# Water Commission Agenda
## Regular Meeting
## 7:00 p.m. – September 12, 2016

**An update occurred on September 12, 2016 to correct the location of the Water Commission Meeting**

**2nd Floor Conference Room, Santa Cruz Public Library, Downtown Branch**
**224 Church Street**
**Santa Cruz, California 95060**

Water Department

## Agenda

**Call to Order**

**Roll Call**

**Presentation** *Organized groups may make presentations to the Water Commission. Presentations that require more than three minutes should be scheduled in advance with Water Department staff.*

**Statements of Disqualification** *Section 607 of the City Charter states that "…All members present at any meeting must vote unless disqualified, in which case the disqualification shall be publicly declared and a record thereof made."*

*The City of Santa Cruz has adopted a Conflict of Interest Code, and Section 8 of that Code states that no person shall make or participate in a governmental decision which he or she knows or has reason to know will have a reasonably foreseeable material financial effect distinguishable from its effect on the public generally.*

**Oral Communications** No action shall be taken on this item.

**Announcements** No action shall be taken on this item.

**Consent Agenda** (Pages 1-6)

*Items on the consent agenda are considered to be routine in nature and will be acted upon in one motion. Specific items may be removed by members of the advisory body or public for separate consideration and discussion. Routine items that will be found on the consent agenda are City Council Items Affecting Water, Water Commission Minutes, Information Items, Documents for Future Meetings, and Items initiated by members for Future Agendas. If one of these categories is not listed on the Consent Agenda then those items are not available for action.*

1. City Council Actions Affecting Water ✰ (accept info) (Pages 1-2)
2. Approve the August 1, 2016 Water Commission Minutes ✰ (Pages 3-6)

**Items Removed from the Consent Agenda**

**General Business** (Pages 7-210)

*Any document related to an agenda item for the General Business of this meeting distributed to the Water Commission less than 72 hours before this meeting is available for inspection at the Water Administration Office, 212 Locust Street, Suite A, Santa Cruz, California. These documents will also be available for review at the Water Commission meeting with the display copy at the rear of the Council Chambers.*

3. Presentation on Loch Lomond ADA Improvements (Pages 7-8)
Recommendation: Receive presentation on the ADA improvements at Loch Lomond Recreation Area.

4. System Water Loss Evaluation ✰(Pages 9-188)

Recommendation: Receive presentation on the System Water Loss Evaluation project.

5. WSAS Quarterly Review ✰(Pages 189-210)

Recommendation: Receive information regarding the status of the various components of the Water Supply Augmentation Strategy and provide feedback.

**Subcommittee/Advisory Body Oral Reports**

**Director's Oral Report** No action shall be taken on this item.

**Adjournment** The next meeting of the Water Commission is scheduled for October 3, 2016 at 7:00 p.m. in the Council Chambers.

✰Denotes written materials included in packet

**APPEALS** - Any person who believes that a final action of this advisory body has been taken in error may appeal that decision to the City Council. Appeals must be in writing, setting forth the nature of the action and the basis upon which the action is considered to be in error, and addressed to the City Council in care of the City Clerk.

Other - Appeals must be received by the City Clerk within ten (10) calendar days following the date of the action from which such appeal is being taken. An appeal must be accompanied by a fifty dollar ($50) filing fee.

**WATER COMMISSION REPORT**

DATE: August 24, 2016

TO: Water Commission

FROM: Rosemary Menard
Water Director

SUBJECT: City Council Items Affecting Water

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**August 23, 2016**

2015 Urban Water Management Plan Update (WT)
**Resolution No. NS-29,133 was adopted** adopting the 2015 Urban Water Management Plan and authorizing the Director of Water to file a copy of the plan with the California Department of Water Resources.

