WC WD
Warren County
Water District

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COMMISSION

November 10, 2011

MR JEFF DEROUEN
EXECUTIVE DIRECTOR
PUBLIC SERVICE COMMISSION
P O BOX 615
FRANKFORT KY 40602

RE: Case No. 2011-00220

Dear Mr. Derouen:

Enclosed are the original and ten copies of the Responses to Commission Staff's Request for Information on the referenced case.

If you need anything further, please let me know.

Sincerely,

Alan H. Vilines, P.E.
General Manager

AHV:jh

Enclosures

COMMONWEALTH OF KENTUCKY

RECEIVED
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PUBLIC SERVICE COMMISSION

BEFORE THE PUBLIC SERVICE COMMISSION

In the Matter of:

JOINT APPLICATION OF WARREN COUNTY WATER DISTRICT, SIMPSON COUNTY WATER DISTRICT, AND BUTLER COUNTY WATER SYSTEM, INC. FOR A DEVIATION FROM APPROVED METER TESTING PROGRAM	)	CASE NO. 2011-00220

RESPONSES TO
COMMISSION STAFF'S REQUEST FOR INFORMATION
ON BEHALF OF
WARREN COUNTY WATER DISTRICT,
SIMPSON COUNTY WATER DISTRICT,
AND BUTLER COUNTY WATER SYSTEM, INC.

The Warren County Water District, Simpson County Water District, and Butler County Water System, Inc., by counsel, hereby provide answers and responses to the Commission Staff's request for information. An original and ten (10) copies of the answers and responses are filed with the Commission. Alan H. Vilines, PE shall be the witness who will be responsible for responding to questions relating to the information provided:

1. a. Identify the authors of "Revised Determination of Cost-Effective Meter Testing Frequency."

RESPONSE: The authors of "Revised Determination of Cost-Effective Meter Testing Frequency" are Alan H. Vilines, P.E. and Bryan R. Tillery, P.E.

b. Provide each author's *curriculum vitae.*

RESPONSE: The *curriculum vitae* for each author are attached as Exhibit 1.

c. Identify each author's academic and professional experience in sample testing and statistical analysis.

RESPONSE: Mr. Tillery's academic experience in statistical analysis consists of undergraduate coursework related to engineering statistics. Mr. Vilines completed several undergraduate and graduate level courses in statistics, industrial engineering and engineering economics which included topics on sample testing and statistical analysis. His professional experience includes sample testing for material quality control and since the mid 1980's he has worked extensively on sample testing and analysis related to water meter testing.

2. a. State whether "Revised Determination of Cost-Effective Meter Testing Frequency" underwent any peer review prior to its submission to the Commission.

RESPONSE: The report titled "Revised Determination of Cost-Effective Meter Testing Frequency" did not undergo a peer review. However, the methodology used in that study is the same that was used in an earlier study by Mr. Vilines that was reviewed.

b. If it was subjected to peer review, identify the persons who performed the review, describe each reviewer's academic and professional experience, and provide their comments regarding the study.

RESPONSE: Richard R. Noss, PhD was a project manager at the firm of Bennett & Williams, Inc. when he was asked to review the report by Mr. Vilines titled "Determination of a Cost-effective Meter Testing and Maintenance Program" dated January 20, 1988. Sensus Model SR meters were the subject of this 1988 report.

Dr. Noss was a leading authority on the issue of meter testing. Dr. Noss was an environmental engineer with an academic background in environmental chemistry and biology, including masters level work in sanitary engineering and water resources engineering. He also held a PhD in water resources and environmental engineering. His area of expertise included hydrology, systems analysis, engineering economics, computer modeling, policy making, water quality management, and the development of water regulations and interpretation of water law. He graduated cum laude in 1972 from Harvard University and received his masters degree from the University of Michigan. He also did post-graduate work at the Massachusetts Institute of Technology where he received a masters degree and a PhD. Dr. Noss published several articles on the subject of optimal meter testing frequency.

The review by Dr. Noss of the earlier Vilines work is presented in his report titled "Calculating the Optimal Meter Testing Frequency", dated November 10, 1989 and is included as Exhibit 2.

3. Provide for each of the Joint Applicants a breakdown of its total meter population as of June 30, 2011 by manufacturer, model, and age.

RESPONSE: The breakdown for 5/8 x 3/4" meters is shown in Exhibit 3.

4. State for each of the Joint Applicants whether it has a written policy regarding the purchase of new water meters. If yes, provide a copy of that policy.

RESPONSE: None of the Joint Applicants have a written policy regarding the purchase of water meters.

5. Describe the type of meter (manufacturer and model) that each Joint Applicant plans to purchase for the next ten years.

RESPONSE: It is impossible to state with any certainty what meters will be purchased over the next ten years. Changes in regulations, technology, meter design, meter pricing, operating costs, etc. will impact those decisions. However, under current conditions it is probable that the Joint Applicants would continue to purchase Sensus SR II meters.

6. State the time period (i.e., beginning and ending dates) over which the meters in the study group were tested for the current study.

RESPONSE: The meters in the sample groups included in this study were tested between October 27, 2010 and December 20, 2010.

7. State whether "Revised Determination of Cost-Effective Meter Testing Frequency" addresses the testing of any meter other than Sensus Model SRII meters.

RESPONSE: The study described in that report does not address the testing of any meters other than the Sensus Model SRII.

8. State for each of the Joint Applicants whether the Applicant intends to purchase only Sensus Model SRII meters for the next ten years.

RESPONSE: See the answer to Number 5 above.

9. State whether the Joint Applicants conducted any inquiry as to the intentions of the manufacturer of the Sensus Model SRII meters regarding the continued manufacture of that type of meter. If yes, describe the results of those inquiries.

RESPONSE: No such inquiry has been made.

10. State whether, as the study involved only Sensus Model SRII meters, Commission approval of the proposed meter testing and replacement program should be limited to the use of Sensus Model SRII meters and not applicable to other types of meters.

RESPONSE: Commission approval of the proposed meter testing and replacement program should be limited to only 5/8" x 3/4" Sensus Model SRII meters. Although other meters might display similar characteristics, this has not been determined by the Joint Applicants and therefore the conclusions of the study are not applicable to other brands, sizes or types of meters.

11. State the effect on any Commission approval of the proposed meter testing and replacement program if the manufacture of Sensus Model SRII meters is discontinued.

RESPONSE: If Sensus were to stop manufacturing SRII meters, the Joint Applicants would continue to operate under the proposed program as long as Sensus SRII meters remain in service. For example, new Sensus SRII meters installed in 2012 would remain in service through 2033 and then be replaced. Testing of any other model or brand that might be substituted, would be handled in accordance with PSC regulations, unless a specific deviation is granted for the substitute by the Commission in the future.

12. Identify each government, water industry or trade association standard that recognize and adopt the Weighted Average Meter Accuracy ("WAMA") concept. For each standard listed, provide a copy of the written standard.

RESPONSE: The Joint Applicants are not aware of specific "standards" which have adopted the use of the Weighted Average Meter Accuracy (WAMA). However, the PSC approved the use of the WAMA concept in the development of a meter testing program in Case No. 1997-00434. The same methodology used in Case No. 1997-00434 was used for the current case.

Numerous scholarly and trade association documents and articles have referenced the use of a weighted average meter accuracy. A few of these documents are listed below.

- Noss, Richard R., et. al, *Optimal Testing Frequency for Domestic Water Meters*, Journal of Water Resources Planning and Management, Vol. 113, No. 1, January 1987 (Exhibit 4A).
- Yee, Michael D., *Economic Analysis for Replacing Residential* Meters, Journal AWWA, Vol. 91, No. 7, July 1999 (Exhibit 4B).
- Kelly Jr., Thomas A., *Who's Minding the Cash Register?,* Opflow, American Water Works Association, Vol. 27, No. 8, August 2001 (Exhibit 4C).
- Beenfeldt, Norman, *Determination of Economic Period for Water Meter Replacement*, Journal AWWA, Vol. 58, No. 6, June 1966 (Exhibit 4D).

13. State the number of meters in the testing sample that were radio-read meters.

RESPONSE: None of the meters tested were radio-read meters.

14. Provide the minutes of the meetings of each Applicant's board of commissioners or board of directors in which the current request for deviation was discussed.

RESPONSE: See Exhibit 5 and Exhibit 6.

15. Provide the resolution or the minutes of the meetings of each Applicant's board of commissioners or board of directors in which the appropriate governing body authorized the current request for deviation.

RESPONSE: See Exhibit 6.

16. Describe how the sampling size for each year of manufactured meters from 1990-1997 was determined. Address in this description the difference between the Sample Size for Testing shown in Exhibit 1 from the Joint Applicants' Response to Staff's First Set of Interrogatories in Case No. 2003-00391[1] and the Sample Size used in the Joint Applicants' Application in the current processing. Show all calculations and supporting documentation.

RESPONSE: The sample size for each year of manufactured meters was determined based on the following equation:

$$n = \left(z * \frac{\sigma}{E} \right)^2$$

where:

n = sample size

$z = 1.96$, constant for 95% confidence level

σ = standard deviation of population

E = acceptable error = $\pm 1\%$

To calculate a standard deviation for each year of meters, previous meter test results for each year of meters was used. The population in the evaluation group for each year of meters consisted of a sub-set of readily available meter test data. The standard deviations were normalized using linear regression. For further assurance that the sample size for each year would yield valid results, the sample size for each year of meters was rounded up to the nearest multiple of five or to a minimum sample size of 30. The calculations of sample size are shown in Exhibit 7.

The sample size indicated in Exhibit 1 from the Joint Applicants' Response to Staff's First Set of Interrogatories in Case No. 2003-00391 was based on 8 percent of the total meter population for each year. This percentage was used on a preliminary basis because it would result in the maximum sample size required for the confidence level desired. At that time the maximum number was computed so that age groups large enough were reserved and held out of routine testing to insure a successful study. Also see the answer at Number 19.

The smaller sample group used in the current proceeding resulted in a statistically acceptable result. For each age group of meters tested, the actual error was calculated to determine if the sample yielded results within the pre-determined acceptable error level. The result of these calculations are included in Tables A-1 through A-8 of "Revised Determination of Cost-Effective Meter Testing Frequency." For each age group of meters tested the calculated actual error was less than the acceptable error of ±1 percent. The equation used for this calculation is:

$$E = z * \sqrt{\frac{\sigma}{n}} * \sqrt{\frac{N-n}{N-1}}$$

where:
E = actual error
$z = 1.96$ for 95% confidence level
σ = standard deviation of population
n = sample size
N = total population sample size

17. Refer to "Revised Determination of Cost-Effective Meter Testing Frequency," Appendix A, Table A-7; and Case No. 2003-00391, Joint Applicants' Response to Staff's First Set of Interrogatories, Exhibit 1. The total population size in Table A-7 conflicts with the total number of 1991 meters in Exhibit 1. Provide a revised Table A-7 as shown in Appendix A of the Revised Determination of Cost-Effective Meter Testing Frequency report with a corrected Total Population Size.

RESPONSE: Due to an input error, the total population size of 18 year old meters was inserted in both Tables A-6 and A-7. Table A-7 should have indicated the total population size of 19 year old meters which is 1,525. The revised Table A-7 is attached as Exhibit 8.

18. Refer to "Revised Determination of Cost-Effective Meter Testing Frequency," Appendix A. For each year of manufacture, state for each of the Joint Applicants the number of meters from the vintage that were in service on that Applicant's water distribution system.

RESPONSE: A summary of meters for each year of manufacture for each Applicant is attached as Exhibit 9.

19. Refer to "Revised Determination of Cost-Effective Meter Testing Frequency," Appendix A. This study is based upon the testing of 425 meters. In Case No. 2003-00391, the Joint Applicants proposed that a sample group of approximately 200 meters from each year of manufacture from 1990 to 1997 be randomly selected to remain in service for a study which would be conducted in 2010. The total sample population would be 1,600 meters. Provide the status and/or testing results for the remaining meters not listed in Appendix A. Provide in summary form these results by utility and year of manufacture.

RESPONSE: The number of meters expected to be tested in each age group in Case No. 2003-00391 was not 200. The number of meters requested to be allowed to be reserved for future testing was 200. This was also explained in Item No. 1 of the Joint Applicant's Answers and Responses in Case No. 2003-00391, dated August 27, 2004. The 425 meters tested for this study were randomly selected from these groups of 200 meters of each year of manufacture which were retained in place in accordance with Case No. 2003-00391. The remaining meters from these groups have not been disturbed pending the results of this case.

20. Refer to "Revised Determination of Cost-Effective Meter Testing Frequency" at 9. Explain how the Joint Applicants calculated an incremental water rate of $3.09/1,000 gallons. The response shall state all assumptions, show all calculations, and provide all work papers used to make the determination.

RESPONSE: The incremental water rate of $3.09/1,000 gallons assumed a monthly water usage of 4,160 which was the average residential usage in 2010. The actual rate block for this volume of water was $3.09/1,000 gallons.

21. Refer to "Revised Determination of Cost-Effective Meter Testing Frequency," Table 3. Provide a revised Table 3 that includes the effect of Warren County Water District's recent rate adjustment on the revenue-gained calculations.

RESPONSE: The revised Table 3 is attached as Exhibit 10 which includes the effect of WCWD's recent rate adjustment. Although the rate adjustment does have an effect on the present value calculation, the rate adjustment does not change the meter age at which the revenue gain of the program exceeds the costs.

22. Explain how the Joint Applicants determined the use of a three percent compound interest rate in its present value calculations.

RESPONSE: Generally the selection of the interest rate to be used in time value of money computations is based on either the opportunity cost (investment rate) or the actual cost of capital (loan or bond rates). Although current low risk investment rates over a moderate investment period are currently less than 3 percent, that appears to be a reasonable estimate of such rates looking toward the next several years. Because funding for meter replacements for the Joint Applicants is not expected to come from borrowing, that basis for the interest rate selection was not considered to be as significant. However, an average bond or loan rate of approximately 3 percent is currently available for moderate length periods. Considering all of these factors, a 3 percent rate was selected.

23. State the service lives that each of the Joint Applicants has assigned to Sensus II meters for accounting purposes.

RESPONSE: The service life assigned to Sensus SRII meters is 20 years.

24. Refer to “Revised Determination of Cost-Effective Meter Testing Frequency,” Table 3.

a. Describe how the Joint Applicants determined the replacement cost of a 5/8-inch x 3/4-inch water meter.

RESPONSE: The replacement costs of a 5/8-inch x 3/4-inch water meter was based on the Joint Applicants actual cost for a 5/8-inch x 3/4-inch water meter minus the scrap value of the meter which was to be replaced. The scrap value price was based on the average of the Joint Applicants previous three scrap meter sales.

b. Describe how the Joint Applicants determined the cost to test a 5/8-inch x 3/4-inch water meter.

RESPONSE: The Joint Applicants assume question refers to "Total Unit Retrieval & Test Cost" as indicated on "Revised Determination of Cost-Effective Meter Testing Frequency," Table 3. The data used for this calculation was based on the actual average expenses and production rates of the Joint Applicants' current meter testing program. The average expense associated with personnel and equipment was multiplied by the actual average rates of production to result in the average unit cost per meter.

DATED this 10th day of November, 2011.

COLE & MOORE, P.S.C.
9221 College Street
Bowling Green, KY 42101
(270) 782-6666

BY: ______________________
Frank Hampton Moore, Jr.

CERTIFICATION OF PERSON PREPARING/SUPERVISING THE PREPARATION OF THE RESPONSE

This is to certify that the undersigned prepared and/or supervised the preparation of this response on behalf of the Joint Applicants and that this response is true and accurate to the best of his knowledge, information, and belief formed after reasonable inquiry.

BY: ______________________
Alan H. Vilines, PE

COMMONWEALTH OF KENTUCKY

COUNTY OF WARREN

SUBSCRIBED AND SWORN to before me by Alan H. Vilines on the 10th day of November 2011.

____
Notary Public
My Commission Expires: 12/21/13

CERTIFICATION OF SERVICE

The undersigned herby certifies that a true and correct copy of the foregoing was on the 10 day of Nov., 2011, mailed for overnight deliver, postage prepaid, to the following:

Original and 10 copies to:

Jeff Derouen
Executive Director
Public Service Commission
P O Box 615
Frankfort, KY 40602

Copies to:

Alan H. Vilines
General Manager
Warren County Water District
523 U.S. 31W Bypass
P. O. Box 10180
Bowling Green, KY 42102-4780

____
Frank Hampton Moore, Jr.

CURRICULUM VITAE
ALAN H. VILINES

EDUCATION

1982, University of Tennessee, Knoxville, TN, Master of Science in Engineering Administration.

1974, Western Kentucky University, Bowling Green, KY, Bachelor of Science in Civil Engineering Technology.

REGISTRATION

Professional Engineer - Commonwealth of Kentucky.

EXPERIENCE

1980 - Present

Warren County Water District, Bowling Green, KY. Held several engineering positions, Assistant General Manager and began serving as General Manger in October 2005. Responsibilities have included design and contract administration of various water and sewer improvement projects. Conducted capital improvement plans, management studies, hydraulic analyses, financial and rate studies. Developed meter testing study and analysis that resulted in PSC approved program. Worked extensively with various groups, agencies and leaders in the community. Now responsible for all aspects of the Water District's activities including operations, engineering, finance & administration, and customer service.

1975 - 1980

Robert S. Miller Co., Inc., Nashville, TN. Engineer. Performed design work on sewage collection systems, sewage treatment plants, water transmission and distribution projects, and water treatment plants. Also designed streets, curbs and gutters, storm drainage, retaining walls, and other general municipal projects.

1974 - 1975

Kenco Associates, Inc., Ashland, KY. Associate Engineer. Responsible for field and office work on industrial sites, property, and sewer system surveys. Assisted in design of water and sewer systems.

CURRICULUM VITAE
BRYAN R. TILLERY

EDUCATION

2005, Tennessee Technological University, Cookeville, TN, Bachelor of Science in Mechanical Engineering.

REGISTRATION

Professional Engineer (Civil Engineering) - Commonwealth of Kentucky.

EXPERIENCE

2005 - Present

Warren County Water District, Bowling Green, KY. Engineer. Performed design and contract administration on water transmission/distribution systems and sewer interceptor/collection systems. Completed capital improvement studies, efficiency studies, hydraulic analyses, and financial studies.

2003 - 2004

Jackson Energy Authority, Jackson, TN. Co-op Engineer. Assisted in the design of various water and wastewater facilities, including sewer rehabilitation. Performed sewer inflow and infiltration study.

CALCULATING THE OPTIMAL METER TESTING FREQUENCY

Prepared for:

Butler County Water System, Inc.
Grayson County Water District
Simpson County Water District
Warren County Water District

for

Presentation to

Kentucky Public Service Commission

Submitted by:

BENNETT & WILLIAMS, INC.
2700 E. DUBLIN-GRANVILLE RD.
COLUMBUS, OHIO 43231

November 10, 1989

BENNETT & WILLIAMS, INC.
CONSULTING GEOLOGISTS

2700 EAST DUBLIN GRANVILLE ROAD
SUITE 550
COLUMBUS, OHIO 43229
614/882-9122
FAX: 614/882-4260

November 10, 1989

Mr. Joe Lisles, Manager
Butler County Water System, Inc.
Grayson County Water District
Simpson County Water District
Warren County Water District
951 Fairview Avenue
Bowling Green, Kentucky 42102

Re: Evaluation of Domestic Water Meter Testing Program

Dear Mr. Lisles:

The attached report presents the calculation of an optimal domestic water meter testing frequency for the Warren County Water District (WCWD). Our calculations are based on data from the report entitled "Determination of a Cost-Effective Meter Testing and Maintenance Program," provided by your office. We conclude that the optimal domestic water meter testing frequency is once every thirteen years.

Meters from the Simpson County Water District and the Butler County Water System may have higher weighted average meter accuracies at the ages tested than the WCWD meters. If this is so, the economic analysis used in the attached report would suggest that meter testing periods longer than 13 years would be appropriate. Recognizing that the meter manufacturer's warranty replacement policy is in effect for only 15 years, and that the three smaller water districts' meter testing programs are integrated with the WCWD program, we recommend that all four water districts follow the same meter testing program.

Dr. Richard Noss, Project Manager on this work, will be available to answer questions the water districts or the Kentucky Public Service Commission may have with respect to the report.

We appreciate this opportunity to be of service.

Very truly yours,
BENNETT & WILLIAMS, INC

Richard R. Noss, PhD
Project Manager

Attachment

INTRODUCTION

Accurate metering of water delivered to consumers is essential to the efficient operation of a water utility. Most importantly, metered water is the basis for billing customers. Meters also ensure a basic fairness that all consumers are paying in proportion to their water usage. In addition, metered water usage data is the basis for water use and supply calculations.

Water meters need periodic maintenance because meter accuracy decreases with age and with the amount of water metered. Consumers with inaccurate meters do not pay for the full amount of water they use. As a result, the utility does not recover full revenue for the water it is delivering. Occasionally a meter will "fail", that is, to badly under-register the water used or even to stop registering altogether. Failed meters are detected by the Water Districts' billing office during the review of monthly water bills and are replaced immediately.

Meter testing and repair programs are established to provide meter maintenance on a regularly scheduled basis. The frequency at which meters are pulled, tested and repaired determines the number of meters tested each year and therefore the cost of the meter testing program. There is also a "cost" associated with having inaccurate meters in the system. This is the "cost" of the water delivered to consumers that is not generating revenue because it is not registered on the meter. The longer the interval between meter tests the lower the cost of the meter testing program will be because fewer meters are maintained each year. The longer the interval between meter tests, however, the greater the amount of unmetered water and therefore the greater the cost of lost revenues. The optimal meter testing interval is determined by balancing these costs, taking the time value of money into account.

This presentation is based on the results of domestic water meter testing conducted by the Warren County Water District. The meter testing data is used to calculate the decline in meter accuracy with age, which in turn is used with cost data for the Warren County Water District to determine an optimal water meter testing frequency. The calculations indicate that a meter testing interval of once every 13 years is most cost effective, given the rate of decline in meter accuracy with age characteristic of the Warren County Water District's domestic water meters.

BACKGROUND

Studies of domestic water meter testing cite a wide range of meter testing frequencies, ranging from once every five years to more than twenty years between tests. In some cases the meter testing frequencies have been based on local studies of meter performance; in other cases the reasoning behind the testing interval chosen is less clear. The results of several meter testing studies are presented in Table 1.

Meter testing programs serve multiple purposes. The purposes, in turn, may provide guidance to the design of "good" or "best" meter testing programs. For example, meter testing serves the following purposes:

1. fairness -- to ensure that each customer is fully charged for the water used.

2. check warranties -- to determine whether meters are performing as specified in the manufacturer's warranty, and if not, to replace them with meters that do perform properly.

TABLE 1

Meter Testing Frequencies Determined by

Meter Accuracy Studies

Location	Meter Testing Period (yrs.)	Reference
Albany, NY	20	(1)
California AWWA	720	(2)
Indianapolis, IN	9-15	(3)
Taunton, MA	7-9	(4)
Westchester Co., NY	25-28	(4)
Rochester, NY	11-15	(5)

REFERENCES

1. Betz, Converse, Murdoch Inc., "Unaccounted-for Water Analysis: Albany, New York", New York District Army Corps of Engineers, Principal Author Alfred S. Ciottoni, March 1982, 56 pp.

2. American Water Works Association Committee Report, "Determination of Economic Period for Water Meter Replacement", J. American Water Works Association, Vol. 58, no. 6, June 1966, pp. 642-650.

3. Williams, R.L., "Water Meter Maintenance", 1976 AWWA Annual Conference Proceedings, New Orleans, Louisiana, June 1976, Vol. 2, paper no. 2-3, 11 pp.

4. Newman, G. and Noss, R., "Inspection and Maintenance Programs for 5/8 Inch Water Meters" in Male, J., Noss, R. and Moore, C., Identifying and Reducing Losses in Water Distribution Systems, Park Ridge, N.J., Noyes Publications, 1985.

5. Watson, E., "How Often Should Water Meters be Serviced?" Technical Report, Rockwell International, no date.

3. revenue enhancement -- to minimize the amount of water that is not registered on customers' meters (Unregistered water generates no revenue.)

The guidance each of these purposes provides to the choice of an optimal meter testing frequency is discussed below.

Fairness More frequent testing results in a water system with smaller differences between the most accurate and the least accurate meters. The difference in the range of accuracies is not great, however. After 15 years in service the Warren County Water District's meters still have an average weighted average accuracy of 96.19%. This amounts to a maximum difference of $6.36 out of an annual bill of $166.92 for the average domestic water user.

Check Warranties All of the meters used by the Warren County Water District are Rockwell SR meters. These meters have a 15 year warranty. Thus meter testing frequencies greater than 15 years would be unwise because they would not detect the meters that fail to meet specifications in time to replace them while they are still under warranty.

