Validity of Water Audit and Water Loss Evaluations for Florida

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INTRODUCTION

Water audits and water loss control are important parts of water conservation programs. Water loss can be viewed as a water use category so that its relative importance in terms of gpcd can be compared with other uses. The cost-effectiveness of water loss control can then be compared with water conservation options and supply augmentation. Friedman and Heaney (2009) evaluated the new third edition of the AWWA M36 manual titled *Water Audits and Loss Control Programs* (AWWA 2009a) and associated free software for evaluating water losses (AWWA 2009b). They recommend that Florida water utilities adopt the water audit and loss control procedures that are described in M36 including the water audit procedures outlined in Chapter 2. They also recommend using Version 4.0 of the AWWA Free Water Audit Software, which offers a top down method to compile water audit data and analyze loss levels and cost impacts. Current procedures for estimating water losses in Florida are not uniform and the accuracy of the reported estimates of water loss is questionable. The quality of the water audit is directly dependent upon the quality of the input data. The AWWA software requires that the user input estimates of up to 18 parameters. The reliability of these estimates ranges from excellent for measured water uses with accurate meters to poor for unsupported estimates of unmetered quantities. The AWWA software addresses the question of the validity of the data using a weighted scoring system that provides a normalized score ranging from 0 to 100 based on the user's estimates of the quality of the data. The AWWA software includes weights for each of the 18 inputs. However, these weights are not known to the user. The relevant parameters and weights should be a function of the purpose of the audit and water loss control program. The AWWA software provides output performance estimates for four financial and six operational measures. The most relevant measure for utilities in Florida at present is the % unaccounted for water (%UAW) because this metric is used for regulatory purposes with specified upper limits of 10 to 12% UAW. However, this metric is not recommended by AWWA because of the various ways that it is calculated and because it only represents performance in relative terms. Friedman and Heaney (2009) suggest using %UAW and associated gallons per capita per day (gpcd) as the measures of the importance of UAW for Florida. The use of gpcd provides a measure of the importance of UAW in absolute terms. This paper describes how a water audit can be done and UAW or its equivalent can be calculated following the procedures outlined in the 3rd edition of the AWWA (2009a) M36 manual and the AWWA (2009b) software. The specific focus is on how the validity of these estimates can be quantified using the procedures outlined in the AWWA (2009b) software. Thus, only the subset of the 18 parameters that deal with the water audit will be evaluated. The AWWA (2009b) software is described in the next section with emphasis on the scoring procedure. Then, our evaluation of relevant procedures for Florida is presented.

OVERVIEW OF AWWA WATER AUDIT SCORING METHOD

Friedman and Heaney (2009) present a detailed description of the AWWA water audit and water loss evaluation procedure. This paper focuses on the water audit component and relevant scoring methods. One new feature of Version 4.0 of the AWWA software is a scoring system to estimate the reliability of the data used to evaluate the extent of water losses and the potential cost-effectiveness of a water loss control program. Quantitative measures of meter accuracy are an essential part of water audits and water conservation evaluations. Regulations regarding meters should require quantitative estimates of meter performance following accepted national procedures as described in AWWA M6, M22, M33 and M36. It is important to establish standardized water audit data collection protocols and carry out such data collection over a period of several years. Systematic improvement of data validity should be the primary focus of this phase of activity. Only when a sufficient pool of reliable data exists can reliable assessments of loss levels and realistic target reduction levels be developed.

The AWWA audit prompts the user to assign a data validity score ranging from 1-10 for each of the 18 possible inputs in the AWWA (2009b) software with 1 denoting the poorest quality data and 10 denoting the best quality data. These 18 inputs are organized into the four major categories shown in Table 1.

Table 1. Inputs for AWWA (2009) Version 4.0 Audit.

