Report on Unaccounted-for Water for Kentucky American Water Company Distribution Operations, March 11, 2003

by Greg Tomko

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I. Introduction

This study was done because Kentucky-American Water Company management has expressed a concern over the recent percentage of unaccounted-for water reported on the monthly form 329 Operating Data Report. The approach taken was not one of attempting to find every gallon of unaccounted-for water but rather to develop a big picture of unaccounted-for water and determine if there is opportunity for improvement.
In doing the study, various production and operations personnel were consulted or interviewed, a walk along was done with the leak detection crew, company reports, records and operating procedures were reviewed and several papers written on water loss were consulted.

II. Definitions

System Delivery – Water delivered to the distribution system for sale to customers after production uses have been eliminated. In the KAWC system this is all high service pumpage measured at the outlet of the plants since there is no production usage downstream of plant outlet measurement.

Non-Revenue Usage – Volumes of water used in providing service after delivery into the distribution system such as flushing, draining storage for maintenance, substantiated leakage or for other uses in the public interest such as fire fighting and street cleaning. Some of these volumes are measured and some calculated.

Water Sales – The total volume of water measured at the meters of all customers.

Unaccounted for Water – The difference between system delivery and water sales less non-revenue usage.

III. Performance Standards

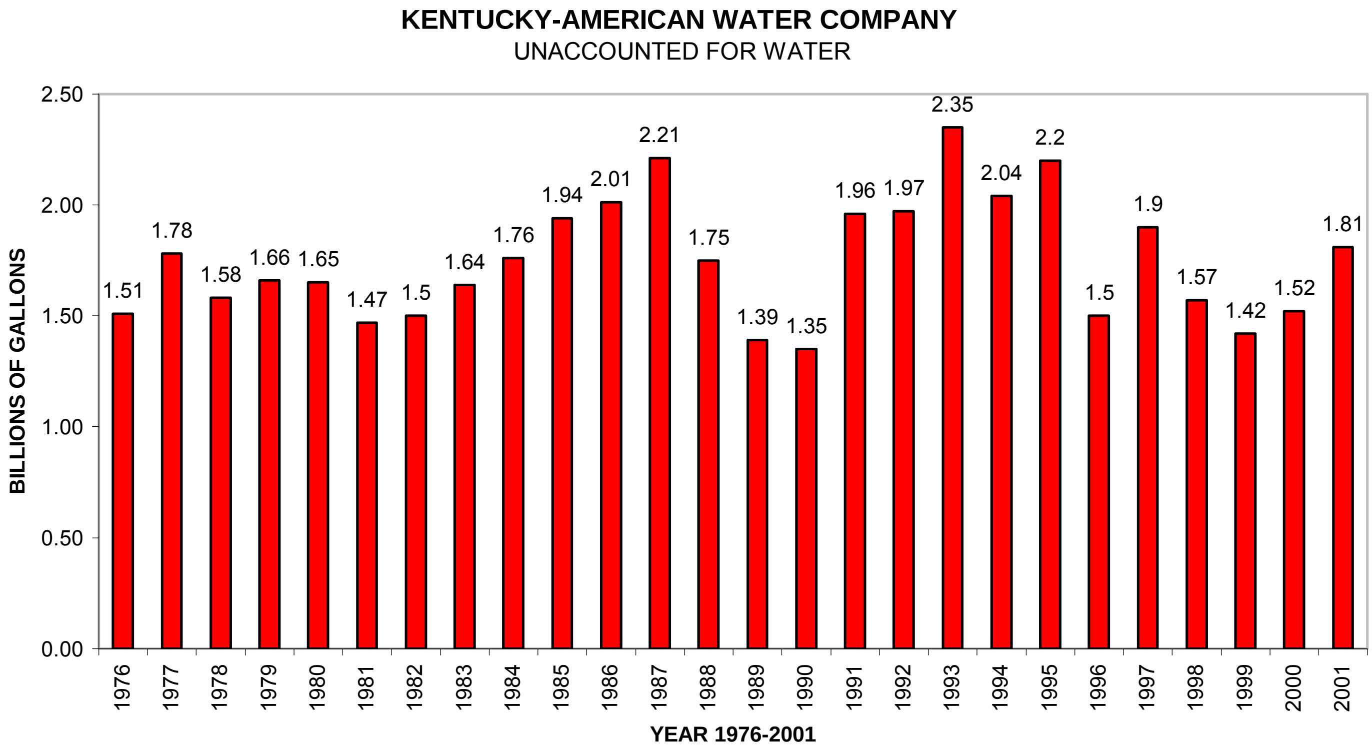
807 KAR 5:066.Water
KRS Chapter 278.280(2), Section 6 .(3) Unaccounted-for water loss: Except for purchased water rate adjustments for water districts and water associations, and rate adjustments pursuant to KRS 278.023(4), for rate making purposes a utility's unaccounted-for water loss shall not exceed 15% of total water produced and purchased, excluding water used by a utility in its own operations." **In other words for ratemaking purposes the PSC standard is 15 % or less unaccounted for water.**

American Water Works System Policy No. P-48 Rev. 8/5/88, ACCOUNTING FOR WATER: A standard objective is to minimize water losses to no more than 10% which shall be the maximum difference that cannot be otherwise accountable through water sales and measured known non-revenue usage and total system delivery, including water purchased for resale. **This sets the unaccounted for water goal at 10% or less.**

The 2002 Operational Excellence Goal was for the ratio of sales to system delivery to be greater than 85%. In comparing it to the above two standards, non-revenue usage and unaccounted-for combined must be less than 15%. **Since non-revenue usage for KAWC has generally been in a range of between one and two percent this standard for unaccounted for water is less demanding than AWWS P-48. If, for example, non-revenue usage averaged 1.5% for the 12 month period between Jan 1.and Dec.31, then unaccounted-for would have to be less than 13.5% for that same period to be considered operationally excellent.**