Enhance Revenue This may be interpreted in two ways: 1) concentrate on revenue not collected because of under-registering meters or 2) concentrate on the revenue recovered by returning accurate meters to the system. The optimal water meter testing program can be described by cost-based algebraic equations that can be solved to yield the corresponding meter testing frequency.

DETERMINING AN OPTIMAL METER TESTING FREQUENCY

The decision criterion for the revenue/cost based meter testing frequency is:

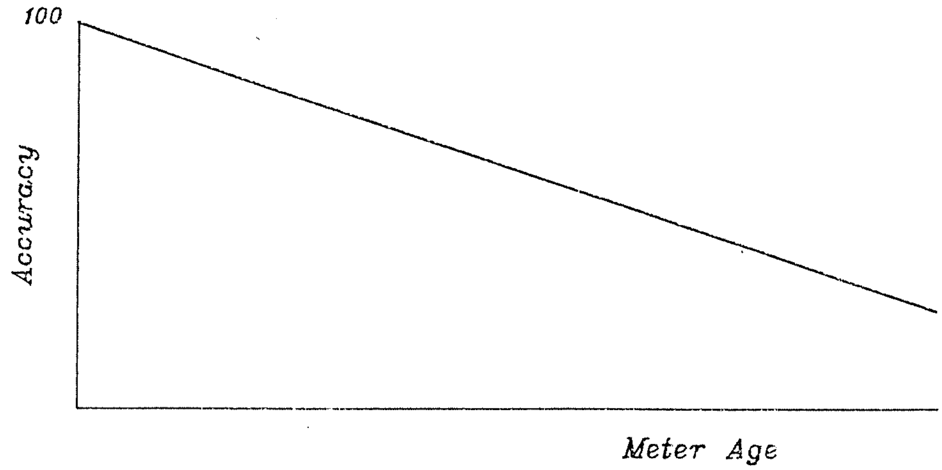
> "Test/repair meters as frequently as possible except that the revenue recovered by the improved accuracy of the repaired meters should cover the cost of the testing program."

This is described in the literature as the "break even" approach. For the optimal meter testing frequency, the cost of the meter testing program is paid for by the increased revenues generated by the repaired meters. There is no net cost to the consumers for the testing and repair program. The decision problem is illustrated first with a simple, hypothetical example.

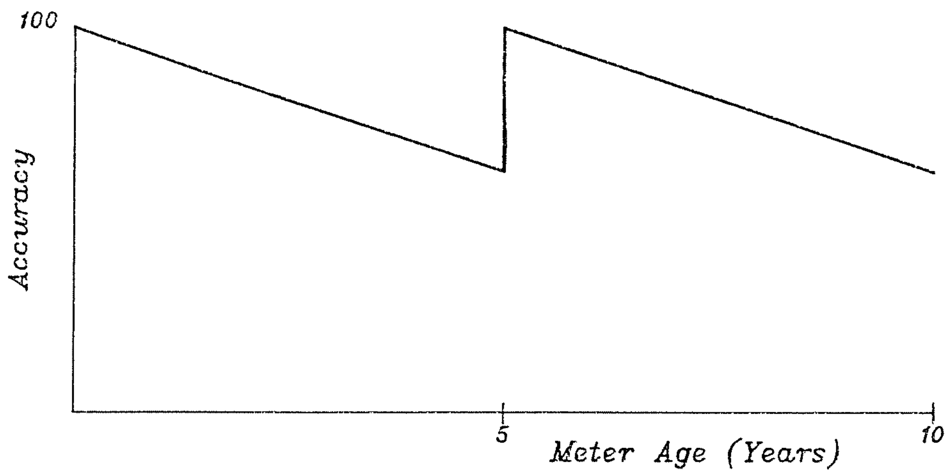
HYPOTHETICAL EXAMPLE

Consider the schematic of a simplified meter testing program presented in Figure 1. The hypothetical meter loses accuracy at a constant rate (Figure 1a). When the meter is tested and repaired after five years the accuracy returns to 100%, following which the accuracy declines with age the same as it did over the first five years (Figure 1b). (For all intents and purposes this is a "new" meter at age 5.) In Figure 1c the y axis is now the amount of water registered instead of the accuracy of the meter. (The amount of water registered equals the meter accuracy multiplied by the true water use rate.) Now, when the meter is repaired at age five, the difference between the amount registered by the repaired meter (Line AB) and the amount that would have been registered if the meter had not been repaired (Line CD) is the amount of water recovered by the meter testing program (Area Q). This amount of water, Q, is the recovered water associated with a once-in-a-five-year meter testing frequency. The amount of water, Q, is more easily calculated if an average accuracy for each year is used instead of the continuous decline in accuracy of Figure 1a. In this case the smooth lines of Figure 1 become the step functions in Figure 2. The value of Q is now calculated as:

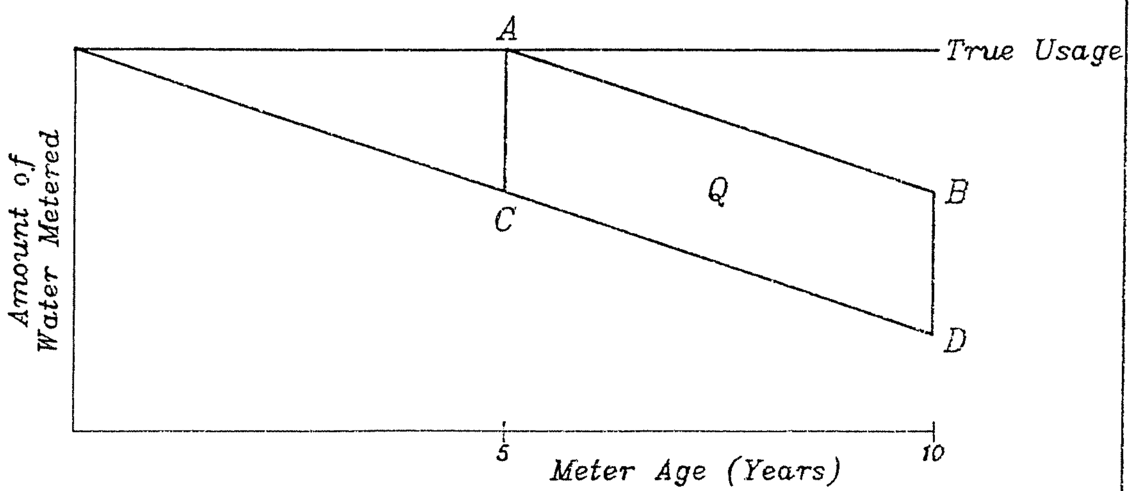
Figure 1
Meter Accuracy and Water Recovered



a) Meter accuracy decreases with age.

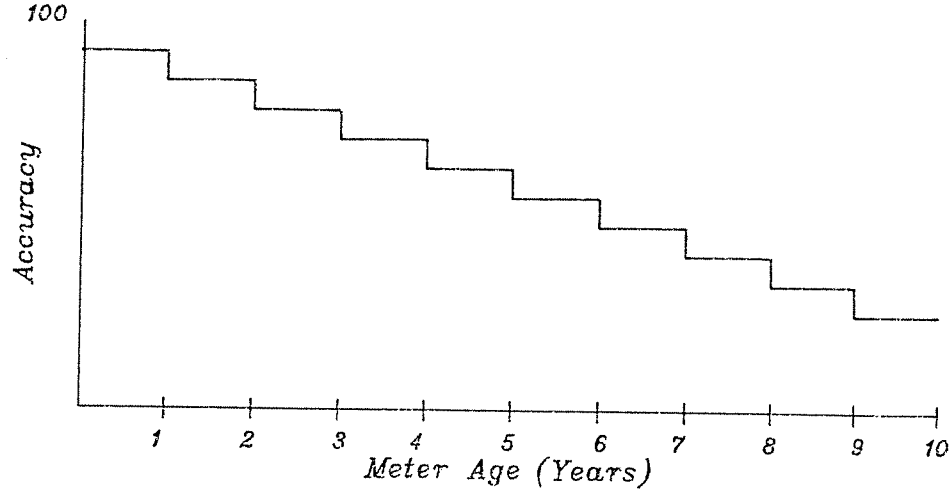


b) Accuracy of a meter that is repaired at age 5.

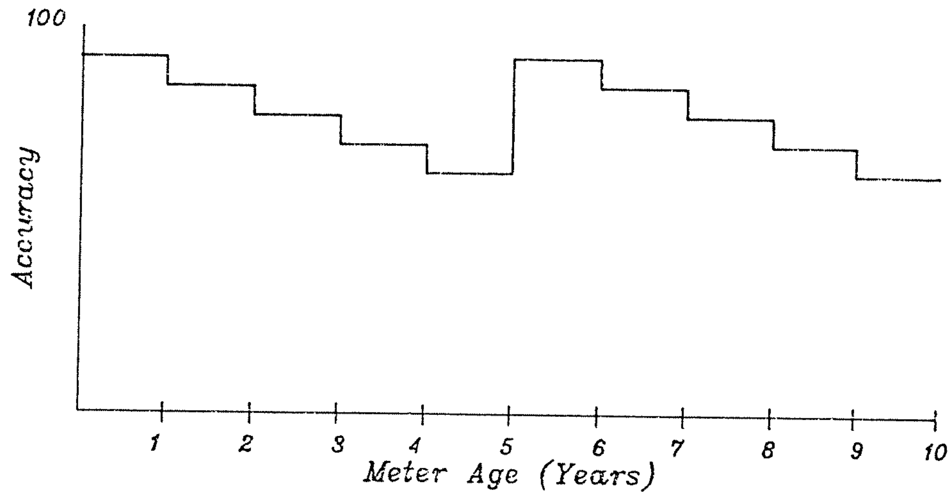


c) Area Q = Gain in water metered due to meter testing and repair.

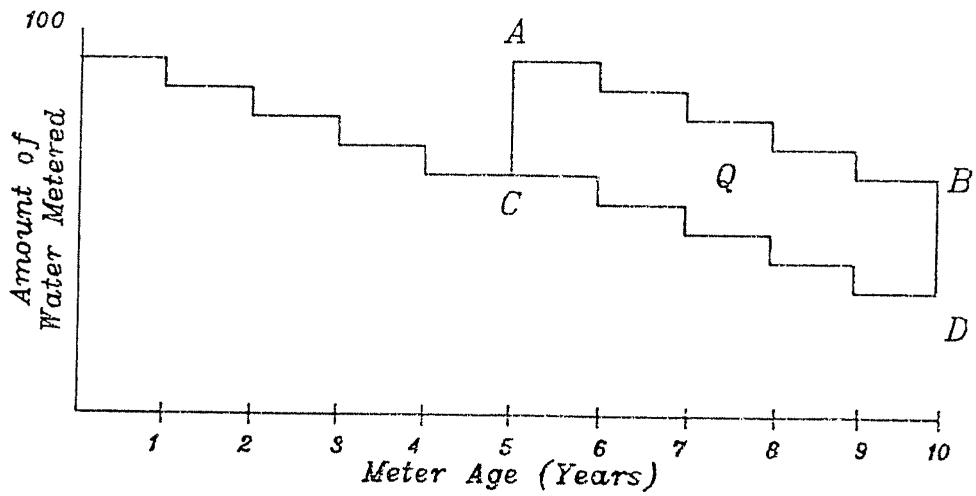
Figure 2
Meter Accuracy and Water Recovered
Using Annual Average Meter Accuracy



a) Meter accuracy decreases with age.



b) Accuracy of a meter that is repaired at age 5.



Area Q = Gain in water metered due to meter testing and repair.

Q = [Accuracy (1) - Accuracy (6)] [True Water Usage]

+ [Accuracy (2) - Accuracy (7)] [True Water Usage]

.

+ [Accuracy (5) - Accuracy (10)] [True Water Usage]

Table 2 uses hypothetical accuracy versus age values to illustrate the calculation of the water recovered by a once-in-five-year meter testing frequency. The calculation is expressed graphically in Figure 3 using average meter accuracy over the meter testing interval instead of the year by year values. This substitution is accurate if meter accuracy decreases linearly with age and permits calculation of recovered water even if meter testing data is not available for meters older than the selected meter testing interval. The algebraic expression for recovered water derived at the bottom of Figure 3 is applied to Warren County Water District meter testing data in the next section.

Calculation of the Optimal Meter Testing Frequency for the Warren County Water District

This section presents the calculation of the break even point for domestic water meter testing using meter testing data and water system characteristics from the Warren County Water District. Several refinements to the preceding

TABLE 2

Hypothetical Example
Water Recovered by a Five Year Meter Testing Interval

Age	Hypothetical Accuracy Without Testing and Repair	Hypothetical Accuracy With Testing and Repair	Improvement in Accuracy	Recovered Water*
1	.999	.999	n/a	n/a
2	.998	.998	n/a	n/a
3	.997	.997	n/a	n/a
4	.996	.996	n/a	n/a
5	.995	.995	n/a	n/a
6	.994	.999	.005	500
7	.993	.998	.005	500
8	.992	.997	.005	500
9	.991	.996	.005	500
10	.990	.995	.005	500

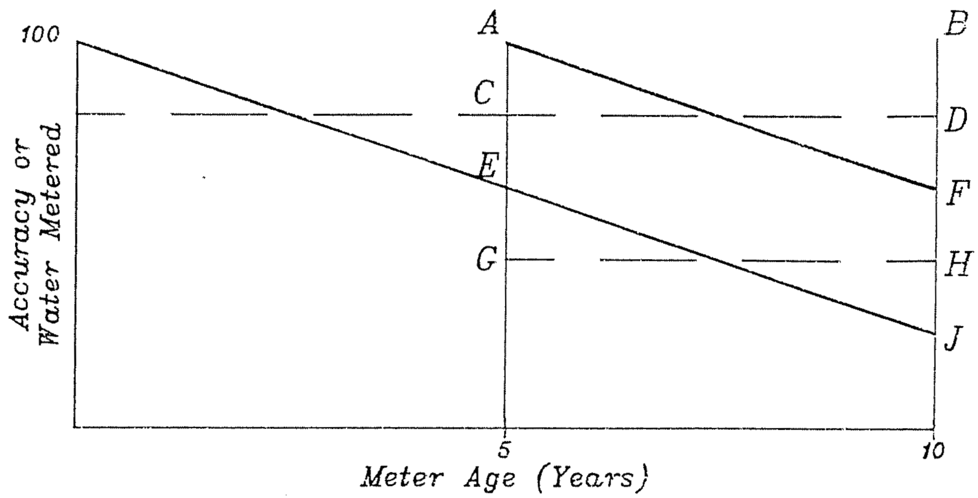
Total Water Recovered = 2500 gal

* Assume the true use rate is 100,000 gallons per year

Note: Average Accuracy of Repaired Meters = 0.997

Average Accuracy of Non-Repaired Meters During Years 6 through 10 = 0.992

Figure 3
Calculating Recovered Water



Line CD = Average accuracy of a repaired meter
Line GH = Average accuracy of a non–repaired meter, years 6–10
Point E = Accuracy of a meter before repair
Area AFJE = Water recovered due to improved accuracy of repaired meter

Area AFJE = Area CDHG
i.e., can calculate recovered water by working with average accuracy of repaired and non-repaired meters over time interval.

"Height" of Rectangle CDHG = Average accuracy of a repaired meter – Average accuracy of a non–repaired meter
= Accuracy at C – Accuracy at G

Because this is a system of parallel lines:
Accuracy at C – Accuracy at G =
Accuracy at A – Accuracy at E

Thus, recovered water can be estimated as
(Accuracy at A – Accuracy at E) x
Water use rate x No. of years
= (1.0 – 0.995)(100,000 gpy)(5)
= 2500 Gallons

hypothetical example are made:

1. Meter accuracies are taken from the "best fit" curve of meter accuracy versus age. This curve was calculated from Warren County Water District test data on 577 meters using regression analysis.

2. The value of the recovered water is expressed in present value (PV) terms by assuming that the value of the recovered water is a series of equal annual amounts over the meter testing interval. An annual interest rate of 7% and annual compounding are used.

3. The cost of the meter testing program is included in the analysis. This cost is the sum of the cost of retrieving and testing the meters ($13.35 per meter) plus the cost of replacing/repairing meters that do not meet the AWWA meter accuracy specifications. The AWWA specifications are used rather than the PSC specifications because the warranty for the Rockwell SR meters is based on the AWWA specifications. Meters that meet the AWWA specifications also meet the PSC specifications.

The retrieval and testing cost is calculated from the actual cost of the Warren County Water

District's meter testing program. The cost of replacing/repairing inaccurate meters is assumed to be $4.00. This is the cost to the District of replacing a meter that is still under warranty. The Rockwell SR meters used by the District have a warranty period of 15 years. For meter testing periods greater that 15 years a different, higher, cost of repair/replacement would have to be used.

The Water District has decided that meters that meet the AWWA specifications will also be replaced. The cost of a new meter is $24.70. An economic evaluation of the decision to replace meters that meet specifications is presented in the Appendix.

Other costs of a meter testing and repair program such as administration, overhead, benefits, physical facilities, and equipment are not included in this analysis.

The net present values of alternative meter testing frequencies are calculated in Table 3. A positive net present value indicates a meter testing frequency for which the revenue from the recovered water (taking the time value of money into account) exceeds the cost of conducting the meter testing and replacement program.

TABLE 3
Break Even Analysis for Calculation of the
Optimal Meter Testing Frequency
With Replacement of Meters That Meet Specifications

Meter Test Interval	Meter Accuracy Year	% Below AWWA Specifi-cations	Unit $/yr Recovered Water	Unit PV of Recovered Water	Unit Retrieval & Testing Cost	Unit Replace-ment Cost	NPV of Program Per Meter
1	99.97	10.83	0.031	0.03	13.35	22.46	-35.78
2	99.88	20.86	0.123	0.22	13.35	20.38	-33.51
3	99.78	30.11	0.225	0.59	13.35	18.47	-31.24
4	99.66	38.62	0.347	1.18	13.35	16.71	-28.87
5	99.52	46.42	0.490	2.01	13.35	15.09	-26.43
6	99.35	53.53	0.664	3.16	13.35	13.62	-23.82
7	99.15	59.99	0.868	4.68	13.35	12.28	-20.94
8	98.93	65.82	1.092	6.52	13.35	11.08	-17.92
9	98.67	71.05	1.358	8.85	13.35	9.99	-14.48
10	98.37	75.72	1.664	11.69	13.35	9.03	-10.72
11	98.03	79.84	2.011	15.08	13.35	8.17	-6.45
12	97.64	83.46	2.410	19.14	13.35	7.42	-1.63
13	97.21	86.59	2.849	23.81	13.35	6.78	3.69
14	96.73	89.27	3.339	29.20	13.35	6.22	9.64
15	96.19	91.53	3.890	35.42	13.35	5.75	16.33

$$\text{Unit \$/yr of Recovered Water} = (1-\text{Acc}(n))(71{,}400)\frac{(1.43)}{1000}$$

Assumptions

Average Consumption 71,400 gal/yr
Acc(n) = Accuracy after n years in service
Marginal billing rate for 5000-8000 gal/mo is $1.43/1000 gal.
PV uses i = 7%
and number of years in testing cycle
Unit Replacement Cost = ($4.00)(% below specifications) + ($24.70)(1-% below specifications)

CONCLUSION

The shortest meter testing frequency with a positive net present value is once-in-thirteen-years. Thus the optimal program is for the Warren County Water District to test domestic water meters on a once-in-twelve years cycle.

DISCUSSION

The following factors would tend to increase or decrease the length of the optimal meter testing interval:

<u>Factors that increase the time between testing</u>

- if all costs of the meter testing program (administration, overhead, benefits, physical facilities, equipment, etc.) are included

- if an interest rate greater than 7% is used

- if future meter testing indicates that fewer meters fail to meet the AWWA accuracy requirements than in the sample used for this study

- if future meter testing indicates that meters lose accuracy as they get older at a slower rate than the meters in the sample used for this study

<u>Factors that decrease the time between testing</u>

- if the marginal water rate increases

- if an interest rate less than 7% is used

- if true meter accuracies at advanced ages are used instead of the linear algebraic approximation

- if future meter testing indicates that more meters fail to meet the AWWA accuracy requirements than in the sample used for this study

- if future meter testing indicates that meters lose accuracy as they get older at a faster rate than the meters in the sample used for this study

The calculations in Table 3 assume that all meters will be replaced after 13 years. Those meters that do not meet the AWWA meter accuracy specifications cost $4.00 to replace because they are covered by the manufacturer's warranty. Meters that meet the AWWA meter accuracy specifications also would be replaced at a cost of $24.70 each, the cost of a new Rockwell SR meter. The following discussion compares the cost of purchasing new meters to replace the 13-year old meters that perform within the AWWA specifications with the cost of leaving these 13-year old meters in service for another 13 years. The cost of not replacing the meters has two components: 1) the cost of replacing the meters at a later time and 2) the "cost" of the additional water not registered by these meters relative to the water unregistered by new meters. These costs are calculated separately in the following sections.

1. The Cost of the Additional Unregistered Water Relative to a New Meter's Performance

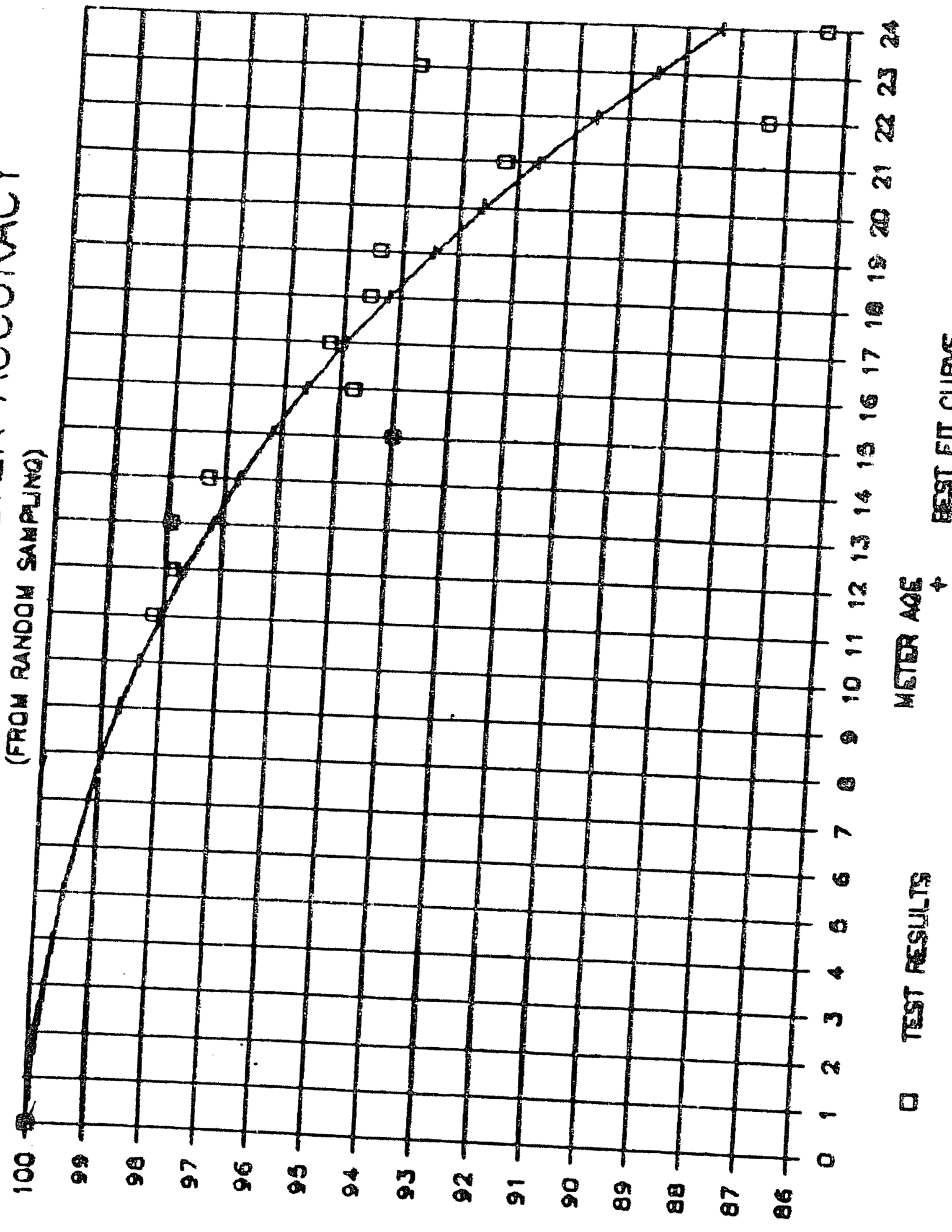
The weighted average meter accuracy graph in Figure A-1 is the graph of the weighted average meter accuracy for all meters of a given age. (Figure A-1 is a reproduction of Figure 1 from the January 20, 1988 report "Determination of

