CHAPTER 4 – WATER LOSS CONTROL

4.1 Introduction

Volume 2, Chapter 3 – Water Budget compares current water demand with population and states that the water loss from the GWA system is approximately 50 percent, or 22.5 mgd. Typical water loss should not be greater than 15 percent. The magnitude of GWA's water loss and its associated financial impacts emphasize the need to make water loss control a top priority.

GWA's power costs are approximately $790 per million gallons of production and distribution, or approximately $6.0 million dollars per year for lost water. GWA's marginal supply and distribution costs for illegal, un-metered connections is $3,100 per million gallons in the Central System. GWA's lost revenue for illegal, un-metered connections ranges from $2,400 to $3,500 per million gallons.

GWA initiated a water loss control program in 2005, to identify leaks and illegal connections to its water transmission and distribution system. Identification of water leaks is only the first step. The second step is to establish a prioritized water loss control program to recover the water and revenue that is being lost, based on findings from a water distribution system audit. This audit will include estimates of apparent and real water losses for the purposes of more accurately defining priorities for controlling water system water loss as defined by the International Water Association (IWA).

There was insufficient data available to conduct a water audit as part of the master plan process. Additional data collection is needed that will enable GWA to perform a comprehensive audit with more detailed recommendations. For example, estimates for metering inaccuracies need to establish a baseline or create the "bookends" of (1) the system inputs through production meter testing to better understand total source of supply, and (2) total metered customer demand through a statistical sampling program and better information on meter repair and replacement programs. The following section provides a description of key data collected to date and general guidance for additional data collection and analysis.

Several key parameters such as the Infrastructure Leakage Index and Economic Level of Leakage as defined by the *Performance Indicators for Water Supply Services (IWA, 2000)* should be calculated for each of the three public water systems as part of a comprehensive water audit. These indicators will provide the level of cost-effective main replacement and leak repair within each system. While this occurs, key activities (such as an active leak detection and repair program) can occur simultaneously.

The value of a water loss control program must be understood by GWA's human infrastructure and incorporated into their operational commitment to provide revenue enhancement, protect the investment of GWA's clients, reduce operational costs and achieve their best in class utility goal.

4.2 Leak Detection Program Assistance and Recommended Future Actions

The goals of water loss control are to reduce overhead costs and to enhance revenue for funding additional system repairs. A general overview of an overall water loss control program combines several elements of the work effort GWA and the consultant project team has already undertaken. A summary list is provided below as referenced in the Water Loss Control Manual (Thorton, 2002):

- **Overhead Reduction Tasks**
  - Leakage reduction
  - Hydraulic controls

  - Pipe repair and replacement
  - Customer service line replacement
  - Condition assessment and rehabilitation
  - Energy management
  - Staff resources management

- **Revenue Stream Enhancement Tasks**
  - Baseline Analysis
  - Meter population management
  - Meter testing and change-out
  - Correct meter sizing and change-out
  - On-going meter testing program
  - Automatic meter reading (AMR)

- **Billing Structure, Analysis and Improvement**
  - Nonpayment actions
    - Turn off supply
    - Reduce supply to minimum
    - Legal action
    - Prepayment schemes
    - Reduction of theft, fraud from illegal connections
    - Continuous field inspections
  - Rate management
  - Customer management
  - Modeling for efficient installation (from meter setting to billing payment - walk through schematic)
  - Modeling to ensure on-going rate adjustments for economic efficiency

Additionally, one of the key areas to recover water loss, a leak detection survey has already been conducted for the south, central and north systems. However, the study identified only 0.6 mgd. These findings indicate the water loss control program needs to broaden and encompass other areas of uncovering sources of water loss, including a more concentrated effort on leaks from service line connections where significant leaks are often found. In addition, leak surveys on the customer side of the meter should also be undertaken as a key initiative. This is discussed further in Volume 2, Chapter 5 – Water Conservation.