Number	Category	Item
1	Water Supplied	Volume from own sources
2	Water Supplied	Master meter error adjustment
3	Water Supplied	Water imported
4	Water Supplied	Water exported
5	Authorized Consumption	Billed metered
6	Authorized Consumption	Billed unmetered
7	Authorized Consumption	Unbilled metered
8	Authorized Consumption	Unbilled unmetered
9	Apparent Losses	Unauthorized consumption
10	Apparent Losses	Customer metering inaccuracies
11	Apparent Losses	Systematic data handling errors
12	System Data	Length of mains
13	System Data	Number of active and inactive service connections
14	System Data	Average length of customer service line
15	System Data	Average operating pressure
16	Cost Data	Total annual cost of operating water system
17	Cost Data	Customer retail unit cost (Applied to Apparent Losses)
18	Cost Data	Variable production cost

The audit provides data quality criteria for each data validity score. A grade of 5 is given if a user selects a default value provided in the audit for certain inputs such as unauthorized consumption. Once grades are assigned to each input, the audit calculates a composite data validity score according to Equation 1.

$$DVS = \sum_{i=1}^{i=18} (s_i * w_i) \quad (1)$$

Where;

- DVS = composite data validity score
- s_i = user input score for input i
- w_i = weighting factor for input i

AWWA SCORING RATINGS

Each of the 18 parameters in the AWWA Version 4.0 software has a scoring system that provides the user with eleven choices: not applicable, and integer scores from 1 to 10. A brief description of the basis for each score is included. The primary parameters of interest in this evaluation are the subset that deals with metered water use or the associated meter errors. Thus, the items of interest are the four categories under Water Supplied; the billed and unbilled metered under Authorized Consumption; and customer metering inaccuracies under Apparent Losses. The descriptions for three of the items under Water Supplied are the same and are shown in Table 2. The scoring depends on three categories: 1) percent of customers that are metered, 2) frequency of meter accuracy testing, and 3) the calibrated accuracy of the meters.

Table 2. Scoring criteria in the AWWA (2009) Version 4.0 software for Volume from own sources (#1), Water imported (#3), and Water exported (#4)

Grade	Description
n/a	Select this grading only if the water utility purchases/imports all of its water resources (i.e. has no sources of its own)
1	Less than 25% of water production sources are metered, remaining sources are estimated. No regular meter accuracy testing.
2	25%-50% of water production sources are metered, others are estimated. No regular meter accuracy testing.
3	Conditions between 2 and 4
4	50%-75% of water production sources are metered, others are estimated. Occasional meter accuracy testing.

5	Conditions between 4 and 6
6	At least 75% of water production sources are metered, or at least 90% of the source flow is derived from the metered sources. Meter accuracy testing and/or electronic calibration conducted annually. Less that 25% of tested meters are found outside of +/- 6% accuracy.
7	Conditions between 6 and 8
8	100% of water supply sources are metered, meter accuracy testing and electronic calibration conducted annually, less than 10% of meters are found outside of +/- 6% accuracy.
9	Conditions between 8 and 10
10	100% of water supply sources are metered, meter accuracy testing and electronic calibration conducted semi-annually, with less than 10% found outside of +/- 3% accuracy.

The output from the master meter error adjustment is the volume of water per year that should be added to or subtracted from the water supplied from all sources. Accordingly, this error adjustment should apply to all source master meters. The criteria for meter error shown in Table 3 overlap the criteria shown in Table 2 with regard to frequency of meter testing and meter calibration.

Table 3. Scoring for master meter error adjustment (#2)

Grade	Description
n/a	Select this grading only if the water utility fails to have meters on its sources of supply, either its own source, and/or imported (purchased) water sources
1	Inventory information on meters and paper records of measured volumes in crude condition; data error cannot be determined.
2	No automatic data logging of production volumes; daily readings are scribed on paper records. Tank/storage elevation changes are not employed in calculating “Volume from own sources” component. Data is adjusted only when grossly evident data error occurs.
3	Conditions between 2 and 4
4	Production meter data is logged automatically in electronic format and reviewed at least on a monthly basis. “Volume from own sources” tabulations include estimate of daily changes in tanks/storage facilities. Meter data is adjusted when gross data errors occur,

	or occasional meter testing deems this necessary.
5	Conditions between 4 and 6
6	Hourly production meter data logged automatically & reviewed on at least a weekly basis. Data adjusted to correct gross error from equipment malfunction and error confirmed by meter accuracy testing. Tank/storage facility elevation changes are automatically used in calculating a balanced “volume from own sources” component.
7	Conditions between 6 and 8
8	Continuous production meter data logged automatically & reviewed daily. Data adjusted to correct gross error from equipment malfunction & results from meter accuracy testing. Tank/storage facility elevation changes are automatically used in “volume from own sources” component.
9	Conditions between 8 and 10
10	Computerized system (SCADA or similar) automatically balances flows from all sources and storages; results reviewed daily. Mass balance technique compares production meter data to raw (untreated) water and treatment volumes to detect anomalies. Regular calibrations between SCADA and source meter(s) ensure minimal data transfer error.