FIGURE A-1

FIGURE 1

WEIGHTED AVERAGE METER ACCURACY

(FROM RANDOM SAMPLING)



a Cost-Effective Meter Testing and Maintenance Program".) To calculate the cost of excess unregistered water relative to a new meter the weighted average meter accuracy of meters that meet AWWA meter accuracy specifications must be calculated separately. For 13 year old meters (1974 Age Group, Appendix A of the above report), the weighted average meter accuracy of meters that meet the AWWA specifications is 0.9956. This weighted average meter accuracy is approximately equal to the weighted average meter accuracy of all 5-year old meters. That is, for the purpose of estimating the future accuracy of the meters that meet the specifications at age 13, it is assumed that they will lose accuracy with age at the same rate as all meters of age 5 lose accuracy with age. Specifically, the future accuracies of the meters that are not replaced at age 13 will be as follows:

Age	Weighted Average Meter Accuracy
13	0.9952 (same as an age 5 meter)
14	0.9935 (same as an age 6 meter)
15	0.9915 (same as an age 7 meter)
.	
.	
26	0.942 (same as an age 18 meter)

* Figure A-2 was created by superimposing the weighted average meter accuracy curve of Figure A-1 with the same curve

FIGURE A-2

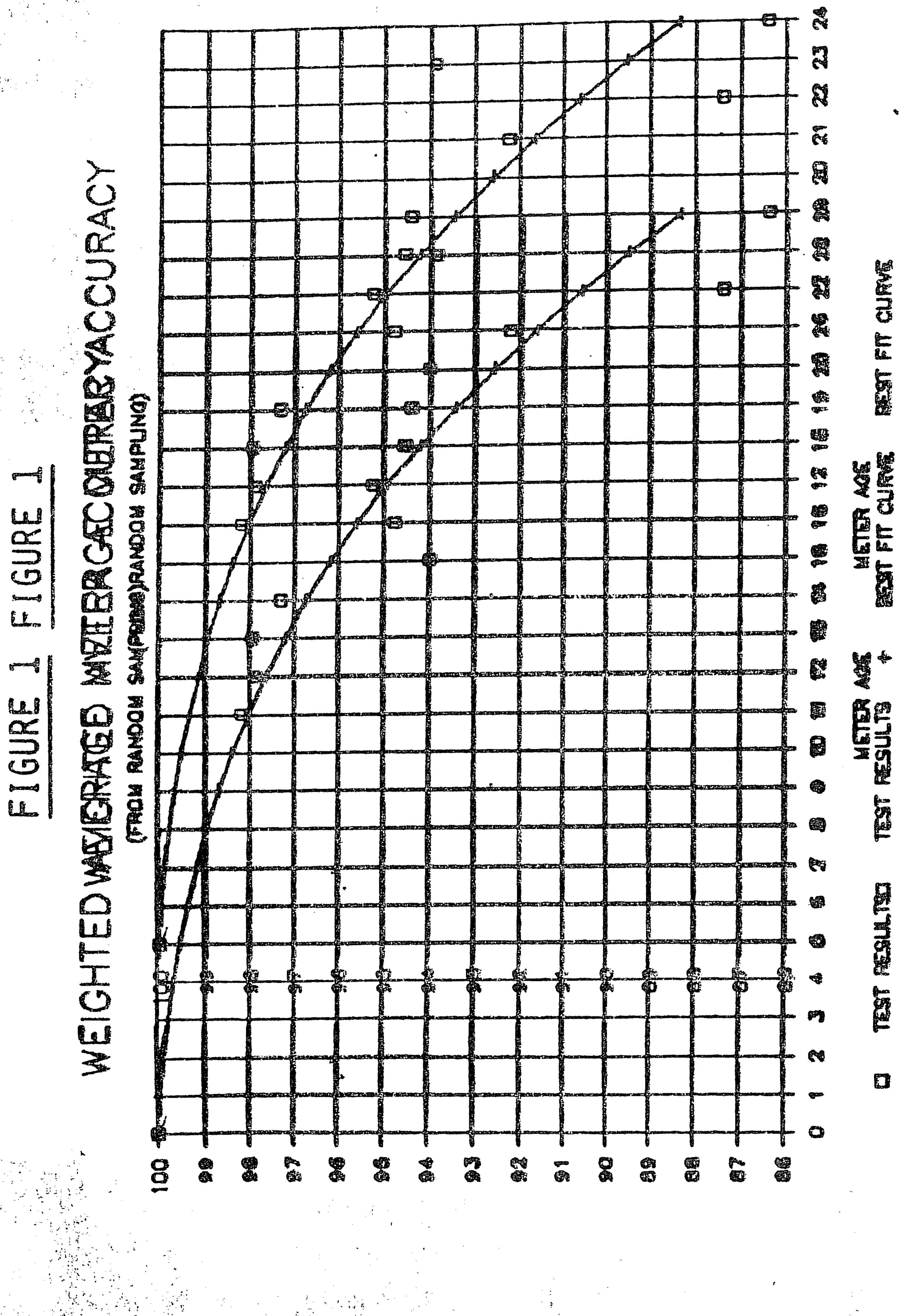


FIGURE 1
WEIGHTED AVERAGE METER ACCURACY
(FROM RANDOM SAMPLING)
100
99
98
97
96
95
94
93
92
91
90
89
88
87
86
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
METER AGE
TEST RESULTS
BEST FIT CURVE

shifted 5 years. In Figure A-2 the upper curve is the weighted average meter accuracy vs. age curve for the replacement meters. The lower curve is the weighted average meter accuracy vs. age curve for the meters not replaced at age 13. Note that the water above the upper curve will be "lost" even by a new meter. This lost water is not considered here. This analysis considers only the additional water lost by the non-replaced meter.

The difference between the two curves of Figure A-2 represents the amount of water that the non-replaced meter will lose in addition to the amount that a new meter would lose over 13 years. This additional water loss is estimated by calculating the difference between the meter accuracies:

Weighted Average Meter Accuracy

new meter	non-replaced meter	difference
Age 1 =.9997	Age 5 =.9956	.0041
Age 13=.9721	Age 18=.942	.0301

Using the average difference in accuracies over the 13 year period ((.0041+.0301)/2) = .0171, the value of the excess water lost by the non-replaced meter can be calculated as:

(.0171)x(71,400)x($1.43/1000) = $1.75 per meter per year.

Treating this lost water as an annual series, the present value in year 13 of the lost water is $14.62 per meter.

2. The Cost of Replacing Non-replaced Meters in the Future

This analysis considers only the cost of the meters that will need to be replaced in year 26. From the meter testing data for the Warren County Water District, it can be calculated that 85.59% of the 13 year old meters and 98% of the 26 year old meters fail to meet the AWWA meter accuracy specifications. (See Figure A-3, which is taken from Figure 2 of the above-referenced report.) That is, 13.41% of the meters will not be replaced at age 13. At age 26, 85% of the nonreplaced meters will need to be replaced. The unit replacement cost is:

(cost of new meter) x (percentage replaced at age 26) =

($24.70) x (.85) = $21.01

This cost is incurred in year 26. The present value of this unit cost in year 13 is $8.72.

FIGURE 2

COMPARISON WITH AWWA SPECIFICATIONS

(FROM RANDOM SAMPLING)

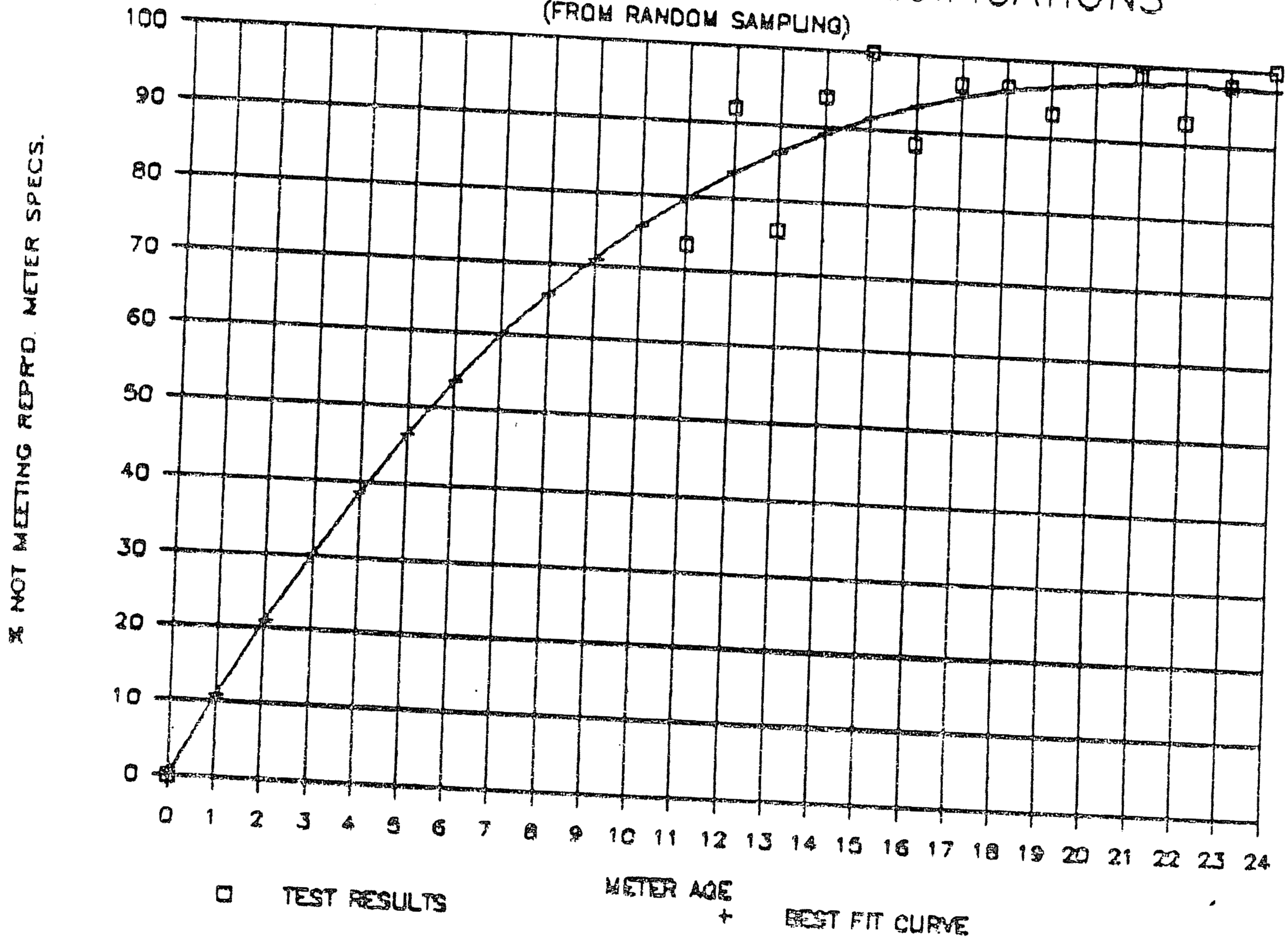


FIGURE A-3

3. Cost Comparison

A. Cost of not replacing meters that meet the AWWA meter accuracy specifications at age 13:

Cost of additional unregistered water	=	$14.62
+		
Cost of replacing meters in year 26	=	8.72
Total Cost (PV year 13)		$23.34

B. Cost of Replacing Meters that Meet the AWWA meter accuracy specifications at age 13:

= $24.70

C. Conclusion

There is a 6% difference in the costs (present value in year 13) between the two options. Considering the variability of the data and the approximations used in the analysis, the two options are essentially equivalent in economic terms. Other nonquantitative factors may make one option preferable to the other.

BREAKDOWN OF TOTAL METER POPULATION
5/8 X 3/4 INCH SIZE METERS
AS OF NOVEMBER 7, 2011 *

Meter Manufacturer	Meter Model	Age	Meter Population			Total Population
			Warren	Butler	Simpson	
Precision	PMM Series	31	0	7	0	7
		20	0	5	0	5
		18	0	5	0	5
		17	0	41	0	41
		16	0	107	0	107
		15	0	2	0	2
		14	0	4	0	4
		13	1	0	0	1
		Total - PMM Series	1	171	0	172

Meter Manufacturer	Meter Model	Age	Meter Population			Total Population
			Warren	Butler	Simpson	
Sensus	SR	49	1	0	0	1
		48	0	0	0	0
		47	6	2	0	8
		46	3	0	0	3
		45	3	0	0	3
		44	0	0	0	0
		43	11	2	3	16
		42	4	0	1	5
		41	2	0	0	2
		40	29	0	0	29
		39	8	0	1	9
		38	2	1	0	3
		37	5	0	0	5
		36	4	0	0	4
		35	12	7	9	28
		34	28	30	5	63
		33	14	6	7	27
		32	43	5	5	53
		31	15	4	3	22
		30	22	21	10	53
		29	6	1	12	19
		28	57	15	9	81
		27	401	20	61	482
		26	229	21	78	328
		Total - SR Meters	905	135	204	1,244

Meter Manufacturer	Meter Model	Age	Meter Population Warren	Butler	Simpson	Total Population
Sensus	SRII	25	523	107	15	645
		24	483	110	41	634
		23	669	122	68	859
		22	1,289	470	137	1,896
		21	1,148	61	122	1,331
		20	1,119	239	172	1,530
		19	1,054	224	246	1,524
		18	1,499	212	128	1,839
		17	723	411	117	1,251
		16	772	170	215	1,157
		15	1,080	147	391	1,618
		14	760	143	152	1,055
		13	1,191	138	150	1,479
		12	726	150	4	880
		11	698	155	41	894
		10	327	39	2	368
		9	661	44	1	706
		8	573	115	43	731
		7	2,315	522	387	3,224
		6	2,020	335	266	2,621
		5	775	81	33	889
		4	655	29	7	691
		3	530	115	54	699
		2	1,135	252	108	1,495
		1	166	9	2	177
		Total - SRII Meters	22,891	4,400	2,902	30,193
		Grand Total - All Meters	23,797	4,706	3,106	31,609

* *The meter database does not have the capability of generating reports as of a prior date.*

EXHIBIT 4A

Journal of Water Resources Planning and Management

International System of Units (SI)

Each author shall have the privilege of giving preference to SI, and to units acceptable in SI, and to other units. When preference is given to SI units, no other units are required. When preference is given to other units, the SI units shall be given in parentheses; in a supplementary or a dual-unit table; or in an appendix. A complete guide to the SI system and its use may be obtained from the American Society for Testing Materials (1916 Race Street, Philadelphia, PA 19103) by asking for the latest edition of ASTM E-380. Other useful references include the "ANMC Metric Editorial Guide" (*ANMC Pub. 1*, 3rd ed., 1981, American National Metric Council, Bethesda, MD); "The International System of Units (SI)," David T. Goldman and R. J. Bell, editors, (NBS Pub. 330, 1981, National Bureau of Standards, Washington, D.C.); "The Metric System of Measurement (SI)" (*Federal Register Notice of October 26, 1977*, National Bureau of Standards); and "Metric Manual" by Lawrence D. Pedde and others (U.S. Department of the Interior, Bureau of Reclamation, Denver, CO, 1978).

All authors of *Journal* papers are being asked to prepare their papers in SI units. To provide preliminary assistance to authors, the ASCE Committee on Metrication recommends the following conversion factors and guides:

To convert	to	Multiply by
acre-foot (acre-ft)	cubic meter (m^3)	1.23×10^3
acre (acre)	hectare (ha)	0.405
pound mass (lbm)	kilogram (kg)	0.454
mile (mile)	kilometer (km)	1.61
pound force per square inch (psi)	kilopascal (kPa)	6.89
U.S. gallon (gal)	liter (L)	3.79
inch (in.)	millimeter (mm)	25.4
kilogram force (kgf)	newton (N)	9.81
pound force (lbF)	newton (N)	4.45

Optimal Testing Frequency for Domestic Water Meters

By Richard R. Noss,[1] A. M. ASCE, Gregory J. Newman,[2] and James W. Male,[3] M. ASCE

Abstract: A procedure is developed to determine the optimal testing frequency for 5/8-in. meters. The objective is to minimize the cost to the utility, including the cost of the meter testing program itself and the cost (revenue loss) of the water not registered due to meter inaccuracy. Water losses due to both working, but inaccurate, meters and failed meters are accounted for. The rate of decline of meter accuracy with age was found to be the most significant influence on the optimal testing frequency.

Introduction

Most utilities in the United States meter water delivered to customers. The measured amounts of water delivered are used to calculate individual consumer's water bills. Meters are also used by some as a means of effecting water conservation through billing surcharges, increasing block rate structures, and general heightening of awareness of the amount of water used.

Although the average residential consumer uses far less water than most industrial users, the number of domestic users is large and total domestic use often dominates total industrial water use. Unless the domestic meters are tested and maintained, the lost (i.e., unmetered) water due to domestic meter inaccuracies can be a significant portion of the system's total unaccounted for water. Because of the large number of domestic meters in service and the relatively high costs of pulling, testing, repairing, and replacing them, however, it is possible to spend too much on a meter maintenance program. Too frequent testing may result in spending more money on the meter maintenance program than is recovered in terms of the value of water formerly lost through inaccurate meters. On the other hand, spending too little on a meter maintenance program, and, therefore, testing meters too infrequently, can result i large revenue losses due to excessive under-registration of the meters in service.

Meter Testing Programs

Testing programs are described by the frequency at which the average meter is tested. The meters to be tested come from three sources: (1) Those pulled because billing records indicated that they had failed (either stopped absolutely or registering extremely low amounts of water use);

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Note.—Discussion open until June 1, 1987. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on August 6, 1985. This paper is part of the *Journal of Water Resources Planning and Management*, Vol. 113, No. 1, January, 1987. ©ASCE, ISSN 0733-9496/87/0001-0001/$01.00. Paper No. 21145.

(2) those pulled due to customer complaints (e.g., leaky meters); and (3) those pulled as part of the routine testing program. The usual strategy for routine testing programs is to pull a predetermined number of meters each year for testing and repair. Meter testing programs can also be characterized by the percentage of the total meter population tested each year. If 5% of the meters are tested each year, the associated frequency of meter testing would be once every 20 yrs.

Many states have regulations concerning the frequency of domestic meter testing, ranging from once in 20 yrs in California to once in five years in Kentucky. The most common regulation is a frequency of once every ten years (3). Since accuracy varies with flow rate, most regulations also specify the flow (or flows) at which the meters must be tested. Williams (13) found that, for the utilities surveyed, the frequency of change-outs (removing meters for testing or repair) ranged from once in three years to once in 20 yrs. The most common period was from 10–15 yrs. While an AWWA committee on unaccounted-for water (2) suggested that the optimal period of testing depends on local conditions and should be determined by experience, many utilities admitted that their testing programs were not up-to-date.

Regulations notwithstanding, individual investigators have come to widely divergent conclusions about desirable meter testing frequencies. A study of domestic meter change-outs for Albany, New York, indicated 20 yrs as the optimal meter testing frequency (4). The California section of the AWWA Committee on Unaccounted-for Water (1), found that meters should remain in service for at least 20 yrs. Williams (13) found that the optimal period for testing domestic meters in Indianapolis was between 9–15 yrs, depending on which domestic water-use profile was used. He also recommended that each utility make its own study to establish a testing interval.

Several strategies for improving the efficiency of meter testing have been proposed:

1. Periodic testing of all meters. This entails the establishment of a testing interval during which each meter is removed, tested, repaired, and/or replaced at least once.
2. Statistical sampling program (12). In this approach, the meter population is divided into different subgroups and a statistically significant sample is tested from each subgroup. The results of the testing then determine whether or not each subgroup as a whole should be tested and repaired. This procedure requires a large meter population that has defined subgroups with expected similar behavior characteristics.
3. Pulling failures only. This procedure relies on the utility having some means of identifying failed or failing meters.

Purpose of Paper

This paper addresses the problem of determining the optimal frequency of testing domestic meters (strategy 1).

The optimal period of testing model described below uses an accuracy versus age relationship for meters in service and the rate at which meters fail in the system, together with information on the meter testing

program and the utility's costs and water usage to determine an optimal frequency for testing meters. The following section briefly reviews the determination of the relationship between meter accuracy and age, and of the overall meter failure rate. Subsequent sections develop the model and present results for two case studies.

Meter Accuracy and Failure Rate

Using routine meter testing data from the Westchester (N.Y.) Joint Water Works (WJWW) and the Taunton (Mass.) Water Works (TWW), relationships between accuracy and age were calculated for each of the tested flows. These curves are shown in Fig. 1; a more detailed discussion of these calculations can be found in Ref. 9.

The accuracy versus age relationships were then weighted according to water usage profiles from the literature to calculate a single meter accuracy versus age relationship for the assumed water usage pro[illegible] Several reported water use profiles are presented in Table 1. Becau[illegible] meter accuracy typically falls off sharply at low flows (see Fig. 2), the important differences between the water use profiles presented in Table 1 are the amount of water used at low flow rates (less than 1 gpm). Fig. 2 presents typical accuracy curves plotted through WJWW meter testing data for 1, 10, and 20-yr old meters. (Failures are removed from the sample.) The last column of Table 1 presents the percent of total water use occurring at rates of 1 gpm or less.

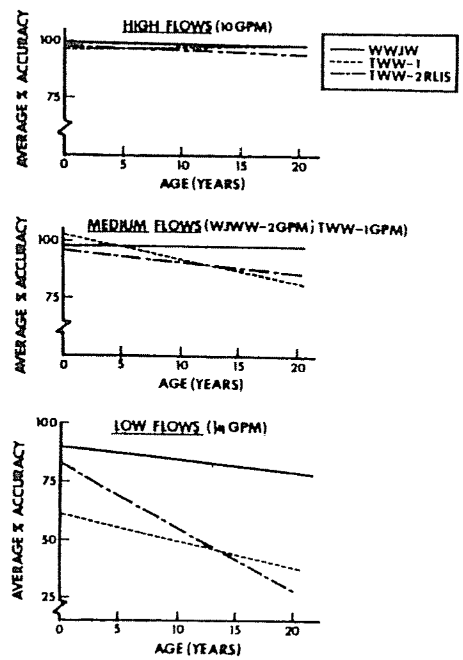

FIG. 1.—Accuracy versus Age for 5/8-in. Meters

TABLE 1.—Reported Domestic Water-Use Profiles (Percent of Total Flow)

Study (1)	Year of publication (2)	Flow Ranges 0.0–0.25 (3)	0.25–0.50 (4)	0.50–1.00 (5)	1:00–2.00 (6)	2.00–4.00 (7)	4.00–6.00 (8)	6.00–10.00 (9)	10.00+ (10)	Total percent of use at flows less than 1 gpm (11)
AWWA (2)	1966	4.60	5.90	(5.90)[b]	13.70	59.00	(59.00)[b]	16.80	—	10.5
Graeser (6)	1958	5.00	6.00	8.00	31.00	40.00[a]	10.00[a]	(10.00)[b]	—	19
Hudson (7)	1964	13.00	3.40	6.80	13.30	43.00	20.50	(20.50)[b]	—	24.2
Kuranz (8)	1942	13.60	1.80	5.00	11.80	52.40	14.70	0.70	—	20.4
Nielson (10)	1969	8.00	(8.00)[b]	11.00	18.00	39.00	20.00	(20.00)[b]	—	19.0
PSWCO (5)	1970	2.59	1.55	10.23	21.93	33.50	19.70	10.50	4.0	14.37
Sisco (11)	1969	1.00	4.00	(4.00)[b]	81.00	(81.00)[b]	14.00	(14.00)[b]	—	5.0 ←

[a]These percentages actually represent flow ranges of 2.0 to 5.0 gpm and 5.0 to 10.0 gpm.
[b]Use of parentheses indicates that the flow ranges are inclusive of amounts in previous column.