Conduct a Public Hearing Required to Adopt a Resolution Establishing a New Water Rate Structure and Adjusting Water Rates and Charges, Monthly Ready-to-Serve Charges Beginning on October 1, 2016, for Five Consecutive Years and Continuing the Drought Cost Recovery Fee (WT)
**Resolution No. NS-29,134 was adopted** establishing a New Water Rate Structure and Adjusting Water Rates and Charges, Monthly Ready-to-Serve Charges effective October 1, 2016 and for Five Consecutive Years with rate increases scheduled for July 1, 2017, July 1, 2018, July 1, 2019, and July 1, 2020; and continuing the existing Drought Cost Recovery Fee schedule with implementation if and as needed as authorized by the City Council during the period October 1, 2016 through June 30, 2021; and rescinding Resolutions Nos. NS-29,012, NS-28,836 and NS-26,803.

**Motion carried** to accept the Cost of Service Report prepared by Raftelis Financial Consultants, Inc. which provides the basis for the proposed water rates and structure for the next five years.

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**Water Commission**
**DRAFT**
**7:00 p.m. – Monday, August 1, 2016**
**Council Chambers**
**809 Center Street, Santa Cruz**

## Minutes of a Water Commission Meeting

**Call to Order:** Vice-Chair L. Wilshusen called the meeting to order at 7:02 p.m. in the City Council Chambers.

**Roll Call**
Present: L. Wilshusen (Vice-Chair), D. Baskin, D. Engfer, D. Schwarm, D. Stearns
Absent: W. Wadlow (Chair), A. Schiffrin (both with notification)

**Staff Present**: R. Menard, Water Director; H. Luckenbach, Deputy Director/Engineering Manager; T. Goddard, Administrative Service Manager; K. Moore, Associate Planner II; A. Poncato, Administrative Assistant III.

**Others**: 4 members of the public.

**Presentation**: Presentation by J. Paul and S. McGilvray.

**Statements of Disqualification**: There were no statements of disqualification.

**Oral Communications**: There were no oral communications.

**Announcements**: There were no announcements.

**Consent Agenda**
1. City Council Actions Affecting Water
2. Approve the June 6, 2016, Water Commission Minutes

Commissioner Schwarm moved item 1. City Council Actions Affecting Water of the Consent Agenda. Commissioner Baskin seconded.
VOICE VOTE: MOTION CARRIED
AYES: All.
NOES: None.
ABSENT: W. Wadlow, A. Schiffrin

Commissioner Schwarm moved approval of the June 6, 2016, Water Commission Minutes. Commissioner Stearns seconded.
VOICE VOTE: MOTION CARRIED
AYES: All.

NOES: None.
ABSTAIN: D. Baskin due to absence from the June 6, 2016, Water Commission meeting
ABSENT: W. Wadlow, A. Schiffrin

**Items Removed from the Consent Agenda**

No items removed from the Consent Agenda.

**General Business**

3. Urban Water Management Plan
Mr. Goddard and Ms. Moore presented an overview of the draft 2015 Urban Water Management Plan and responded to Commissioners questions on this item.

Why was a three drought sequence chosen for this analysis rather than the longer "designer" drought that was analyzed during the WSAC process?

- The drought scenario used in WSAC ranged from 1976 - 1977 and 1987 – 1992. The Department of Water Resources specifically requires suppliers to address a three year drought sequence and historically we have used the 1976, 1977 sequence because it represents the worst case given our historical record.

Regarding the follow-on work that will occur to review and revise if/as needed the City's General Plan's section on Water Policies, will the Water Commission be a part of Water Department policy review process?

- Yes, the Water Commission will play a role in this effort.

On page 7-5 it states that the Water Department is not going to change the place of use when part of our strategy is to change the place of use. Can you please elaborate on this?

> This statement is a result of an internal miscommunication. The City does plan to ask the State Board (Board) to change the places of use for all of its San Lorenzo River water rights to make it available for use in mid and northern Santa Cruz County when it asks the Board to take action on the other three elements of the Water Rights Conformance Project (i.e., direct diversion from Felton, direct diversion from Newell Creek, and an extension of time to fully utilize the Felton Permit water.

Is there any scope for us to expand the rights that we have?

> We have water right allocations, particularly at the Felton Diversion that we have not fully utilized. If we can prove that we have the ability to fully utilize what we currently have and continue to meet fish flow commitments, if we need more water in the future, the chances of being successful in obtaining that water is likely to be higher than it is now.