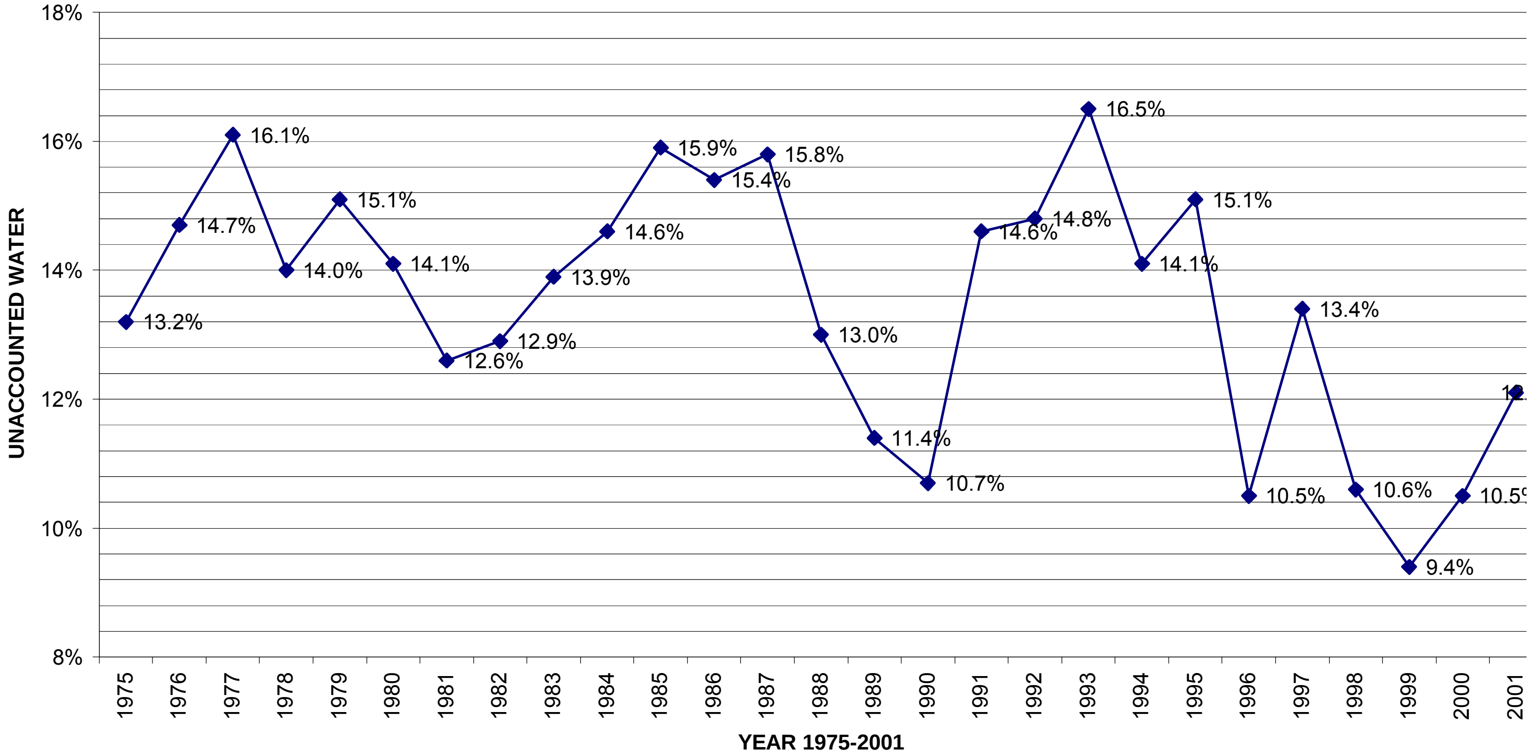
A current modification to the 2002 operational excellence goal is to attain a ratio of sales to system delivery of greater than 90% (less than or equal to 10% unaccounted for and non-revenue usage combined). **This is the current and most demanding goal of those listed. If the non-revenue usage were to average 1.5% as in the example above then unaccounted-for would have to be 8.5% or less to be operationally excellent.**

IV. Historical Data

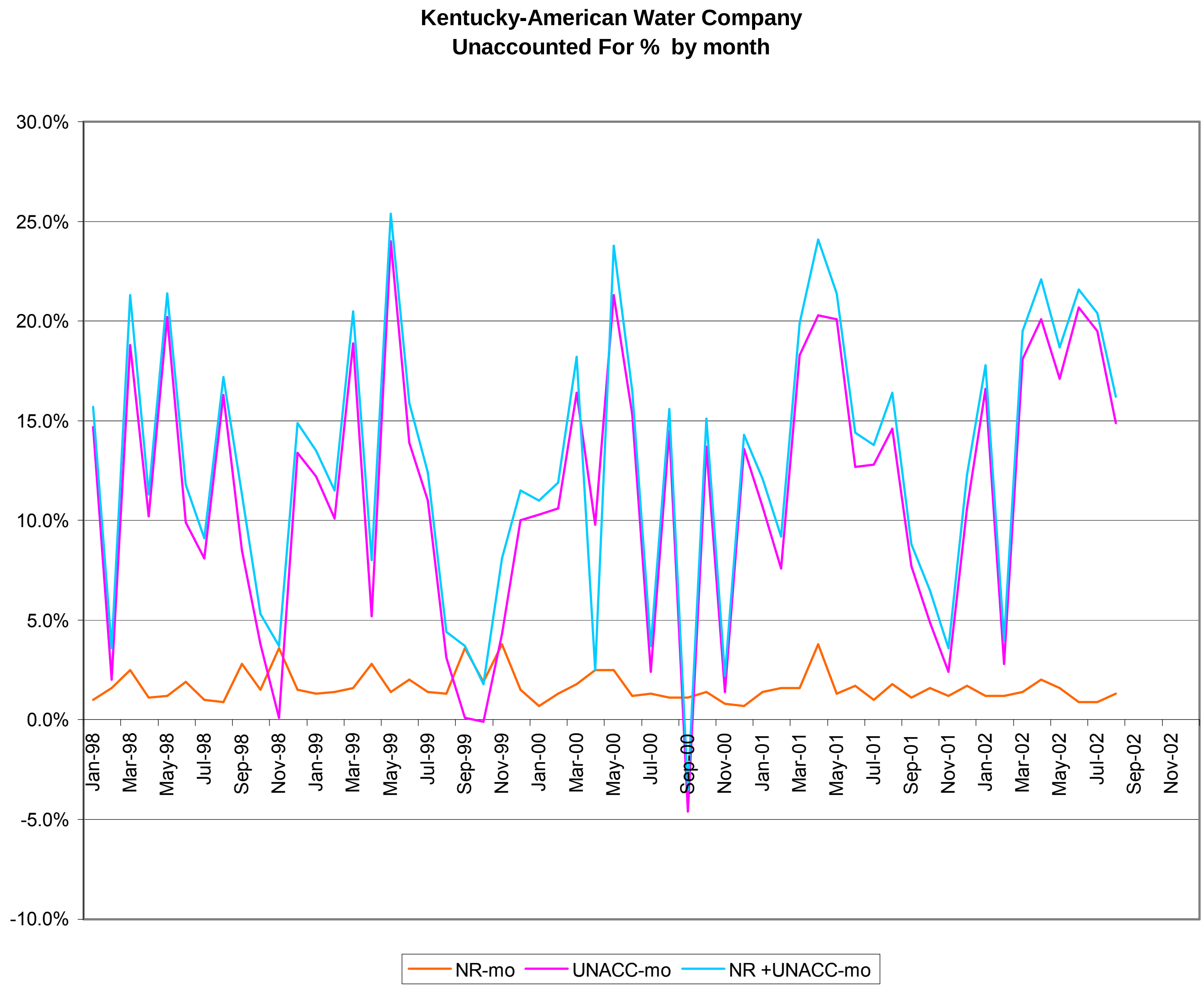


The chart above illustrates the amount of unaccounted-for water in billions of gallons each year from 1976 to 2001. It has been as low as 1.35 billion gallons and as high as 2.35 billion gallons per year. With an average unaccounted-for of 1.8 billion gallons per year at a production cost of approximately $230 per million gallons or $230,000 per billion gallons of water produced the annual value of unaccounted-for water would be approximately $414,000.