This study used two water use profiles to calculate weighted meter accuracy versus age relationships: one developed by the Philadelphia Suburban Water Company (PSWCO) in 1970 and documented by Brittain (5), and one developed by Kuranz in 1942 (8). As shown in Table

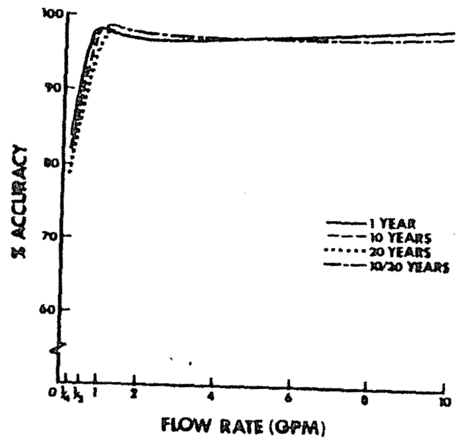

FIG. 2.—Typical Accuracy Curves for Single Meter

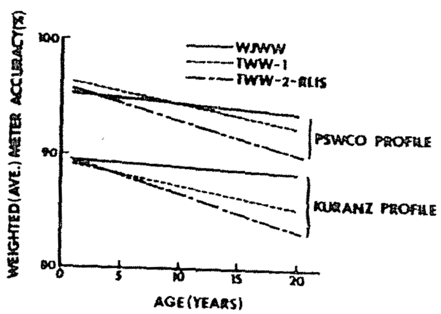

FIG. 3.—Weighted Meter Accuracy versus Age Curves

TABLE 2.—Meter Accuracy Data

Description (1)	WJWW (2)	TWW (3)
Number of 5/8-in. metered services	7,934	9,966
Average annual 5/8-in. metered rate (1,000 cu ft/meter-yr)	10.3	10.7
Average 5/8-in. meter age	14	10
5/8-in. meter failure rate (failure/meter-yr)	0.031	0.013
Estimate of total water unregistered due to meter failure[a] (1,000 cu ft/yr)	422	231

[a]Assumes two month average detection-replacement time for failure.

1, these two profiles are representative of the range of water use profiles reported in the literature. The Kuranz profile generally gives lowe weighted accuracy estimates because it allocates a greater fraction of daily water use to low flow rates where meters are least accurate. Fig. 3 shows weighted meter accuracy versus age relationships for three sets of meter data using two different water use profiles.

Meter failure rates (failure/meter-yr) were estimated from distribution system data (9). Table 2 summarizes the information on meter failure rates. Table 3 presents estimates of overall unmetered water passing through 5/8-in. meters for the two case study utilities and the two water use profiles studied.

The slope and intercept of the weighted accuracy versus age curves (Fig. 3) were used to characterize the process by which meters lose their accuracy. Several assumptions were made in this process: (1) Other factors influencing a meter's accuracy were not accounted for; (2) the distribution of meter ages was assumed to be uniform; and (3) meter failures were assumed to occur independently and could be characterized by an annual meter failure rate. Therefore, water that is unmetered due to meter inaccuracy is estimated by characterizing the accuracy of an "average" meter of a given age and multiplying that by the number of meters in that age cohort. Using the uniform age distribution assum

TABLE 3.—Estimates of Unmetered Water Passing through 5/8-in. Meters

Water-use profile used to derive flow weighted accuracy (1)	Kuranz (9) (2)	PSWCO (6) (3)	Kuranz (4)	PSWCO (5)
Flow weighted % accuracy at average age	88.8	94.3	86.3	93.2
Estimate of total water unregistered due to working meter inaccuracies (1,000 cu ft/yr)	10,307	4,940	16,928	7,784
Total unmetered water passing through meters (working and failed) (1,000 cu ft/yr)	10,729	5,362	17,159	8,015
Unmetered water delivered/meter/yr (cu ft/yr)	1,352	676	1,722	804

tion, the total amount of water that is unmetered due to meter inaccuracy can be estimated using the accuracy of the average-aged meter and the total number of meters in service.

The assumption that the age distribution of meters in service is uniform is inherent in the periodic nature of the meter testing program. That is, the testing program is specified as testing a fixed fraction of the meters in service each year. Therefore, once one cycle of the meter testing program is completed the age distribution of the meters in service will be uniform. One situation that may affect the age distribution is the possibility of adding an unusually large (or small) number of new services in a year but this is unlikely to be significant except in utilities with a small number of existing services. Furthermore, as the number of meters in service increases, the number of meters tested each year also increases (since a fixed percentage is tested each year), so that the periodic testing program would immediately begin to damp out any skew in the age distribution of meters in service due to changes in the rate of addition of new services.

Cost data were collected from the two utilities on: (1) The cost to remove and replace meters; (2) the cost of testing and repair; and (3) the retail cost of water. Data were also collected on the total number of meters in the system and the average metered consumption rate.

Optimal Period of Testing Model (OPTM)

The optimal period of testing is found by minimizing the total annual cost of meter repair. This cost has three components, each of which is a function of the period of meter testing (PER):

1. Cost of the repair policy (CRP).—The cost of removing, testing, repairing, and replacing meters.
2. Cost of water lost through failed meters (CWLF).—After a meter fails it remains in service for a length of time allowing water to flow through unmetered, calculated from the meter failure rate.
3. Cost of water lost through inaccurate meters (CWLI).—Calculated from the accuracy versus age relationship.

The total annual cost can be calculated as follows:

$$\text{TCOST} = \text{CRP} + \text{CWLF} + \text{CWLI} \quad \text{(1)}$$

Each of the component costs can be derived separately.

In order to minimize the total annual cost and find the optimal period for meter testing (PER), the derivative of the total annual cost with respect to PER can be set equal to zero and solved for PER.

Cost of Repair Policy (CRP).—This component can be estimated as follows:

$$\text{CRP} = \left(\frac{\text{NMET}}{\text{PER}}\right) \times (\text{CRR} + \text{CTR}) \quad \text{(2)}$$

where NMET = the number of domestic metered services in the system; and PER = the testing period, the average interval the meter is designed to stay in service (yrs). PER is the unknown variable, to be determined by OPTM. Thus NMET/PER represents the number of meters pulled and tested each year. CRR = the average cost associated with removing and replacing a meter; and CTR is the average cost associated with testing and repairing a meter.

Cost of Water Lost through Failures (CWLF).—CWLF can be derived as follows: let X = number of failed meters detected by billing records each year; Y = number of failed meters detected by the routine repair policy each year; ANNF = number of failures occurring in a year; RFAIL = rate of meter failure (failures/meter-yr); NMET = number of metered services; PER = design period of testing meters (yrs); and TFAIL = duration that an average failed meter stays in service before it is pulled (yrs). All failed meters are pulled after TFAIL unles they happened to be included in the meters routinely pulled for testing.

It follows that

$$\text{ANNF} = \text{NMET} \times \text{RFAIL} = X + Y \quad \text{(3)}$$

The number of meters routinely tested per year in excess of those failures detected by billing readings is (NMET/PER) − X, thus

$$Y = \text{TFAIL} \times \text{RFAIL}\left[\left(\frac{\text{NMET}}{\text{PER}}\right) - X\right] \quad \text{(4)}$$

That is, given the assumption that the average meter stays in service only TFAIL yrs before it is recognized by inspection of billing records and pulled, the only failed meters that could be detected by the routine testing program are those that have failed in the last TFAIL yrs. Therefore, although RFAIL × (NMET/PER − X) meters would be expected to fail in a year, only TFAIL × RFAIL × (NMET/PER − X) would be detectable by a routine testing program.

Combining Eqs. 3 and 4, simplifying, and solving for X:

$$X = \text{NMET} \times \text{RFAIL} \times \left[\frac{1 - \left(\frac{\text{TFAIL}}{\text{PER}}\right)}{1 - (\text{TFAIL} \times \text{RFAIL})}\right] \quad \text{(5)}$$

The meters in the Y group have a fail time ranging from 0–TFAIL, after which they would be detected by billing readings. Since the routine testing of meters is random, it is expected that the average time to detect failures in the Y group would be TFAIL/2. The total meter years of failure per year (MYF) can be expressed as

$$\text{MYF} = X \times \text{TFAIL} + Y \times \frac{\text{TFAIL}}{2} \quad \text{(6)}$$

The annual cost of water lost through failures (CWLF) then becomes

$$\text{CWLF} = \text{MYF} \times \text{MRATE} \times \text{CW} \quad \text{(7)}$$

where MRATE = the average annual domestic metered rate (1,000 cu ft/yr-meter); and CW = the retail cost of water ($/1,000 cu ft). Solving Eq. 3 for Y and combining with Eqs. 5–7 yields

$$\text{CWLF} = \text{MRATE} \times \text{CW} \times \text{TFAIL} \times \text{NMET} \times \text{RFAIL}$$

$$\times \left[\frac{1}{2} + \frac{1}{2} \times \frac{1 - \dfrac{\text{TFAIL}}{\text{PER}}}{(1 - \text{TFAIL} \times \text{RFAIL})}\right] \quad \text{(8)}$$

Eq. 8 accounts for the cost of water lost through failed meters detected by billing readings and failed meters repaired as part of the routine testing procedure.

Cost of Water Lost through Inaccurate Working Meters (CWLI).—This cost can be estimated as follows:

$$\text{CWLI} = \frac{100 - \text{AVGACC}}{100} \times \text{NMET}$$

$$\times (1 - \text{TFAIL} \times \text{RFAIL}) \times \text{USERATE} \times \text{CW} \quad \text{(9)}$$

where AVGACC = the average meter accuracy expressed as percent; and USERATE = the average actual water use through the meter (1,000 cu ft/meter-yr). The actual and metered rates can be related by AVGACC

$$\text{USERATE} = \text{MRATE} \times \frac{100}{\text{AVGACC}} \quad \text{(10)}$$

Combining Eqs. 9 and 10 yields

$$\text{CWLI} = \text{NMET} \times (1 - \text{TFAIL} \times \text{RFAIL}) \times \text{MRATE}$$

$$\times \text{CW} \times \left[\left(\frac{100}{\text{AVGACC}}\right) - 1\right] \quad \text{(11)}$$

The average accuracy can be estimated using the previoulsy derived linear accuracy/age relationship and the average age of the meters in service

$$\text{AVGACC} = M \times \left(\frac{\text{PER}}{2}\right) + B \quad \text{(12)}$$

where M (%/yr) and B (%) = the slope and intercept, respectively, of the accuracy/age relationship. Combining Eqs. 11 and 12 yields

$$\text{CWLI} = \left[\frac{100}{M \times \left(\dfrac{\text{PER}}{2}\right) + B} - 1\right] \times \text{NMET}$$

$$\times (1 - \text{TFAIL} \times \text{RFAIL}) \times \text{MRATE} \times \text{CW} \quad \text{(13)}$$

Solving for Optimal Period of Testing (PER).—Taking the derivatives of Eqs. 2, 8, and 13 with respect to PER, inserting them into Eq. 2 and removing the common factor (NMET), yields

$$\frac{\text{RFAIL} \times \text{TFAIL} \times \text{MRATE} \times \text{CW} \times \left(\dfrac{1}{2}\right) \times \left[\dfrac{\text{TFAIL}}{(1 - \text{TFAIL} \times \text{RFAIL})}\right]}{\text{PER} \times \text{PER}}$$

$$- \frac{(\text{CRR} + \text{CTR})}{\text{PER} \times \text{PER}}$$

$$- \frac{(1 - \text{FAIL} \times \text{TRFAIL}) \times \text{MRATE} \times \text{CW} \times 100 \times \dfrac{M}{2}}{\left[\left(M \times \dfrac{\text{PER}}{2}\right) + B\right]^2} = 0 \quad \text{(14)}$$

To combine constants in Eq. 14, let D = CRR + CTR; E = RFAIL × TFAIL × MRATE × CW × (1/2) × [TFAIL/(1 − TFAIL × RFAIL)]; and F = (1 − TFAIL × RFAIL) × MRATE × CW × 100 × (M/2). Substituting and putting in quadratic form yields

$$\text{PER}^2 \times \left(\frac{M^2}{4F} - \frac{1}{E - D}\right) + \text{PER} \times \left(\frac{M \times B}{F}\right) + \frac{B^2}{F} = 0 \quad \text{(15)}$$

Solving for the optimal period for testing meters ($\text{PER}_{(opt)}$) yields:

$$\text{PER}_{(opt)} = \frac{-\left(M \times \dfrac{B}{F}\right) + 2B \times \sqrt{\dfrac{(-1)}{[F \times (D - E)]}}}{2 \times \left(\dfrac{M^2}{4F} + \dfrac{1}{D - E}\right)} \quad \text{(16)}$$

Since F is negative and $D >> E$, the root of the radical is real and a minimum can be found. Also, $1/(D - E) >> (M \times M)/4F$, thus the denominator is positive. Only the positive root needs to be evaluated since a negative frequency would have no real meaning. This formulation for determining the optimal period of testing meters is the basis for the interactive computer program, ECONANAL, which analyzes the economics of meter repair.

ECONANAL—A Computer Program to Calculate Optimal Testing Periods

Overview of the Program ECONANAL.—ECONANAL was designed as a tool to aid water utility managers making decisions about repair policies for domestic water meters. ECONANAL could also be applied to maintenance scheduling for larger size meters if the assumption of a linear relationship between accuracy and age can be verified for the meters in question. The output from ECONANAL is a two-page report on the optimal period of testing meters. The first page (Appendix I) lists the input data, followed by the results showing various statistics at optimality, and a sensitivity analysis of selected input variables at optimality. The second page (Fig. 4) is a graph showing how the total annual cost (the value of unmetered water plus the cost of meter testing) varies with the design period of meter testing.

In order to determine the sensitivity of the solution to a change in the value of an input parameter, it is necessary to multiply a small change in the parameter by the appropriate PER/X column value. The corresponding change in the predicted optimal period of meter testing will

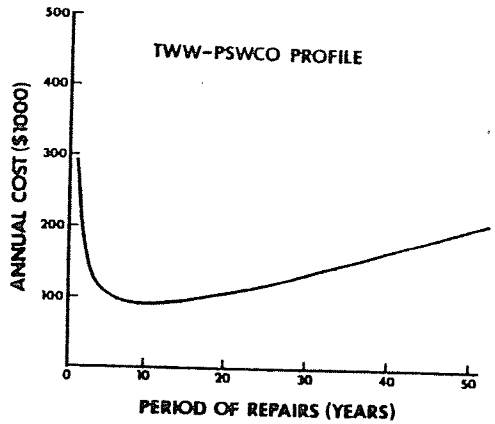

FIG. 4.—Example of Graphical Output from Program ECONANAL

result. For example, if the slope of the accuracy versus age relationship increased from −0.3 to −0.295 (i.e., by 1% of the range), the optimal testing frequencies would increase by 3.44 yrs.

The average meter age in the TWW sample is 10 yrs; therefore, testing meters on a continuous and consistent basis would represent a test period of approximately 20 yrs. The results summarized in Table 4 indicate that TWW should consider more frequent testing; once in 7.3 yrs or once

TABLE 4.—Summary of ECONANAL Predicted Optimal Metering Operations for WJWW and TWW

Water use profile (1)	Notation (2)	WJWW Kuranz (3)	WJWW PSWCO (4)	TWW Kuranz (5)	TWW PSWCO (6)
Optimal test period (yrs)	$PER_{(opt)}$	28.4	25.5	7.3	9.1
Averge age of meters at optimality (yrs)	PER/2	14.2	12.7	3.7	4.6
Average accuracy estimate (%)	AVGACC	88.7	95.2	89.1	95.4
Water loss through inaccurate meters (*M* cu ft/yr)	CWLI/CW	10.40	4.16	13.3	5.7
Water loss through failures (*M* cu ft/yr)	CWLF/CW	0.63	0.63	0.39	0.34
Cost of water lost ($1,000/yr)	CWLI + CWLF	82.7	35.9	153.5	63.4
Cost of repair testing policy ($1,000/yr)	CRP	7.0	7.8	34.0	27.4
Total cost at optimality ($1,000/yr)	TCOST	89.7	43.7	187.5	90.5

*Assumes two month average detection-replacement time for failures.

in 9.1 yrs depending on which water use profile is used. The average age of meters in the WJWW sample is approximatley 14 yrs. The ECONANAL results indicate that WJWW is operating very close to the optimal 5/8-in. meter testing frequency. The difference in optimal test periods for the two utilities is largely due to the different rates of deterioration of the meters, as represented by the slopes of the accuracy versus age relationships.

Results

The results of the application of ECONANAL to the two case studies are shown in Fig. 4 and Appendix I and are summarized in Table 4. The water loss estimates and the cost estimates reported in Appendix I are those predicted to occur at optimality. The actual cost experienced by the utility would be the "Cost of Repair/Replacement." Of the total annual cost of the optimal meter testing policy for the Taunton Water Works (PSWCO profile), $90,842 (30%) is due to the meter testing and replacement activities, and the other 70% is revenue lost due to the remaining meter inaccuracy. In contrast, Taunton's current policy of testing each meter aproximately once every 20 yrs has a total annual cost of $104,630.

Caution should be taken in generalizing these results, as the samples in both cases were made up of predominantly one kind of meter. Both utilities have several kinds of domestic meters in service and the performance of each kind of meter could vary significantly.

Sensitivity analyses can indicate which of the input data is most critical to the outcome of the analysis. A summary of the sensitivity analyses performed for the two utilities is presented in Table 5. The optimal testing period is most sensitive to changes in the slope of the linear accuracy/age relationship. It is also sensitive, but much less so, to the cost

TABLE 5.—Evaluation of Sensitivity of Optimal Meter Testing Policies to Input Parameters

Input parameter (1)	Expected range of values (2)	Maximum effect on optimal test period of change in value of parameter equal to 1% of range (yrs) (3)	Maximum effect on optimal policy cost of change in value of parameter equal to 1% of range ($1,000) (4)
Slope (%/meter-yr)	−0.6–−0.1	3.44	19.2
Cost of water ($1,000/cu ft)	7.5–15.0	0.15	19.9
Costs associated with repair or testing ($)	25–50	0.15	18.9
Failure rate (failure/meter-yr)	0.01–0.05	0.0006	18.9
Fail time (yr)	0.25–0.50	0.0009	18.8
Average use rate (1,000 cu ft/meter-yr)	10–12	0.028	19.1

Note: These results are derived from the sensitivity analyses as reported by ECONONAL for WJWW and TWW data.

parameters of the metering system, i.e., cost of removal, repair, testing, and replacement of meters and the retail cost of water. Conversely, the optimal period of testing appears to be relatively insensitive to the duration that an average failed meter stays in service before it is pulled, the rate of meter failures, and the average 5/8-in. meter water use rate. This type of sensitivity analysis could help water utility managers decide if further research using particular 5/8-in. meter data would be cost effective. Depending upon the combination of meter data used as input, it is expected that the relative sensitivities of the analysis may change.

The optimal testing period is also sensitive to the water use profile chosen. Ideally, each water utility would use its own water use profile in designing its optimal meter testing program. However, as is seen in Table 2, the differences due to the characteristics of the system have a much greater influence on the optimal testing period than the water use profile used since even the widely divergent water use profiles used here only produced differences of 2–3 yrs in the optimal test period. That is, the total water lost due to inaccurate meters, the major component of the total cost of a meter testing program, is affected more by the inaccuracy of older meters (i.e., the slope of the accuracy versus age curve) than by the higher inaccuracy of domestic meters at low flows (i.e., the use of alternative water use profiles).

Conclusion

An equation to calculate the optimal frequency of testing 5/8-in. meters has been derived from routine meter testing data and readily available cost, water usage, and meter data. The meter testing data is used to calculate the overall decline in meter accuracy with age and the rate at which meters fail in the system being evaluated. The otpimal frequency of testing is calculated by minimizing the sum of: (1) The value of water unmetered due to meter inaccuracy; (2) the value of water unmetered due to outright meter failures; and (3) the cost of the meter testing/repairing program itself. Sensitivity analysis of results for two New England utilities with well-documented meter testing programs indicates that the optimal testing period is most sensitive to the rate of decline of meter accuracy with age.

Acknowledgments

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Appendix I.—Example of Text Output from Program ECONANAL; TWW—PSWCO Profile

DOMESTIC WATER METER STUDY

UTILITY: TWW—PSWCO profile

Cost to remove & replace meters;	CRR = 5.00 $/MET

Cost to test & repair meters;	CTR = 20.00 $/MET
Retail cost of water;	CW = 11.50 $/1000 CUFT
Number of meters in the system;	XMET = 9966.0 METERS
Average metered consumption;	ARATE = 10.70 1000 CUFT/MET-YR
Rate of occurrence of failures;	RFAIL = 0.013 FAIL/MET-YR
Slope of accuracy/age relation;	*XM* = −0.4460 %/YR
Intercept of accuracy/age line;	*XB* = 97.40%
Time to detect & repair a failure;	TFAIL = 0.2500 YRS

Statistics at Optimality for TWW—PSWCO profile

Optimal Test Perod:	9.1 YRS
Average Age of Meters:	4.5 YRS
Average Accuracy:	95.4 %
Water Loss Thru Inaccur:	5174.6 1000 CU FT/YR
Water Loss Thru Failures:	342.4
TOTAL WATER LOSS:	5516.9 1000 CU FT/YR
Cost of Water Loss Thru Inaccur:	59507.8 $/YR
Cost of Water Loss Thru Failures:	3937.1
Cost of Repair/Replacement:	27396.8
TOTAL COST OF POLICY:	90841.7 $/YR

Sensitivity Analysis of Optimality:

VARIABLE(X)	FREQ/X	TCOST/X
SLOPE (*XM*)	11.37 −9.61	1723491.8 1908778.6
CRR	0.17 −0.18	36883.2 35763.2
CW	−0.37 0.41	127787.1 114419.2
RFAIL	−0.69 0.69	23015984.0 22405156.0
TFAIL	−0.08 0.07	3649427.5 3617888.8
ARATE	−0.41 0.42	461385.5 447019.4

Optimal frequency of meter repair and least annual cost at optimality depend on the variables listed above. The reported values are changes in optimal Frequency and Cost per change in variable value (above-increase, below-decrease). Interpretation of these results requires that the user is aware of the magnitude of change likely for each variable value.

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Appendix III.—Notation

The following symbols are used in this paper:

ANNF = number of failures occurring in a year;
AVGACC = average meter accuracy (%);
B = intercept of the accuracy versus age relationship (%);
CRP = cost of the repair policy ($);
CRR = average cost of removing and replacing a meter ($);
CTR = averge cost of testing and repairing a meter ($);
CW = retail cost of water ($/1,000 cu ft);
CWLF = cost of water lost through failures ($);
CWLI = cost of water lost through inaccurate meters ($);
M = slope of the accuracy versus age relationship (%/yr);
MRATE = average annual domestic metered rate (1,000 cu ft/yr-meter);
MYF = total years of meter failure/yr;
NMET = number of domestic metered services;
PER = period of meter testing (yrs);
RFAIL = rate of meter failure (failures/meter-yr);
TCOST = total annual cost of meter repair policy ($);
TFAIL = duration that an average meter stays in service before it is pulled (yrs);
USERATE = average actual water use (1,000 cu ft/meter-yr);
X = number of failed meters detected by billing records each year; and
Y = number of failed meters detected by the routine repair policy each year.

Size and Location of Detention Storage

By Wesley P. James,[1] M. ASCE, J. Frank Bell,[2] and Deborah L. Leslie[3]

Abstract: Basinwide planning, including channel improvements, is essential to prevent misapplication of detention storage. The concept of reducing the peak outflow from an on-site detention pond to the predevelopment peak discharge does not insure a reduction to the predevelopment discharge for larger streams and has little merit in sizing most detention ponds. The size of the detention ponds has little effect on the total storage required for a watershed. The amount of detention storage can be significantly reduced by selective location of detention ponds within the watershed. Small detention ponds will require considerably more land area and maintenance than regional detention ponds. Channel improvements within the watershed tend to favor the use of upstream detention ponds. Multipurpose use should be encouraged to insure public support and continued maintenance of the detention facilities.

Introduction

The simple concept of storage to reduce runoff peak flow has resulted in widespread misapplication of detention ponds. Typically, cities have passed ordinances which require that the peak runoff from a site after development not exceed the peak runoff from the site before development. As a result of this type of ordinance, small on-site detention ponds are often located haphazardly throughout the watershed area and are ineffective in controlling basinwide runoff. Detention basins are commonly placed at locations in the watershed where they actually increase the peak flow in a downstream channel. The misuse of detention ponds may result in waste of land and construction cost, increased maintenance, and adverse effects upon neighborhood property values (3).

During the last several years there has been considerable discussion over the choice between a regional detention facility or a number of smaller detention ponds in the headwater of the watershed. In general, the larger detention pond will be more effective in controlling downstream flooding but will provide no protection upstream of the facility. Small ponds located in the headwater may provide local benefits but will not control all of the watershed area. The purpose of this paper is to provide some general guidelines for sizing and locating detention facilties within a watershed.

General Considerations

The design criteria for detention ponds should depend on the purpose of the facility. If the facility is to be a multipurpose pond, then the lo-

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EXHIBIT 4B

Economic analysis for replacing residential meters

Statistical sampling was used to chart the degradation of water meter accuracy over time and to determine an optimal replacement age.