4.2.1 Recommended Priorities for System Repairs and Data Collection

Two key areas to focus water loss strategies are to quantify water losses by type and to recover the highest dollar value and highest volume loss quickly. The most expensive water loss should be recovered first by GWA. The most expensive water purchased is from the U.S. Navy. Creation of a "District Metered Area" should be considered to pinpoint most quickly the key water loss control measures to implement. The following list prioritizes areas where GWA should focus its efforts:

- Conduct source meter testing for Navy purchased water supply.
- Assess storage tank overflows in the north and central systems fed by Navy water. Resolve any potential overflows by concentrating on level switch and manual checking until SCADA system repairs completed.
- Conduct source meter testing for wells in the north and central systems.
- Assess storage tank overflows in north and central system fed by wells.
- Measure nighttime pressure and flow for assessing background water losses from northern and central systems, and secondary priority for the southern system for better pressure management and targeting water savings from the purchased Navy supply.
- Repair the largest leaks on transmission mains. Focus on repairing leaks in the vicinity of the Navy supply connections and work outwards with routine, active leak detection and expedient repairs for the central and northern systems.
- Conduct additional leak surveys of service line connections where a majority of water loss from leaks is expected to be occurring. From experience with other U.S. water systems, typical leak volumes are found to be 80 percent on service line connections and less than 20 percent by volume from leaks in transmission mains [American Water Works Association (AWWA), 1999]. Note that GWA's ongoing meter replacement program may result in significant reductions in service line connection leaks because some may be repaired when the meters are replaced.
- Conduct large customer meter testing (larger than 1.5-inch connections or higher than $1,500 revenue per year would be cost effective to test every six months and $1,000 would be cost effective to test once per year).
- Conduct inventory of date installed (if possible) and small meter testing (estimated percent of use).
- Cross-reference with billing system accounts to audit for illegal connections.
- Identify and eliminate water loss from theft.
- Repair smaller service line leaks identified from leak detection survey or meter inventory (AMR installations), and recommend planned new meter replacements and AMR installation on customers nearest the Navy connection first to ensure most accurate revenue collection and data measurement.
- Use AMR readings to best understand larger customers' demands closest to the feed point and concentrate water conservation efforts for saving Navy supplies (see Volume 2, Chapter 5 – Water Conservation).
- Track customer meter billing systems to ensure fullest revenue recovery.
- Track illegal connections.

- Create a protocol and implementation for follow-up on water waste calls by customers using this highest value source and have a water waste ordinance in place to allow enforcement of warnings or fines. The objective being to emphasize to GWA's customers the necessity for preserving this most costly supply source through customer and village leadership outreach. The ultimate message is reduction of water waste, which will in turn help lessen planned rate increases by being more efficient with existing supplies.

The following water loss reduction goals have been estimated to be achievable through implementation of the priorities listed above:

- With more than a 50 percent current water loss rate, an aggressive but reasonable water loss reduction goal could be as much as 20 percent over the next 5-10 years. However, for financially conservative revenue planning purposes (as documented in Volume 1, Chapter 14 – Financial Program), we have assumed that the water loss rate will decline from 55 percent to 45 percent over the next five years from the combined impact of a 1 percent annual drop in losses and from the effects of water meter replacements, demand elasticity and growth in demands. Specifically, we estimate that by FY 2010-11 billed water demand will increase from 18.8 mgd (in FY 2005-06) to 21.4 mgd, and overall production is estimated to drop by five percent from 40 mgd to 38 mgd.
- A total reduction of 10 percent in water losses will be due to improving meter accuracy with an aggressive meter replacement program by FY 2007-08. It is recognized that larger meters (greater than 1.5-inch) are expected to have higher inaccuracies, and are targeted for early replacement. A drop in water losses from higher customer meter accuracy will increase billed charges, but will not lead to a reduction in water production. Reduced production relies on reduced demands through conservation measures discussed in Volume 2, Chapter 5 – Water Conservation.
- Less than five percent of the total mileage of water transmissions mains is expected to be replaced over the next 20 years through the CIP, which leads GWA to need a strong effort on leak detection and repair of existing transmission mains and service lines.
- A leak detection and repair team, consisting of a minimum of 12 individuals (e.g., two planners, two field supervisors and two of three field crew repairman plus a two-man leak detection crew) is needed to fully staff a water loss control program.
  - The role and responsibility of the planners is to: 1) direct and/or conduct the data collection and analysis necessary for completing the overall comprehensive water system audit annually; 2) plan areas of the leak survey, 3) track work orders with GIS mapping to assist with prioritizing areas for leak detection or transmission mains for replacement rather than repair, and 4) assist supervisors with direction of the leak repair crews.
  - The leak detection crew should be cross-trained with the field repair crews to optimize workload between mileage covered with the leak

survey versus leaks identified to be repaired. Additional resources, such as more equipment and training from outside specialty consultants with highly-experienced field technicians, may be needed.