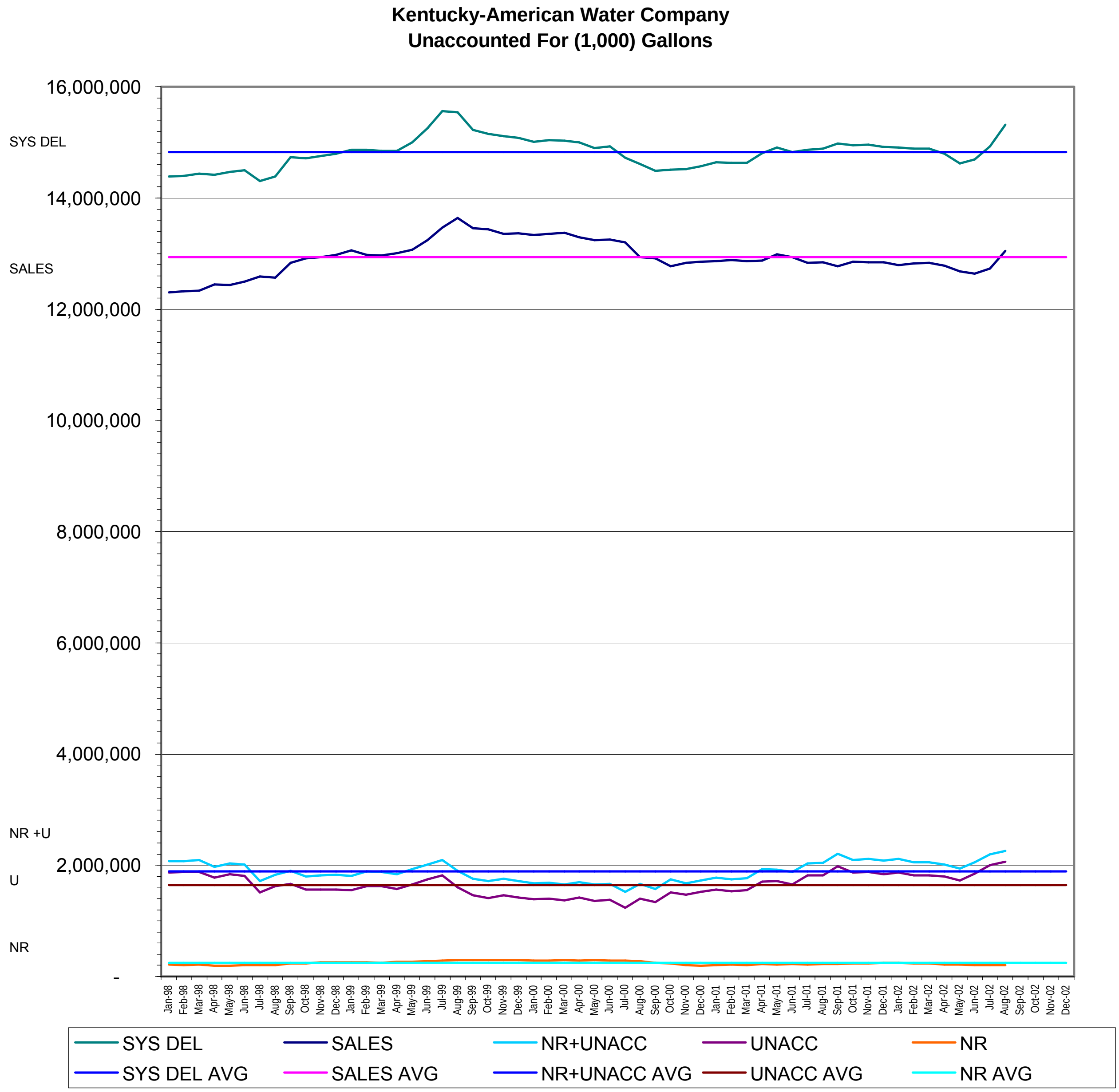
KENTUCKY-AMERICAN WATER COMPANY
ANNUAL % UNACCOUNTED FOR WATER



This chart for the period 1975 through 2001 shows the calculation and plot of the percentage of unaccounted-for water once each year for the 12-month period ending December 31. The unaccounted-for calculated for any individual month could vary significantly from the percentages plotted.



On the chart above the unaccounted-for water percentage is calculated and posted for each individual month based on that months measured delivery, metered sales and non-revenue usage. The unaccounted-for water percentage appears to change radically. The major reason for this appearance is that customer meter reading and billing for usage is out of phase with the up to date summary of daily deliveries at the end of the month. It's necessary to take a long-term view of unaccounted-for water if it is to be meaningful.



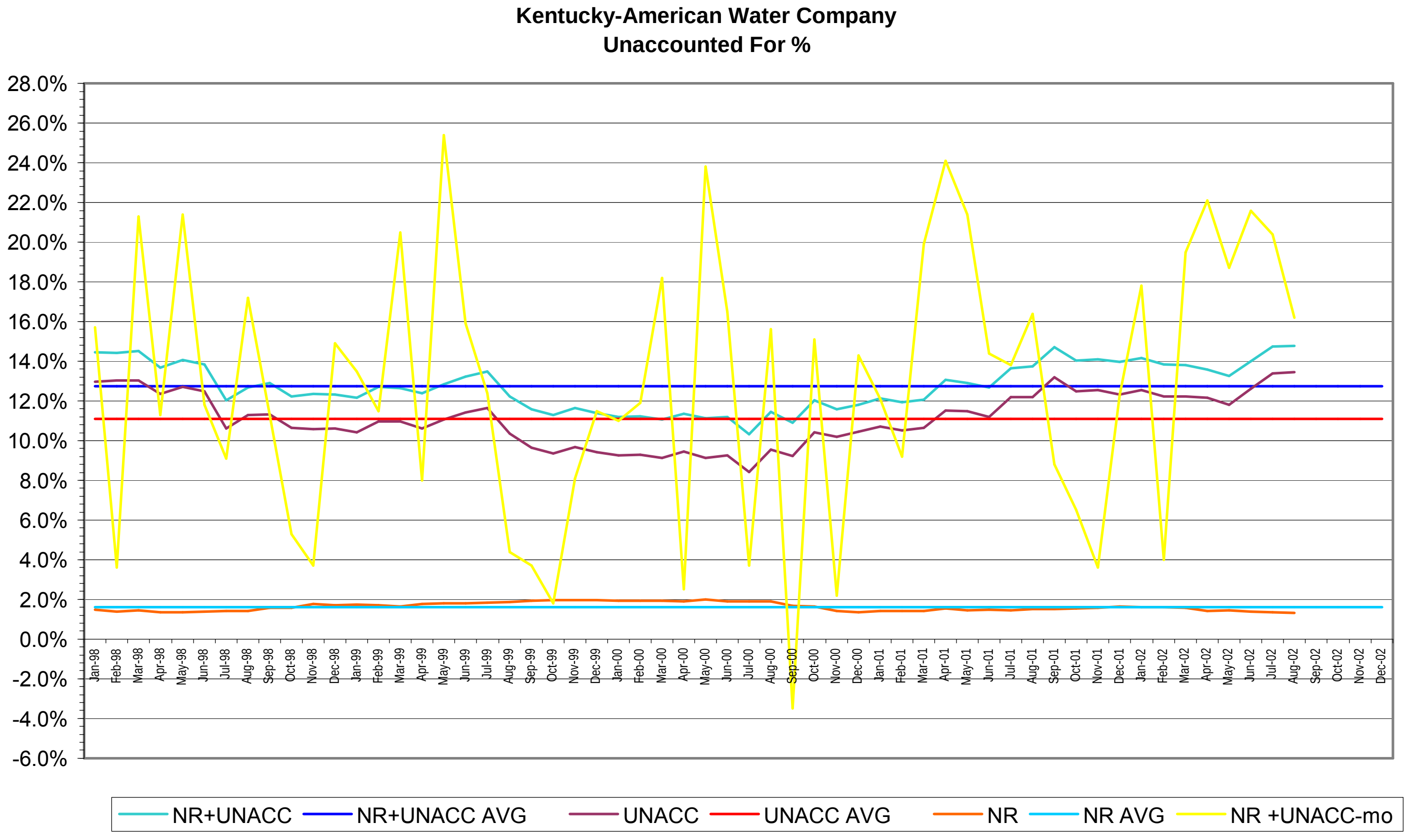
On the chart above volumes of water are plotted for each month in thousands of gallons over a four year and eight month period. The top wavy green line is the volume of system delivery each month. The straight blue line through it is the average over the entire time span.

The next dark wavy blue line represents monthly sales volumes with the straight magenta line through it the average.

Toward the bottom of the chart the next wavy light blue line represents the difference between System Delivery and Sales, which is equivalent to Non-Revenue plus Unaccounted-For (NR+U). The straight dark blue line through it is its average.

At the very bottom the wavy orange line is the calculated Non-Revenue (NR) usage. The straight light blue line through it is the average.

Above that is a wavy purple line, which represents monthly Unaccounted-For volumes (U) and the straight orange line through it, the average over the time span.