Michael D. Yee

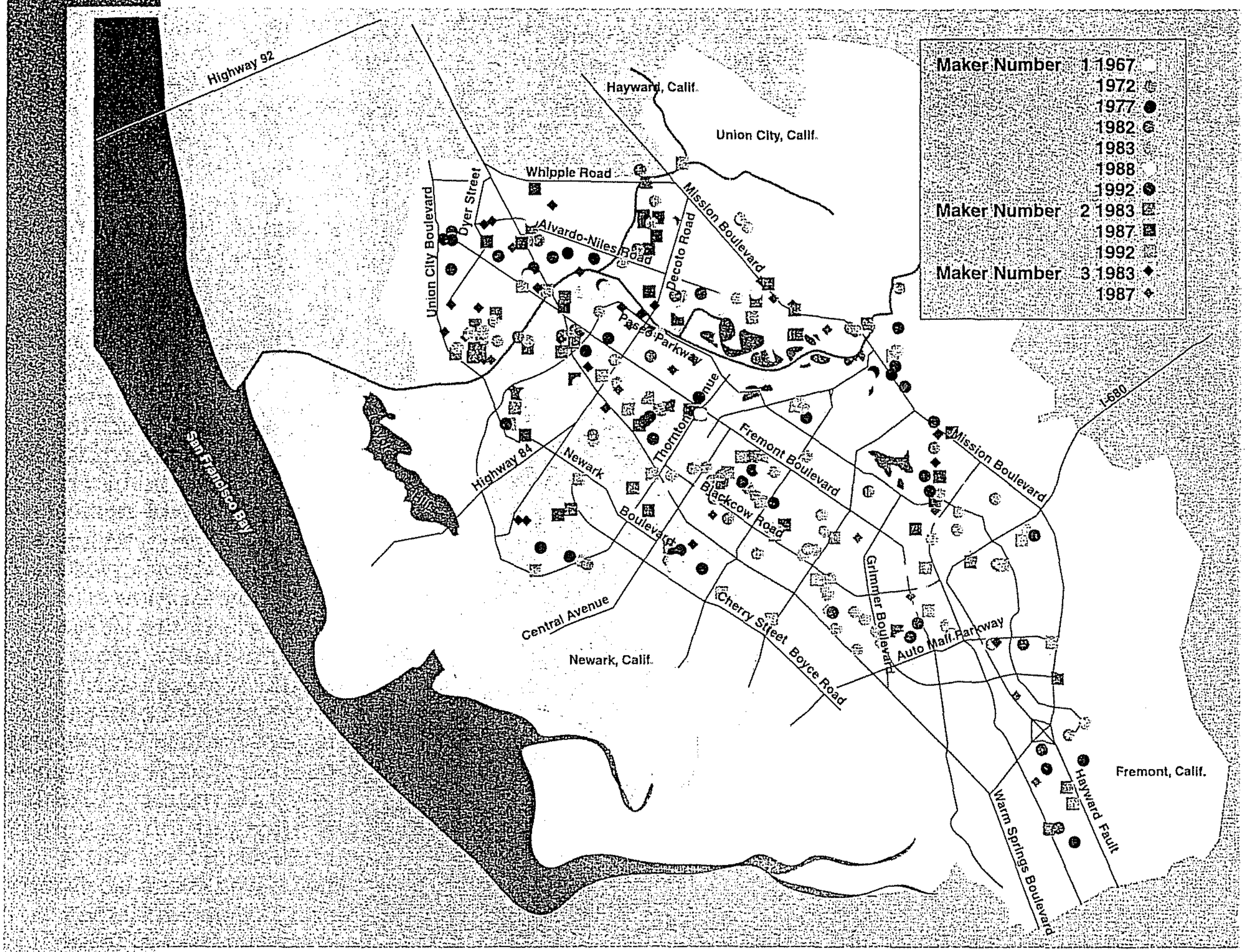
Single-family residential 0.6-in. (15-mm) meters make up about 90 percent of all meters for the Alameda County Water District in Fremont, Calif., and generate about half of all annual revenues from water consumption. Like all mechanical devices, these meters degrade in accuracy over time, resulting in an increasing amount of lost revenue. To increase meter accuracy requires replacing meters at an additional cost. The optimal economic replacement age is when the average cost per year (cumulative lost revenue plus replacement cost divided by meter age) is at a minimum. Statistical sampling was used to profile the degradation of these meters' accuracy over time. The annual lost revenue over time was then calculated. When economic and operational factors were considered, the optimal age at which to replace residential meters in the district was determined to be 15 years.

Revenue generated from the water consumption of its single-family residential customers with 0.6-in. (15-mm) meters is the predominant source of income for the Alameda County Water District (ACWD) in Fremont, Calif. This meter class represents about half of all consumption revenue, roughly $15 million, and makes up about 88 percent of all ACWD meters. Economical operation of these meters is thus an integral part of ACWD's effort to provide high-quality water at a reasonable cost.

Like other mechanical devices, water meters typically degrade in accuracy over time. This degradation results in a corre-

For executive summary, see page 173.

FIGURE 1 Alameda County Water District meter-sampling locations



sponding loss of potential revenue. However, to gain accuracy would mean replacing the meters at additional cost. How old does a meter have to be before it makes economical sense to replace it? To answer this question, the accuracy degradation of the meters in question must be profiled. Statistical sampling methods were used to determine the accuracy of ACWD's 0.6-in. (15-mm) meters over time. An economic analysis was then performed to determine an optimal replacement age.

All-brass and plastic meters are included in sampling

Sample meters are categorized by age. ACWD's 0.6-in. (15-mm) meters were categorized by age (Table 1). Most—approximately 98 percent—of these meters serve single-family residential customers. Before 1983, ACWD only installed all-brass (i.e., both the casing and drive mechanism were made of brass) meters. Since 1983, only meters with plastic drive mechanisms have been installed.

The sampling groups were divided between all-brass and plastic meters in approximate five-year intervals for each of the primary meter makers. For all-brass meters, most of which were produced by a single maker, samples were taken from groups that were 15, 20, 25, and 30 years old. Because the 20-year-old meters appeared to be from a bad lot year, their results were omitted from the study. Three primary makers produced the plastic meters. Samples were taken from groups that were 5, 10, and 14 years old.

Number of samples must be determined. After the sampling categories were chosen, the number of samples to be taken had to be determined. Generally in statistical sampling, the greater the number of samples, the more representative the results will be of the total population. The more homogeneous, or well-mixed, the entire population, the fewer samples that need to be taken to obtain a good representation. ACWD's 0.6-in. (15-mm) meter population was considered to be fairly homogeneous and random in character within each of the meter groups.

A balance had to be found between the number of samples that would yield meaningful data versus the number that could be realistically tested with the resources available. When both statistical and operational considerations were taken into account, the total number of samples was about 30 for each group,

TABLE 1 All active ACWD* 0.6-in. (15-mm) meters by year installed

Age	Year Installed	Total Number	Weighted Average Accuracy *percent*
Brass meters (48.5 percent of installed meters)			
30	1967	1,691	96.6
29	1968	2,607	
28	1969	1,006	
27	1970	686	
26	1971	1,332	
25	1972	2,198	98.5
24	1973	3,299	
23	1974	3,487	
22	1975	4,096	
21	1976	2,456	
20	1977	760	
19	1978	1,223	
18	1979	1,969	
17	1980	1,578	
16	1981	1,087	
15	1982	744	99.0
Subtotal		30,219	98.0
Plastic meters (51.5 percent of installed meters)			
14	1983	1,413	95.4
13	1984	2,148	
12	1985	3,027	
11	1986	4,073	
10	1987	8,224	96.8
9	1988	2,237	
8	1989	1,518	
7	1990	973	
6	1991	1,097	
5	1992	877	98.3
4	1993	1,035	
3	1994	1,892	
2	1995	1,879	
1	1996	1,633	
Subtotal		32,026	96.6
Total		62,245	97.0

*ACWD—Alameda County Water District

TABLE 2 Percentage of average household consumption by flow rate

Category	Low Flow 0–0.25 gpm (0–0.94 L/min) *percent*	Medium Flow 0.25–2 gpm (0.94–7.57 L/min) *percent*	High Flow >2 gpm (>7.57 L/min) *percent*
AWWA California–Nevada 1969 study of several West Coast utilities[1]	5.0	25.0	70.0
AWWA California–Nevada 1969 study—EBMUD*[1]	1.2	12.0	86.8
AWWA 1993 study[2]	8.8	18.5	72.8
Average of the three studies	5.0	18.5	76.5
Figures used for ACWD† study	5.0	15.0	80.0

*EBMUD—East Bay Municipal Utility District

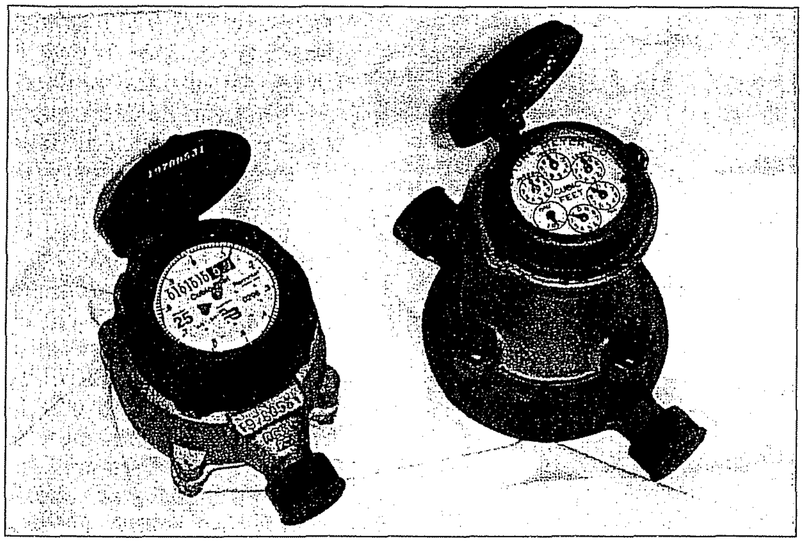
or about 350 in all. This provided a cushion of a couple of extra meters in each group to allow for unusable customer records, odd field conditions, and other problems. Such meters could be eliminated from the mix without compromising the integrity of the study.

Meters were randomly selected. Samples were randomly chosen for each group from a database containing all 0.6-in. (15-mm) meter customers. To maintain the study's statistical reliability, it was important to ensure the randomness of the final chosen samples. Both qualitative and quantitative checks were performed on the sample data. In the qualitative check, the sample meters were plotted on a map of ACWD generated by a geographic information system. The samples appeared to be well-mixed and scattered, confirming the relative randomness of the sampling (Figure 1). The quantitative check used statistical measures such as confidence limits, which will be discussed later in this article.

Final list is sorted by location. The meters on the final list to be sampled were sorted by location to minimize travel time between them. Because field crews would replace each meter taken away for testing, each page of the final list provided necessary blanks and labels to replace the usual form that is filled out during normal meter replacement. Additional blanks and labels were provided on which the meter shop could record the results of the accuracy tests.

Meters have different accuracies at different flows

Tests were performed at AWWA standard rates. Because meters typically have different accuracies at different flows, it is an industry and an ACWD standard to test meters at three flow rates. Each sampled meter was tested at AWWA standard rates of 0.25, 2.00, and 15.00 gpm (0.94, 7.57, and 56.78 L/min). However, these test results alone were not enough to calculate the overall expected accuracy of the meter. That determination required an estimate of the percentage of total consumption of the average single-family residential household at the three flow rates. It would have been extremely difficult to determine these percentages empirically from the field, and existing literature was scarce. However, some usable AWWA study results[1,2] were located (Table 2), and



Because all-brass meters (right) are no longer manufactured, the Alameda County Water district decided to use plastic meters (left) as replacements for the foreseeable future.

the final percentages (5, 15, and 80 percent) used for this study were derived from an average of the three studies reviewed. These figures are probably within a reasonable margin of error and seem probable because most ACWD residential home water use is assumed to occur at high flow rates (e.g., that produced by showers, toilets, sprinklers, and kitchen faucets).

Formula used to calculate weighted average accuracies. The percentages were used to calculate the weighted average accuracies for each group using the following formula:

$$\text{Weighted average meter accuracy} = (PTC_L \times GAA_L) + (PTC_M \times GAA_M) + (PTC_H \times GAA_H) \quad (1)$$

in which PTC_L is the percentage of total consumption at low flow, PTC_M is the percentage of total consumption at medium flow, PTC_H is the percentage of total consumption at high flow, GAA_L is the group average test result accuracy at low flow, GAA_M is the group average test result accuracy at medium flow, and GAA_H is the group average test result accuracy at high flow.

Table 1 shows the weighted average accuracy for each group. The weighted average accuracy was calculated for each separate meter year tested (five-year increments), for consolidated groups such as all-brass versus plastic, and for the overall grand total sampling. The overall ACWD average accuracy is 97.0 percent, based on the sampling data.

Given the statistical integrity of the study, a standard "normal curve distribution" (i.e., a bell-shaped curve that can be found in statistics textbooks) can be assumed for the accuracy test results for each grouping, and "confidence limits" can be calculated around the average test results. Confidence limits are a statistical concept: given a large number of samples for a given group, the test values will be within stated high and low confidence limits *x* percent of the time. A standard *x* percent for confidence limits is 95 percent.

Confidence limits were calculated by flow rate. To provide a quantitative check on the statisti-

TABLE 3 Average annual cost for plastic meters

Year Meters Installed	Number of Years Old	Accuracy Degradation Profile *percent*	Annual Unrecorded Water *gal (m³)*	Annual Lost Revenue *$*	Meter Replacement Cost *$*	Accumulated Cost *$*	Average Cost per Year *$*
	0	100.00					
	1	99.66	427.26 (1.6)	0.79	55.72	56.51	56.51
	2	99.32	854.52 (3.2)	1.59		58.10	29.05
	3	98.98	1,281.77 (4.9)	2.38		60.48	20.16
	4	98.64	1,709.03 (6.5)	3.17		63.65	15.91
1992	5	98.30	2,136.29 (8.1)	3.96		67.61	13.52
	6	98.00	2,513.28 (9.5)	4.66		72.28	12.05
	7	97.70	2,890.27 (11.0)	5.36		77.64	11.09
	8	97.40	3,267.26 (12.4)	6.06		83.70	10.46
	9	97.10	3,644.26 (13.8)	6.76		90.47	10.05
1987	10	96.80	4,021.25 (15.2)	7.46		97.93	9.79
	11	96.45	4,461.07 (16.9)	8.28		106.21	9.66
	12	96.10	4,900.90 (18.5)	9.09		115.30	9.61
	13	95.75	5,340.72 (20.2)	9.91		125.21	9.63
1983	14	95.40	5,780.54 (21.9)	10.73		135.94	9.71
	15	95.12	6,127.62 (23.2)	11.37		147.31	9.82
	16	94.80	6,533.33 (24.7)	12.12		159.43	9.96
	17	94.48	6,939.05 (26.3)	12.88		172.31	10.14
	18	94.16	7,344.76 (27.8)	13.63		185.94	10.33
	19	93.83	7,750.48 (29.3)	14.38		200.32	10.54
	20	93.51	8,156.19 (30.9)	15.13		215.45	10.77

TABLE 4 Accuracy degradation profile of brass meters

Year Meters Installed	Number of Years Old	Accuracy Degradation Profile *percent*	Annual Unrecorded Water *gal (m³)*	Annual Lost Revenue *$*	Accumulated Cost *$*
	0	100.00			
	1	99.93			
	2	99.87			
	3	99.80			
	4	99.73			
	5	99.67			
	6	99.60			
	7	99.53			
	8	99.47			
	9	99.40			
	10	99.33			
	11	99.27			
	12	99.20			
	13	99.13			
	14	99.07			
1982	15	99.00	1,257 (4.75)	2.33	2.33
	16	98.95	1,319 (5.00)	2.45	4.78
	17	98.90	1,382 (5.23)	2.57	7.35
	18	98.85	1,445 (5.47)	2.68	10.03
	19	98.80	1,508 (5.71)	2.80	12.83
	20	98.75	1,571 (5.95)	2.91	15.74
	21	98.70	1,634 (6.18)	3.03	18.77
	22	98.65	1,696 (6.42)	3.15	21.92
	23	98.60	1,759 (6.66)	3.26	25.18
	24	98.55	1,822 (6.90)	3.38	28.57
1972	25	98.50	1,885 (7.13)	3.50	32.06
	26	98.12	2,362 (8.94)	4.38	36.45
	27	97.74	2,840 (10.75)	5.27	41.72
	28	97.36	3,318 (12.56)	6.16	47.87
	29	96.98	3,795 (14.36)	7.04	54.91
1967	30	96.60	4,273 (16.17)	7.93	62.84
	31	96.22	4,750 (17.98)	8.81	71.66
	32	95.84	5,228 (19.79)	9.70	81.36
	33	95.46	5,705 (21.60)	10.59	91.94
	34	95.08	6,183 (23.40)	11.47	103.42

cal validity of the study, high and low confidence limits were calculated for each meter group by flow rate. The difference between these high and low numerical limits—and correspondingly the size of the standard deviation—helps indicate how closely the tested accuracy of the sampled meters probably represents all the other similar meters in ACWD. For the most part, the limit differences for the various sampled meter groups turned out to be extremely small—in the range of 1–2 percent. This meant that the accuracies obtained from the samples were probably quite representative of their respective groups as a whole. However, the high and low confidence limits for the low-flow figures had the largest differences. These differences bring up some concern about accuracy, but the concern is mitigated by the fact that low flow accounts for only about 5 percent of total household consumption.

Economic analysis is based on plastic meters

The engineering economic analysis method used is based on work performed by Hans D. Allender.[3] Because all-brass meters are no longer manufactured, ACWD decided to use plastic meters as replacements for the foreseeable future. The economic analysis for the plastic meters assumes that this practice will continue. An optimal replacement age can be determined at the point at which the lowest average cost per year (cumulative lost revenue plus replacement cost divided by meter age) is achieved. The optimal replacement age for the all-brass meters will be addressed separately because these meters are already 15–30 years old and will be replaced with plastic meters.

Plastic meters will be replaced on 15-year cycle. The minimum average annual cost, based on the Allender method, can be found in Table 3, which also shows meter replacement cost and lost revenue because of increasing meter inaccuracy. The accuracy degradation profile is taken from the actual sampling test results. Gaps between data points are filled with interpolated values that assume linearity. This is a common simplifying assumption made in other studies on this subject.[1,3] From this profile, unrecorded water consumption is calculated based on ACWD's 1996 actual average bimonthly consumption for a single-family residence, i.e., 2,800 cu ft (79 m^3). The resulting annual revenue lost is determined based on the ACWD's current water rate. Although the amount of lost revenue will change each year because of inflation, it is assumed that the discount rate used to bring all these costs back to present value is about equal to the inflation rate. Thus, to simplify the analysis, all dollar amounts are stated in present value.

An estimated meter replacement cost for materials and labor can then be used to determine an optimal meter age with the least average yearly cost. To calculate this, the cost of meter replacement and cumulative revenue lost (shown as the "Accumulated Cost" column in Table 3) are added, and the sum is divided by the number of years that the meter has been in the system. This yields the "Average Cost per Year" column in Table 3. Technically, the optimal replacement age appears to be 12 years old; however, the 15-year cycle is preferred, as discussed later in this article. When the small difference between the 12- and 15-year average cost figures and the tolerances of the study was taken into account, this preference for the 15-year cycle was considered acceptable.

Accuracy degradation profile was created for all-brass meters. An accuracy degradation profile was produced for all-brass meters (Table 4). These meters will eventually be replaced with plastic ones. Thus, the optimal age at which to replace them is when their accuracy degrades to the same value as the accuracy provided by plastic meters at their optimal age.

Replacing them any earlier would not be cost-effective because they would still be more accurate than the plastic meters. Replacing them any later would mean additional unnecessary revenue losses that would result in a larger average cost than the optimal average cost per year. A 15-year cycle for plastic meters would mean a corresponding target accuracy of 95.12 percent (Table 3). This target accuracy corresponds to an optimal replacement age between 33 and 34 years for brass meters (Table 4). However, sampling data could only be obtained through 30 years, which is the age of ACWD's oldest brass meters.

The next five years of accuracy figures (Table 4) were extrapolated using linear regression based on the past five years of data. Depending on the actual accuracy degradation that occurs in the future, the initially indicated optimal bracket of 33–34 years may change. Thus, one recommendation would be to wait a few more years before a brass meter replacement program is implemented. In the meantime, another sampling could be conducted. Given the tolerances and results of the study, a replacement age of about 30 years would probably be within an acceptable margin of error.

Fifteen-year replacement cycle has a number of advantages. A 15-year-cycle replacement program has many advantages compared with a shorter cycle. This is because the existing distribution of plastic and brass meters lends itself to a 15-year cycle rather than a shorter one. Because 32,000 plastic meters are in service, a 15-year cycle would mean an average of 2,100 meters being replaced every year. However, the actual number to be replaced would vary from year to year (Table 1).

The same situation applies to the brass meters. Once a replacement program begins for the 30,000 brass meters in operation, an average of 2,000 meters a year would need to be replaced. The brass meters are already 15–30 years old and thus have 15—not 30—installation years. Together, about 4,100 brass and plastic meters would need to be replaced annually. This cycle would go on for 15 years, until all of the brass meters were replaced with plastic ones. During that time, the original plastic meters that replaced the brass meters would have to be replaced again in accordance with the 15-year replacement cycle for plastic meters. The program would eventually reach a point at which all meters will be plastic at the optimal age of 15 years or younger, with the continued replacement of 4,100 meters per year.

A replacement period shorter than 15 years would have introduced overlapping phase-in complications because all existing plastic meters older than a chosen optimal point will have to be initially replaced over some period of time. Also, a cycle shorter than 15 years would have necessitated replacement of the plastic meters that replaced the existing brass ones before all the brass meters had been switched out. These phase-in complications could have meant large fluctuations in the number of meters needing to be replaced in the first 15 years.

Summary and conclusions

Determining an optimal replacement age for a specific agency's meters can be a complex task. It takes a concerted effort to research meter demographics, determine relevant factors in accuracy degradation, develop meter sample lists, coordinate field sampling and testing, validate statistical data integrity, interpret results, and formulate practical recommendations. The ACWD study resulted in a program to replace plastic meters when they become 15 years old. Although the data for brass meters were not as conclusive, a replacement age of about 30 years seemed to be reasonable.

A study to determine a meter replacement program can be useful for most agencies. Meter accuracy sampling should be done regularly, e.g., every five years, and meter replacement policy can then be reviewed based on the study results. Because of the random margin of error in measurement, ever-changing meter manufacturers and models, and different sampling choices, regular review is recommended.

Acknowledgment

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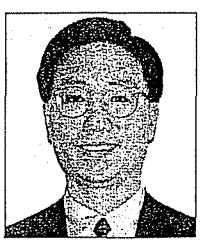

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EXHIBIT 4C

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Who's Minding the Cash Registers?

Accuracy Key to Testing Meters

by Thomas A. Kelly Jr.

The question of when to replace residential water meters is an ongoing concern for the Washington Suburban Sanitary Commission, a large water and wastewater utility that serves nearly 400,000 residential customers in Maryland's Prince George and Montgomery counties near Washington, D.C. The first parameters tested when considering replacement have been meter accuracy and performance in registering residential consumption concerning those meters that have been in service for more than two decades.

But now, following a meter replacement study completed in 1998, we have discovered that it's important not only to test the accuracy of the meters but to measure the accuracy of the testing methods and devices as well.

Testing Parameters

The 1998 Optimum Meter Age Study began with some known factors, including the fact that the accuracy of positive displacement meters deteriorates over time because of accumulated registration. Disk nutations or piston oscillations in the measuring chamber of the meter create wear and tear that has a negative effect on accuracy and indicated consumption. Because WSSC water and sewage charges are based on the amount of water registered, any loss of accuracy in measuring water passing through the meter is compounded by a reduction of sewage revenue as well.

Shop meter mechanic Margaret Gallion (front) and unit coordinator Trene Gilliam test meters in the WSSC shop.

As a matter of policy, WSSC management believes that an evaluation of residential meter accuracy

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Inside Opflow

Accuracy Key to Testing Meters

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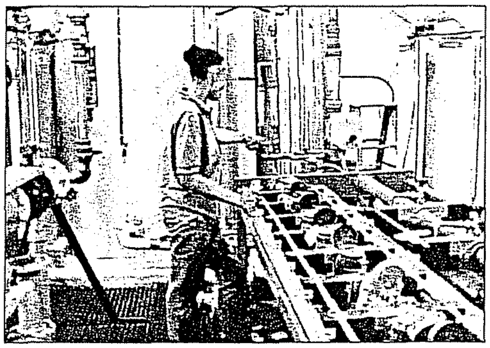

Trene Gilliam adjusts equipment used for testing the meters.

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should be an ongoing process, performed at intervals of no more than five years. During the evaluation process, it is important to ensure that any comparisons made are equitable. For example, older positive displacement meters have a rated capacity of 15 gpm, but newer meters of the same size have a rated capacity of 25 gpm, with a larger chamber that translates into fewer nutations or oscillations, and, therefore, less wear on components. Comparisons can only be drawn between meters of equal rated capacity.

