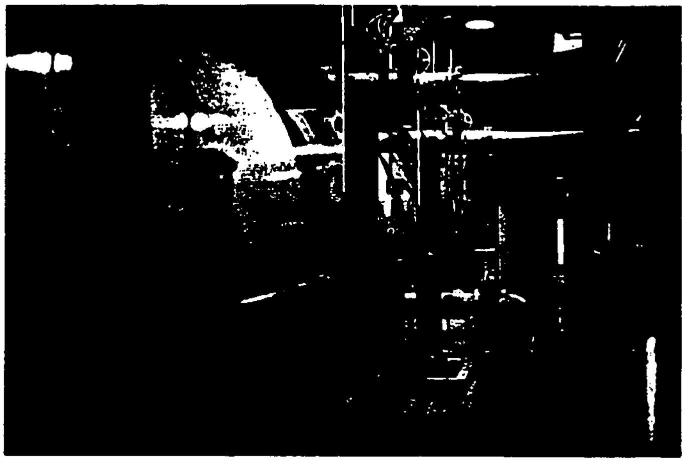


As soon as Saugus water utility crews remove the surrounding soil from the damaged pipe, the pressurized water makes a spectacular escape from the previously invisible leak (right). Approximately 80,000 gallons of water per day were lost through the leak (above).

Water Services





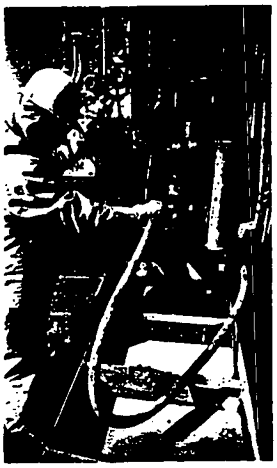


Full service for water utilities. Donohue can help you tackle the challenges of the 1986 Safe Drinking Water Act Amendments — challenges that include increasing contaminant restrictions, challenges that impact filtration, disinfection, and disinfection by-products. We offer planning, design, and construction-related services tailored to your water projects. From a shallow supply well to a complex treatment system, our engineers, designers, scientists, and technical specialists have the expertise you need. We can respond to changing regulations, evaluate alternatives, perform analyses, offer innovative technologies, and develop reclamation/reuse programs. Our goal is to provide our clients with a safe, high quality, and cost-effective water supply.

Donohue

Supply

Groundwater Investigations. Where groundwater is a cost-effective source. Donohue prepares studies ranging from regional aquifer investigations and modeling to site-specific testing and contamination investigations. We study alternate well sites, well field protection, well and aquifer performance, and contamination. Highly technical field equipment, such as seismic, resistivity, electro-magnetic, and ground-penetrating radar, is complemented by in-house engineering computing systems and programs. Our professionals can identify and evaluate your resources, then design systems and facilities to protect your water supply and its quality.

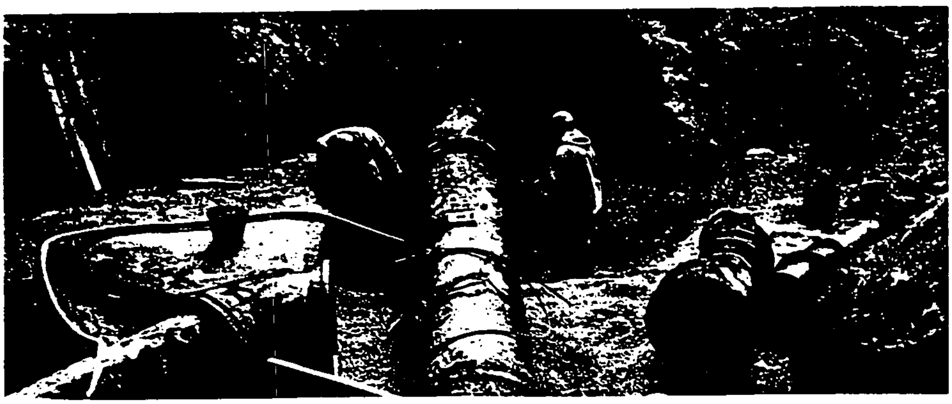


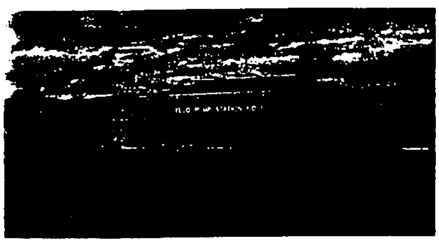
Supply Development. To meet long-term supply needs, all potential sources must be investigated. Surface supplies may include lakes, streams, or reservoirs. Groundwater alternatives may include one or more aquifers. Existing wells may need evaluation and rehabilitation. Donohue's experienced team searches for the most cost-effective solutions to achieve water quality objectives.