The chart above is a percentage chart similar to the one on page four but different in that the percentages, plotted each month, represent the twelve month running average at the end of that month. The wavy yellow line is the exception to this and represents the percentage of Non-Revenue plus Unaccounted-For based on monthly figures. The yellow plot is transposed from the chart on page four and overlaid on the 12 month running percentages and provides a comparison of the short term view versus the long term view and the dampening effect the long term view has on the out of phase delivery and sales figures.

The top wavy light blue line represents Non-Revenue + Unaccounted-For. Its range over the 4 2/3 year time span has been between 10.4% and 14.8% and its average is 12.8%.

Non-Revenue has had a range of between .5 and 2% with a long-term average of 1.6%

Unaccounted for has a range as low as 8.4% and as high as 13.3% with a long-term average of 11.2%.

You can see on the graph that although Non-Revenue is not a constant it fluctuates within a narrow range that is nearly constant.

The area of the chart where Unaccounted-For dips below and stays below the average was at a time when leakage surveys were done on a continuing basis. As leakage surveys tapered off, Unaccounted-For has ranged upward.

V. Potential Sources of Unaccounted-For Water

Accuracy of System Delivery Measurement

If high service (system delivery) measurement is inaccurately higher than actual system delivery, the gap between system delivery and measured water sales will be greater and unaccounted-for water will appear to be higher than it really is. Likewise if high service measurement is inaccurately lower than actual system delivery, the gap and unaccounted-for water will appear to be less.

KY River Station

System delivery measurement at the KY River Station consists of two (North and South) 30" venturi meters, downstream of the high service pumps. These provide an electronic signal to totalizer charts, which register the measured volume. The accuracy of measurement is checked using the draw down method by which volumes pumped from the clearwells are measured and recorded on totalizer charts and then compared to the calculated volume of water drawn down from a uniform cylindrical storage tank to refill the non-uniform clearwells to their previous level.

Results from the draw down tests for 1997, 1998 and 2001 are shown on the on the table below. Units are expressed in units of MGD flow rate extrapolated from the draw down time and volume.

Notes on the Daily Pumpage reports indicate that in the past, adjustments have been made in the totalizer readings based on results of the draw down tests. From 9/1/94 to 12/31/95, the South totalizer readings were adjusted down by 2% and the North totalizer down by 3%. In 1996 the North totalizer readings were to be adjusted down by 2%. Based on April 2001 draw down tests no adjustments were to be made to either totalizer reading.

From the table below of draw down results in 1997, 1998 and 2001 there appears to be less variance between readings and draw down at higher volume flow rates. In 2001 the variance between low volume totalizer readings and draw down are not as great as in the past years tests. There is however, still a variance. At higher flow rates the variance is greater than 1% at both the North and South meters with the average of the two being 1.63%. It is difficult to explain the cause/effect relationship of the variance but some of it may be due to the difficulty in determining how closely the clearwells refill to their previous marked level and how accurately that can be determined. Part of the variance could be in how the electronic signal expressing pressure differential is translated into volume since the curve for pressure differential vs. volume is not directly linear between the limits of the electronic signal.

The venturi formula for an individually designed venturi is empirically derived through numerous tests and is generally good to +or- .75 % and with transmitter and totalizer included the overall accuracy is generally good to + or - .9 %. In addition the totalizer totals and draw down totals are closer in value at the higher flow rates above 12 MGD. These rates of pumpage are encountered more than 80% of the time at the KY River Plant. Also error could result in reading the mark on the clearwell, which could result in an error in estimating draw down volume. It is also possible that lines leading back into the clearwell could have slight leaks which could affect the drawdown readings. Also the volume between totalizer registration marks is 100 cubic feet or 750 gallons so there is potential for inaccuracy in extrapolating the totalizer volumes from 20 minutes to a 24-hour flow.

* Units are in MGD

KRS Venturi Accuracy Check

May-97

South Meter	Totalizer	Draw down	Difference	%
Test 1	18.864	19.296	-0.432	-2.29%
Test 2	8.040	8.581	-0.541	-6.73%
Total	26.904	27.877	-0.973	-3.62%
Test 5	16.968	16.681	0.287	1.69%
Test 6	5.496	5.851	-0.355	-6.46%
Total	22.464	22.532	-0.068	-0.30%
North Meter				
Test 3	17.928	18.584	-0.656	-3.66%
Test 4	7.536	8.581	-1.045	-13.87%
Total	25.464	27.165	-1.701	-6.68%
Test 7	17.544	17.491	0.053	0.30%
Test 8	6.888	7.318	-0.430	-6.24%
Total	24.432	24.809	-0.377	-1.54%

	South Meter	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
-0.40%	-6.62%	-2.11%
	North Meter	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
-1.70%	-10.23%	-4.16%
	Both Meters	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
-1.05%	-8.48%	-3.14%

Apr-98

South Meter	Totalizer	Draw down	Difference	%
Test 1	18.504	18.193	0.311	1.68%
Test 2	8.304	8.074	0.230	2.77%
Total	26.808	26.267	0.541	2.02%
North Meter				
Test 3	17.568	18.060	-0.492	-2.80%
Test 4	8.064	8.270	-0.206	-2.55%
Total	25.632	26.330	-0.698	-2.72%

	South Meter	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
1.68%	2.77%	2.02%
	North Meter	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
-2.80%	-2.55%	-2.72%
	Both Meters	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
-0.50%	0.15%	-0.30%

Apr-01

South Meter	Totalizer	Draw down	Difference	%
Test 1	17.616	17.411	0.205	1.16%
Test 2	8.880	8.839	0.041	0.46%
Total	26.496	26.250	0.246	0.93%
North Meter				
Test 3	16.032	15.688	0.344	2.15%
Test 4	8.064	8.456	-0.392	-4.86%
Total	24.096	24.144	-0.048	-0.20%

	South Meter	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
1.16%	0.46%	0.93%
	North Meter	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
2.15%	-4.86%	-0.20%
	Both Meters	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
1.63%	-2.07%	0.39%

Richmond Road Station

System delivery measurement at the Richmond Road Station consists of two (North and South) 24” venturi meters, downstream of high service pumps, which provide an electronic signal to totalizer charts, which register the measured volume. Measurement is checked by the Pitometer method by which volumes pumped from the clearwells are measured and recorded on totalizer charts and then compared to the same pumpages measured by a pitometer that has been placed in the water stream. The volumes of the same pumpages are also calculated based on manometer readings and compared to both the pitometer calculations and totalizer readings.

The table below shows the totalizer readings, calculated flows based on pitometer and manometer readings and the difference and percentage difference between them. The two charts to the right show the comparison of totalizer to pitometer and manometer readings separately for the north and south meters and for both meters combined. It can be seen that for the north and south meters individually, the manometer readings (which are considered to be the more accurate method) are within 1% of the totalizer readings when the high and low flows are averaged. When the flows of both meters are averaged together the difference between totalizer and manometer volumes is less than ½ percent.

RRS Venturi Accuracy Check

Jul-99

North Meter	Totalizer	Pitometer	Diff	%	Manom.	Diff	%
Test 1	6.330	6.360	-0.030	-0.47%	6.450	-0.120	-1.90%
Test 2	10.440	10.290	0.150	1.44%	10.440	0.000	0.00%
Total	16.770	16.650	0.120	0.72%	16.890	-0.120	-0.72%
South Meter							
Test 3	11.520	12.170	-0.650	-5.64%	11.520	0.000	0.00%
Test 4	8.040	8.410	-0.370	-4.60%	7.990	0.050	0.62%
Total	19.560	20.580	-1.020	-5.21%	19.510	0.050	0.26%

Totalizer vs. Pitometer

	North Meter	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
1.44%	-0.47%	0.72%
	South Meter	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
-5.64%	-4.60%	-5.21%
	Both Meters	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
-2.28%	-2.78%	-2.48%

Totalizer vs. Manometer

	North Meter	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
0.00%	-1.90%	-0.72%
	South Meter	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
0.00%	0.62%	0.26%
	Both Meters	
Avg	Avg	Avg
Hi-Vol	Lo-Vol	Tot-Vol
0.00%	-0.49%	-0.19%

In looking at several years of accuracy tests for KRS and RRS delivery measurement it appears that correction factors cannot be determined with a very high degree of accuracy and does not justify their application.

