Task C: An Evaluation of Unaccounted-for Water

Comprehensive Water Master Plan
DWSD Contract No. CS-1278

Final Report

For Submittal to

Detroit Water and Sewerage Department

March 2004

CH2MHILL

IN ASSOCIATION WITH CDM

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Contents

Appendix

Tables

Figures

General

Purpose

The report's purpose is to identify strategies to reduce unaccounted-for water (UFW) that will be based on categorizing and quantifying the UFW in the system. In an attempt to quantify the system's estimated UFW into unique categories, certain assumptions and estimates were made regarding: estimated annual volume of leaks; unavoidable transmission and distribution losses per mile of pipe; quantities of flow relative to water main breaks; accuracy of retail and suburban water meters, accuracy of meters and estimating techniques at the water treatment facilities; unmetered use through fire hydrants, and other losses that were unable to be accounted for due to lack of useable information. As such, this report is not intended to allocate responsibility for costs of unaccounted-for water, but rather to allocate UFW for modeling purposes and to make recommendations regarding the reduction of these estimated amounts. The UFW information will aid in improving the CWMP model by using the data to provide a better distribution of UFW in the model between the Detroit distribution system and the transmission mains supplying the suburbs.

DWSD UFW

UFW is the difference between the total annual water produced and total annual metered consumption. The DWSD's UFW is estimated annually for the entire system. Table 1 lists water production and consumption data for the fiscal years 1991 through 2000. Figure 1 also shows the corresponding UFW. The data used for Table 1 and Figure 1 were obtained from the DWSD annual *Summary of Operating Statistics* reports for 1991 through 2000.

TABLE 1
DWSD Water Use

Fiscal Year	Production (ft^3)	Suburban Metered Consumption (ft^3)	Detroit Metered Consumption (ft^3)	UFW(ft^3)	% UFW
2000	31,965,777,700	20,688,679,400	6,200,683,700	5,076,036,100	15.88%
1999	32,833,366,800	20,729,464,300	6,798,900,700	5,304,422,400	16.16%
1998	31,078,136,500	19,155,752,700	6,477,818,300	5,439,151,600	17.50%
1997	31,157,997,500	18,884,149,700	6,838,114,600	6,247,608,600	19.54%
1996	32,968,384,500	19,563,766,100	7,011,560,300	6,388,784,700	19.38%
1995	31,157,977,500	19,308,239,100	6,623,326,300	5,225,486,200	16.77%
1994	31,260,410,400	18,825,712,500	6,712,812,800	5,713,480,000	18.28%
1993	28,368,665,200	18,164,067,600	6,674,615,900	3,628,469,900	12.79%
1992	31,184,559,900	19,583,854,900	7,616,150,700	3,963,182,600	12.71%
1991	30,012,820,000	18,542,018,000	7,368,626,800	3,981,078,100	13.26%
Avg.	**31,198,809,600 (4,171 MG)**	**19,344,570,430 (2,586 MG)**	**6,832,261,010 (913 MG)**	**5,096,770,020 (681 MG)**	**16.34%**

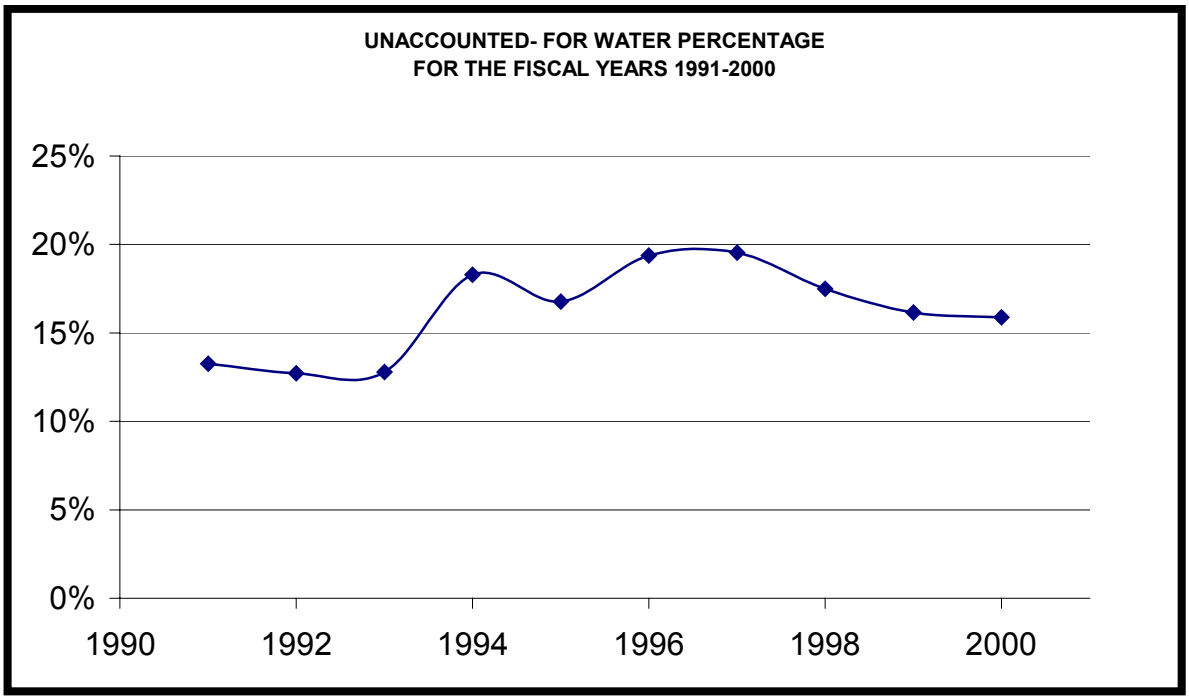

FIGURE 1
UFW Percentages

It is worth noting on Figure 1 that DWSD had a leak detection program from 1991-1993 and an ongoing program active since 1997 to which recent UFW reductions may be attributed.

Factors Attributing to Unaccounted for Water

Many factors determine the quantity of UFW. According to industry best practices and the information obtained from DWSD, UFW can be associated with the factors summarized in the following table:

TABLE 2
Factors of UFW

Leakage	- Pipe & appurtenance leaks
	- Main breaks
Inaccurate Meter Readings	- Inaccurate and nonfunctional meters
Un-metered Water and Miscellaneous	- Fire-hydrant use for flushing, firefighting, flow testing
	- Miscellaneous (illegal connections, construction water use, etc.)

UFW for the DWSD system has been estimated for these three categories. The quantity, by category, is provided below.