- Field supervisors should be trained in leak causes (e.g., corrosion identification and control techniques), which will assist with field data collection, future pipe type specifications, and identification of necessary repairs to cathodic protection or other actions, as appropriate.
- The goal of the leak repair crews is to have each identified leak repaired within 10 days.

4.2.2 Leak Detection Study Results

The Water Leak Detection Team prepared a detailed report, *Guam Waterworks Authority – Water Leak Detection Study on All Three Public Water System*, dated September 12, 2005. The results of the study located leaks of approximately 600,000 gallons per day (gpd), which amounts to $1,440 to $2,100 per day of lost revenue. A section of the report is included in Appendix 2B – GWA Water Leak Detection Study. Table 4-1 presents a summary of the major leaks found in the water system. The results of this study were GWA's first effort at leak detection. It represents a small portion of the anticipated leaks in the system. The number of leaks detected will improve as GWA staff becomes more experienced with the detection tools.

Table 4-1 – Water Leak Detection Study Summary

Water System	Water Loss gpd
Central	
Turner Road/Nimitz Hill	18,150
Cabras Area	35,858
Piti Village	38,000
Illegal connection	7,880
Piti Main Village	28,000
Santa Rita Village	
Chalan Kindo – Vicinity of House #180B	28,000
Minor leaks (6)	970
Anonas Court	*
Talisay Drive/Aga Drive House #191	*
Asan Village	
Consolation Street	*
Agat Village	
North Santa Cruz St/Tomas Rivera St	72,000
Calle de los Marteres St House # 148	14,400
Minor leaks (8)	2,160
Umatac Village	
Umatac Mayor's Office	14,400
Umatac Subdivision	1,440
Minor leaks (2)	360
Rte 4 Next to Mobil Gas Station	14,400
Rte 2 Before Ishizaki Lane	*

Table 4-1 – Water Leak Detection Study Summary (continued)

Water System	Water Loss gpd
Southern	
Merizo Village	
Espinosa/Geus Rd	1,440
Off Rte 4 Across J Cruz House # 130	14,400
Jaotan or Barcinas Housing	14,400
Rte 4 – In front of House # 1145	36,000
Rte 4 – Before the bridge after Arriola Beach	28,000
Minor leak	144
Inarajan Village	
Minor leak	180
Talofofo Village	
Enrique San Nicolas – 2nd Hydrant	1,440
Ugum 2 million reservoir valve box	720
Ugum Dam Pump #1	540
Minor leaks (3)	630
Yona Village	
Water Booster Pump Station 25	28,880
Jota Road Across House # 386	56,000
Minor leaks (4)	900
Chalan Pago/Ordot Village	
Access Road 2 defective FH Left side	1,440
Justice Monissa Lujan Road	1,440
Corner of Tun Bihue/Ramirez Drive	1,440
Main Road to Judge Sablan St behind JM Store	1,440
Rte 4 between Chalan Untalan and Chalan Laia	*
Rte 4 Chalan Asusana Front of House # 568	*
Gogue Drive Across House # 188	*
Minor leaks (4)	900
Sinajana Village	
Lemai Court front of House # 399	14,400
Minor leaks (9)	1,260
Agana/Agana Heights Village	
West O'brien Drive/Chalan Santo Papa	1,440
Padre Palomo St/Hesler Place	1,440
Minor leaks (4)	360
Mangilao Village	
Astrom Circle - Across 3MLS Bldg	1,440
Washington Dr - Across Puti Tai Nobia Lane	1,440
Main entrance Spotsa lane left side	1,440
Minor leaks (6)	1,170
Barrigada Village	
Minor leaks (10)	1,890
Hatgana and Tamunin Rte 30	
Hatgana - Ada Commercial Bldg Paradise Fitness	1,440
Pas St - Back side of Guam Premium Outlet	2,880

Table 4-1 – Water Leak Detection Study Summary (continued)