Accuracy of Water Sales Measurement

If sales measurement is inaccurately lower than actual system end usage, the gap between system delivery and measured water sales will be greater and unaccounted-for water will appear to be higher than it really is. Likewise if sales measurement is inaccurately higher than actual system sales, the gap and unaccounted-for water will appear to be less.

Residential Metering

In order to get an idea of residential metering accuracy, the test results from the pilot domestic meter-sampling program for meters over 10 years old were reviewed. Two hundred meters were tested from each of the 11, 12 and 13 year old meter populations at low (1/4 gpm), medium (2gpm) and high (15 gpm) rates of flow. From the table below the average accuracy for the combined three years of sampling was 95.43 % for low flow, 99.70% for medium flow and 99.81 for high flow.

2001 Meter Sampling Test Results

	Low (1/4 gpm)	Med (2 gpm)	High (15 gpm)
11 year old	95.96%	99.68%	99.71%
12 year old	96.55%	99.93%	99.76%
13 year old	93.77%	99.50%	99.95%
3 year avg.	95.43%	99.70%	99.81%

To flow-weight meter accuracy by the expected ratio of low, medium and high flow occurrence the table below from an article in the AWWA Journal written by W.D. Hudson in 1964, then Vice President of Pitometer Associates, was used. Although this flow profile from 1964 may no longer be an ideal model it will at least serve to provide an approximation of flow distribution.

% of Total Flow at Various Flow Rates

Flow Rate (gpm)	0 to 1/4	1/4 to 1/2	1/2 to 1	1 to 2	2 to 4	>4
% of Total Flow	13.00%	3.40%	6.80%	13.30%	43.00%	20.50%

Since the 2001 meter sampling flow rates and Hudson's flow rates do not directly match, 0 to 1gpm was assumed to be low flow, 1 to 4 gpm to be medium flow and greater than 4 to be high flow. The accuracies from low, medium and high flow from the 2001 meter sampling tests were used for these ranges. The % of total flow is multiplied by the % accuracy for each flow rate and the results totaled to get a flow-weighted % accuracy of 98.73% for all flow rates combined.

Combined % of Total Flow at Various Flow Rates

Flow Rate (gpm)	0 to 1 gpm	1 to 4 gpm	>4 gpm	Total
% of Total Flow	23.20%	56.30%	20.50%	
% Accuracy	95.43%	99.70%	99.81%	
Flow Weighted % Accuracy	22.14%	56.13%	20.46%	98.73%

This implies that the domestic meters for residential sales may be under-registering by as much as 100.00 % - 98.73 % = 1.27 %. Looking at 2001 sales volumes we find that residential load comprised approximately 46 % of total sales, thus the impact of residential metering under-registration may be as much as .58 % of total sales. (46 % x 1.27 % = .58 % of total sales)

Commercial, Industrial and Other Large Volume Metering

In order to get an idea of commercial, industrial and other large volume metering accuracy, a sampling of meter test results for various size meters was taken. There were 8 – 2" from 1999-2002 and 42 – 2" from 2002-2003, 8 – 4" from 1999 – 2002 and 4 – 4" from 2002-2003, 62 –6" from 1999-2002 and 8 – 8" from 1999-2002. The results are found in the table below.

Meter Accuracy of Commercial, Industrial and Other Large Volume Meters

2" Meters

Low Flow	Medium Flow	High Flow	Unweighted Avg.
99.34%	100.35%	100.33%	100.01%

4" Meters

Low Flow	Medium Flow	High Flow	Unweighted Avg.
98.94%	101.19%	101.02%	100.50%

6" Meters

Low Flow	Medium Flow	High Flow	Unweighted Avg.
99.55%	99.76%	99.92%	99.74%

8" Meters

Low Flow	Medium Flow	High Flow	Unweighted Avg.
99.61%	99.71%	100.39%	99.90%

Overall	Unweighted	Average	100.04%

A flow profile could not be found for the typical large volume customer as was found for residential flow. However in a 1975 study on unaccounted-for water by Burgess and Niple for the Butler District of Pennsylvania American Water it was determined from referencing monthly customer usage and deriving average gallon per minute flow that a high percentage of the total flow was expected to be in the intermediate to high range which would tend to place the overall registration higher than the average.

The results of our meter test sampling indicate that our large volume meters have a high overall accuracy and there is no justification for applying a correction factor.

In addition, the results from all meters tested over the one-year period in 2001 and reported on the PSC report were considered. Out of 4,535 meters tested, 81 were out of the acceptable range of less than 98% or greater than 102% registration with the average being 95.2%. This is an average under-registration of 4.48%. The 81 meters represent 1.8% of the meters tested. If this is representative of the general population of all KAWC meters it follows that 1.8% of all meters are under registering by 4.48%.
This calculates as: 1.8% x 4.48% = .081% or less than 1/10 %.

The rough approximation of under-registration for residential (.58%) is conceivably the only correction factor that could justifiably be refined and applied. This may serve to explain something around 1/2% of the total volume sold as unaccounted-for. However it may not be meaningful to do so if domestic meter accuracy cannot feasibly be improved in the future and if Kentucky-American Water Company is to be compared to other sister companies and external companies that do not make the same distinction.

A more meaningful comparison may be to disregard the sales meter accuracy issue as a significant factor and focus on improving the percentage of unaccounted-for water relative to past and mean performance.

Stuck and Burst Meters

Stuck and burst meters were considered for the volumes they contributed to unaccounted-for water.

In 2001, there were 125 burst 5/8" meters reported. Wayne Mattingly estimates the average leak rate of a burst meter to be around 20 gpm. If the average leakage rate is around 20 gpm and an average open leak time around 20 hours, the lost water for the year would be in the neighborhood of 20hr x 60min x 20gpm x 125meters = 3 million gallons or about .02 % of annual delivery with a value of about $700. This would be a portion of unaccounted for water and unavoidable leakage. **If 2001 is typical it appears that burst meters do not have a substantial impact on unaccounted-for water.**

There were 14 - 2" and 26 - 5/8" stuck meters reported in 2001. There is a printout of meters that register zero usage three months in succession and triggers an investigation. If we assume that a stuck meter will not be changed until 10 days have passed after the issuance of the printout (about 100 days total), that the average daily usage of a 2" meter is 4090 gallons and that of a 5/8" meter is 180 gallons the lost water would be calculated at:
4090 gpd x 100 days x 14 mtrs. + 180 gpd x 100days x 26 mtrs. = 6.2 million gallons or about .04 % of annual delivery with a water production value of $1,426. Most of this comes from the 2" meters. **We are not only losing the production cost of $230 per million gallons but also the revenue on this volume**. **The estimated revenue from 6.2 million gallons is $12,906**. Larry Burns reviews the consumption records of a group of our largest customers each month for potential meter problems and recommends an investigation if problems are apparent. However other customers are subject only to the three-month computer comparison. **It may be cost effective to decrease this three-month interval on the printout for 2" and larger meters and on certain types of customers.**

Accuracy of Non-Revenue Usage Volume Estimation

Each month Wayne Mattingly takes a tally of the volumes from various sources of non-revenue usage in the distribution department. I have reviewed the method of doing this with Wayne and find it to be reasonable. There is always some possibility for error in calculating or transferring data, but since there are many sources that make up non-revenue usage, unless the error or errors are extraordinary they would not have much impact on the non-revenue percentage.