Please provide insight as to why we do not satisfy the California Urban Water Conservation Council's standard for conservation pricing for sewer service.

- We have a low volume sewer rate but most pay the regular flat monthly rate because the low volume sewer rate is set so low that it is difficult for a household of one or two people to qualify for it. The Public Works Department has never expressed much interest in a more progressive rate structure because they have a lot of revenue stability and they aren't very excited about the prospect of introducing uncertainty into their revenue stream.

In regards to climate change, why is there no mention of the sea level rise issue?

- Climate change is an optional section to the Urban Water Management Plan. When the plan was submitted five years ago, we dedicated an entire chapter to climate change and highlighted the negative impacts of sea level rise to a coastal community. This year we have been asked to address climate change in the Service Area, Climate, Supply, and Demand portions of the Urban Water Management Plan, so it may seem as though the Plan hasn't addressed Climate Change because the discussion is spread out rather than covered all in one place.

In regards to the potential for receiving state funding (grants or loans), are there any items in this Urban Water Management Plan that could limit our ability to access state or federal funding that may be available?

- There is nothing in this plan that will limit our ability to access state or federal grant on loan funding in the future.

**Final Comments and Requests for Follow Up**

- Update the language in table 6-10 to reflect that the 100 million gallons are not necessarily a limit out to 2035, rather a near-term goal.
- Correct the section on page 7-12 that refers to increasing water storage by 1.2 billion gallons. The agreed upon need for approximately 2.4 billion gallons of accessible water in storage can provide for the 1.2 billion to be delivered in a worst case hydrological year.
- Include the Cooperative Water Transfer Pilot Project for Groundwater Recharge and Water Resource Management agreement between the City of Santa Cruz and Soquel Creek Water District in this Urban Water Management Plan.
- Include Appendix 8 from the WSAC report into this Urban Water Management Plan.
- Add a narrative about customer classifications applying to both inside/outside customer's service charges as well as any cost differential between inside and outside customers.

Commissioner Baskin moved that the Commission instruct staff to consider the Commissioner's comments on the draft 2015 Urban Water Management Plan and that the Commission recommend that City Council pass a resolution to adopt the plan and to authorize the Water Department to file a copy with the California Department of Water Resources. Commissioner Stearns seconded.
VOICE VOTE: MOTION CARRIED
AYES: All.

NOES: None.
ABSENT: W. Wadlow, A. Schiffrin

**Subcommittee/Advisory Body Oral Reports** No items.

**Director's Oral Report** No action shall be taken on this item.

- We have been operating solely off of the San Lorenzo river supply. Demand is currently at 8.5mgd.
- The next Water Commission meeting is slated for September 12, 2016. Due to scheduling conflicts we are unable to use the City Council Chambers and will hold the Water Commission meeting in the second floor conference room of the Santa Cruz Public Library.
- Since the Director will not be present at the September 12, 2016, Water Commission meeting, the Public Health Goals Report will be presented at the October 3, 2016, Water Commission meeting.
- A CEC report will be sent to the Commissioners soon and will be released to interested parties in the next week. We are working to create and distribute a Water Quality report geared toward the public and the CEC report will be integrated into this publication.
- September Water Commission meeting agenda items will include the WSAC update and the water loss report.

**Adjournment** Meeting adjourned at 8:36p.m. The next meeting of the Water Commission is scheduled for September 12, 2016, at 7:00 p.m. in the second floor conference room of the Downtown Branch of the Santa Cruz Public Library.

Respectfully submitted,

Amy Poncato

Digitally signed by Amy Poncato
DN: cn=Amy Poncato, o=Water Department, ou=Administration, email=aponcato@cityofsantacruz.com, c=US
Date: 2016.09.08 14:14:53 -07'00'

Staff

CITY OF SANTA CRUZ

WATER COMMISSION
INFORMATION REPORT

DATE: 9/7/2016

AGENDA OF: September 12, 2016

TO: Water Commission

FROM: Matthew Zeman, Engineering Associate

SUBJECT: Accessibility Improvements at Loch Lomond

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RECOMMENDATION: Receive presentation on ADA improvements at Loch Lomond Recreation Area.