Leakage

Pipe Leakage

To estimate the volume of water loss due to pipe leaks, it is important to know the length of pipe within the system. Using the length of pipe, the leakage was estimated based on information obtained from recent water loss reports, the ongoing Water Loss Survey (CS-1264), and information obtained from our literature review.

The total length of the pipe for the DWSD system shown in the following table was collected from the DWSD *Summary of Operating Statistics* for the fiscal year ending June 30, 2000. Transmission pipes are considered to be those greater than 16-inch diameter (20" to 120"). Total lengths of each individual pipe size are shown in Table 15 in Appendix A.

TABLE 3
DWSD Pipes

	Total Length in Miles	Percentage
Length of DWSD pipes in Detroit	3,036 (309 transmission)	88%
Length of DWSD pipes in Suburban Communities	396 (all transmission)	12%
Total Length of pipes in Detroit System	**3,432**	**100%**

The estimated volume of leaks in Table 4 includes main leaks, service leaks, abandoned service leaks, hydrant leaks, valve packing leaks, and blow-off leaks. The leaks found and reported during these surveys are mostly blind leaks that have not surfaced. Most of these leaks are on pipes 16-inch and smaller, though transmission pipes (larger than 16-inch) are also covered during these surveys.

TABLE 4
Water Loss Surveys

Reporting Period 1993-Dec. 2001	Surveyed Pipe Length (Miles)	DWSD Length of Pipe (Miles)	% of Surveyed Pipe	# of Leaks	Estimated Volume of Leaks Found (MGD)	Estimated Volume of Total Leaks in City of Detroit (MGD)	(gpd/mile)	Estimated Yearly Volume of Total Leaks in City of Detroit (MG)
1993-1994 Report	795	3,036	26	118*	7.06	26.98	8,883	9,848
1997-1999 Report	678	3,036	22	646	5.53	24.76	8,156	9,037
1999-Dec. 2001	745	3,036	25	634	8.68	35.36	11,648	12,906
Avg.					**7.09**	**29.03**	**9,562**	**10,596**

* The Pitometer Water Loss Survey Report does not include an accounting of the number of valve packing leaks found.

Table 4 summarizes leakage data obtained from the Pitometer Water Loss Survey Report for 1993-1994, the TYJT Water Loss Survey Report for years 1997 through 1999, and from ongoing work through December 2001.

The volume of leaks and the miles of pipe surveyed were then used to estimate an average of water lost per mile of pipe. Leaks on transmission pipes seem to come to the surface quickly. Sample calculations for this table are found in Appendix A. Very few leaks on these larger pipes have been found within the City of Detroit during the leak surveys, limiting the use of Water Loss Survey results for estimating total leakage in the transmission system. For this reason, the "unavoidable losses" approach was used for transmission piping.

This concept of "unavoidable losses" was first developed and calculated by Emil Kuichling in 1897 and has recently been defined as that portion of underground system leakage lost but considered not economical to locate and repair or too small to detect using current technology. Kuichling's calculations have determined that most systems lose 1,000 to 3,000 gallons per day (gpd) per mile (gpd/mile) of main. A 1987 AWWA Research Foundation (AWWARF) study questioned the adequacy because Kuichling excluded the effects of water pressure, pipe material, and pipe age. The International Water Association (IWA) has conducted further research and is working with AWWARF to develop more accurate formulae for the calculation of unavoidable losses. Another source of calculating these unavoidable losses comes from AWWA standards for testing new pipes before they are placed in service. However, these are for new pipes and neglect the effects of age. Other formulae have been developed which assign losses per mile per diameter of pipe for both mains and services. Use of these formulae on water systems, while more accurate for specific systems, have yielded results that still fall within the 1,000 to 3,000 gpd/mile of main most often quoted as unavoidable losses.

The range of 1,000 to 3,000 gpd/mile of main was used in assessing unavoidable losses in the DWSD system. Distribution pipes typically have numerous contact points (valves, hydrants, etc.) spaced relatively close together (about every 300 feet). A leak detection survey on these pipes is therefore quite complete in detecting most leaks. A lower-end value of 1,500 gpd/mile was used in the City of Detroit for the distribution pipes, since DWSD annually surveys its mains within the City.

However, the suburban mains are not typically surveyed. Additionally, these transmission mains are large pipes, ranging from 20- to 120-inch in diameter. Contact points for these mains (air valves, valves, etc.) are spaced quite far apart, making smaller leaks harder to detect. For these reasons the higher value of 3,000 gpd/mile was assumed for unavoidable losses on transmission pipes. Table 5 summarizes the unavoidable losses for the distribution and transmission parts of the DWSD system. Appendix A provides the sample calculations for this table.

TABLE 5
Unavoidable Losses

	Unavoidable Distribution Losses (gpd/mile)	Total Annual Distribution Losses (MG)	Unavoidable Transmission Losses (gpd/mile)	Total Annual Transmission Losses (MG)	Total Annual Losses (MG)
City of Detroit	1,500	1,493	3,000	339	1,832
Suburban Transmission System	-	-	3,000	434	434
Totals		**1,493**		**773**	**2,266**

Main Breaks

Main breaks are leaks that have surfaced and been reported to DWSD outside of the ongoing leak survey. DWSD records these breaks in reports called, "Report of Broken Main." The reports identify location, soil type, type of pipe and joint, area of service, backfill used, and time out of service.

The report does not indicate an estimated flow rate from the break. Additionally, it appears that the recorded Time Out of Service recorded derives from the time of repair crew and not when the break was first recorded. Therefore, since a volume of water lost for each of the breaks is not known, only a general estimation of main breaks can be made.

In an attempt to estimate the volume of UFW due to main breaks, the project team contacted Mr. James Heath, who at the time was Assistant Director of Water Supply Operations. Mr. Heath stated that DWSD uses the following averages to estimate the total annual volume of UFW due to breaks:

Average duration of a main break until it is fixed = 3 days
Average flow rate of break = 500 – 600 gpm

Table 6 on Page 10 summarizes the total number of main breaks for the last 5 years for which data is shown in the DWSD annual *Summary of Operating Statistics*. The annual estimated volume of water lost is based on the information provided by Mr. Heath. The data provided does not indicate whether the breaks occurred within the City or suburban transmission system. It is also worth noting that there were no breaks recorded for pipes greater than 48 inches in diameter during this period.

Summary of Leakage

Table 7 below summarizes the estimated UFW attributed to leakage. The average volume of leaks equals 16,349 MG annually or 45 MGD. Of the total, 97 percent is within the City of Detroit and 3 percent outside the City. In order to estimate the leakage from main breaks in the city and suburban systems, the total transmission leakage from Table 6 (larger than 16") is assumed to be from the entire system, not just within the City of Detroit. This total is then weighted by length of transmission pipe in the City (309 miles) and in the transmission system (396 miles).