Non-revenue usage is averaging approximately 1.6 % of delivered volume as a long-term trend. A large error from any source may only throw off the non-revenue by a small portion of a percentage point. When looked at for 12 months running it has barely any impact at all. Unless there would be a huge undisclosed usage of water the impact on unaccounted-for water by a calculation error or omission is not significant.

Public use of water makes up a portion of non-revenue usage. In a report by W.D. Hudson, VP of Pitometer Assocs. published in the Feb. 1964 AWWA Journal entitled Reduction of Unaccounted-for Water he states, "The effect of public uses on the total percentage of unaccounted-for water, therefore, is comparatively unimportant."

Leakage

Hudson states "underground leakage is frequently the principal cause of high unaccounted-for water". It cannot be entirely eliminated but it can be controlled. He advises " **Keeping underground leakage at a minimum requires constant attention and a plan for its control".**

Unavoidable Leakage

Unavoidable sub-surface leaks are those, which would cost more to locate and repair than it does to permit them to exist. They are leaks that cannot be found by current technology and those that can be found but are not economical to repair.

Unavoidable leakage is that portion of unaccounted-for water, which the operator cannot control or it does not make economic sense to control. There are a number of theories on how to estimate the amount of unavoidable leakage in a system. Below, two of them are described.

Kuichling Method – In 1897 Mr.Kuichling, the chief Engineer of the Rochester, NY water proposed an estimate based on one drop/sec./joint, five drops/sec./hydrant, five-drops/sec./stop valve and three-drops/sec./service line. The following equation summarizes Kuichling's method:

UL = (DV) [J+5H+5SV+3SP], where:
UL=undiscoverable* leakage in gpd, DV=volume of one drip per second expressed as 3 gallons/day, J= joints per mile of main, H= hydrants per mile, SV= stop valves per mile, SP=services per mile

Using this method a system the size of KAWC with average18 foot pipe lengths would have allowable leakage of 1,500-2,500 gpd/mile of main. This would be about 2.5 to 4.2 million gallons/day or 6.1% to 10.3% unavoidable leakage based on an average daily delivery of 40.82 million gallons for KAWC.

*In Kuichling's day the technology was such that non-surfacing undiscoverable leaks would have included leaks that with today's technology would have been discoverable but uneconomical to repair and so would essentially be unavoidable.

Smith Method (modified AWWA) – Jeffrey C. Smith in his 1987 masters degree thesis presented to the Brigham Young University Civil Engineering Department, proposed a method which is a variation of the Kuichling method and the AWWA method for new pipe. He believes Kuichling's method is not adequate as there are unconsidered factors such as drip size and rate, pressure and pipe material type and age. Below is Smith's formula:

$$L = \frac{(AF)\,[N+F+V+O+(1.5S)]\,D(P)^{1/2}}{TF}$$, where:

L=unavoidable leakage in gph, AF=age factor, N=number of joints, F=number hydrants, V=number valves, O=number other appurtenances, S=number service connections, D=nominal diameter, P=avg.pressure and TF=pipe material type. Using Smith's formula, the spreadsheet below was developed to plug in assumed values for KAWC facilities to calculate the unavoidable leakage and was by this method was estimated at 2.7%.

L = unavoidable leakage in gph
AF= pipe age factor
N= number of joints being considered
F=number of fire hydrants connected — .00089 hydrants per foot x feet — or 6,986
V= number of valves connected — .0028 valves per foot x feet — or 21,506
O= other appurtenances (fire services, blowoffs, air releases — .00054 other per foot x feet
S= number of service connections — .01412 services per foot x feet — or 110,713
D= nominal diameter in inches
P= average pressure in psi — 72.3psi
TF= material type conversion factor

$$L = \frac{(AF)\,[N+F+V+O+(1.5S)]\,D\,(72.3)^{1/2}}{TF}$$

D	feet	N	type	TF	AF	F	V	O	S		L
						0.328	1.030	0.199	5.196		
36	368	20.44	DI	7400	4	52.599	165.295	31.878	833.560		4.67
30	59034	3279.67	DI	7400	3	42.918	134.870	26.011	680.132		467.97
30	48168	3705.23	Con	7400	6	74.298	233.484	45.029	1177.424		965.20
24	83387	6414.38	Con	1850	6	209.075	657.026	126.712	3313.286		5346.94
24	234652	13036.22	DI	7400	3	10.795	33.925	6.543	171.078		1488.08
20	12116	673.11	DI	7400	3	16.159	50.781	9.793	256.080		64.03
20	18136	1395.08	Con	7400	6	156.530	491.901	94.867	2480.587		242.27
16	175679	9759.94	DI	1850	3	48.366	151.992	29.313	766.476		2970.92
16	54283	4175.62	Con	7400	6	16.949	53.262	10.272	268.591		580.12
16	19022	1056.78	CI	3700	6	0.446	1.400	0.270	7.060		321.68
16	500	27.78	AC	3700	5	3.074	9.660	1.863	48.714		7.05
14	3450	191.67	PEP	7400	1.5	256.066	804.698	155.192	4057.975		6.38
12	287392	15966.22	CI	3700	6	244.051	766.940	147.910	3867.567		3645.08
12	273907	15217.06	AC	3700	5	386.132	1213.433	234.019	6119.170		2895.04
12	433369	24076.06	DI	7400	3	18.059	56.750	10.945	286.184		1374.14
12	20268	1126.00	PVC	7400	3	22.093	69.429	13.390	350.120		64.27
10	24796	1377.56	CI	3700	6	2.750	8.641	1.666	43.574		262.08
10	3086	171.44	AC	3700	5	0.078	0.246	0.048	1.243		27.18
10	88	4.89	DI	7400	1.5	717.473	2254.686	434.832	11370.059		0.12
8	805245	44735.83	CI	3700	6	428.338	1346.069	259.599	6788.035		6808.78
8	480739	26707.72	AC	3700	4	322.326	1012.922	195.349	5108.023		2709.94
8	361758	20097.67	PVC	7400	3	1435.270	4510.388	869.861	22745.244		764.71
8	1610853	89491.83	DI	7400	3	857.997	2696.288	519.998	13596.995		3405.16
6	962960	53497.78	CI	3700	6	480.797	1510.922	291.392	7619.364		6106.76
6	539615	29978.61	AC	3700	5	147.661	464.030	89.492	2340.037		2851.71
6	165725	9206.94	PVC	7400	3	307.768	967.173	186.526	4877.316		262.74
6	345419	19189.94	DI	7400	3	209.691	658.960	127.085	3323.043		547.63
4	235343	13074.61	AC	3700	5	82.537	259.375	50.022	1307.992		829.15
4	92634	5146.33	CI	3700	6	35.288	110.894	21.387	559.223		391.63
4	39605	2200.28	PVC	7400	3	1.081	3.396	0.655	17.128		41.86
4	1213	67.39	GAL	3700	3	17.535	55.104	10.627	277.882		2.56
4	19680	1093.33	DI	7400	3	0.053	0.168	0.032	0.847		20.80
4	60	3.33	STL	3700	3	35.551	111.720	21.546	563.388		0.13
3	39900	2216.67	AC	3700	5	92.720	291.376	56.194	1469.370		105.43
3	104063	5781.28	PVC	7400	3	0.683	2.148	0.414	10.830		82.49
3	767	42.61	GAS	3700	3	0.040	0.126	0.024	0.635		1.22
3	45	2.50	STL	3700	3	38.456	120.848	23.306	609.419		0.07
2.5	43160	2397.78	PVC	7400	3	68.780	216.143	41.685	1089.979		28.51
2.25	77194	4288.56	CI	3700	6	66.629	209.384	40.381	1055.894		183.58
2	74780	4154.44	CI	3700	6	63.704	200.192	38.608	1009.538		158.08
2	71497	3972.06	PVC	7400	3.5	13.212	41.518	8.007	209.371		44.08
2	14828	823.78	GAL	3700	3	1.859	5.841	1.126	29.454		15.67
1.25	2086	115.89	CI	3700	6	0.010	0.031	0.006	0.155		2.76
1	11	0.61	PVC	7400	1	6,986	21,954	4,234	110,713		0.00
	7840881	439,963			4.20			Est. Unavoidable			46098.64 gph
											1106367.39 gpd
								Avg. System Delivery			40,822,000 gpd
									% Unavoidable		2.71%