Water System	Water Loss gpd
Southern	
Minor leaks (8)	1,980
Tamuning - Governor C.G. Camacho - Rte 30- Rte 14	
Minor leaks (4)	720
Dededo - Liguan Terrace	
South Hasmin Court	180
Dededo	
East Liguan and Diseplina Court	1,440
Northern	
Macheche/Dededo - Mogfog - Rte26	
Ahau Lane - House # 141D	1,440
Minor leaks (6)	1,620
Dededo - Rte3	
Minor leaks (3)	1,440
Dededo - Wusstig Road Left side	
Minor leaks (2)	720
Northern	
Dededo Village	
Minor leaks (2)	360
Dededo - Astumbo Subdivision	
Minor leaks (4)	1,800
Dededo - Ysengsong Road	
Ysengsong Road adjacent to House # 1624	1,440
Dededo - Old Kaiser - Ysengsong Road	
Minor leaks (4)	720
Dededo Village - Kaiser Housing	
Minor leaks (2)	360
Dededo Main Village	
Santa Barbara St - Ysengsong Road	*
Yigo Village	
Chalan Donne St - Across House #134	1,440
Chalan Tun Luis Takano	28,000
Rte 1 - Infront of Well Y-21A	14,880
Pacita Villa	1,440
422 Chalan Padiron Lagu	1,440
Minor leaks (10)	1,690
Yigo – Rte 9 Agafu Gumas	
Azud Ave	1,440
Yigo – Machananao	
Gill - Baza Subdivision	4,800
Total	~600,000

* Follow up assessment required by leak detection investigation team
Minor leak Classification = <1000 gpd

4.2.3 Develop Information Necessary to Complete a Comprehensive Water Distribution System Audit

The IWA audit format is being updated currently in the AWWA Manual M36. This section provides an outline of the Water Audit format and corresponds to the master table input values and definitions. The purpose is to aid in calculations in the form of a summary containing general guidelines, definitions, place-holder text and recommendations for completing this audit format. Data collected by GWA staff in 2006 that follow recommendations listed above and pertain to specific sections listed below should be done in the future to continue to track "non-revenue" water and achievements to reduce water losses.

Table 4-2 provides a summary of the format of the IWA's guidance for a water distribution system audit. The following subsections need to be updated and Table 4-2 completed by GWA upon completion of a Comprehensive Water Distribution System Audit. Data limitations are hindering currently the calculation of key parameters for the water. As a result, the following discussion is focused on specific recommendations for gathering the necessary data to complete the water audit in the future.

Table 4-2 - IWA Water Audit Format[1]

<table>
<tr><td rowspan="6">Raw Water Sources
____
MGD
_____
MG/YR
1</td><td rowspan="6">System Input
MGD
MG/YR
2</td><td rowspan="3">Authorized Consumption
____
MGD
_____
MG/YR 3</td><td>Billed Authorized Consumption
___
MG/YR 5</td><td>Billed Water Exported 6</td><td rowspan="3">Revenue Water
____
19</td></tr>
<tr><td></td><td>Billed Metered Consumption 7</td></tr>
<tr><td></td><td>Billed Unmetered Consumption ? 8</td></tr>
<tr><td rowspan="3">Water Losses
___MGD
___%
4</td><td>Unbilled Authorized Consumption
MG/YR 9</td><td>Unbilled Metered Consumption 10</td><td rowspan="4">Non-Revenue Water
_____
20</td></tr>
<tr><td></td><td>Unbilled Unmetered Consumption 11</td></tr>
<tr><td>Apparent Losses ? 12</td><td>Unauthorized Consumption ? 13
Customer Metering Inaccuracies 14</td></tr>
<tr><td>Real Losses
_____ 15</td><td>Leakage on Mains 16
Leakage and Overflows at Storages 17
Leakage on Service Connections up to Customer Metering 18</td></tr>
</table>

Note: ***Leakage – miles of pipe by density of connections – I have tables that you can measure leakage and losses by leaks on laterals.
1. Source: AWWA Journal Volume 95:8. August 2003. Peer-Reviewed. Committee Report: Applying worldwide BMPs in Water Loss Control.

The following steps outline the basic definitions of terms used in Table 4-2, with numbers in each box corresponding to the numbers assigned to steps below. The general methodology for data collection and/or calculations is also described under each step to assist with performing comprehensive water system audit in the future.

Step 1. Determine Raw Water Sources

Sum all potable water entering the system including wells, reservoirs, tunnels, shafts and other sources adjusted for transmission system losses, meter accuracy and downstream diversions.