TABLE 6
Summary of Main Breaks

	Pipe Size																		
FY	**2"**	**3"**	**4"**	**5"**	**6"**	**8"**	**10"**	**12"**	**16"**	**24"**	**30"**	**36"**	**42”**	**48"**	**Total No. of Breaks**	**Total Est. Water Lost (MG)***	**Total No. of Breaks 16” and Smaller**	**16” and Smaller Est. Water Lost (MG)***	**Total No. of Breaks Larger than 16”**	**Larger than 16” Est. Water Lost (MG)***
2000	*1*	*6*	*6*	*1*	*803*	*672*	*11*	*71*	*33*	*6*	*-*	*1*	*1*	*-*	**1,612**	**4,178**	**1,604**	**4,158**	**8**	**21**
1997	*-*	*1*	*4*	*-*	*435*	*395*	*7*	*45*	*30*	*6*	*3*	*2*	*2*	*1*	**931**	**2,413**	**917**	**2,377**	**14**	**36**
1996	*-*	*2*	*25*	*-*	*608*	*632*	*17*	*52*	*32*	*13*	*-*	*4*	*4*	*-*	**1,389**	**3,600**	**1,368**	**3,546**	**21**	**54**
1995	*-*	*-*	*11*	*-*	*417*	*430*	*7*	*53*	*37*	*13*	*2*	*2*	*1*	*1*	**974**	**2,525**	**955**	**2,475**	**19**	**49**
1994	*-*	*2*	*18*	*-*	*826*	*835*	*16*	*75*	*35*	*5*	*-*	*5*	*3*	*-*	**1,820**	**4,717**	**1,807**	**4,684**	**13**	**34**
Average															**1,345**	**3,487**	**1,330**	**3,448**	**15**	**39**

Assumes each break lasts for 3 days with a volume lost of 600 gpm.

TABLE 7
Average Annual UFW Attributed to Leaks, Unavoidable Losses, and Main Breaks

	Water Loss Surveys (Leaks) (MG)	Unavoidable Losses (MG)	Main Breaks (MG)	Total Leakage (MG)	% of Total
City of Detroit	10,596	1,832	3,465	15,893	97
Suburban System	-	434	22	456	3
Totals	**10,596**	**2,266**	**3,487**	**16,349**	**100**

Inaccurate Meters

The water meters in the DWSD system can be categorized into three groups:

- Water Plant
- Retail
- Wholesale

The inaccuracies of each type, along with the estimated UFW, are discussed below.

Water Treatment Plant Meters

Accurate measurement of the water produced at the treatment plants is critical in calculating the amount of UFW in a system. All five DWSD water plants meter and record the water leaving the plants. The type of meters used at each plant is shown in Table 8.

TABLE 8
Water Treatment Plant Metering

	Meters		
Plant	No.	Type	Metering Issue
Lake Huron	1	Annubar	Strip chart recording accuracy to nearest 5 MGD
Northeast	6	Venturi	Oversized / Reporting Uncertainties
Springwells	7	Venturi	Oversized / DP cells disconnected
Southwest	5	Venturi	Oversized
Water Works Park	14	Venturi	Oversized / DP cells not connected

For the most part, however, these meters (mostly Venturi meters) are inaccurate because they are oversized or the instrumentation is not working. Therefore, while some plants measure discharge flows, most of the plants calculate the discharge flow rates. Based on our team's investigations, it is our understanding that the plant flows are instead calculated as follows:

- Springwells, Water Works Park and Southwest estimate plant flows based on high lift pump curves.
- Northeast calculates plant flows based on their six FWFM meters.

- Lake Huron calculates plant flows based on an annubar.

Although Northeast and Lake Huron measure their plant flows, sufficient data in the field has not been collected to verify their accuracies.

To accurately assess the flow from the FWFM's at Northeast and the other four plants, it will be necessary to compare the calculated flow rates to the measured flow rates. Some of this work was recently completed as part of the CS-1332 Detroit model field program in June 2003. The field program collected flow data from insertion magnetic meters for a 3 week period at Water Works Park and Springwells High Pressure. The data from these two plants found that:

- The difference between the calculated discharge flow rate at Water Works Park was approximately 25 percent higher than the measured flow.
- The difference between the calculated discharge flow rate for Springwells High Pressure was approximately 10 percent higher than the measured flow.

Since Water Works Park averages 100 MGD and Springwells High averages approximately 120 MGD, it appears that the two facilities may be overestimating the supply into the system by more than 30 MGD.

It is likely that the three remaining water treatment plants (Southwest, Northeast, and Lake Huron) also experience some under-registration of flow. The impact of such under-registration of flow on the overall volumes of UFW could be significant. However, more data is needed to accurately assess any additional UFW attributable to this category. Therefore, the estimated amount of UFW associated with Water Treatment Plant meters is limited to the review of data for Water Works Park and Springwells, and is included as part of the miscellaneous calculated UFW in this report.

Retail Meters

The information obtained from DWSD's Meter Shop indicate that most of the residential/ commercial meters for the City of Detroit are 20 years old, except for some recently replaced meters. The older meters are mostly Badger meters, with some newer Rockwell meters, with a mix of plastic and brass drives.

Several sources within the water industry were reviewed to better estimate DWSD's residential and commercial water meter inaccuracies within the City of Detroit. Such meters tend to fail in favor of consumers, meaning they may under-register. Most of the residential under-registration occurs at low flows.

Meters are usually tested at AWWA standard rates of 0.25, 2, and 15 gpm. Most residential water use is assumed to occur at high flow rates, as most showers, toilets, sprinklers, clothes washers, and dishwashers use more than 2 gpm.

A report in *Journal AWWA*, "Economic Analysis for Replacing Residential Meters,"(July 1999) reviewed several previous studies and concluded that residential consumption typically occurs at 5, 15, and 80 percent for low, medium, and high flows, respectively. This study concluded that 15- to 20-year-old all-brass meters (no longer manufactured) have an

overall accuracy of 98.5 to 99 percent, while 15-year-old meters with plastic drives have tested out at 95-percent accuracy.

In another study, information received from Bega Valley Shire Council in Australia indicated that 6 percent of the water delivered to 11,000 residential properties was not measured due to inaccuracy in the flow meters, but nothing is mentioned in regarding the age and calibration of meters.