Different assumptions could be made regarding age, condition, the number of appurtenances and pressure that would render a higher percentage of unavoidable leakage. For instance if the average pressure is raised by 10 psig from 72.3 psig to 82.3 psig the avoidable leakage increases by 137,417 gpd from 2.7% to 3.05%. If the age factor is increased from 4.2 to its maximum of 6 the leakage increases by an additional 387,300 gpd and by nearly another 1% to 4%. This is still lower than the range found using the Kuichling formula. It should be noted however that there has not been empirical data developed to support the theoretical factors for age, type of pipe, etc. established in Smiths method.

L = unavoidable leakage in gph
AF= pipe age factor
N= number of joints being considered
F=number of fire hydrants connected — .00089 hydrants per foot x feet — or 6,986
V= number of valves connected — .0028 valves per foot x feet — or 21,506
O= other appurtenances (fire services, blowoffs, air releases — .00054 other per foot x feet
S= number of service connections — .01412 services per foot x feet — or 110,713
D= nominal diameter in inches
P= average pressure in psi — 82.3 psi
TF= material type conversion factor

D	feet	N	type	TF	AF	F	V	O	S		(AF) [N+F+V+O+(1.5S)] D (82.3)1/2 / TF	
36	368	20.44	DI	7400	6	0.328	1.030	0.199	5.196		7.87	
30	59034	3279.67	DI	7400	6	52.599	165.295	31.878	833.560		1052.20	
30	48168	3705.23	Con	7400	6	42.918	134.870	26.011	680.132		1085.10	
24	83387	6414.38	Con	1850	6	74.298	233.484	45.029	1177.424		6011.16	
24	234652	13036.22	DI	7400	6	209.075	657.026	126.712	3313.286		3345.87	
20	12116	673.11	DI	7400	6	10.795	33.925	6.543	171.078		143.97	
20	18136	1395.08	Con	7400	6	16.159	50.781	9.793	256.080		272.37	
16	175679	9759.94	DI	1850	6	156.530	491.901	94.867	2480.587		6679.96	
16	54283	4175.62	Con	7400	6	48.366	151.992	29.313	766.476		652.19	
16	19022	1056.78	CI	3700	6	16.949	53.262	10.272	268.591		361.64	
16	500	27.78	AC	3700	6	0.446	1.400	0.270	7.060		9.51	
14	3450	191.67	PEP	7400	6	3.074	9.660	1.863	48.714		28.70	
12	287392	15966.22	CI	3700	6	256.066	804.698	155.192	4057.975		4097.88	
12	273907	15217.06	AC	3700	6	244.051	766.940	147.910	3867.567		3905.60	
12	433369	24076.06	DI	7400	6	386.132	1213.433	234.019	6119.170		3089.68	
12	20268	1126.00	PVC	7400	6	18.059	56.750	10.945	286.184		144.50	
10	24796	1377.56	CI	3700	6	22.093	69.429	13.390	350.120		294.64	
10	3086	171.44	AC	3700	6	2.750	8.641	1.666	43.574		36.67	
10	88	4.89	DI	7400	6	0.078	0.246	0.048	1.243		0.52	
8	805245	44735.83	CI	3700	6	717.473	2254.686	434.832	11370.059		7654.59	
8	480739	26707.72	AC	3700	6	428.338	1346.069	259.599	6788.035		4569.86	
8	361758	20097.67	PVC	7400	6	322.326	1012.922	195.349	5108.023		1719.42	
8	1610853	89491.83	DI	7400	6	1435.270	4510.388	869.861	22745.244		7656.31	
6	962960	53497.78	CI	3700	6	857.997	2696.288	519.998	13596.995		6865.36	
6	539615	29978.61	AC	3700	6	480.797	1510.922	291.392	7619.364		3847.15	
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4	39605	2200.28	PVC	7400	6	35.288	110.894	21.387	559.223		94.12	
4	1213	67.39	GAL	3700	6	1.081	3.396	0.655	17.128		5.77	
4	19680	1093.33	DI	7400	6	17.535	55.104	10.627	277.882		46.77	
4	60	3.33	STL	3700	6	0.053	0.168	0.032	0.847		0.29	
3	39900	2216.67	AC	3700	6	35.551	111.720	21.546	563.388		142.23	
3	104063	5781.28	PVC	7400	6	92.720	291.376	56.194	1469.370		185.48	
3	767	42.61	GAS	3700	6	0.683	2.148	0.414	10.830		2.73	
3	45	2.50	STL	3700	6	0.040	0.126	0.024	0.635		0.16	
2.5	43160	2397.78	PVC	7400	6	38.456	120.848	23.306	609.419		64.11	
2.25	77194	4288.56	CI	3700	6	68.780	216.143	41.685	1089.979		206.38	
2	74780	4154.44	CI	3700	6	66.629	209.384	40.381	1055.894		177.71	
2	71497	3972.06	PVC	7400	6	63.704	200.192	38.608	1009.538		84.96	
2	14828	823.78	GAL	3700	6	13.212	41.518	8.007	209.371		35.24	
1.25	2086	115.89	CI	3700	6	1.859	5.841	1.126	29.454		3.10	
1	11	0.61	PVC	7400	6	0.010	0.031	0.006	0.155		0.01	
	7840881	439,963			6.14	6,986	21,954	4,234	110,713		67,963	gph
								Est. Unavoidable			1,631,104	gpd
								Avg. System Delivery			40,822,000	gpd
									% Unavoidable		4.00%	

What is Economically Repairable?

In 2001 the KAWC leak detection program was run for 134 days, 111 leaks were detected and repaired. The estimated leak rates ranged from .5 gpm to 306 gpm and averaged 14.6 gpm. If the leaks were left un-repaired, the projected annual loss from the time the leaks were found until the end of the year was estimated at 344 million gallons. At a production cost of $230 per mg the savings in water production costs would be $79,000. If the average repair cost were $600 the total cost of repairs for the year would be $67,200. If the cost of detection were approximately $200 per day the annual detection cost would be $26,800. Thus the combined annual detection and repair cost of $94,000 would exceed the savings of $79,000. However water production savings, if extended into the second year after the repairs were made, would exceed the combined detection and repair costs.

Smith has suggested the use of an equation to calculate the threshold flow to determine what leak size is economically justified to repair.

$$Q = \frac{(1.9026)\,C}{V*T}$$

Where Q = min. flow in gpm, C = avg. leak repair cost, T = Economic return period in years, and V = Value of leaked water in $ per million gallons.

For KAWC the economic return period and avg. repair cost would have to be determined. The cost of leaked water is approximately $230 per million gallons. As an example, assume a return period of 1 year and an average repair cost of $600 then: Q = 5 gallons/minute for the minimum leak size to be economically repaired. For a two year economic return period Q = 2.5 gallons/minute and for 3 yrs Q = 1.7 gpm.

Similar equations could probably be derived with other variables and specific information for that utility, such as the cost of money, the specific return period, etc. through the assistance of the Shared Service Finance Department.