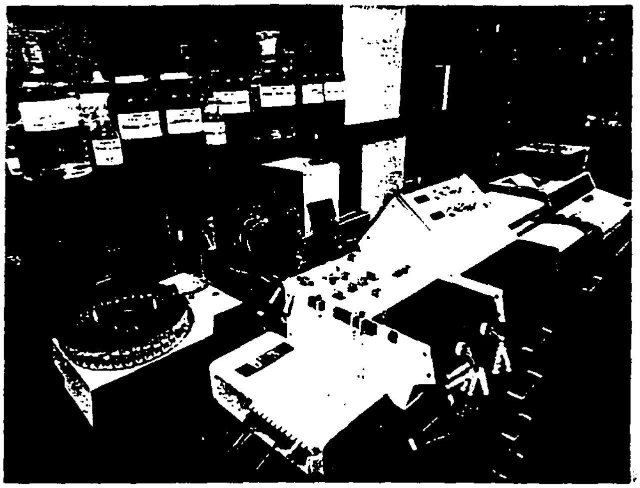
Reclamation and Reuse. From the frozen Arctic to the arid Southwest, water conservation is a major concern. Reclamation and reuse of nonpotable water can create added resources, improve groundwater management, and augment stream flows. Whether your needs include agricultural or landscape irrigation, recreational or industrial uses, or any other nonpotable uses, Donohue can analyze your alternatives and establish appropriate programs for storage, treatment, and distribution.

Distribution

System Design. Comprehensive planning of your distribution system is essential for proper sizing and location of system mains, storage facilities, pumping stations, and related facilities. Donohue's designers emphasize efficient distribution from supply sources to maintain adequate pressure and flow capacity throughout the system. When dual systems are required for irrigation, recreation, or other nonpotable uses, we can implement a design that will meet your needs. Our expertise includes long-term CADD (computer-aided design and drafting) experience along with computer model preparation and calibration. Analyses are performed on single and multiple pressure zone systems for customer demand, time-of-day demand, storage, and pressure and flow deficiency.







Treatment

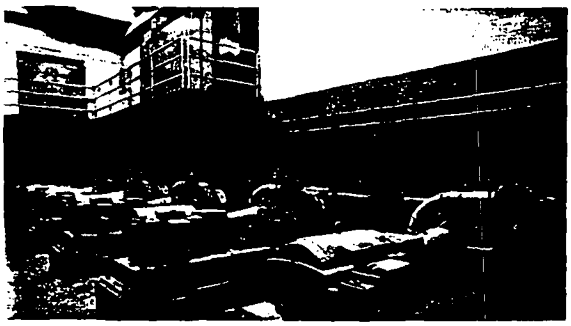
New treatment technologies, along with conventional methods, are often required to respond to consumer needs and changing regulations resulting from the 1986 Safe Drinking Water Act Amendments. As the list of contaminant standards lengthens, effective planning for and evaluation of treatment processes are necessary. Donohue is experienced in process performance evaluations, feasibility studies, surface and groundwater treatment, contaminant removal, facility siting and design, facility startup, and operations and management. Our full-service approach, which includes innovative and proven technologies, can provide treatment solutions uniquely designed for your water utility.

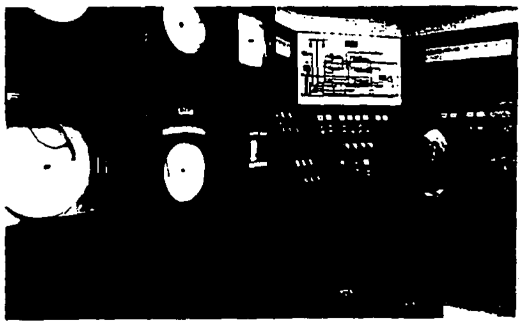
Analytical Services

Donohue maintains a state-of-the-art analytical laboratory. Our facilities, methodologies, and quality assurance/quality control programs meet and often surpass stringent federal and state regulatory agency requirements. We offer sample collection and analysis, reporting, and regulatory agency liaison. Also among our analytical services are priority pollutant testing under the Safe Drinking Water Act, chemical profiling, volatile organic screening, process monitoring and evaluation, and bench scale and pilot treatment testing. Our team of analytical staff, engineers, and scientists can respond to diverse water quality and treatment problems.