The 1998 meter age study yielded mixed results. The weighted accuracy of a meter was determined to simulate its performance when in service. The methodology used to determine weighted accuracy was to assign each portion of the meter flow test a percentage that represents the amount of time the meter will operate at that particular flow rate when in service at a customer's account. In this case, the percentages used were 20 percent for low flow, 76 percent for intermediate flow, and 4 percent for high flow. The results for each flow-rate test are then added together for an overall weighted average.

For example, assume a 5/8-in. meter has a standard three-flow test. The low-flow test result is 0 percent, intermediate-flow result is 74 percent, and high-flow is 95 percent. After weighting the low flow at 20 percent ($0 \times 0.2 = 0$), intermediate flow at 76 percent ($74 \times 0.76 = 56.2$), and high flow at 4 percent ($95 \times 0.04 = 3.8$), they are added together to determine the weighted overall accuracy of 60 percent ($0 + 56.2 + 3.8 = 60$).

The traditional method of computing overall accuracy divides the total quantity registered on the meter by the total quantity of water used to test the meter. Using that method (0 gal + 7.4 gal + 95 gal = 102.4 total registered gal), the meter would have an overall accuracy of 85.3 percent (102.4 registered gal divided by 120 gal used to test the meter). The result is a significantly different overall accuracy.

According to an analysis of test results from meters removed from the distribution system, 5/8-in. meters older than 14 years had an average weighted accuracy of 56 percent. Therefore, we inferred that replacing meters older than 14 years should result in a 44 percent increase in the registered consumption and a corresponding increase in water and sewage revenues on accounts where the meters were replaced. Accordingly, we pursued an aggressive replacement program of those meters.

Expectations Don't Match Reality

Surprisingly, the anticipated level of increase in consumption and revenues did not materialize. The actual level of increase was approximately 5 percent, not the expected 44 percent. So the new, all-important question became, "Why not?"

To determine the reason for the lack of increase, we pursued three separate but related activities:

- placing tandem setters to analyze the shop test method,
- recalculating the weighted percentages given to each test flow, and
- evaluating the effect of the meter-change notice left at residences.

Analyzing the Test Method

To analyze the method used to bench-test meters after removal from the distribution system, we placed a tandem setter on 10 different properties. The tandem setter allows two meters—a new meter and the existing old meter—to be placed in series at one service. Before setting up the tandem configuration, we bench-tested the new meter at the shop to ensure accuracy. The new meter was then placed in series with the old meter at the property. All water going to the property passed through both meters, which were both read at two-week intervals for six weeks.

Afterward, the old meters and tandem setters were removed, rendering the new meter as the property meter. The old meters were immediately sent to the meter shop for bench-testing.

Each old meter was flow-tested, and its overall accuracy was compared with the accuracy of its indicated performance in the field in relationship to the new meter, which had been previously tested and used as a standard. In eight of the 10 meters tested, there was a strong (less than 5 percent difference) correlation between their field and bench-test accuracy. One meter had a fair correlation (less than 20 percent difference), and another had a poor correlation. A review of the results and strength of the correlation validated the method used to test meters in the shop. All the old meters, except one, registered less water than the new meters. The amount of under-registration varied from 1 percent to 47 percent.

Analyzing the Test Results

Because the method used to test meters was valid, further investigation was necessary to determine why the rise in accuracy and consumption did not materialize when the old meters were replaced. An analysis of the test results from the original group of sample meters was the next step.

According to the 1993 AWWA Research Foundation study, *Residential Water Use Patterns,* residential water "usage at lower flow rates (less than 1.0 gpm) composed about 13 percent of the total daily use ... 80 percent of residential use occurred between 1.0 and 8.0 gpm ... and usage at higher flow rates (above 8.0 gpm) composed about 7 percent of the total daily use." These percentages are close to the percentages of 20 percent, 76 percent, and 4 percent that we used to weight our test results during the 1998 meter age study.

Because our initial results were questionable, we ran the WSSC test results again, using percentages to weight meter flow results that were outlined in "Economic Analysis for Replacing Residential Meters," by Michael Yee, in the July 1999 *Journal AWWA*:

- 5 percent for low-flow testing,
- 15 percent for intermediate-flow testing, and
- 80 percent for high-flow testing.

When these percentages were used as an alternative for earlier WSSC test results, the impact was significant. Many of the meters performed much better than the level indicated during the earlier study in which the flows had been weighted at 76, 20, and 4 percent respectively.

Yee's *JAWWA* article indicated that any flow in excess of 2 gpm is considered a high flow, which effectively eliminates the intermediate flow test. This is because very few appliances—humidifiers and icemakers come to mind—operate at less than 2 gpm. The vast majority of other usage takes place at flows greater than 2 gpm. Under this assumption, meters measure consumption in only two categories—leaks and everything else.

To follow this line of reasoning, we needed to understand what percentage of overall consumption leaks represent. A 1999 AWWA Research Foundation report, *Residential End Uses of Water,* outlines a typical profile of single-family-home water use. The study used dataloggers to record usage at 100 detached single-family homes at 12 different locations during two winter weeks and two summer weeks. Although some fluctuations were noted and a smaller percentage of homes were responsible for the majority of leakage recorded, the study showed that overall average leakage from a residential property was 14 percent of total consumption.

Therefore, we decided to weigh our low-flow test at 14 percent, the high-flow test at 86 percent, and eliminate the intermediate-flow test. When the new percentages were applied to the original meters tested, the overall results were virtually identical to the earlier findings at weighted flows of 5, 15, and 80 percent respectively.

Interpreting the Data

A number of problems were noted with the original analysis of the data from our 1998 study. Determining the weighted accuracy of a meter by weighting the test-flow results is already a form of averaging. This was compounded by taking all the sample results together and averaging them to come up with an overall average accuracy. What this actually accomplished was an averaging of the averages, which simply moved the statistics further away from hard data and provided the mean of the sample, not the information that revealed the actual performance of the sample.

To interpret the hard data, all raw meter test data was graphed on a scatter diagram that showed the relationship between meter age and accuracy. Very little of the data showed up in the aforementioned overall average zone of 56 percent for the entire sample. Regardless of the percentages used to weigh the flow-test results, the effect on the scatter diagram was minimal.

In other words, the grouping of meter accuracies did not change significantly regardless of the percentages used to weight the different flow rates. The majority of meters tested at an overall accuracy of 80 percent or better. A much smaller percentage of meters tested at an overall accuracy of 30 percent or less, and only a smattering of meters showed up in the "void" between 30 and 80 percent. Only four meters from the entire sample came anywhere close to the 56 percent average weighted

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polyethylenes are suitable for NaOCl storage, although you should always confirm that the tank you choose is approved for this application. If an FRP or polyethylene tank is to be used in an outdoor setting, it should be UV-rated. The life expectancy of all system components is critical—remember, regularly scheduled tank cleaning can extend the life of the tank.

A Final Thought

So, is on-site generation of sodium hypochlorite or calcium hypochlorite, or even purchasing bulk NaOCl, best suited to your needs? You could toss a coin, but as with all major capital expenditures, it's better to

1) determine your operational requirements,
2) evaluate alternative systems, and
3) compare capital and operational costs before making your final decision.

Accuracy Key to Testing Meters

(from page 5)

accuracy on which the replacement decision and projected increases were initially based.

The bottom line is we discovered that averaging was not the proper tool for analyzing the available data. A trend line on the graph is certainly more appropriate than averaging, but even so, a trend line is not necessarily the best tool for analyzing the data. A more thorough statistical model should be developed for analysis.

Notification Effect

The last factor that we tested was the effect of meter-change notices left at customers' property when meter changes were performed. Standard practice had been to leave a notice informing customers that their meter was replaced because it was old and no longer accurate. The notice recommended that the customers monitor their water use because their new meter would be more accurate, registering lower flows than the old meter registered. This difference in registered consumption could cause their bill to go up, and we didn't want them to be caught off-guard.

To determine whether our notices influenced customers' usage, at 100 homes we left a modified notice that simply stated a meter change had been performed. An additional 100 homes received the usual meter change notice, and consumption was tracked at all 200 homes. The homes that received the usual notice showed an average increase in consumption of 4.5 percent. The sample of homes that received the modified notice showed an average increase of 11.2 percent. We determined that the 6.7 percent difference can most likely be attributed to the meter-change notice—some customers were influenced by the notice and changed their usage patterns.

Assessing the Time Frame

Satisfied with the study's method and results, we returned to our original question: "What is the most cost-effective time frame for residential meter replacement?" To find an answer, we needed to determine the optimal interval for recouping the cost of replacing meters.

We constructed a graph displaying the varying times it would take to recover costs associated with meter replacement, based on the average residential customer's usage and WSSC's current water and sewer rates. We learned that replacement of a meter measuring only 80 percent of the water passing through it will pay for itself in just under one year, while payback is 3 1/2 years for a meter that is 95 percent accurate. Obviously, the less accurate a meter, the faster the payback time.

Thus, we modified our changeout parameters for residential meters. Now, all 5/8-in. meters are to be replaced after 15 years of service, and 3/4-in. and 1-in. meters are to be changed after 20 years.

Our study taught us that the performance of important measurement devices should be evaluated at regular intervals. Because meters are literally the "cash registers" of a utility, their accuracy is far too critical to allow decades to pass without ensuring optimum performance.

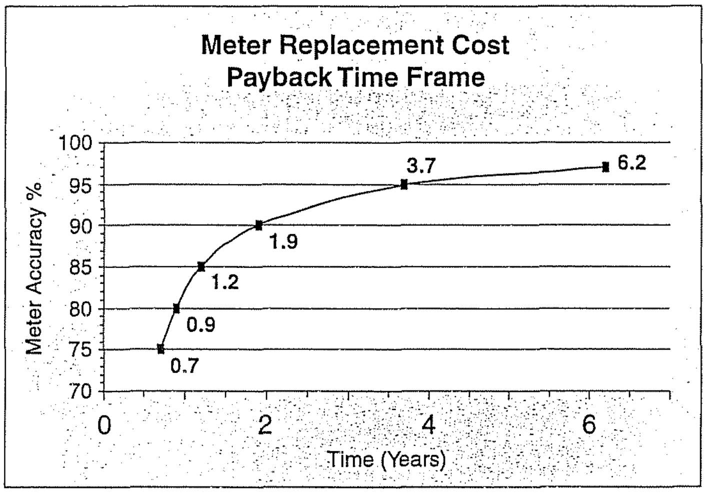

Figure 1.

EXHIBIT 4D

Journal

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Determination of Economic Period for Water Meter Replacement

California Section Committee Report

A report of a committee appointed by Business Management Div. of California Section AWWA, presented on Oct. 28, 1965, at the California Section Meeting, San Francisco, Calif., by Norman Beenfeldt, Chairman. Other committee members are Robert C. Sisco, Walter Burns, Firley C. Cleveland, Harold E. Wilson, and Eugene M. O'Neill.

THE age-old problem of when to remove, repair, test, and put back into service a water meter is one that water utility operators have had to face since the first meter started nutating. Management and operators always have realized that it is the responsibility of the utility to make sure that the customer pays only for water he receives and that the utility is paid only for water delivered to the customer. To ensure this, an economic balance must be maintained between the point of revenue lost owing to meters that underregister and the cost of removing, repairing, and testing them.

The California public utilities commission, on Jul. 1, 1956, under its General Order 103, made it mandatory that all investor-owned water utilities under its control remove, test, and overhaul all water meters every 10 years. Some relief from this order was given by allowing the utilities a 5-year grace period, Jul. 1, 1956 to Jul. 1, 1961, during which studies could be made to show that a different removal time should be applied. Four utilities, the California Water Service Co., California Water & Telephone Co., Southern California Water Co., and Pacific Gas & Electric Co., took advantage of this grace period. Each utility studied the problem further and one, Pacific Gas & Electric Co., accumulated data that showed it was economic for its systems to remove meters in 10–20 year periods. The other utilities were unable to arrive at any reasonably definite removal period, because lengthy and thorough testing of meters of different size by various methods showed no correlation between years in service and accuracy in performance.

Task Committee

In 1960, this problem was brought to the attention of the Business Management Division of the California Section AWWA. As a result, it asked the Executive Committee of the California Section for authority to form a task committee to determine the feasibility of recommending uniform methods and procedures for determining the economic period to leave a meter in service. Authority was granted and, in March 1960, the Business Management Division appointed a seven member committee, representing four investor-owned utilities and three government-owned utilities. The original investor-owned utilities were the California Water Service Co., California Water & Telephone Co., Southern California Water Co., and Pacific Gas & Electric Co. The original government-owned utilities were the Los Angeles department of water and power, the East Bay Municipal Utility District, and the San Francisco water department. Three utilities, the San Francisco water department, California Water Service Co., and Pacific Gas & Electric Co., were unable to continue as members. Subsequently, the San Diego and Long Beach water departments were appointed as replacements.

TABLE 1

Selected Flows

Meter Size	Flow Rates gpm				
	Rate *A*	Rate *B*	Rate *C*	Rate *D*	Rate *E*
⅝ by ¾ in.	0–0.25	0.25–1	1–2	2–6	6+
¾ in.	0–0.50	0.50–2	2–4	4–10	10+
1 in.	0–0.75	0.75–3	3–7	7–15	15+

Plan of Procedure

The committee first met in April 1960, in Monterey, Calif., during the Spring Conference of the California Section. After several other meetings, it decided that, to resolve properly its problem, it had to have more information with respect to flow patterns through the domestic meter, so as to permit comparison with the shop tested meters. In this way, it would be able to determine the economic removal period. Very little information on flow of water through domestic meters was available. The New York Water Service Co. had made some studies on flow rates through smaller meters, but results obtained in these studies were not considered valid for use in California.

The committee knew that the only reasonably accurate recording device to measure the flow of water through a domestic meter was a type supplied by a major meter manufacturer.* This company's Southern California representative convinced his main office of the importance of the committee's work and the company agreed to furnish a number of its recording devices to the committee.

TABLE 2

Number of Meters Sampled

Utility	Meter Size—*in.*			Tot. No. of Meters Tested
	⅝ by ¾	¾	1	
EBMUD	459			459
CW&T	439		100	539
DW&P	151	94	42	287
SCW	173	14	21	208
L. Beach	250			250
S. Diego	510	24	25	559
Total	1,982	132	188	2,302
Per cent of meters tested	87.7	6.5	5.8	100.0

Sampling

The committee had estimated that, in 1961, approximately 3,000,000 metered domestic water consumers were in California and that 2,300 observations or samples would be needed to attain a 90 per cent level of accuracy in its analysis. The committee and the meter manufacturer agreed that 60 recording devices would be required to record the necessary observations and to complete the work within the re-

* Neptune Meter Co., Long Island City, N.Y.

TABLE 3

Flow Distribution Data for $\frac{5}{8}$- by $\frac{3}{4}$-in. Meters in All Types of Plumbing Systems

Utility	No. of Meters Tested	Flow Rates—*cu ft*					Total Flow	Percentage of Total Flow per Flow Rate				
		A	*B*	*C*	*D*	*E*	*cu ft*	*A*	*B*	*C*	*D*	*E*
EBMUD	459	3,398	13,736	34,277	182,301	44,858	278,570	1.2	4.9	12.3	65.5	16.1
CW&T	439	10,865	15,867	31,224	142,698	49,438	250,092	4.3	6.3	12.5	57.1	19.8
DW&P	151	11,678	7,288	13,993	46,291	13,228	92,478	12.7	7.9	15.1	50.0	14.3
SCW	173	8,151	5,366	18,847	62,121	2,514	96,999	8.4	5.5	19.4	64.1	2.6
L. Beach	250	9,520	10,806	15,740	114,109	39,837	190,012	5.0	5.7	8.3	60.0	21.0
S. Diego	510	12,243	18,770	52,196	166,856	52,764	302,829	4.1	6.2	17.2	55.1	17.4
All utilities	1,982	55,855	71,833	166,277	714,376	202,639	1,210,980	4.6	5.9	13.7	59.0	16.8

TABLE 4

Flow Distribution Data for $\frac{5}{8}$- by $\frac{3}{4}$-in. Meters in Copper Plumbing Systems

Utility	No. of Meters Tested	Flow Rates—*cu ft*					Total Flow	Percentage of Total Flow per Flow Rate				
		A	*B*	*C*	*D*	*E*	*cu ft*	*A*	*B*	*C*	*D*	*E*
EBMUD	92	682	4,184	7,696	39,364	15,261	67,187	1.0	6.2	11.5	58.6	22.7
CW&T	129	2,961	2,934	8,797	50,747	12,703	78,142	3.8	3.8	11.3	64.9	16.2
SCW	1	15	16	28	302	1	362	4.1	4.4	7.7	83.5	0.3
L. Beach	5	105	374	1,032	2,879	1,217	5,607	1.9	6.7	18.4	51.3	21.7
S. Diego	343	7,272	12,138	35,096	114,923	41,525	210,954	3.4	5.8	16.6	54.5	19.7
All utilities	570	11,035	19,646	52,649	208,215	70,707	362,252	3.1	5.4	14.5	57.5	19.5

TABLE 5

Flow Distribution Data for $\frac{5}{8}$- by $\frac{3}{4}$-in. Meters in Iron Pipe Plumbing Systems

Utility	No. of Meters Tested	Flow Rates—*cu ft*					Total Flow	Percentage of Total Flow per Flow Rate				
		A	*B*	*C*	*D*	*E*	*cu ft*	*A*	*B*	*C*	*D*	*E*
EBMUD	367	2,716	9,352	26,581	142,937	29,597	211,183	1.3	4.4	12.6	67.7	14.0
CW&T	309	7,845	12,893	22,052	91,605	36,596	170,991	4.6	7.5	12.9	53.6	21.4
DW&P	136	10,375	6,672	12,665	41,475	12,079	83,266	12.5	8.0	15.2	49.8	14.5
SCW	166	8,025	5,251	18,551	59,955	2,492	94,274	8.5	5.6	19.7	63.6	2.6
L. Beach	245	9,415	10,432	14,708	111,230	38,620	184,405	5.1	5.7	8.0	60.3	20.9
S. Diego	167	4,971	6,632	17,100	51,933	11,239	91,175	5.4	7.2	18.6	56.5	12.3
All utilities	1,390	43,347	51,232	111,657	499,135	130,623	835,994	5.2	6.1	13.4	59.7	15.6

TABLE 6

Flow Distribution Data for $\frac{3}{4}$-in. Meters in All Types of Plumbing Systems

Utility	No. of Meters Tested	Flow Rates—*cu ft*					Total Flow	Percentage of Total Flow per Flow Rate				
		A	*B*	*C*	*D*	*E*	*cu ft*	*A*	*B*	*C*	*D*	*E*
DW&P	94	7,944	11,023	14,383	23,333	41,635	98,318	8.1	11.2	14.6	23.7	42.4
SCW	14	8,566	2,424	860	197	6	12,053	71.1	20.1	7.1	1.6	0.1
S. Diego	24	7,432	11,339	10,811	1,926	742	32,250	23.0	35.2	33.5	6.0	2.3
All utilities	132	23,942	24,786	26,054	25,456	42,383	142,621	16.8	17.4	18.3	17.8	29.7

quired time. Deliveries of the recording devices were begun in the spring of 1961 and all had been received by the end of the year. Because of the fact that the domestic or residential customer represents over 90 per cent of the total customers in most water systems, the committee decided to confine its study to the smaller meters, namely, the $\frac{5}{8}$ by $\frac{3}{4}$-in., $\frac{3}{4}$-in., and 1-in. meters. The committee also divided meter users into brackets based on annual consumption and decided to make an equal number of observations in the low, middle, and high brackets. It felt that such sampling would assure representative observations.

Recording Devices

The 60 recording devices were used by five of the participating members. The East Bay Municipal Utility District developed its own recording device. This is basically a photocell and electronic amplifier that produce a current recorded by instrument * and printed on a continuous chart. Each recording device was set to obtain a continuous 14-day observation.

The customer whose meter was to be sampled was interviewed, informed of the committee's work, and given a com-

TABLE 7

Flow Distribution Data for 1-in. Meters in All Types of Plumbing Systems

Utility	No. of Meters Tested	Flow Rates—*cu ft*					Total Flow	Percentage of Total Flow per Flow Rate				
		A	*B*	*C*	*D*	*E*	*cu ft*	*A*	*B*	*C*	*D*	*E*
CW&T	100	6,730	14,864	34,540	22,512	12,065	90,711	7.4	16.4	38.1	24.8	13.3
DW&P	42	5,624	11,222	7,444	7,190	2,616	34,096	16.5	32.9	21.8	21.1	7.7
SCW •	21	4,953	3,596	4,074	814	37	13,474	36.8	26.7	30.2	6.0	0.3
S. Diego	25	5,850	6,597	6,818	7,957	12,208	39,430	14.8	16.7	17.3	20.2	13.0
All utilities	188	23,157	36,279	52,876	38,473	26,926	177,711	13.0	20.4	29.8	21.6	15.2

TABLE 8

Inactive Meter Time for Meters in All Types of Plumbing Systems

Utility	$\frac{5}{8}$- by $\frac{3}{4}$-in. Meters				$\frac{3}{4}$-in. Meters				1-in. Meters			
	No. Sampled	Recorded Time *hr*	Inactive Meter Time *hr*	Inactive Time *per cent*	No. Sampled	Recorded Time *hr*	Inactive Meter Time *hr*	Inactive Time *per cent*	No. Sampled	Recorded Time *hr*	Inactive Meter Time *hr*	Inactive Time *per cent*
EBMUD	459	153,424	130,128	85								
CW&T	439	173,512	133,963	77					100	32,832	27,452	84
DW&P	151	52,224	28,279	54	94	33,082	17,794	54	42	14,303	6,611	46
SCW	173	58,344	36,979	63	14	4,776	3,509	73	21	7,056	4,705	67
L. Beach	250	83,928	59,037	70								
S. Diego	510	164,088	135,114	82	24	6,768	5,279	78	25	8,232	6,169	75
All utilities	1,982	685,520	523,500	76	132	44,626	26,582	60	188	62,423	44,937	72

* Rustrak strip-chart recorder; a product of Rustrak Instrument Co., Manchester, N.H.

plete explanation of what was to be done. In all but a few instances, the customer was very cooperative. The recording devices generally were set in a meter yolk,† on a pretested, accurate meter in tandem with the customer's meter, which remained operative while the test was being made. Both the recording meter and the customer's meter were housed in a plywood cabinet with an electric flasher fastened to the top.

Twenty-four-hour charts were used and changed daily. Each chart subsequently was analyzed to determine the amount of water used at the flow rates selected by the committee for each meter size.

At the time the recording device was set, the installer recorded on a data sheet information on the customer being sampled, such as size and kind of his piping, area of his lot, amount of landscaping, and number of occupants.

TABLE 9

Weighted Accuracy Increase for 50 Meters in Service 5 Years*

Flow		Accuracy			
		Before Repair		After Repair	
Rate *gpm*	Per cent	Per cent	Weighted	Per cent	Weighted
¼	3	92.74	278.22	93.28	279.84
2	81	99.40	8,051.40	99.76	8,080.56
10	16	99.26	1,588.16	99.18	1,586.88
Total	100		9,917.78		9,947.28

* Weighted accuracy increase equals 0.994728 minus 0.991778, or 0.30 per cent.

† Ford twinsetter; a product of Ford Meter Box Co., Wabash, Ind.

TABLE 10

Weighted Accuracy Increase for 50 Meters in Service 10 Years*

Flow		Accuracy			
		Before Repair		After Repair	
Rate *gpm*	Per cent	Per cent	Weighted	Per cent	Weighted
¼	3	90.04	270.12	92.10	276.30
2	81	99.09	8,026.29	99.76	8,080.56
10	16	99.15	1,586.40	99.21	1,587.36
Total	100		9.882.81		9,944.22

* Weighted accuracy increase equals 0.994422 minus 0.988281, or 0.61 per cent.

Selected Flow Points

Points of flow pattern curve for each meter size were selected by the committee in an attempt to conform to prescribed critical points of AWWA and General Order 103 of the California public utilities commission (see Table 1).

Results

After 4 years of collecting data, during which 2,300 domestic meters were sampled, the committee completed its work. Each observation, from the time the recording device was set to the time the data was put into final form, required approximately 15 man-hr. As a result, the 2,300 samples taken required approximately 35,000 man-hr of work. This sampling in itself represents many thousands of dollars.

All the data were put on punched cards and then processed through the electronic data-processing equipment of the Los Angeles department of water and power. To save space, the following abbreviations will be used to designate the participating utilities: East Bay Municipal Utility District, EBMUD; California Water & Telephone Co., CW & T; Los Angeles department of water and power, DW & P; Southern California Water Co., SCW; Long Beach water department, L.Beach; San Diego water department, S.Diego. Table 2 shows the breakdown by meter sizes of the number of samples taken.