Step 2. Determine System Input

Adjust the raw water source measurements to determine actual system input. The following may be applicable:

- Contributions from reservoirs for this audit should be included from a study of telemetered data and adjusted if reading is above the flow meter readings, or under registering.
- The recommendation for 2007 is to complete one cycle of checking all facilities throughout the island to gather baseline information for future years. Water loss control is important enough that outside resources might be required if GWA staff cannot allocate sufficient time. In addition, a regular source meter calibration program needs to be developed, adopted and implemented, preferably by the GWA staff.
- Determine accuracy of source meters (reference AWWA Manual M33: Flowmeters in Water Supply, Second Edition). The typical estimated differences can range up to 10 percent. These validations have not been completed by GWA. It is recommended to conduct a small pilot to compare the telemetered data (SCADA) with ultrasonic and magnetic flow tests at the facilities when the SCADA system is back in operation. Upon completion of this evaluation/calibration, the following information should be collected to determine appropriate adjustments to meter measurements:
  - The average meter readings under-registering as an average percent and over-registering given as a percent. It is difficult to apply this across the island because each well contributes different amounts of flow. However, each meter adjustment should be applied to measured flow from the corresponding well.
  - The apparent water loss due to over- and under-meter registration is determined as an accumulated total system input adjustment across the island and results in the following:
    - Total under-registered source meter flow
    - Total over-registered source meter flow
    - Total adjusted system input (mgd)

Step 3. Determine Authorized Consumption

The authorized consumption is the sum of all billed and unbilled authorized consumption, including GWA use, fire flow, and other identified uses.

Step 4. Total Water Losses

Total water loss is the sum of all apparent losses, including unauthorized consumption from theft and meter inaccuracy from Step 12, plus all real losses from distribution system overflows and leakages (i.e. mains, storage tanks, laterals, service connections, etc.) up to the customer meter from Step 15. The difference between total system input and authorized consumption should equal the sum of apparent and real water losses.

Step 5. Billed Authorized Consumption

Sum Steps 6, 7, and 8 as applicable.

Step 6. Billed Water Exported

Not applicable for GWA.

Step 7. Billed Metered Consumption

Billed water exported and billed metered consumption (including estimates for inaccuracy in residential meter readings and in large meter readings based on AWWA cold water meter testing protocol from AWWA Manual M6: Water Meters: Selection, Installation, Testing, and Maintenance (M6), Fourth Edition, 1999):

- Total billed authorized consumption, excluding reservoir fill and depletion rates/quantities for the audit. (The assumption is made that reservoir fill and depletion rates will balance each other out.)
- Distribution water loss without adjustments.

Adjustments:

- Meter accuracy
  - Estimate residential meter error as +/- percent due to the accuracy of AMR and the age of the meters (majority under 10 years of age).
  - Large meter error +/- percent partially due to age and to human error in recording.
  - Recommendation is to continue to communicate with the field services manager for large meters and work to establish meter accuracy.
- Expressing the magnitude of potential impact of meter accuracy, the apparent loss of the over- and under-registration of residential and large meters is applied across the three systems and results in adjusted billed authorized consumption (mgd) for both residential and large commercial and industrial metered connections.

Step 8. Billed Unmetered Consumption

Estimate amounts of use based on customer type (allotment).

Step 9. Unbilled Authorized Consumption

Sum the unbilled metered and unmetered consumption estimates from Step 10 and Step 11 and subtract the total billed authorized consumption determined in Step 5.

Step 10. Unbilled Metered Consumption

- Some special rate customers are labeled as free service and will continue to be tracked and documented for water audit purposes.
- There are other known situations of unbilled and unmetered service as in the case of the industry or military uses. To date, GWA has not registered or documented any of this use.
- All water should be metered, including free service. The customer will need to be issued a meter just like a building contractor would. This is a quick and economical recommendation using the procedures developed by other utilities as examples for issuing temporary meters.

Step 11. Unbilled Unmetered Consumption

Sum the unbilled, unmetered consumption from the estimated use from GWA facilities (including hydrant and pipeline flushing) and certain fire fighting and training uses. The Fire Department water use should be estimated in MG/year.

- GWA should meet with the fire chief and communicate the need for all battalions to track their water usage and explain the purpose of the audit.
- Existing pipeline flushing quantities are estimated in MG/year and are of low confidence. GWA should be following standard Water System Operator requirements for flushing water lines at 2.5 feet/second (ft/s) and record the estimated duration of the flush to be six hours each day for three consecutive days. For greater accuracy, GWA should meter each flush. Until this can be implemented, each inspector at the job should take notes on the actual duration of the flush and estimate the quantity in gpm through inspection or through a meter if possible.
- There are also mains that are flushed regularly for water quality reasons. These flushes are not measured, but should be in the future.
- Each main that is flushed should be logged by the person opening and closing the valve. Staff from GWA should be on-site when any main is being flushed and should measure this flow and apply the flowrate (e.g., monthly, weekly ,etc.).