Financial Planning/ Rate Analysis

For water utilities with limited in-house financial capabilities, Donohue offers capital improvements planning, finance planning, cash flow analysis, cost of service studies, and related rate planning and design services. We prepare depreciation studies, rate cases, regulatory agency rate applications, and grant applications. Proper financial planning helps assure capital improvements programs that are consistent with your utility's financial constraints.





Water Audit/Leak Detection. Donohue's skilled specialists perform leak detection, leak quantification, and related services. Our hands-on approach to locating unaccounted-for water involves in-field testing, system surveys, computerized modeling, and recording systems with the scope of services adapted to each project's needs. The audit's cost is often quickly recovered through reduced water loss and increased revenues from improved meter accuracies.

Field Testing. Field testing of your existing system is critical for proper evaluation, planning, and design of facility improvements. In field testing programs tailored to individual client needs, experienced technical staff use advanced equipment and techniques. We provide customer demand measurements, trunk main surveys, pressure monitoring, and surge analysis. Tests are run of master meter accuracy, pump and motor efficiency, flow quantities, and in-place pipe roughness.

System Controls. Recent advances in control and monitoring technology offer opportunities to improve system operations and efficiency. Our instrumentation specialists can assist in planning, design, and implementation of control and telemetry systems, ranging from simplified pump controls to sophisticated SCADA systems. Often utility operating costs can be substantially reduced by automating operation and maintenance or by improving facility control.

Meeting Your Needs

Services provided from concept to completion. Projects located just around the corner or around the world. Clients whose satisfaction brings them back again and again. And staff noted for their innovation, dedication, and professionalism.

Donohue ... meeting our clients' needs for engineering, architecture, and related services since 1910.

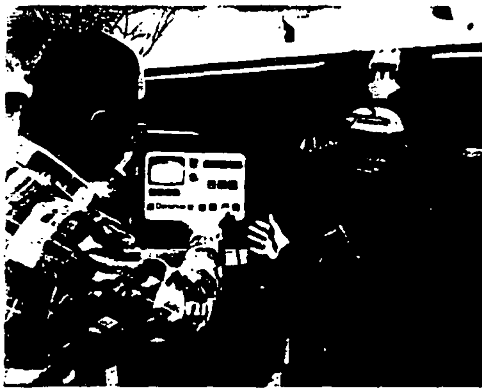
For information on office locations in your area, contact the Donohue corporate office.

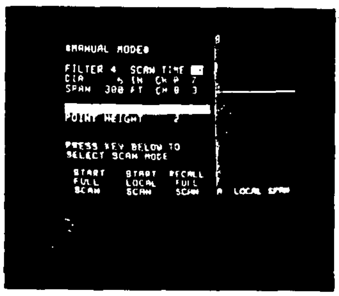
Offices in Arizona; Illinois; Indiana; Iowa; Minnesota; Washington, D.C.; and Wisconsin

Donohue

Corporate Office: 4738 North 40th Street
P.O. Box 1067
Sheboygan, Wisconsin 53082-1067
(414) 458-8711

Leak Location Services





Computerized leak location adds new dimensions of speed and accuracy to finding costly leaks in water systems. Donohue uses the most advanced leak sound correlation and, as technology advances, continues to update equipment.

Combined with this technology are our nearly 75 years of engineering experience with water systems. A thorough understanding of water system operation serves as the foundation of our approach.

We provide these benefits:

- ☐ Cost savings following leak repairs.
- ☐ Accurate and efficient leak location.
- ☐ Reduced property damage and liability from leakage.
- ☐ Postponement of capital improvements by reducing wasted water.
- ☐ High quality training for your staff in leak location.

This combination of state-of-the-art technology and extensive engineering experience means Donohue can meet your needs for accurate, cost-efficient leak location.

Donohue
4738 North 40th Street
Sheboygan, Wisconsin 53081
(414) 458-8711