Furthermore, a study of residential and commercial meters in a Detroit suburb, *Report on Water Loss Investigation Program, Westland, Michigan, 1994*, (Pitometer Associates), indicated that its residential meters had an average under-registration of 5.6 percent. This same study also looked at commercial meters (2-inch and larger) and concluded an 8.8-percent average overall under-registration rate

In the City of Detroit, only new meters are tested and calibrated prior to installation. Furthermore, old meters that are removed are not tested. Therefore, the accuracy of the meters is unknown and has to be estimated based on the information presented.

For the purpose of estimating the UFW due to retail meter inaccuracies, we have assumed a 5-percent under-registration rate for residential meters (quarterly accounts) and 9 percent for commercial meters (monthly accounts). These percentages are mostly based on the cited Westland study, as this community is in suburban Detroit and has similar types and ages of meters. The other studies show under-registering in the same range as well. Table 9 summarizes the metered consumption for the last 5 fiscal years from the DWSD *Summary of Operating Statistics*.

TABLE 9
Retail Meter UFW

FY	Residential Metered Consumption (MG)	Commercial Metered Consumption (MG)	Unregistered Residential Consumption* (MG)	Unregistered Commercial Consumption* (MG)	Total Unregistered Consumption (MG)
2000	31,098	15,283	1,637	1,512	3,149
1999	31,567	19,288	1,661	1,908	3,569
1998	30,396	18,058	1,600	1,786	3,386
1997	32,949	18,202	1,734	1,800	3,534
1996	35,644	16,803	1,876	1,662	3,538
Avg.	32,331	17,527	1,702	1,734	3,435

* Assume under-registration of 5 percent for residential meters and 9 percent for commercial meters.

Wholesale Meters

The master meters for the suburban wholesale customers were considered more accurate than residential meters due to the frequent meter calibration by DWSD's Instrument Section. Additionally, DWSD has completed project DWS-805, which replaced and tested most master meters over the last 2 years. Taking into consideration the calibration strategy of trying to capture the majority of flows, which lowers the accuracy at the extreme ends of the

flow rates that a meter might experience, and the design data for these meters, the department believed prior to the completion of DWS-805 that 3 percent was a representative percentage rate for the under- registration and meter inaccuracy. Therefore, this information was used to estimate the UFW attributed to the master meters in the hydraulic models utilized for the Master Plan, and this assumption was applied to determine the figures summarized in Table 10 below. A review of suburban master meter data subsequent to the completion of DWS-805 indicates that the 3 percent figure may be low. The Department believes that the under-registration of the master meters experienced prior to the completion of the project was more likely in the range of 7 to 8 percent.

TABLE 10
Wholesale Meter UFW

FY	Metered Consumption	Unregistered Consumption
2000	154,751 MG	4,786 MG
1999	155,056 MG	4,796 MG
1998	143,285 MG	4,431 MG
1997	141,253 MG	4,369 MG
1996	146,337 MG	4,526 MG
Avg.	148,136 MG	4,582 MG

Miscellaneous UFW

Several miscellaneous categories of water use were identified for quantifying UFW, each of which is shown below along with its estimated amount.

Fire Hydrant Use

Fire hydrants are used for other purposes than fire fighting throughout the year, including street sweeping by the Detroit Department of Public Works (DPW) and by DWSD and its contractors for system maintenance and testing, such as "C" factor tests, fire flow tests, and flushing mains.

Fire Use

The Detroit Fire Department estimates the volume of water used to fight each fire and formerly provided this information to DWSD for billing purposes. However, the Fire Department agreed a few years ago to pay DWSD an annual flat rate of $200,000. The Fire Department estimates each fire lasts 2 hours at a rate of 1500 gpm and that there were 12,395 fires incidents in the City of Detroit in 2000. This gives 2,231 MG used for the year.

Street Sweeping

The Department of Public Works (DPW), Solid Waste Division/Street Sweeping Section sweeps City streets from April to November. This process starts with water vehicles flushing the areas to control airborne dust particles, and follows with sweeper vehicles collecting street dirt and debris as close to the curb as possible. The vehicles are filled from fire hydrants in the areas being cleaned. The sweeping program is summarized in Table 11.

TABLE 11
Street Sweeping

	Flushing Vehicle Capacity (gallons/load)	# of Days/Week	# of Flushing Vehicles/Day	# of Loads/ Vehicle/ Day	# of Weeks/Year	Annual Sweeping Use
Day shift	2100	5	8	4	37	**12.43 MG**
Night shift	2100	7	5	2	37	**5.44 MG**
Totals						**17.87 MG**

"C" Factor Testing

The Operational Services Section of the Systems Operations Control Division of DWSD is responsible for conducting tests to determine the carrying capacity of the pipes in the DWSD system. It is also responsible for overseeing the contractors conducting these same tests. The most common indicator used for the carrying capacity of pipes is the Hazen-Williams "C" factor. Although records are kept of the test results, the water used to conduct them is not normally calculated and recorded. TYJT performed some of these tests for DWSD in Fall 2000, allowing an estimated 30,000 gallons used per test. Our review of DWSD records, however, show that the TYJT tests were the only ones performed on the system since the early 1990s. Since these tests were done in FY 2001, no UFW for "C" tests is applied to the total UFW for the years covered in this report.

Fire Flow Testing

The Operational Services section also conducts many fire flow tests throughout the year. These tests compute the amount of water available to fight fires in specific areas of the system. Table 12 shows the number of fire flow tests conducted during FY 1996 to 2000 (fiscal years end on June 30). Each test assumed a 30-minute duration at the reported flow rates.

TABLE 12
Yearly Fire Flow Tests

FY	# of Tests Conducted	Total Yearly Flow (MG)	Average Daily Flow (MGD)
2000	77	1.70	0.005
1999	85	1.91	0.005
1998	63	1.55	0.004
1997	61	1.35	0.004
1996	83	1.65	0.005
Avg.	**74**	**1.63**	**0.005**

Other Uses

This report has quantified the UFW use in the DWSD water system to the extent possible. However, there are other uses not accounted for, either because information is not readily available or the quantity is not large. Examples are:

1. Illegal acts, such as unauthorized connections, unauthorized alterations or modifications to pipelines and/or water meters; installing an unauthorized water meter in place of the meter assigned to the account; damaging the meter to stop registration; or repositioning the meter, thereby altering registration.

2. Authorized un-metered uses of DWSD water include City-owned accounts, such as water and wastewater plants, fairgrounds, parks, golf courses, cemeteries, playgrounds, landscapes, swimming pools, City shops, offices, and water fountains; community facilities, such as state and county offices, schools, churches, hospitals, and rest homes; special events, such as fairs, etc.; maintenance equipment and procedures, such as water line flushing, sewer cleaning, storage tank drainage, pump and turbine cooling, and filter backwashing; and construction projects. Although the majority of City-owned facilities are metered, investigations at the water treatment plants, for example, show that potable water use, for restrooms, heating, etc., is not metered. It is understood that any un-metered uses are billed to the various city departments based on estimates of use. However, inaccuracies are inherent in estimates. DWSD's Water Quality Division of performs water main flushing, and while it keeps records of each flushing job performed, there is no accounting of the water used.