The difficulty in classifying an actual sub-surface leak as at the threshold or not would be in quantifying the rate of flow by listening. So a general idea of what is economically repairable or not would have to be developed through time and experience. Smith suggests that leaks would more than likely fall into general categories of small, medium and large by listening rather than being able to gauge a rate of flow. Then it could be determined what size is economically repairable. Perhaps all but small or very small would fit roughly into the economically repairable category. For those gaining experience it may take digging up a few detected leaks to tell.

Optionally, leaks that are not economically repairable could be put in a database and re-inspected at some predetermined interval such as once per year to determine if they have gotten worse and justify repair.

Putting Unaccounted-For Recovery in Perspective

What % of unaccounted-for water could reasonably be expected to be reached?

Smith in his 1987 thesis, after reviewing a study conducted by the California Dept. of Water Resources in the mid 1980s, expresses that up to 50% of the leakage in a water system could be considered unavoidable. If this % is applied to KAWC's current level of unaccounted-for water of approximately 13.5% then up to 6.75% could be unavoidable leakage. This implies that 6.75% or lower unaccounted-for could be achieved. If you add to that KAWC's non-revenue average of 1.6% the total of 8.35% would be the ratio of sales to delivery. This is 1.65% to 6.65% less than the sales to delivery ratio (10 % to 15%) considered to be good in a system of similar description to KAWC in the two scenarios immediately below.

In his 1964 paper, Hudson submits that in a city with large industrial consumption with a sales to delivery ratio of 90% there still may be much room for improvement. However a city with little industrial use may have very good performance with a ratio of 85-90%.

The AWWA committee report Revenue–Producing vs. Unaccounted-for Water from 1957 indicates that good performance is generally indicated by a metered ratio of 85-90% where the daily use per capita is between 100 and 125 gpd. Where large industrial users cause a higher daily per capita use, the ratio may approach 100%. The KAWC per capita usage is approximately 125 gpd.

VI. Summary and Conclusions

1. The most stringent standard and the current operational excellence goal related to unaccounted-for water is to attain a sales to delivery ratio of 90% or greater. This means an unaccounted-for plus non-revenue usage of 10% or less.

2. To be meaningful, unaccounted-for water should not be too carefully scrutinized by fluctuations in monthly results but by the longer-term trend of 12-months running (which are available each month) and by annual results.

3. During the period from 1976-2002 KAWC has had an annual unaccounted-for volume as low as 1.35 billion gallons and as high as 2.35 billion gallons. During the same period the annual unaccounted-for percentage has been as low as 9.4% and as high as 16.5%.

4. During the recently graphed 4yr. 8-month period from January 1998 through August 2002 the 12-month running unaccounted-for percentage was as low as 8.4% and as high as 13.3% with an average of 11.2%.

5. During the same 4 yr. 8 month period the 12-months running non-revenue plus unaccounted-for percentage was as low as 10.4% and as high as 14.8% with an average of 11.2%. This indicates that in the past we have been within .4% of the operational excellence goal of 90% sales to delivery ratio.

6. There is a period on the chart where the 12-months running unaccounted-for percentage drops and remains below the average. This trend follows a period when the leak detection program was well implemented. The swing of the unaccounted-for percentage upward follows a curtailment of the program.

7. Review of the accuracy tests for the KRS and RRS system delivery measurement indicates that correction factors cannot be determined with a very high degree of accuracy and does not justify their application.

8. Domestic sales measurement under-registration could be responsible for as much as .58% of total sales in unaccounted-for water.

9. A sampling of large volume sales measurement indicates an overall average of almost 100% and does not justify a correction factor being applied to the sales volumes.

10. The method and accuracy of calculating and reporting non-revenue usage is reasonable and acceptable. The volumes and percentages are relatively constant and essentially inconsequential in reducing unaccounted-for water.

12. Burst meters do not contribute substantially to unaccounted-for water.

13. Although stuck meters do not contribute substantially to unaccounted-for water they result in lost revenue at a much higher rate than of lost water production cost.

14. Sub-surface leakage is the principal cause of high unaccounted for water.

15. Keeping sub-surface leakage at a minimum requires constant attention and a plan.

16. A percentage of leakage is unavoidable because it is undetectable or economically infeasible to locate and repair. A range of this level can be estimated as a guideline using the Kuichling and Smith methods.

17. A threshold flow in gpm can be estimated for what constitutes an economically repairable leak using the proper financial and operational input.

18. Determining what is an economically repairable leak by sounding is difficult since you cannot sound the rate of flow. Leaks could be classified as large, medium, small etc. Through sounding and repair experience it could be decided which of those classifications meet the repairable threshold.

19. KAWC appears to be in the category defined by Hudson and the AWWA Revenue Committee that would indicate good performance at a sales to delivery ratio of 85% - 90%.

20. It appears that KAWC could reach the 90% sales to delivery ratio for operational excellence since it nearly did so previously.

21. At the end of 2002 the annual sales to delivery ratio is 84.8%, non-revenue 1.4% and unaccounted-for 13.8%. The unaccounted-for volume is 2.2 billion gallons with a value of $505,000. The difference in volume for a 90% sales to delivery ratio vs. an 84.8% ratio would be 926 million gallons. The value difference at $230/mg would be $212,980. However this was a high pumpage year and included Tri-Village.

22. From Stan Stockton's April 18, 2002 memo the estimated annual cost for the additional person for a continuous leak detection program was $53,000, if an existing vehicle is not available another $18,000 and the annual cost of repairing the additional leaks on overtime labor with materials/paving $43,000.

VII. Recommendations for Improvement

1. Plan and implement a continuous and dedicated leakage detection survey and repair program to find and repair economically repairable leaks. Include in the plan; prioritization, scheduling and frequency of areas to be surveyed based on predominate age and type of pipe and past history that will provide the best bang for the buck.

2. Distribution Superintendent and Operations Vice President determine a goal and the timing to reach it for the 12-month running and annual sales to delivery ratio.

3. Determine the threshold for economically repairable leaks using the appropriate financial and operational information for KAWC.

4. Determine as well as possible through leak sounding, the size of leak that corresponds to the threshold for economically repairable leaks. Since rate of flow cannot be determined through sounding, consider general classification such as very small, small, medium, large and which of these meet or exceed the threshold for repair.

5. Add leaks not economically justifying repair to a database to be scheduled for reinspection after an established period of time to determine if they have worsened and justify repair.

6. Consider reducing the pressure of the system or of zones since pressure is a significant factor in the volume of leakage. Engineering, through use of the system model could look for zones where it may be economically justified to reduce pressure full or part time but will not compromise customer satisfaction. Pennsylvania American has initiated pressure control in zones but their main motivation was to prevent severe washouts during a main break under their high head pressures with leak control as a secondary benefit.

7. Establish a main information tracking system (MITS). Smith's research with other companies yields that by keeping records of open and repaired leak locations a possible pattern may be visually identified. When a leakage pattern is identified for a particular section of main, plans for replacement are considered. An active pipe rehabilitation and replacement program can be an effective means of reducing unavoidable leakage in trouble areas of a system. Some utilities have used colored pins on a map to identify locations of past leaks. With the current technology available this may me done using electronic maps and database software.

8. Make it policy to repair all leaks that do not require excavation, when encountered. These are usually stopped at minimal cost and yield immediate results.

9. Stuck or non-recording meters, particularly large volume meters contribute to unaccounted for water and lost revenue. It may be worthwhile to reduce the trigger period from three months on larger meters and meters of certain types of customers.

10. Track unaccounted-for water separately for the Tri-Village system. If not, problems at Tri-Village would be absorbed in the Lexington report and go unrecognized.

11. Train meters readers and service associates to detect leaks in their day-to-day activities. (Stockton)

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Other

AWWARF and NRW presentation of 10/22/02 by Chris Leauber
of Water Systems Optimization, arranged by Coleman Bush