Similar, but not identical, scoring criteria exist for the unbilled and billed metered usage by customers as shown in Table 4 for billed metered usage.

Table 4. Criteria for billed metered usage (#5) under Authorized Consumption

Grade	Description
n/a	Select n/a only if the customer population is not metered, and is billed for water service on a flat or fixed rate basis.
1	Less than 50% of customers with volume-based billings from meter readings; flat or fixed rate billed for the majority of the customer population.
2	At least 50% of customers with volume-based billing from meter reads; flat or fixed rate billed for remainder. Manual meter reading used, less than 50% read success rate; failed reads are estimated. Limited customer meter records, no regular meter testing replacement. Billing data maintained on paper records, with no auditing.
3	Conditions between 2 and 4.

4	At least 75% of customers with volume-based billing from meter reads; flat or fixed rate billed for remainder. Manual meter reading used, at least 50% read success rate; failed reads are estimated. Purchase records verify age of customer meters; only very limited meter accuracy testing is conducted. Customer meters replaced only upon failure. Computerized billing records, but only periodic internal auditing conducted.
5	Conditions between 4 and 6.
6	At least 90% of customers with volume-based billing from meter reads; remaining accounts are estimated. Manual customer meter reading gives at least 80% read success rate; failed reads are estimated. Good customer meter records, limited meter accuracy testing, and regular replacement of oldest meters. Computerized billing records with routine auditing of global statistics.
7	Conditions between 6 and 8.
8	At least 97% of customers with volume-based billing from meter reads. At least 90% customer meter read success rate; or minimum 80% read success rate with planning and budgeting for trials of automatic metering reading (AMR) in one or more pilot areas. Good customer meter records. Regular meter accuracy testing guides replacement of statistically significant number of meters each year. Routine auditing of computerized billing records for global and detailed statistics; verified periodically by third party.
9	Conditions between 8 and 10.
10	At least 99% of customers with volume based billing from meter reads. At least 95% customer meter read success rate; or minimum 80% read success rate, with automatic meter reading (AMR trials underway. Statistically significant customer meter testing and replacement program in place. Computerized billing with routine, detailed auditing, including field investigation of representative sample of accounts. Annual audit verification by third party.

Scoring for Customer meter inaccuracies (#10) is presented in Table 5. Unlike Table 2, no quantitative criteria in terms of the frequency of meter testing and minimum accuracy ranges are included in the ratings.

Table 5. Scoring criteria for Customer meter inaccuracies (#10).

Grade	Description
n/a	Select n/a if the customer population is unmetered.
1	Customer meters exist, but with unorganized paper records on meters; no meter accuracy

	testing or meter replacement program. Workflow is driven chaotically by customer complaints with no proactive management. Loss volume due to aggregate meter inaccuracy is guesstimated.
2	Poor recordkeeping and meter oversight is recognized by water utility management who has allotted staff and funding resources to organize improved recordkeeping and start meter accuracy testing. Existing paper records gathered and organized to provide cursory disposition of meter population.
3	Conditions between 2 and 4.
4	Reliable recordkeeping exists; meter information is improving as meters are replaced. Meter accuracy testing is conducted annually for a small number of meters. Limited number of oldest meters replaced each year. Inaccuracy volume is largely an estimate, but refined based upon limited testing data.
5	Conditions between 4 and 6.
6	A reliable electronic recordkeeping system for meters exists. Population includes a mix of new high performing meters and dated meters with suspect accuracy. Routine, but limited, meter accuracy testing and meter replacement occur. Inaccuracy volume is quantified using a mix of reliable and less certain data.
7	Conditions between 6 and 8.
8	Ongoing meter replacement and accuracy testing result in highly accurate customer meter population. Testing is conducted on samples of meters at varying life spans to determine optimum replacement time for various types of meters.
9	Conditions between 8 and 10.
10	Good records of number, type and size of customer meters; ongoing meter replacement occurs. Regular meter accuracy testing gives reliable measure of composite inaccuracy volume for the system. New metering technology is embraced to keep overall accuracy improving.