3. As the previous section indicates, water treatment plant meter inaccuracies are included in "other uses." Additional testing would be required to estimate this quantity.

For this study, the total reported UFW was assumed to be reasonably accurate for modeling purposes and is not intended to allocate costs for unaccounted-for-water. Therefore, the total quantity assessed to "other uses" is simply the difference between the total and estimated UFW. As additional data regarding inaccurate water metering at the plants becomes available, the quantity of UFW attributed to "other uses" may change accordingly. The following table shows the totals attributed to the remaining miscellaneous category, which include the unknown categories of main flushing, un-metered authorized uses, and water treatment plant metering errors.

Summary of DWSD UFW

Table 13 provides a summary of the UFW for the last 5 years. This same information is shown graphically in Figure 2. On average, the total quantity of water attributed to UFW is 42,570 MG each year.

Although an extensive effort was performed to quantify the UFW, nearly 38 percent is still unknown. The largest known quantity of UFW is attributed to leaks, then hydrant use (mainly by other City departments).

TABLE 13
Miscellaneous Unknown UFW

FY	Total UFW (MG)	Estimated Leakage (MG)	Estimated Meter Inaccuracies (MG)	Miscellaneous	
				Estimated Hydrant Use (MG)	Other Uses (MG)
2000	37,969	17,040	7,935	2,251	10,743
1999	39,677	16,349*	8,365	2,251	12,712
1998	40,685	16,349*	7,817	2,250	14,269
1997	46,732	15,274	7,903	2,250	21,305
1996	47,788	16,461	8,064	2,251	21,012
Avg.	**42,570**	**16,295**	**8,017**	**2,251**	**16,007**

* No main break data was available for FY 1999 or FY 1998. The average main breaks from Table 6 are used here.

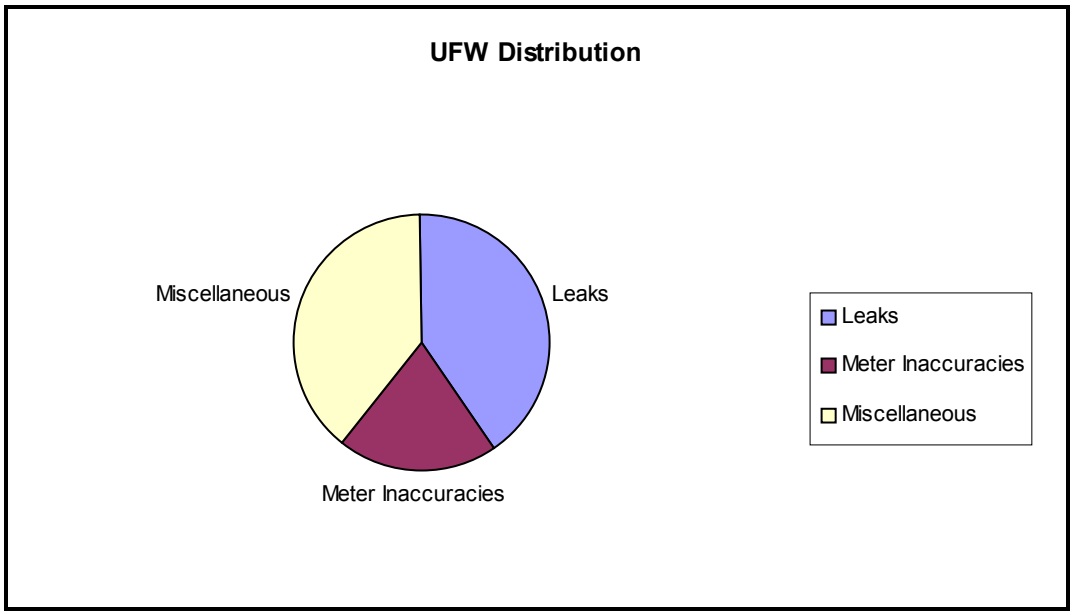

FIGURE 2
UFW Distribution

As shown in Figure 1, DWSD is benefiting from the ongoing leak detection program. The total UFW has been reduced from a high of nearly 20 percent in 1997 to 16 percent in 2000. The data presented will be used to update the distribution of the UFW in the CWMP models.

As indicated in the previous sections, the UFW attributed to leaks, breaks, unavoidable losses, and meter inaccuracies was separately identified for the City distribution and

transmission systems. Since all the hydrant use quantified was for Detroit and because DWSD's transmission mains outside of the City do not have hydrants, all of the hydrant use was applied to the City of Detroit UFW. The percentages of other uses are more difficult to distribute between the City of Detroit and the suburbs, as this category is termed "other uses" because the exact nature of the UFW is hard to define. Table 14 shown below identifies the quantities of UFW by category as well as the percentages applied to the City and the suburbs.

The data presented in Table 14 will be used to update the UFW nodal distribution in the CWMP models. As shown, a majority of the UFW appears to be occurring in the City of Detroit. Once again, this is a spatial distribution based on several assumptions designed to enhance and facilitate the modeling requirements and is not intended to allocate costs of UFW.

TABLE 14
FY 2000 UFW Breakdown

UFW Category	Detroit	Suburbs	Other	Total
Leaks	10,596 MG	-	-	10,596 MG
Main Breaks	4,173 MG	5 MG	-	4,178 MG
Unavoidable Losses	1,832 MG	434 MG	-	2,266 MG
Meters	3,149 MG	4,786 MG	-	7,935 MG
Fire Hydrant Use	2,251 MG	-	-	2,251 MG
Subtotal	22,001 MG (81%)	5,225 MG (19%)	-	27,226 MG
Other Uses	-	-	10,743 MG	10,743 MG
Total	22,001 MG (58%)	5,225 MG (14%)	10,743 MG (28%)	37,969 MG

The assumed distribution of UFW for the models will be based on FY 2000, the most recent year of data. For the models' spatial distributions, it was assumed that the other uses are distributed between the City of Detroit and the suburban transmission mains using the same percentages as the other quantified UFW. As stated earlier in this report, the overestimation of supply into the system appears to be more than 30 MGD from Water Works Park and Springwells plants. Assuming the remaining treatment plants experience no overestimation of supply, the total volume of UFW attributed to "Other Uses" could be attributed to this overestimation. Therefore, rather than allocating the "Other Uses" of UFW based on the same percentages of the other quantified UFW, it can reasonably be justified that the "Other Uses" UFW be allocated to retail and wholesale customers based on consumption, which would result in a lower percentage of UFW allocated to Detroit and a higher percentage of UFW allocated to Suburban wholesale customers.