TABLE 11

Weighted Accuracy Increase for 2,448 Meters in Service 15 Years*

Flow		Accuracy			
		Before Repair		After Repair	
Rate *gpm*	Per cent	Per cent	Weighted	Per cent	Weighted
¼	3	82.23	246.69	92.64	277.92
2	81	98.89	8,010.09	99.79	8,082.99
10	16	99.09	1,585.44	99.15	1,586.40
Total	100		9,842.22		9,947.31

* Weighted accuracy increase equals 0.994731 minus 0.984222, or 1.05 per cent.

Flow Patterns and Plumbing

The following three tables show the flow patterns of ⅝- by ¾-in. meters as they are related to the size and kind of customer plumbing. The committee had suspected that a customer's plumbing could have some effect on the rates at which water was consumed. It was felt that iron piping, because of its tendency to corrode and become tuberculated, would show less water use in the high range and more in the low. Copper plumbing should show the converse—more use in the high range and less in the low. Table 3 shows total and percentage of use for all ⅝- by ¾-in. meter customers, regardless of size or kind of plumbing. Table 4 shows the same data for customers having all copper plumbing, regardless of size. Table 5 shows the data for customers having iron pipe plumbing, regardless of size.

As may be noted, use in the low-rate range (0–¼ gpm) for customers with copper plumbing was 3.1 per cent, as compared with 5.2 per cent for those with iron pipe. Similarly, the tables indicate that use in the high-rate range (more than 6 gpm) was at a higher percentage (19.5 per cent) for copper plumbing customers than for those with iron pipe (15.6 per cent). This indicates that customers with copper plumbing were using 40 per cent less water at the low range and were able to use 25 per cent more at the high. The bulk of the use in both cases, 77.4 per cent and 79.2 per cent, copper and iron, respectively, occurs in the so-called normal range. This relationship holds for each of the utilities, but not for the Southern California Water Co., where only one customer with copper plumbing was tested.

Although a breakdown is not presented, it is interesting to note that 186 customers, who were served with ⅝ by ¾-in. meters, had ½ in. iron pipe

TABLE 12

Weighted Accuracy Increase for 2,163 Meters in Service 22 Years*

Flow		Accuracy			
		Before Repair		After Repair	
Rate *gpm*	Per cent	Per cent	Weighted	Per cent	Weighted
¼	3	67.21	201.63	88.97	266.91
2	81	98.17	7,951.77	99.90	8,091.90
10	16	98.64	1,578.24	99.07	1,585.12
Total	100		9,731.64		9,943.93

* Weighted accuracy increase equals 0.994393 minus 0.973164, or 2.12 per cent.

plumbing. In their case, 5.4 per cent of the use was found at the low rate and only 8.3 per cent at the high, the bulk, 85.3 per cent, being at the normal rate. This showed that the customers were using 77 per cent more water at the low rate and 57 per cent less at the high rate than their neighbors with copper plumbing.

TABLE 13

Revenue Loss for ⅝-by ¾-in. Meters

Meter Age years	Percentage*	Revenue† Loss—$ Per Year	Revenue† Loss—$ Accumulated
1	0.06	0.047	0.047
2	0.12	0.095	0.142
3	0.18	0.142	0.284
4	0.24	0.189	0.473
5	0.30	0.237	0.710
6	0.36	0.284	0.994
7	0.42	0.331	1.325
8	0.48	0.378	1.703
9	0.54	0.426	2.129
10	0.61	0.481	2.610
11	0.69	0.544	3.154
12	0.76	0.599	3.753
13	0.85	0.670	4.423
14	0.95	0.749	5.172
15	1.05	0.828	6.000
16	1.17	0.922	6.922
17	1.30	1.025	7.947
18	1.44	1.135	9.082
19	1.59	1.254	10.336
20	1.75	1.379	11.715
21	1.93	1.522	13.237
22	2.12	1.671	14.908

* Weighted accuracy increase after meter repair.
† Average yearly revenue from ⅝- by ¾-in. meter is $78.84.

It seems that customers with iron pipe are perhaps experiencing more small leakage problems in their systems than their neighbors with copper plumbing, who seem able, because of the ability of copper to resist corrosion and internal buildup, to use more water at the high rate.

Flow Patterns in Other Meters

Only three of the utilities, namely, the Los Angeles department of water and power, Southern California water Co., and the San Diego water department, tested ¾-in. meters. Analysis of the flow distribution of 132 samples showed the pattern of use given in Table 6. The table shows that, as was the case with the ⅝- by ¾-in. meters, small usage is experienced at the low (0–½ gpm) and high (more than 10 gpm) rates. The table does show very wide variances in rate usage by the individual utilities. The inconsistency of the results would tend to indicate that either inaccurate chart reading or key punching was responsible.

One hundred eighty-eight metered customers in the 1-in. category were analyzed by four of the utilities. Table 7 shows the observed flow pattern.

Again, the picture is generally the same as that for the other two meter sizes. Only 13 per cent of the water is being delivered to the customer at the low rate (0–¾ gpm) and merely 15.2 per cent at the high rate (more than 15 gpm). Again, the bulk of the use (71.8 per cent) occurs at the so-called normal rate.

Inactive Meter Time

The committee was interested in, among other things, the amount of time the various size meters were not registering delivery of water. Table 8 shows the results of the analysis of this factor. As can be noted, the ⅝- by ¾-in. meters were inactive 76 per cent of the time, the ¾ in., 60 per cent, and the 1 in., 72 per cent. Inactive meter time for all meter sizes amounted to 75 per cent. Management and operators must be made aware of the amount of investment needed to account for customer use by means of a measuring device that operates only 6 out of every 24 hr.

Removal Periods

One of the utilities, the California Water & Telephone Co., was able to make a rather complete study of when it should remove ⅝- by ¾-in. meters in each of its three operating divisions. This investor-owned utility serves approximately 89,000 customers in its three California divisions. The San Diego Bay division, located in the southwesterly portion of the state, serves approximately 36,000 customers. Eighty-seven per cent of the meters in the division are ⅝ by ¾ in. in size. Over 85 per cent of the supply of this division comes from the untreated Colorado River source, known for its excessive mineral content and inherent corrosive activity. Loss of meter accuracy becomes apparent early in the service life.

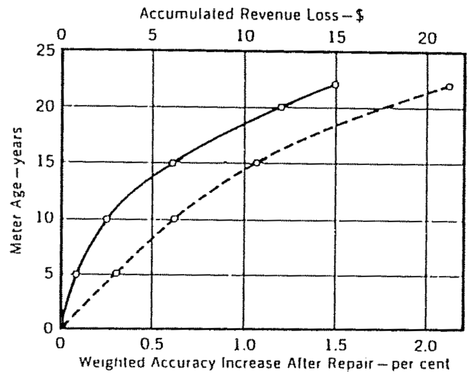

Fig. 1. Effect of Meter Age on Revenue Loss—Accuracy Increase After Repair

Solid curve represents revenue loss; dashed curve, accuracy increase.

Realizing this, and, in order to study more completely meter deterioration as it progressed, the company shop test repaired, and retested 50 ⅝- by ¾-in. n ters that had been in service 5 yea in addition to 50 that had been in se ice 10 years. There were also 2,4 15-year-old meters and 2,163 22-ye old meters that were removed, test repaired, and retested under the quirements of the California pub utilities commission.

Flow distribution through 181 ⅝- ¾-in. meters, which were sampled the company in this division under committee's program, indicated th there was 3 per cent use at the lo rate, 16 per cent at the high rate, a that the balance, or 81 per cent, o curred at the so-called normal rate.

Accuracy After Repair

Shop tests developed data th showed the increase in accuracy mete in each age group attained after th meters were repaired. This accurac increase then was weighted by the flo distribution, and a weighted accurac increase was obtained for each ag group. The weighted accuracy in crease then was plotted against th meter age and a curve was drawn The average amount of annual revenu the company derived from a custome with a ⅝- by ¾-in. meter then was de termined. The annual loss was accu mulated annually until it approached or equaled the repair cost. Tables 9–12 show the method of determining the weighted accuracy increase of the various age groups of meters.

The curve shown as Fig. 1 was used to develop the yearly percentage points, which then were used to develop the accumulated annual revenue loss shown in Table 13 and in Fig. 1.

The most recent average cost experienced by the company in connec tion with removing, testing, repairing, and retesting $\frac{5}{8}$- by $\frac{3}{4}$-in. meters was $12.80. From the above, the company concluded that $\frac{5}{8}$- by $\frac{3}{4}$-in. meters should remain in service for 20 years. It should be remembered that this conclusion was made by this particular utility.

It will be noted that most of the data and analyses are related to the $\frac{5}{8}$- by $\frac{3}{4}$-in. meter performances. The committee felt this was justified because of the time and money involved, and also because approximately 90 per cent of installed meters in most systems are of this size. Obviously, similar studies could be made on meters of other sizes.

Summary

As a guide for utilities that wish to use these procedures to determine meter removal periods, the following steps are given:

1. Select a flow pattern of a committee participant that most closely represents its own pattern. Water quality should be the prime factor determining this selection.
2. Determine accuracy increase after repair of meters in various age groups and weight with the selected flow pattern. Construct a curve.
3. Determine annual revenue from the metered customer.
4. From the weighted accuracy increase curve, determine, tabulate, and then accumulate the annual revenue loss.
5. Determine the average cost of removing, testing, repairing, and retesting the meter.
6. Select a removal period in which accumulated revenue loss approaches or equals cost of repair.

Conclusions

1. Flow patterns through the small domestic meters indicate relatively small customer usage in the low and high rates, with the bulk of consumption at the so-called normal rate.
2. No definite or specific time can be prescribed for keeping a meter in service.
3. Application of flow distribution to meter accuracy before and after repair to determine revenue dollars lost over a period of years is a most reasonable approach in attempting to determine the economic meter-removal period.

Acknowledgments

The committee wishes to express its gratitude to the Neptune Meter Co. for furnishing meter-recording devices, the Los Angeles department of water and power, for use of their electronic data-processing equipment, and the executive management of all participating utilities, for their faith and patience in seeing this job to completion. Without their help this task would not have been accomplished.

Application of Systems Analysis to Proble in Water and Waste Water Treatment

Walter R. Lynn

A paper presented on Oct. 6, 1965, at the Rocky Mountain Section Meeting, Albuquerque, N.M., by Walter R. Lynn, Assoc. Prof. of Civ. Eng., Dept. of San. Eng., Cornell Univ., Ithaca, N.Y.

A SYSTEM is something everybody seems to understand, or at least have a feeling for, but it is extremely elusive when one tries to describe it. A system consists of components, or subsystems, that function together in a specific way and thus are able to achieve certain observable results. For the purposes of this article, it is helpful to assume that the terms "systems analysis," "systems engineering," and "operations research" are synonymous, even though some special distinctions can be drawn between them.

Systems Analysis

An automobile, for example, is a system; the engine is a subsystem of the automobile and is itself a system, and so on. The atom is a very small system. An atomic system consists of a nucleus and orbiting electric charges. When one analyzes larger systems, things quickly become complicated. For example, a far more complex structure is encountered when one goes from the atom to the molecule. At that level, the system consists of a collection of atoms, each functioning as a component of the larger molecular system. A description of the molecule requires information about each atom and how these different atomic p combine to form the larger stru

A system depends upon each components. Its performance ca determined from the performa its individual components alo cause a system's characteristics a derived from the nature of the actions of the individual ele From an engineering point of all physical objects that are de are systems and may be set up come part of still larger systems

Design Requirements

It is, therefore, apparent that requires analysis of the physical o as well as analyses of how the performs as part of the larger sy Good examples of systems closel lated to water treatment are treat units, treatment plants, and rive sin treatment complexes. Obvi a design is unsatisfactory if it do excellent job at one level and an acceptable one at the next. For ample, a waste treatment plant ca designed so that all units of the operate at maximum efficiency produce an effluent of prescribed ity. As a sewage treatment pla could be said this is an excellent de But it is possible that the effect of

MINUTES
BUTLER COUNTY WATER SYSTEM, INC.

The Butler County Water System, Inc. Board of Directors met in regular session on Tuesday, June 21, 2011, at 4:30 p.m. at the Water System Office, 104 S. Tyler St., Morgantown, Kentucky.

QUORUM CHECK

Those members present were: Garry Robbins – Secretary-Treasurer, Don Lindsey, and David Martin. Also present were Water System Attorney – Dick Deye and Alan Vilines – General Manager.

Mr. Robbins called the meeting to order and determined a quorum was present.

MINUTES APPROVED

Mr. David Martin made a motion to approve the minutes of the Board Meeting and the Annual Meeting of April 19, 2011. Mr. Lindsey seconded the motion and all voted "aye."

OPERATING REPORTS

The Operating Reports for the periods ending April and May 2011 were reviewed.

LIST OF ACCOUNTS

Mr. Lindsey made a motion to transfer the list of accounts dated May and June 2011 for collection. Mr. David Martin seconded the motion and all voted "aye."

GENERAL MANAGER'S REPORT

Mr. Vilines reported on the following:

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1. The report titled "Revised Determination of Cost-effective Meter Test Frequency" was reviewed. This study recommends replacing all residential size SRII meters when they reach 21 years of age. An application will be filed with the Public Service Commission for approval of a deviation from its regulations which would permit this meter program to be implemented.

2. Progress reports prepared by the Corps of Engineers on the Rochester Dam Stabilization Study were reviewed. The Corps has scheduled a meeting in Morgantown on July 11th to present the final results of that study.

3. FEMA has approved the District's application for a grant to refund expenses incurred as a result of the May 2010 flood. The amount of the award is $8,362 which is 95 percent of total expenses. The application for an additional $175,000 to repair pipelines in creek crossings and drainage-ways is still pending.

4. Painting work will begin next week on the Major Maintenance project at the Bowling Green Road Pumping Station. This work will also be performed at the Hwy. 411 and Leonard Oak Pumping Stations and the Rochester Control Valve Station.

5. The pump for the water plant backwash project was manufactured with the wrong shaft length and was sent back to the factory to be corrected. It is expected to be delivered for the second time next week and will be installed soon after that.

6. The contractor on Project 17 is making good progress on grade and seed work. By the end of next week he should have completed final cleanup on all lines and begin working on "touch-up" and punch list items.

7. Heavy rains this spring have caused road embankment slides on Hwy. 79 South and Old Flener-Monford Road. These slides have caused water line breaks and the pipe must be re-laid to prevent further problems. This work is being done by Water System personnel.

8. Routine system flushing and fire hydrant testing has progressed to the northern section of the system in the Elfie area and this work is expected to be totally complete in a few weeks.

9. The Public Service Commission completed its annual compliance inspection in May and the Water System was found to have no deficiencies.

10. Copies of the District's annual Consumer Confidence Report were distributed.

11. This year is the Water System's fortieth anniversary; it was incorporated in February of 1971. Possible ideas to commemorate this anniversary were discussed.

12. The Kentucky Rural Water Association's Annual Conference is scheduled for August 29 – 31 in Lexington.

13. There have been no lost time accidents.

ROCHESTER BAPTIST CHURCH

Mr. Deye summarized events leading up to the Rochester Baptist Church filing suit against the Water System for alleged damages to the pavement on its parking lot. Mr. Deye also discussed possible courses of action to resolve this matter.

ADJOURN

There being no further business, the meeting was adjourned.

Respectfully submitted,

Garry Robbins

Garry Robbins, Secretary

MINUTES
SIMPSON COUNTY WATER DISTRICT

The Simpson County Water District Board of Commissioners met in regular session on Thursday, May 26, 2011 at 1:00 p.m. at the Water District Office, 108 Morgantown Road, Franklin, Kentucky.

QUORUM CHECK

Those members present were: Ray Mann – Chairman, and Joe Richards - Secretary/Treasurer. Also present was Bob Taylor – Attorney and Alan Vilines – General Manager.

Mr. Mann called the meeting to order and determined a quorum was present.

ANNUAL AUDIT

Laney White with Holland CPA's presented the Annual Audit report for the period ending December 31, 2010. Mr. Richards made a motion to accept the audit as presented. Mr. Mann seconded the motion and all voted "aye."

MINUTES APPROVED

Mr. Richards made a motion to approve the minutes of the Board Meeting of March 24, 2011. Mr. Mann seconded the motion and all voted "aye."

OPERATING REPORTS

The Operating Reports for the period ending March and April 2011 were reviewed. Mr. Richards made a motion to approve the Operating Reports. Mr. Mann seconded the motion and all voted "aye."

MMISSIONER'S REPORT

It was noted that Simpson Fiscal Court reappointed Mr. Richards for another term on the Water District's board.

LIST OF ACCOUNTS

Mr. Richards made a motion to transfer the list of accounts dated April and May 2011 for collection. Mr. Mann seconded the motion and all voted "aye."

LEAK ADJUSTMENTS

Mr. Richards made a motion to authorize a leak adjustment in accordance with the standard policy for Renee Burgess. Mr. Mann seconded the motion and all voted "aye."

GENERAL MANAGER'S REPORT

Mr. Vilines reported on the following:

1. The Public Service Commission requires that the District's tariff regarding fire protection include a provision that fire departments can be fined if they do not report water usage. Mr. Richards made a motion ratifying an addition to the District's tariff to include this provision; Mr. Mann seconded the motion and all voted "Aye."

2. A list of current rates for certificates of deposit was distributed. It was agreed to continue the discussion of possible locations for investment of the District's reserve funds at the next meeting.

3. USDA Rural Development has requested that future debt service payments be made by direct debit from the District's bank account. Mr. Richards made a motion to approve an Authorization Agreement

for Preauthorized Payments for this purpose; Mr. Mann seconded the motion and all voted "aye."

4. The draft report titled "Revised Determination of Cost-effective Meter Test Frequency" was reviewed. This study recommends replacing all residential size SRII meters when they reach 21 years of age. An application will be filed with the Public Service Commission for approval of a deviation from its regulations which would permit this meter program to be implemented.

5. The PSC's annual compliance inspection was performed on May 10th and the District was found to have no deficiencies. The inspection report also mentioned that the two deficiencies noted in last year's report have been addressed.

6. All clean-up and grade and seed work is complete on both the Hwy. 100 West water line replacement and the Blackberry Ridge extension.

7. Annual system flushing, fire hydrant testing and fire hydrant maintenance has been completed throughout the entire water system.

8. Graphs showing results of flow monitoring at the new bypass master meters were shown. This monitoring indicates there are currently no large leaks in these areas of the system.

9. The College Heights Foundation at WKU has recommended Stephen Ladd to be this year's Simpson Water Scholarship recipient. A certificate acknowledging this award will be presented to Stephen by Simpson Water at the Franklin-Simpson High School awards ceremony.

10. Copies of the District's annual Consumer Confidence Report were distributed.

11. A lost time accident occurred on April 12th when a Repairman twisted his knee while on a construction site. Because the torn cartilage required surgery, he has been off work for several weeks.

ADJOURN

Mr. Richards made a motion that the meeting be adjourned. Mr. Mann seconded the motion and all voted "aye."

Respectfully submitted,

Joe N. Richards

Joe Richards, Secretary/Treasurer

MINUTES
SIMPSON COUNTY WATER DISTRICT

The Simpson County Water District Board of Commissioners met in regular session on Thursday, July 28, 2011 at 1:00 p.m. at the Water District Office, 108 Morgantown Road, Franklin, Kentucky.

QUORUM CHECK

Those members present were: Ray Mann – Chairman, and Joe Richards - Secretary/Treasurer. Also present was Robert Taylor – Attorney and Alan Vilines – General Manager.

Mr. Mann called the meeting to order and determined a quorum was present.

MINUTES APPROVED

Mr. Richards made a motion to approve the minutes of the Board Meeting of June 23, 2011. Mr. Mann seconded the motion and all voted "aye."

OPERATING REPORTS

The Operating Reports for the period ending June 2011 were reviewed. Mr. Richards made a motion to approve the Operating Reports. Mr. Mann seconded the motion and all voted "aye."

COMMISSIONERS REPORT

Mr. Mann stated that he had received several reports of "musty" tasting water. Mr. Vilines explained that this is due to algae growth in Old Hickory Lake which is more prevalent this time of year. White House Utility District has taken extra measures at the treatment plant to minimize the effect; however it may be several weeks before the water returns to normal. Mr. Richards suggested that the board review the annual audit report for Warren County Water District. It was the consensus of the board to move the next regular meeting back to August 23rd.

LIST OF ACCOUNTS

Mr. Richards made a motion to transfer the list of accounts dated July 2011 for collection. Mr. Mann seconded the motion and all voted "aye."

GENERAL MANAGER'S REPORT

Mr. Vilines reported on the following:

1. The conversion to the new customer information system is going well. There have been three data extractions from the old system with progressively better results. The new software has been installed and was used by cashiers in parallel with the old system for one week in June. This identified certain items that need to be corrected and modified, but overall the comparison of the transactions entered during the week was good. A second parallel test is scheduled for late August and the "go live" date for full implementation is September 26th.

2. An estimate has been submitted to the Highway Department for water line relocations necessary for the proposed widening of Hwy. 100 East. The total project cost of about $300,000 will be reimbursed by the state. Mr. Richards made a motion authorizing an agreement with the Highway Department for the relocation work, the advertisement for bids, and award of the contract to the low bidder. Mr. Mann seconded the motion and all voted "aye".

3. The application has been filed with the Public Service Commission for further deviation from meter testing regulations. It may be several weeks before the PSC responds.

4. Mr. Richards made a motion to appoint Mr. Vilines as the District's voting delegate at the upcoming Kentucky Rural Water Association Annual Conference with Mr. Schubarth as an alternate. Mr. Mann seconded the motion and all voted "aye".

5. Current community relations activities include the Industrial Appreciation Golf Scramble and the upcoming Garden Spot 5k Run/Walk.

6. There have been no lost time accidents.

ADJOURN

Mr. Richards made a motion that the meeting be adjourned. Mr. Mann seconded the motion and all voted "aye."

Respectfully submitted,

Joe H. Richards

Joe Richards, Secretary

MINUTES
WARREN COUNTY WATER DISTRICT

The Warren County Water District Board of Commissioners met in regular session on Tuesday, May 24, 2011, at 4:00 p.m. at the Water District Office at 523 US 31W Bypass, Bowling Green, Kentucky.

QUORUM CHECK

Those members present were: Henry Honaker – Chairman, Tad Donnelly - Vice-Chairman, Glen Johnson - Secretary and Harvey Johnston. Also present was Matt Cook – Cole & Moore, Jeff Peeples – Manager of Administration and Finance and Alan Vilines – General Manager.

Mr. Honaker called the meeting to order and determined a quorum was present.

INVESTMENT OPTIONS

The District's Investment Policy was reviewed. Pete Mahurin and Mac Jefferson with Hilliard Lyons discussed various investment opportunities available that would comply with the policy. Mr. Cook stated that he had reviewed the policy and provided details regarding the section permitting bonds issued by "the Commonwealth of Kentucky and its agencies and instrumentalities." Further discussion centered on current returns on various types of investments and the potential risks. Mr. Jefferson noted that the State Property and Buildings Commission is planning a sale of taxable bonds the week of June 21st.

MINUTES APPROVED

Mr. Johnston made a motion to approve the minutes of the meeting of April 26, 2011. Mr. Donnelly seconded the motion and all voted "aye".

OPERATING REPORTS

The Operating Reports for the period ending April 2011 were reviewed.

LIST OF ACCOUNTS

Mr. Johnston made a motion to transfer the list of accounts dated May 2011 for collection. Mr. Johnson seconded the motion and all voted "aye."

GENERAL MANAGER'S REPORT

The General Manager reported on the following:

1. A Preliminary Summary of Project Costs for a sewer extension to potential industrial property in Allen County was presented. Two options for sizing pumping stations and force mains were included.

2. The draft report titled "Revised Determination of Cost-effective Meter Test Frequency" was reviewed. This study recommends replacing all residential size SRII meters when they reach 21

years of age. An application will be filed with the Public Service Commission for approval of a deviation from its regulations which would permit this meter program to be implemented.

3. The Plano Road water line replacement is installed and is being tested. The Plum Springs Road water line is now in service. About 50 percent of the Detour Road line has been laid and it should be completed in the next few weeks. The Natcher Force Main Extension started on the Pioneer Drive end and has now progressed to a point near the Lost River School property.

4. FEMA has approved the District's application for a grant to refund expenses incurred as a result of the May 2010 flood. The amount of the award is $136,197 which is 95 percent of total expenses. The application for an additional $81,000 to build a flood wall around the Three Springs Lift Station is still pending.