In summary, scoring criteria are presented for the Water supplied and the Authorized consumption. The two basic metrics are the measured mean flow rates and the variability of these estimates. These criteria apply to all metered and unmetered components of the water audit. Water usage associated with some unmetered activities can be estimated fairly accurately if the intensities, durations, frequencies, and water use rates of the activity can be approximated. However, a more rigorous definition of unaccounted for water use would exclude all non-directly metered components.

AWWA WEIGHTING METHOD

The Validity Score for the AWWA method uses two metrics of importance for each of the 18 parameters: 1) an integer score from 1 to 10, and 2) a weight for each parameter based on its importance. As discussed in the previous section, a detailed description is provided for selecting the appropriate score. However, the developers of the AWWA software have decided that the weighting procedure should not be revealed to the user. Apparently, they are concerned that users might adjust the weights to achieve a desired score. We prefer to have the basis for the weights explained so that users can understand the implications of various weighting factors. A variety of multi-attribute scoring procedures are available and they are necessarily subjective since a value judgment is made regarding the "relative importance" of each factor. Techniques from multi-attribute utility theory (MAUT) have been used to address these questions with applications to cost-effectiveness analysis, environmental impact assessments and many other areas (Keeney and Raiffa 1993). For example, Nero and Adams (2006) describe how MAUT can be applied to decision problems at Tampa Bay Water and elsewhere. A major challenge in using MAUT is having a reliable basis for assigning weights. In the case of urban water audits, a defensible method is to assign weights based on the quantity of water associated with each factor. This method is described in the proposed evaluation method that is presented in the next section.

WATER AUDIT VALIDITY EVALUATION PROCEDURE

Alternative procedures for estimating the validity of a water audit using a combination of methods contained in the AWWA software and our suggested approach are presented in this section. The basic features of this approach include:

1. Only metered flow rates are included in the water audit. The difference between metered inputs and outputs is the unmetered water. One goal is to maximize the percentage of the water that is metered.
2. The accuracy of each metered source is evaluated and reported as the extent of under or over recording for that meter. The variance of the meter readings around this mean is not relevant for this evaluation of the average performance of the meters.
3. The definitions of terms from the AWWA Version 4.0 software are acceptable.
4. The gross gpcd should be calculated to provide a measure of the normalized quantity of water associated with the water audit as discussed in Friedman and Heaney (2009). The weights associated with each factor should be assigned based on the metered flow rates for each factor rather than relying on the unknown weighting factors that are contained in the AWWA software.

A comparative example calculation is presented in Table 6. In this example, there are two water supply sources, one entry for master meter error, two components of water delivered (billed and unbilled metered), and customer metering inaccuracies. These categories and associated definitions of terms are consistent with the format in the AWWA software. The entries in the Score column are user inputs following the AWWA criteria. In this example, the total score is 44 out of 60, or 73.3%. The next column is the assumed weights for this example. These weights are unknown to the user in the AWWA method and these parameter estimates are simply our guesses. The products of the scores times the weights are shown in the next column. The weights may be viewed as the number of times that a score is included, e.g., a weight of 20 indicates that the first score of 10 is counted 20 times. The maximum value of the score*weight is 63*10 = 630. The actual sum product is 496 so the associated score is 496/630 = 78.7% as shown in Table 6.