Impact of New Data from DWS-805 – Suburban Water Meters Automation and Replacement

Subsequent to the analysis described above, new data is now available from the "Suburban Water Meters Automation and Replacement" program. The original analysis assumed an inaccuracy of approximately 3 percent underestimation from the wholesale customers' water meters and this was based on estimates provided by the department. With new data now provided by DWS-805, a subsequent analysis shows that the underestimation may be as high as 7.6 percent for these wholesale meters. This is based on a comparison of the water production and water consumption at the wholesale meters for the months of October, November and December during 2001 and 2002.

The data shows that whereas the total water production during these months decreased from 2001 to 2002, the water sold through the wholesale meters for this same period, subsequent to the initiation of the automated meter reading system, actually increased. An analysis of this data is included in Appendix A and shows that the wholesale meter underestimation may be as high as 7.6 percent. Applying this 7.6 percent under-recording as outlined in Appendix A, the unregistered consumption for wholesale customers would increase from the previous 4,786 MG outlined in Table 10 to 11,761 MG. Substituting this value into Table 14, and maintaining the overall water balance, requires a modification to the "other uses" amount down from 10,743 MG to 3,768 MG. This is summarized in Table 15 following:

TABLE 15
FY 2000 UFW Alternative Breakdown

UFW Category	Detroit	Suburbs	Other	Total
Leaks	10,596 MG	-	-	10,596 MG
Main Breaks	4,173 MG	5 MG	-	4,178 MG
Unavoidable Losses	1,832 MG	434 MG	-	2,266 MG
Meters	3,149 MG	11,761 MG	-	14, 910 MG
Fire Hydrant Use	2,251 MG	-	-	2,251 MG
Subtotals	22,001 MG (64%)	12,200 MG (36%)	-	34,201 MG
Other Uses (allocated on the same basis as subtotal above)	2,412 MG	1,356 MG	3,768 MG	3,768 MG
Totals	**24,413 MG**	**13,556 MG**	**3,768 MG**	**37,969 MG**
	(64%)	**(36%)**		
Alternative Allocation Methodology				
Subtotals	22,001 MG (64%)	12,200 MG (36%)	-	34,201 MG
Other Uses (allocated on the basis of historical consumption)	865 (23%)	2903 MG (77%)	3,768 MG	3,768 MG
Totals	**22,866 MG**	**15,103 MG**		**37,969 MG**
	(60%)	**(40%)**		

If the "Other" category is allocated in the same ratio as all of the remaining categories of UFW, then the total allocation remains 64 percent Detroit and 36 percent Suburbs. If however, the "Other" category is allocated in the same ratio as the overall historical consumption – i.e. 23 percent Detroit and 77 percent Suburbs, then the total allocation of UFW becomes 60 percent Detroit and 40 percent Suburbs. All of this is described in Table 15 above.

It must be emphasized that there are many unknowns and assumptions that were made to effect the overall UFW water balance. Unknowns and assumptions relate to such as the water treatment plant production estimates, the losses resulting from pipe leakage and pipe breaks, the range of "unavoidable" losses assessed, etc.

As stated earlier, the primary purpose of this analysis was to distribute the UFW to the various nodes within the transmission system for hydraulic modeling purposes. In addition, the identification of the UFW led to a number of recommendations that will, when effected, reduce not only the UFW but also the cost of the system operation. As these improvements are put into place, more data will become available to assess both the volume and the allocation of the UFW with much greater accuracy. This is most important for future planning purposes.

The estimates of UFW and the initial allocations that were made are considered satisfactory for the purposes of the hydraulic modeling that was undertaken as part of the master plan. Any differences noted in allocations from the new and updated data are not considered significant enough to adversely affect either the modeling results or the recommendations relating to infrastructure improvements.

Recommendations

In quantifying the UFW, several strategies have been developed to minimize this amount. These strategies are best categorized as either capital improvements or operation and maintenance procedures. Therefore, many of these strategies could save DWSD money in operational costs.

Capital Improvements

A majority of main breaks can be attributed to old pipes that have exceeded their useful life. DWSD has a pipe replacement program currently in place to address this issue. Based on the last 5 years, DWSD has replaced an average of 13 miles of pipe annually. Approximately, 1,950 miles of pipe are older than 75 years and should be replaced. However, this will take approximately 150 years to complete at the current replacement rate.

A pipe rehabilitation and replacement program is being developed as part of the CWMP and will be provided to DWSD separate from this report. This report will propose a strategy for the DWSD to better manage its replacement program in order to accelerate the rate of pipe replacement.

Operation and Maintenance Procedures

Recommended strategies for operation and maintenance procedures include continuing practices DWSD currently has in place as well as modifying existing procedures and putting new procedures in place. Each of these is described in more detail below.

Leak Detection Program

Roughly 28 percent of the total UFW is attributed to leaks found through a leak detection program. Elimination of this UFW equates to annual savings of approximately $6.5 million. This number is conservative, as it does not account for subsurface leaks lasting for more than a year or for the additional costs of treating the leaks that drain into the sewer system.

As shown in Figure 1, the ongoing leak detection and repair program has made significant gains in reducing UFW. DWSD also had a leak detection program being performed in the early 1990s. Note that the period between these programs (1994-1997) was the only time that the UFW actually increased.

Based on this data it can be seen that a leak detection and repair program should be ongoing and not a one-time event. Therefore, it is recommended that DWSD continue with its annual leak detection and repair program.

Water Treatment Plant Metering

Knowing the amount of water entering the system is critical in obtaining an accurate calculation of UFW. The methods DWSD uses to quantify plant supply, using pump curves and estimates, should be re-examined.

Findings from the CS-1332 field program indicate that estimating plant flow rates based on pump curves is not accurate. Because metering the plants is more accurate, a thorough study should be conducted at all the water treatment plants to examine the existing metering system and make recommendations for a permanent metering system to be installed at each plant. This could involve the repair or replacement of existing meters. Continuous remote monitoring of the supply meters should also be included as part of the system, similar to the program recently implemented for the wholesale customer master meters. This will provide the ongoing data necessary to properly evaluate water production from each plant source. In order to maintain accuracy of the data, these meters should then be tested and inspected regularly.

Metering of Accounts

There were many authorized uses identified that DWSD does not meter. It is recommended that DWSD perform a thorough review of its accounts and meter the authorized uses. In this way, a more accurate accounting of UFW can be achieved.