5. The College Heights Foundation at WKU recommended Michael Alford to be this year's Warren Water Scholarship recipient. A certificate acknowledging this award will be presented to Michael by Warren Water at the South Warren High School awards ceremony.

6. Copies of the District's annual Consumer Confidence Report were distributed.

7. There have been no lost time accidents.

ADJOURN

There being no further business, Mr. Johnson made a motion to adjourn the meeting. Mr. Johnston seconded the motion, all voted "aye" and the meeting was adjourned.

Respectfully submitted,

Glen Ray Johnson, Secretary

MINUTES
WARREN COUNTY WATER DISTRICT

The Warren County Water District Board of Commissioners met in regular session on Tuesday, July 26, 2011, at 4:00 p.m. at the Water District Office at 523 US 31W Bypass, Bowling Green, Kentucky.

QUORUM CHECK

Those members present were: Henry Honaker – Chairman, Tad Donnelly - Vice-Chairman, Joe Taylor – Treasurer, Glen Johnson - Secretary and Harvey Johnston. Also present were Hamp Moore – Attorney, Alan Vilines – General Manager and Jon Schubarth – Manager of Engineering and Construction.

Mr. Honaker called the meeting to order and determined a quorum was present.

MINUTES APPROVED

Mr. Johnson made a motion to approve the minutes of the meeting of June 14, 2011. Mr. Donnelly seconded the motion and all voted "aye".

OPERATING REPORTS

The Operating Reports for the period ending May and June 2011 were reviewed

BGMU/WCWD JOINT ENGINEERING, PLANNING AND FINANCE COMMITTEE

Mr. Taylor reported on the BGMU/WCWD Joint Engineering, Planning and Finance Committee meeting of June 16th. Updates were presented on the waste water treatment plant project, the backwash project, and several other new projects at the water treatment plant. The Jennings Creek Interceptor video inspection and manhole improvements were also discussed. Major items included in the wholesale rate study were reviewed by staff members and the committee passed a motion to recommend the rates to each respective board.

Mr. Vilines discussed several details of the wholesale rate study as outlined in the joint staff letter of June 16, 2011, and summarized the changes in wholesale rates for each of the service areas. Schedules of proposed retail water and sewer rates were presented along with a comparison of retail bills for the larger systems in Kentucky. Mr. Donnelly made a motion to approve the wholesale rates as recommended by the Joint Committee and to proceed with filing a Purchased Water Adjustment with the Public Service Commission followed by implementation of the retail rate increase. Mr. Johnston seconded the motion and all voted "aye."

ATTORNEY'S REPORT

Mr. Moore stated that the application for a meter testing deviation has been filed with the PSC. He has also been working with management on several aspects of the Nashville Road sewer extension.

LIST OF ACCOUNTS

Mr. Taylor made a motion to transfer the list of accounts dated July 2011 for collection. Mr. Johnson seconded the motion and all voted "aye."

GENERAL MANAGER'S REPORT

The General Manager reported on the following:

1. Mr. Schubarth presented a proposal for funding the Nashville Road sewer extension to Buchanon Park which includes establishing a sewer interceptor capital recovery area. In addition to regular tap

fees, the District would collect capital recovery contributions at the time customers apply for sewer service and these contributions would be used to offset annual debt service on a KIA loan. Under this plan Warren Fiscal Court would pay any difference between the capital recovery contributions collected each year and the annual debt service payments. It was the consensus of the board that this would be a good approach, if the county finds it acceptable.

2. The Mobile GIS pilot has been successful in identifying the best equipment and methods to be used in a fully implemented program. The system has proven to be very beneficial for operations. The employees involved in the pilot have been able to use the system effectively with minimal training. Mr. Johnston made a motion to proceed with the complete Mobile GIS program; Mr. Johnson seconded the motion and all voted "aye."

3. The conversion to the new customer information system is going well. There have been three data extractions from the old system with progressively better results. The new software has been installed and was used by cashiers in parallel with the old system for one entire week in June. This identified certain items that need to be corrected and modified, but overall the comparison of the transactions entered was good. A second parallel test is scheduled for late August and the "go live" date for full implementation is September 26th.

4. The Tabulation of Bids for the Hwy. 31W Water & Sewer Line Relocations was distributed. Mr. Taylor made a motion to award the construction contract to the low bidder, Clay Pipeline, Inc. of Manchester, KY. Mr. Johnston seconded the motion and all voted "aye."

5. Construction on the Natcher Parkway Force Main Extension is complete except for cleanup work.

6. Mr. Johnston made a motion to appoint Mr. Taylor as the District's voting delegate at the upcoming Kentucky Rural Water Association's Annual Conference with Mr. Vilines as an alternate; Mr. Donnelly seconded the motion and all voted "aye."

7. There have been no lost time accidents.

ADJOURN

There being no further business, Mr. Johnston made a motion to adjourn the meeting. Mr. Donnelly seconded the motion, all voted "aye" and the meeting was adjourned.

Respectfully submitted,

Glen Ray Johnson

Glen Ray Johnson, Secretary

MINUTES
BUTLER COUNTY WATER SYSTEM, INC.

The Butler County Water System, Inc. Board of Directors met in regular session on Tuesday, October 19, 2010, at 7:00 p.m. at the Water System Office, 104 S. Tyler St., Morgantown, Kentucky.

QUORUM CHECK

Those members present were: Roland Stephens - President, Weymouth Martin, Jr. - Vice-President, Garry Robbins -- Secretary-Treasurer, David Martin and Don Lindsey. Also present was Alan Vilines -- General Manager.

MINUTES APPROVED

Mr. Lindsey made a motion to approve the minutes of the Board Meeting of August 17, 2010. Mr. David Martin seconded the motion and all voted "aye."

OPERATING REPORTS

The Operating Reports for the periods ending August and September 2010 were reviewed.

LIST OF ACCOUNTS

Mr. Weymouth Martin made a motion to transfer the list of accounts dated September and October 2010 for collection. Mr. Robbins seconded the motion and all voted "aye."

GENERAL MANAGER'S REPORT

Mr. Vilines reported on the following:

1. Several pages of financial information regarding refinancing of the Water System's existing debt were reviewed. Updated estimates prepared by Morgan Keegan & Company indicate potential savings of approximately $23,000 per year. Mr. David Martin made a motion approving a Resolution which authorizes the loan agreement with Butler County and the filing of an application with the Public Service Commission for the refinancing. Mr. Lindsey seconded the motion and all voted "aye."

2. A list of "Areas Expressing Interest in Water Line Extensions" dated October 18, 2010 was distributed. Mr. Weymouth Martin made a motion to fund the 5 distribution lines listed from the Water System's reserves, to proceed with the necessary engineering work and advertise for bids on the construction. Mr. Lindsey seconded the motion and all voted "aye", except Mr. Robbins who abstained.

3. The PSC's meter testing regulations were discussed along with steps taken by the Water System leading up to the meter testing deviation granted by the PSC in 1999. Performance of the Sensus SRII meters currently in use by the Water System, the 2003 application to the PSC and subsequent 2005 PSC Order allowing additional sample testing were also reviewed. Mr. Robbins made a motion authorizing further study of SRII meter accuracy to be followed by a joint application to the PSC for a deviation which would allow an extended meter testing

frequency. Mr. David Martin seconded the motion and all voted "aye."

4. The engagement letter from Buckles, Travis, VanMeter and Hart, PLLC for the 2010 Audit was discussed. Mr. David Martin made a motion to accept this proposal with a revision to allow a change in the fee equal to the annual change in the CPI; Mr. Robbins seconded the motion and all voted "aye."

5. The proposed operating budget for 2011 was reviewed. Mr. Weymouth Martin made a motion to approve the budget as presented. Mr. Lindsey seconded the motion and all voted "aye."

6. Progress on the Project 17 water line construction was reviewed. Twenty-five individual lines have been placed in service out of the total of 43 on the project. About 85 percent of the pipe has been installed to date and most of the lines remaining to be laid are in the Muhlenberg County area.

7. Steel erection on the new Logansport Tank is complete. Blasting and painting will start soon.

8. Several improvements associated with the Major Maintenance Project are underway. The pumps at the Leonard Oak Pump Station are being renovated and all of the old, unused piping at the Rochester Control Valve Station has been removed. A new master meter has been installed at the Hwy. 411 Pumping Station.

9. Photographs were circulated showing problems at several locations where water mains are exposed in creek crossings. About 20 such sites have been identified north of the river and more are expected to be found on the south side. Mr. Lindsey made a motion authorizing an application for funding assistance from FEMA to repair these locations; Mr. Weymouth Martin seconded the motion and all voted "aye."

10. There have been no lost time accidents.

ADJOURN

Mr. David Martin made a motion to adjourn. Mr. Robbins seconded the motion and all voted "aye."

Respectfully submitted,

Garry Robbins

Garry Robbins, Secretary

MINUTES
SIMPSON COUNTY WATER DISTRICT

The Simpson County Water District Board of Commissioners met in regular session on Thursday, October 28, 2010 at 1:00 p.m. at the Water District Office, 108 Morgantown Road, Franklin, Kentucky.

QUORUM CHECK

Those members present were: Ray Mann - Chairman, James Snider - Vice Chairman and Joe Richards - Secretary/Treasurer. Also present were Bob Taylor - Attorney and Alan Vilines – General Manager.

Mr. Mann called the meeting to order and determined a quorum was present.

MINUTES APPROVED

Mr. Richards made a motion to approve the minutes of the Board Meeting of September 23, 2010. Mr. Snider seconded the motion and all voted "aye."

OPERATING REPORTS

The Operating Reports for the period ending September 2010 were reviewed. Mr. Snider made a motion to approve the Operating Reports. Mr. Richards seconded the motion and all voted "aye."

' IST OF ACCOUNTS

Mr. Snider made a motion to transfer the list of accounts dated October 2010 for collection. Mr. Richards seconded the motion and all voted "aye."

LEAK ADJUSTMENTS

Mr. Richards made a motion to authorize a leak adjustment in accordance with the standard policy for Kris Slack and Wayne Woods. Mr. Snider seconded the motion and all voted "aye."

GENERAL MANAGER'S REPORT

Mr. Vilines reported on the following:

1. On October 25th the Franklin City Commission approved the Supplemental Agreement between the District and the city regarding the service area annexation for the Ewing Properties development.

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2. The PSC's meter testing regulations were discussed along with steps taken by the District leading up to the meter testing deviation granted by the PSC in 1999. Performance of the Sensus SRII meters currently in use by the District, the 2003 application to the PSC and subsequent 2005 PSC Order regarding an additional testing deviation were also reviewed. Mr. Snider made a motion authorizing further study of SRII meter accuracy to be followed by a joint application to the PSC for a deviation which would allow an extended meter testing frequency. Mr. Richards seconded the motion and all

voted "aye."

3. The proposed operating budget for 2011 was reviewed. Mr. Richards made a motion to approve the budget as presented. Mr. Snider seconded the motion and all voted "aye."

4. Mr. Snider made a motion to accept the proposal from Holland CPA's for the 2010 Audit as revised and to authorize the general manager to sign the proposal on behalf of the District. Mr. Richards seconded the motion and all voted "aye."

5. Pipeline construction on the Hwy. 100 West Water Line Replacement project is almost complete. Within a few days the new line will be tied in and tested; then existing service lines can be connected.

6. Service for the new TSC Distribution Center in the East Industrial Park will require an extension of the existing 16-inch water main on Raines Drive approximately 500 feet in length. A draft Construction Agreement between the District and the Franklin-Simpson Industrial Authority was presented. Mr. Richards made a motion approving the agreement as revised and authorizing the staff to advertise for construction bids and to award the contract based on the lowest and best bid. Mr. Snider seconded the motion and all voted "aye."

7. The next board meeting is scheduled for December 16th at 6:00 p.m.

8. There have been no lost time accidents.

ADJOURN

Mr. Snider made a motion that the meeting be adjourned. Mr. Richards seconded the motion and all voted "aye."

Respectfully submitted,

Joe H. Richards

Joe Richards, Secretary/Treasurer

MINUTES
WARREN COUNTY WATER DISTRICT

The Warren County Water District Board of Commissioners met in regular session on Tuesday, October 26, 2010, at 4:00 p.m. at the Water District Office at 523 US 31W Bypass, Bowling Green, Kentucky.

QUORUM CHECK

Those members present were: Henry Honaker – Chairman, Glen Johnson - Secretary, Joe Taylor - Treasurer, Harvey Johnston and Tad Donnelly. Also present were Hamp Moore, Jeff Peeples and Alan Vilines.

Mr. Honaker called the meeting to order and determined a quorum was present.

MINUTES APPROVED

Mr. Taylor made a motion to approve the minutes of the meeting of September 30, 2010. Mr. Johnson seconded the motion and all voted "aye".

OPERATING REPORTS

The Operating Reports for the period ending September 2010 were reviewed.

COMMISSIONER'S REPORT

Mr. Donnelly reported on the PSC Training Seminar he attended at Rough River State Park on October 5^{th}. The sessions included several topics of particular interest to board members. Mr. Donnelly also mentioned that he had been contacted regarding improvements to water supply facilities at Jackson's Orchard.

LIST OF ACCOUNTS

Mr. Johnson made a motion to transfer the list of accounts dated October 2010 for collection. Mr. Donnelly seconded the motion and all voted "aye."

GENERAL MANAGER'S REPORT

The General Manager reported on the following:

1. Results of the bid opening for the Olde Stone Water Line and Force Main Repair were reviewed. As authorized at the September meeting, this contract was awarded to the low bidder, Charles Deweese Construction of Franklin, KY.

2. Results of the bid opening for the 2010 Water System Improvements were reviewed. Mr. Taylor made a motion to award this contract to the low bidder, Jackson Excavating, LLC of Franklin, KY. Mr. Johnston seconded the motion and all voted "aye."

3. The PSC's meter testing regulations were discussed along with steps taken by the District leading up to the meter testing

deviation granted by the PSC in 1999. Performance of the Sensus SRII meters currently in use by the District, the 2003 application to the PSC and subsequent 2005 PSC Order regarding an additional testing deviation were also reviewed. Mr. Johnston made a motion authorizing further study of SRII meter accuracy to be followed by a joint application to the PSC for a deviation which would allow an extended meter testing frequency. Mr. Donnelly seconded the motion and all voted "aye."

4. The engagement letter and pricing from Shelton & Associates for the 2010 Audit were discussed. Mr. Taylor made a motion to accept the proposal from Shelton & Associates; Mr. Johnson seconded the motion and all voted "aye."

5. The pre-construction conference for the Natcher Parkway Interceptor Extension has been held, however actual construction work is on hold pending acquisition of all required easements. Minor items are still remaining to complete the North Warren and Lift Station Upgrade projects.

6. One of the small pickup trucks used for meter reading is a four wheel drive 2005 model with about 186,000 miles and another small pickup used for meter testing and line flushing is a two wheel drive 2003 model with about 213,000 miles. It was recommended that both these trucks be replaced. Mr. Johnston made a motion to solicit bids on the new vehicles and purchase them from the low bidder; Mr. Donnelly seconded the motion and all voted "aye."

7. A letter to the board from a water customer, Laura Daves, was discussed along with the resolution of Ms. Daves' concerns.

8. There have been no lost time accidents.

ADJOURN

There being no further business, Mr. Johnson made a motion to adjourn the meeting. Mr. Donnelly seconded the motion, all voted "aye" and the meeting was adjourned.

Respectfully submitted,

Glen Ray Johnson

Glen Ray Johnson, Secretary

CALCULATION OF SAMPLE SIZE

Year	Total Meters	Meters in Evaluation Group	Evaluation % of Total	Calculated Standard Deviation of Meter Accuracy	Normalized Standard Deviation using Linear Regression (1)	*n* Sample Size	USE
1990	1,328	829	62.4%	0.0438	0.0487	91	95
1991	1,525	1,010	66.2%	0.0534	0.0446	77	80
1992	1,569	1,085	69.2%	0.0316	0.0406	63	65
1993	1,907	1,368	71.7%	0.0377	0.0366	51	55
1994	1,349	751	55.7%	0.0340	0.0326	41	45
1995	1,258	608	48.3%	0.0261	0.0285	31	35
1996	1,887	316	16.7%	0.0613	0.0245	23	30
1997	1,227	50	4.1%	0.1260	0.0205	16	30
TOTAL	12,050	6,017				393	435

Note (1) The linear regression equation used to normalize the standard deviation is y=-0.004026x+8.0604 where 'x' is equal to the year of manufacture and 'y' is the normalized standard deviation.

TABLE A-7 (Revised)
METER TESTS - 19 YEAR OLD METERS

Meter No.	-------- Test Results -------- Low	Medium	High	WAMA	Meets PSC Repaired Meter Stds.
44894643	94	100	100	99.6	
44894646	92	99	99	98.5	
44894654	98	101	100	100.7	
44894658	96	101	100	100.6	
44894668	92	99	99	98.5	
44894694	97	101	100	100.7	
44894705	93	99	99	98.6	
44894714	98	101	100	100.8	
44894718	96	100	100	99.7	
44894723	92	100	98	99.3	no
44894724	96	101	100	100.6	
44894735	95	90	99	90.9	no
44894737	96	99	99	98.8	
44894742	91	99	99	98.5	
44894745	97	101	100	100.7	
44894754	98	100	100	99.9	
44894764	99	101	100	100.8	
44894769	99	100	101	100.0	
44894787	94	100	99	99.5	
44894796	96	100	100	99.7	
44894811	93	100	100	99.5	
44904035	92	100	99	99.4	
44904037	97	101	100	100.7	
44904045	96	101	100	100.6	
44983752	88	99	99	98.2	no
44983756	93	100	99	99.5	
44983799	87	99	99	98.1	no
44983806	91	100	99	99.3	
44983807	92	99	99	98.5	
44983825	96	100	100	99.7	
44983828	78	97	98	95.7	no
44983872	98	100	100	99.9	
44983904	96	100	99	99.7	
44992193	94	100	100	99.6	
44992226	97	101	100	100.7	
44992248	98	101	100	100.7	
44992259	79	99	99	97.6	no
44992299	91	99	99	98.4	

	-------- Test Results --------				Meets PSC
Meter No.	Low	Medium	High	WAMA	Repaired Meter Stds.
44992300	98	101	100	100.7	
44992314	89	99	99	98.3	no
45221876	90	99	99	98.4	
45221883	99	100	101	100.0	
45221903	99	101	100	100.8	
45221914	97	101	101	100.7	
45221925	83	98	98	97.0	no
45221930	98	101	100	100.7	
45221934	92	100	99	99.4	
45221961	97	101	100	100.7	
45221975	98	101	100	100.7	
45221992	93	100	99	99.5	
45222002	97	101	100	100.6	
45222013	97	101	100	100.7	
45304352	88	99	99	98.2	no
45304355	96	99	100	98.8	
45415293	88	99	99	98.3	no
45415384	96	100	100	99.7	
45415416	89	99	98	98.3	no
45415428	99	101	100	100.8	
45415452	88	98	99	97.3	no
45415483	99	101	100	100.8	
45468897	95	100	99	99.6	
45468910	89	99	99	98.3	no
45468916	97	101	100	100.6	
45468967	92	99	99	98.5	
45468983	91	100	98	99.3	no
45468993	93	101	56	97.8	no
45469045	84	98	98	97.0	no
45469049	98	101	100	100.7	
45469119	97	101	100	100.7	
45469126	81	99	99	97.7	no
45469131	97	101	100	100.6	
45469138	95	101	100	100.5	
45469211	98	101	100	100.7	
45469668	96	101	100	100.6	
45469682	94	100	99	99.5	
45613350	90	99	100	98.4	

	-------- Test Results --------				Meets PSC
Meter No.	Low	Medium	High	WAMA	Repaired Meter Stds.
45613352	91	99	99	98.4	
AVERAGES	93.7	99.9	98.9	**99.4**	
MIN	78.0	90.0	55.9		
MAX	99.0	101.0	100.7		
% Meeting PSC Repaired Meter Stds.					**77.90%**
MIN				90.9	
MAX				100.8	
STD				1.5	
Total Pop. Size				1,525	
Acceptable Error				0.010	
Std. Deviation				0.015	
Samp. Size (95% Conf. Level)				77	
Actual Error				0.003	

WARREN, BUTLER & SIMPSON COUNTY WATER DISTRICTS
2010 COST EFFECTIVE METER TESTING STUDY
SUMMARY OF METERS TESTED PER SYSTEM

Appendix Table	A-8	A-7	A-6	A-5	A-4	A-3	A-2	A-1	
Meter Age	20	19	18	17	16	15	14	13	
Year	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**TOTAL**
WCWD Total Meters	1,289	1,144	1,196	1,527	664	825	1,264	861	8,770
BCWS Total Meters	3	292	243	178	495	89	144	127	1,571
SCWD Total Meters	36	89	130	202	190	344	479	139	1,609
TOTAL	1,328	1,525	1,569	1,907	1,349	1,258	1,887	1,127	11,950
WCWD Test Group	93	59	46	39	21	27	17	24	326
BCWS Test Group	1	18	9	8	19	4	2	2	63
SCWD Test Group	1	3	10	8	5	4	11	4	46
TOTAL	95	80	65	55	45	35	30	30	435

TABLE 3
COST-EFFECTIVE DETERMINATION

A	B	C	D	E	F	G	H	I	J
Meter Age	Weighted Average Meter Accuracy (WAMA)[1]	Percent Below Repaired Meter Standards[1]	Unit Retrieval Cost	Unit Replacement Cost	Total Program Cost Per Meter	Water Recovered (gals/yr)	Unit **Annual** Revenue Gain	Unit Present Value of Rev. Gain[2]	Net Present Value of Program per Meter
1	100.05%	0.00%	$13.38	$26.92	$40.30	0	$0.00	$0.00	-$40.30
2	100.05%	0.00%	13.38	26.92	40.30	0	0.00	0.00	-40.30
3	100.05%	0.00%	13.38	26.92	40.30	0	0.00	0.00	-40.30
4	100.05%	0.00%	13.38	26.92	40.30	0	0.00	0.00	-40.30
5	100.05%	0.00%	13.38	26.92	40.30	0	0.00	0.00	-40.30
6	100.05%	0.00%	13.38	26.92	40.30	0	0.00	0.00	-40.30
7	100.05%	0.00%	13.38	26.92	40.30	0	0.00	0.00	-40.30
8	100.05%	0.00%	13.38	26.92	40.30	0	0.00	0.00	-40.30
9	100.05%	0.00%	13.38	26.92	40.30	0	0.00	0.00	-40.30
10	100.05%	0.00%	13.38	26.92	40.30	0	0.00	0.00	-40.30
11	100.05%	0.00%	13.38	26.92	40.30	0	0.00	0.00	-40.30
12	100.05%	0.00%	13.38	26.92	40.30	0	0.00	0.00	-40.30
13	100.05%	0.25%	13.38	26.92	40.30	0	0.00	0.00	-40.30
14	100.01%	0.44%	13.38	26.92	40.30	0	0.00	0.00	-40.30
15	99.93%	1.69%	13.38	26.92	40.30	41	0.14	1.67	-38.63
16	99.82%	4.84%	13.38	26.92	40.30	114	0.39	4.90	-35.40
17	99.65%	9.86%	13.38	26.92	40.30	213	0.73	9.61	-30.69
18	99.45%	16.77%	13.38	26.92	40.30	337	1.15	15.82	-24.48
19	99.21%	25.57%	13.38	26.92	40.30	487	1.66	23.78	-16.52
20	98.93%	36.25%	13.38	26.92	40.30	661	2.25	33.47	-6.83
21	98.61%	48.82%	13.38	26.92	40.30	859	2.93	45.17	**4.87**
22	98.25%	63.27%	13.38	26.92	40.30	1,081	3.69	58.81	18.51
23	97.85%	79.61%	13.38	26.92	40.30	1,326	4.52	74.33	34.03
24	97.42%	97.83%	13.38	26.92	40.30	1,593	5.43	91.96	51.66
25	96.95%	100.00%	13.38	26.92	40.30	1,883	6.42	111.79	71.49

Unit Costs for District Operations:		
Cost per Man-hour (Retrieval)	$17.97	
Cost per Man-hour (Admin.)	20.56	
Cost per Truck-hour	5.77	
Unit Retrieval Cost:		
Meters/hr.	1.80	
Unit Cost		$13.21
Unit Admin. Cost:		
Meters/hr.	120.00	
Unit Cost		$0.17
Total Unit Retrieval & Test Cost:		$13.38

Replacement Costs:	
New Meter Cost	$31.88
Scrap Value	4.96
Net Cost	$26.92

Avg. Residential Usage = 61,764 Per Year

Incremental Water Rate = $3.41 per 1,000 gals.

[1] Best fit curve data.

[2] Unit Present Value of Rev. Gain (I) = Unit Annual Revenue Gain (H) * Present Value Factor @ 3.0%.