For water audit purposes, the weights should be proportional to the sizes of the terms in the water audit. The million gallons per year for each of these six elements are shown in the next column of Table 6. The total water supplied of 910 mg./yr. includes a meter error adjustment of 50 mg./yr. The total metered delivery is 750 mg./yr. leaving a total of 160 mg./yr. of unmetered water. The associated % metered is 750/910 or 82.4 %. Alternatively, the % unmetered water is 17.6%. These mg./yr. values can be converted to gpcd using the fact that the population served is 15,000. The resultant gpcd figures indicate a supply of 166 gpcd and unmetered water of 29.2 gpcd. Gpcd is a popular policy metric. In this case, the utility may face an allowable upper limit on its gpcd, e.g., 150 gpcd. Thus, they could reach this target by reducing their unmetered water in combination with other conservation BMPs by 16 gpcd. Lastly, the relative sizes of the gpcd's (or equivalently the mg./yr.) can be calculated as shown in the final column. Each entry is the percent relative to the total water supplied of 910 mg./yr. (166.2 gpcd). The flow weighted score is calculated as the sumproduct of the scores*flow weight or 16.0. The maximum possible score is 1.82*10 = 18.2. Thus, the flow weighted score is 88.0%.

In summary, four water audit ratings have been compared. The resulting ratings are: 1) 73.3% based on the scores alone; 2) 78.7% based on the weighted scoring procedure with unknown weights; 3) 82.4% based on the proportion of the flows that are metered; and 4) 88.0% based on the flow weighted average scores. In addition, the unmetered flow is 29.2 gpcd. We recommend against using the AWWA validity score (option 2) since the basis for assigning weights is unknown. A simple arithmetic average of the scores (option 1) is also inappropriate since it does not distinguish between large and small flows. The proportion of the flows that are metered (option 3) provides a straightforward measure of the quality of the audit. Recall that a primary criterion for the 1 to 10 scoring system is the percentage of the flows that are metered. Utilities that do not meter the vast majority of their flows would have a relatively low score based on option 3. Option 4 flow weights the scores which addresses the question of using a quantitative basis for assigning weights but may result in double counting to some extent. For example, from Table 2, a utility receives a score of 6 if its characteristics are as shown below:

6. *At least 75% of water production sources are metered, or at least 90% of the source flow is derived from the metered sources. Meter accuracy testing and/or electronic calibration conducted annually. Less that 25% of tested meters are found outside of +/- 6% accuracy.*

In this case, the utility with 90% of its sources metered would receive a score of 6 whereas it is metering 90% of its flow. The question of the accuracy of these readings should be addressed in the meter error adjustment section. Thus, it appears to be redundant to do the scoring and the flow weighting. Accordingly, we recommend % metered (option 3) as a simple and meaningful performance measure for water audits.

Table 6. Comparison of water audit validity evaluation methods.

Number	Item	Score	Assumed Weight	Score* Weight	Mil. Gal./ year	Gpcd	Gpcd Weight
		Population =		15,000			
	WATER SUPPLIED						
1	Volume from own sources	10	20	200	800	146.1	87.9%
2	Master meter error adjustment	3	8	24	50	9.1	5.5%
3	Water imported	10	8	80	60	11.0	6.6%
4	Water exported						
	Sub-total, Water Supplied	23	36	304	910	166.2	100.0%
	WATER DELIVERED						
5	Billed metered	8	15	120	650	118.7	71.4%
7	Unbilled metered	8	4	32	50	9.1	5.5%
10	Customer metering inaccuracies	5	8	40	50	9.1	5.5%
	Sub-total, Water Delivered	21	27	192	750	137.0	82.4%
	Totals	44	63	496			16.0
	Maximum Value	60		630			18.2
	Relative Score	73.3%		78.7%			88.0%
	% Metered Water				82.4%		
	Unmetered gpcd					29.2	

SUMMARY AND CONCLUSIONS

A water audit is a fundamental first step in evaluating urban water systems. The database for this audit is recent water use data. At present, water audits are included in EZ Guide as part of the estimated of percent unaccounted for water (%UAW). In Florida, the regulatory allowable maxima for %UAW are 10 or 12. However, the utilities can calculate %UAW in different ways and are not required to support their estimates with information regarding whether the estimates are metered or unsupported guesses. Based on a detailed review of the 2009 AWWA M36 Manual on water audits and water loss, and the associated Version 4.0 software, we recommend estimating the validity of the water audit based on the percentage of the water supplied and used that is metered for the relative importance metric, and the gallons per capita per day of unmetered water as the absolute metric of importance.

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