Meter Testing

A residential/commercial meter change-out program should be put in place for those meters within the City of Detroit. This would include testing a sample of the removed meters, being sure to note age, location, size, and meter type to document inaccuracies. This will provide a better estimate of UFW attributed to the meters. Additionally, this program could be used to develop a schedule for replacing meters that are no longer accurate.

The suburban master, or wholesale, meters should continue to be tested annually to ensure their accuracy and to quantify that portion of UFW attributed to them. These tests should also include a direct measuring of the flow, in addition to the instrumentation testing currently performed. This program would provide for testing at regular intervals, when flows change unexpectedly, or when customers have questions as to accuracy. Meters that operate near their extreme ranges should be tested more frequently.

Water Audit

Based on our investigation, City departments are using water without much regard to recording or estimating the volume. Although specific uses have been estimated for the purpose of this report, there were many others that were grouped in the "Other Uses" category.

A comprehensive water audit would aid in identifying all of the un-metered uses and make recommendations to improve the record-keeping and accounting practices. From our investigations, these accounting practices would include:

- Requiring DPW to record the volume of water used for street sweeping.
- Requiring the fire department to estimate water uses for fires as well as any other time it takes water from fire hydrants.
- Recording the flow and duration from hydrants when flushing the system.
- Recording the time a main break is first reported to better estimate the volume of water lost.

Unidirectional Flushing

Developing and implementing a unidirectional flushing program instead of the complaint-response method used currently has been shown within the water industry to reduce the amount of water used for flushing. "Unidirectional flushing: a powerful tool" in the July 1999, *Journal AWWA* reported that this method may save as high as 40 percent of the water used in a conventional flushing program. This saving is achieved because the systematic approach ensures that all mains are cleaned with high velocities, lowering flushing time and dirty water or taste and odor complaints.

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Appendix A
Data Analysis

APPENDIX A

Data Analysis

Factors Attributing to UFW

Leakage

Pipe Leakage

The calculations for Table 3 are made in the following table. The data is from the DWSD *Summary of Operating Statistics* for fiscal years ending June 30, 2000.

TABLE 16
Pipe Lengths for DWSD System

Pipe Size (in.)	Total Footage	Total City of Detroit Footage	Total City of Detroit Mileage	City of Detroit Trans. Footage	City of Detroit Trans. Mileage	Suburban Mileage
4	84,216	84,216	15.95			0
6	5,642,821	5,642,821	1,068.72			0
8	5,981,881	5,981,881	1,132.93			0
10	245,092	245,092	46.42			0
12	1,658,911	1,658,911	314.19			0
14	1,430	1,430	0.27			0
16	782,769	782,671	148.23			0.02
20	437	383	0.07	383	0.07	0.01
24	790,724	552,212	104.59	552,212	104.59	45.17
30	216,706	147,013	27.84	147,013	27.84	13.20
36	464,416	207,649	39.33	207,649	39.33	48.63
38	131	131	0.02	131	0.02	0
42	527,071	223,285	42.29	223,285	42.29	57.54
44	20,766	20,766	3.93	20,766	3.93	0
48	486,228	282,617	53.53	282,617	53.53	38.56
50	2,635	2,635	0.50	2,635	0.50	0
54	390,894	101,333	19.19	101,333	19.19	54.84
60	157,618	14,576	2.76	14,576	2.76	27.09
66	55,574	27,967	5.30	27,967	5.30	5.23
72	269,537	52,563	9.96	52,563	9.96	41.09
84	33,844	0	0	0	0	6.41
96	169,786	0	0	0	0	32.16
120	138,049	0	0	0	0	26.15
total	**18,121,536**	**16,030,152**	**3,036.01**	**1,633,130**	**309.30**	**396.10**

The calculations for Table 4 are as follows:

Estimated Volume of Total Leaks in City of Detroit (MGD) **=** Estimated Volume of Leaks Found (MGD) **X** (DWSD Length of Pipe/Surveyed Pipe Length)

Estimated Volume of Total Leaks in City of Detroit (gpd/mile) **=** Estimated Volume of Leaks Found (MGD)/Surveyed Pipe Length

Example:

For 1993-1994 Report, these are calculated as:

Estimated Volume of Total Leaks in City of Detroit **=** 7.062 MGD **X** (3036 miles/794.7 miles) **= 26.98 MGD**

Estimated Volume of Total Leaks in City of Detroit **=** 7062000 gpd**/**794.7 miles **= 8883 gpd/mile**

Unavoidable Leakage

The calculations made for Table 5 are as follows:

Unavoidable leakage for City of Detroit mains = (Unavoidable leakage for distribution pipes X mileage of distribution pipes) + (Unavoidable leakage for transmission pipes X mileage of transmission pipes)

Unavoidable leakage in suburban transmission system = Unavoidable leakage for transmission pipes X mileage of suburban transmission pipes

Example:

Unavoidable leakage for City of Detroit mains **=** [1500 gpd/mile **X** (3036.014 miles **–** 309.3049 miles)] + [3000 gpd/mile **X** 309.3049 miles] **= 1493 MG + 339 MG = 1832 MG**

Unavoidable leakage in suburban transmission system **=** 3000 **X** 396.0955 **= 434 MGD**

Main Breaks

The calculations made for Table 6 are as follows:

Estimated Water Loss **=** # of leaks **X** 600 gpm **X** 60 min/hr **X** 24 hrs/day **X** 3 days before fixed

Example:

Total Est. Water Loss **=**1612 **X** 600 **X** 60 **X** 24 **X** 3 **= 4178 MG**

16" and smaller Est. Water Loss **=**1604 **X** 600 **X** 60 **X** 24 **X** 3 **= 4158 MG**

Larger than 16" Est. Water Loss **=**8 **X** 600 **X** 60 **X** 24 **X** 3 **= 21 MG**

Summary of Leakage

The calculations made for this section and Table 7 are as follows:

Total Leakage **=** Water Loss Surveys (Table 4) **+** Unavoidable Losses (Table 5) **+** Main Breaks (Averages from Table 6)

Example:

For the City of Detroit, Total Leakage **=** 10596 MG **+** 1832 MG **+** (3206 MG **+** (309 miles**/** 705 miles) **X** 49 MG) = **15655 MG**

For the suburban system, Total Leakage **=** 0 MG **+** 434 MG **+** ((396 miles/705 miles) **X** 49 MG) = **462 MG**

Inaccurate Meters

Retail Meters

The data for the calculations in Table 9 comes from the DWSD Summary of Operating Statistics for the 5 fiscal years ending June 30, 2000. Residential consumption is assumed to be the quarterly CBIS consumption and the commercial consumption is assumed to be the monthly CBIS consumption. The calculations made for Table 8 are as follows:

Total Unregistered Consumption **=** Unregistered Residential Consumption **+** Unregistered Commercial Consumption

Unregistered Residential Consumption **=** (Residential Metered Consumption/Accuracy) **-** Residential Metered Consumption

Unregistered Commercial Consumption **=** (Commercial Metered Consumption/Accuracy) **-** Commercial Metered Consumption

Example:

For FY 2000:

Unregistered Residential Consumption **=** (31098 MG/0.95) **–** 31098 **= 1637 MG**

Unregistered Commercial Consumption **=** (15283 MG/0.91) **–** 15283 **= 1512 MG**

Total Unregistered Consumption **=** 1637 MG **+** 1512 MG **= 3149 MG**

Wholesale Meters

The data for the calculations in Table 10 comes from the DWSD *Summary of Operating Statistics* for the 5 Fiscal years ending June 30, 2000. Metered consumption is assumed to be the suburban consumption. The calculations made for Table 8 are as follows:

Suburban Unregistered Consumption **=** (Metered Consumption/Accuracy) **-** Metered Consumption

Example:

For FY 2000:

Suburban Unregistered Consumption **=** (154751 MG/0.97) **–** 154751 **=** **4786 MG**

Miscellaneous UFW

Fire Hydrant Use

Street Sweeping

The calculations for Table 11 are as follows:

Total Sweeping Use = Total Day shift + Total Night shift

Total per shift **=** Vehicle capacity **X** # vehicles **X** # loads per vehicle **X** # days per week **X** # weeks sweeping per year

Example:

Total Day shift **=** 2100 gal **X** 8 **X** 4 **X** 5 **X** 37 = **12.43 MG**

Total Night shift **=** 2100 gal **X** 5 **X** 2 **X** 7 **X** 37 = **5.44 MG**

Total Sweeping Use **=** 12.43 MG **+** 5.44 MG = **17.87 MG**

Fire Flow Tests

The water used by DWSD and its contractors for fire flow testing is calculated from DWSD fire flow test records, which record the flow observed for the test. While the actual test may not take the 15 minutes used in these calculations, all hydrants used for the test, including at least two static pressure hydrants, are flowed until running clear before being gauged.

Example:

A sample calculation for a particular fire flow test is as follows:

Fire Flow test on 5/17/2000 at W. Grand Blvd. and Toledo, section map 18-I, has an observed test flow of 2296 gpm **X** 15 mins **=** 34440 gal.

Addition of all tests for FY 2000 **=** **1.70 MG** (Table 12)

Other Uses

Since no information could be obtained under several categories, the remainder of the UFW is listed as Miscellaneous Unknown water. Therefore, the calculations for Table 13 are as follows:

Miscellaneous Unknown UFW **=** Total UFW (Table 1) **–** [UFW due to leakage (Table 4, Table 5, Table 6) **+** UFW due to inaccuracy of meters (Table 9 and Table 10) **+** UFW due to Misc. known use (Table 11 and Table 12)]

UFW due to leakage **=** Water Loss Survey leakage **+** Unavoidable leakage **+** Main Breaks

UFW due to inaccuracy of meters **=** Retail Meter UFW **+** Wholesale Meter UFW

UFW due to Misc. known use **=** Fire Use **+** Street Sweeping **+** Fire Flow Tests

Example:

For FY 2000, these calculations are:

UFW due to leakage **=** 10596 MG **+** 2266 MG **+** 4178 MG **=** **17040 MG**

UFW due to inaccuracy of meters **=** 3149 MG **+** 4786 MG **=** **7935 MG**

UFW due to Misc. known use **=** 2231 **+** 17.87 MG **+** 1.70 MG **=** **2251 MG**

Miscellaneous Unknown UFW **=** 37969 MG **–** (17040 MG **+** 7935 MG **+** 2251 MG) **=** **10722 MG**

Summary of DWSD UFW

Example:

The calculations for Table 14 are as follows:

Detroit pipe leakage **=** Water Loss Surveys **+** Unavoidable losses **=** 10596 MG **+** 1832 MG **=** **12427 MG**

Detroit main breaks **=** (4158 MG **+** (309 miles/705 miles) **X** 21 MG) **=** **4166 MG**

Suburban main breaks **=** 396 miles/705 miles **X** 21 MG = **12 MG**

The miscellaneous unknown total can be broken into suburban and City of Detroit miscellaneous unknown by weighting the total length of pipes for the two parts (Table 2).

Detroit misc. unknown **=** 88.46% **X** 10722MG **=** **25.99 MGD**

For the suburban transmission system **=** 11.54% **X** 10722 MG = **3.39 MGD**

Summary of Analysis of Metering Differences Prior to and After Implementation of "Suburban Water Meters Automation & Replacement"

The months of October through December were chosen for review, as this time frame will not be impacted by such uses as irrigation.

The total system production during this time frame actually decreased from 2001 to 2002 by approximately 5.8 percent as follows:

	Volume (Mcf) 2001	Volume (Mcf) 2002	Difference	Percent Difference
October	2,475,770	2,424,972	(50,799)	-2.1%
November	2,318,027	2,049,328	(268,699)	-11.6%
December	2,314,016	2,224,450	(89,566)	-3.9%
	7,107,814	**6,698,750**	**(409,064)**	**-5.8%**

At the same time, water consumption at the wholesale meters actually increased by approximately 2 percent summarized as follows:

	Volume (Mcf) 2001	Volume (Mcf) 2002	Difference	Percent Difference
October	1,640,767	1,783,352	142,676	8.7%
November	1,334,425	1,150,565	(183,860)	-13.8%
December	1,320,861	1,448,002	127,141	9.6%
	4,295,962	**4,381,919**	**85,957**	**2.0%**

Assuming that the decrease in system production during the October to December time frame from 2001 to 2002 would have applied uniformly to the wholesale customers, the overall impact of the new master meter replacement program is calculated to be approximately 7.6 percent as follows:

	Volume (Mcf) 2001	Pumpage Percent Difference	Restated Vol. (Mcf) 2002	Actual Volume (Mcf) 2002	Difference	Percent Difference
October	1,640,676	-2.1%	1,607,012	1,783,352	176,340	10.7%
November	1,334,425	-11.6%	1,179,742	1,150,565	(29,178)	-2.2%
December	1,320,861	-3.9%	1,269,736	1,448,002	178,266	13.5%
	4,295,962	**-5.8%**	**4,048,724**	**4,381,919**	**325,428**	**7.6%**