Step 12. Apparent Losses

Apparent water losses are the sum of all losses due to customer meter error or theft, from measured and estimated values. This term replaces a portion of the previous "unaccounted-for-water" terminology used in historic statistical reports.

Step 13. Unauthorized Consumption

Sum all unauthorized use from theft including illegal connections, unmetered fire hydrant use and hydrant openings. This has not been addressed at this time. GWA does know that there are unauthorized taps in the system. GWA should identify these illegal connections and estimate the volume and revenue losses.

Step 14. Customer Metering Inaccuracy

Estimate water loss due to meter error adjustments.

- Residential meter error, expressed as a +/- percent multiplied by total residential water demand.
- Large meter error, expressed as a +/- percent multiplied by total large customer water demand (all metered demand other than residential).

Step 15. Real Losses

Real losses equal the sum of all unbilled water use, whether accounted for or not. It includes estimates of known losses such as leakage from open-cut reservoirs and other facilities, reservoir overflows, unavoidable pipeline leakage and service and main breaks. The term "water loss" replaces a portion of the previous "unaccounted-for-water" terminology used in historic statistical reports.

Step 16. Leaks from Mains

Leaks from mains equal the sum of all water losses due to transmission and distribution pipeline leaks and breaks. It includes the following:

- Estimated total of non-visible leaks (high confidence) in MG/year. This includes lateral leaks as well as distribution main leaks.

- Leaks from mains equal the sum of all water losses due to transmission and distribution pipeline leaks and breaks. It includes the following:
  - Estimated total non-visible leaks (high confidence) in MG/year. This includes lateral leaks as well as distribution main leaks.
  - Estimated losses from main failures (high confidence in the values) in MG/year. Using the Greely formula, it is possible to test situations where SCADA data could be compared.

Step 17. Leaks and Overflows at Storage Reservoirs

Water loss from leaks and overflows at storage reservoirs is the total estimated or measured water loss from storage tanks and terminal storage reservoirs in MG/year.

Step 18. Leaks from Service Connections up to Customer Meter

Water loss from service connections is the estimated and measured water loss on laterals from main to customer meter.

For 2006, these lateral leaks should be included in the total for leaks from mains. A baseline of how much lateral leaks contribute to overall leakage in the system should be established. A target area for high return should be the Central System with a high number of large meters using Navy purchased water.

Step 19. Revenue Water

Sum of all Billed Authorized Consumption (see Step 5)

Step 20. Non-Revenue Water

Sum of unbilled authorized consumption from Step 9 and total water losses from Step 4.

4.3 Conclusions

The following conclusions can be drawn from the assessment of water loss from GWA's system:

- Water losses are estimated at approximately 50 percent of total system production.
- Water loss control needs to be a high priority program for GWA.

4.4 Recommendations

The following recommendations are provided to address the high percentage of water loss in GWA's system:

- GWA should implement an aggressive, high-priority water loss control program.
- The program should make the Central System the top priority because the water purchased from the U.S. Navy is the most expensive water.
- Water leak repair and line replacement should be coordinated closely with other needs such as 2-inch line replacement and improvements to meet fire flow and pressure standards.
- A 20 percent loss control program goal should be the targeted for the first five years.

4.5 CIP Impacts

The results of a water loss correction program will impact future water needs. If GWA can achieve the 20 percent program goal, new water sources for the year 2026 will not be necessary. Given the

uncertainty of GWA's ability to achieve water loss of 20 percent in 4 to 5 years, a more conservative reduction in water losses is used in projecting water demands for the CIP.

References

- AWWA Manual M36: Water Audits and Leak Detection. 1999 (currently under rewrite, new version pending).
- AWWA Manual M6: Water Meters: Selection, Installation, Testing, and Maintenance (M6), Fourth Edition, 1999.
- AWWA Manual M33: Flowmeters in Water Supply, Second Edition, 2006.
- AWWA Manual M22: Sizing Service Lines and Meters, 2003.
- *Guam Waterworks Authority – Water Leak Detection Study on All Three Public Water System*, dated September 12, 2005.
- Thorton, Julian. Water Loss Control Manual. 2002.