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BACKGROUND: Staff has made a number of accessibility improvements at Loch Lomond and the accompanying presentation will provide an overview of those items which include:

- paved and re-stripped the parking lots;
- installed a new ADA and doggy compliant drinking fountain;
- installed pliant porta-potty as well as reconfigure two permanent restrooms which are all ADA compliant;
- construct a decomposed granite path suitable for wheelchair travel from the parking lot to restrooms and the Park store; and
- constructed an ADA view deck overlooking the lake with a wheelchair accessible picnic table.

FISCAL IMPACT: No new funds are necessary to complete the existing work. Phase II may require new funds and will be included in the Capital Improvement Program (CIP).

PROPOSED MOTION: No motion necessary.

ATTACHMENTS: Presentation will be provided at the meeting on September 12, 2016.

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CITY OF SANTA CRUZ

WATER COMMISSION
INFORMATION REPORT

DATE: 9/8/2016

AGENDA OF: September 12, 2016

TO: Water Commission

FROM: Toby Goddard, Administrative Services Manager

SUBJECT: System Water Loss Evaluation

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RECOMMENDATION: Receive presentation on the System Water Loss Evaluation project.

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BACKGROUND: In May 2015, the Water Department contracted with Water Systems Optimization, Inc. of San Francisco, CA to conduct a water loss control study. The project was one of the fundamental measures recommended in the City's Water Conservation Master Plan – that the City contract with a firm specializing in water loss control to examine the City's water system and operations practices to better validate where losses are occurring, evaluate intervention strategies, and set forth a formal strategy to improve water accountability and reduce lost water. In addition, as a member of the California Urban Water Conservation Council, the City is committed to implementing listed Best Management Practices, which requires taking additional steps to support water loss control activities.

The specific goals of the project were to:

1. Complete a comprehensive water audit;
2. Establish internal mechanisms to ensure consistency and reliability of water auditing year to year;
3. Conduct a Component Analysis of real losses; and
4. Design a cost effective water loss control program and recommend improvements in data management.

DISCUSSION: The consultant has more than adequately completed the work specified in its contract and produced two comprehensive reports summarizing its findings and recommendations. The first is labeled "Program Report" and is a shorter, executive summary level report intended for a broad audience. The second is labeled "Analytic Report", which delves into far greater depth and detail about the work that was conducted. That work ranged from multiple tests of the large production meters at the water treatment plant to sonic leak detection of a portion of the distribution system, and assessing real and apparent water losses for the audit period (calendar year 2014). Both reports are included as part of this agenda packet. In addition to the two written reports, the consultant has delivered a number of appendices for reference and use in conducting future water audits.

The project involved an internal team approach that included input and assistance from almost every section of the Water Department, including Administration, Production, Engineering, Distribution and the Meter Shop, Customer Service, and Conservation.

The consultant will be present at the Water Commission meeting to give a presentation and offer an opportunity to answer any questions about the project.

One of the early actions the Water Department is taking in response to the recommendations regards the City's Computerized Maintenance Management System or CMMS. This is an asset management and work order system that was initiated late in 2014 but has not been fully developed. Currently, staff members from the water engineering, distribution, and conservation sections are working with IT and a software implementation consultant to improve the functionality of the system, in part to better capture information about ongoing leak repair activity and associated water losses.

Another activity related to this study is a number of department staff members are currently participating in a Water Loss Technical Assistance Program (TAP) sponsored by the CA-NV Chapter of the American Water Works Association. The Water Loss TAP will specifically aid water suppliers in complying with the provisions of California Senate Bill 555, which established the requirement that each urban retail water supplier, on or before October 1, 2017 (and annually thereafter) submit a completed and validated water loss audit report to the California Department of Water Resources.

The State of California is also looking at minimizing urban water system losses beyond the requirements of SB 555. There is currently an urban advisory group that is working with state agencies responding to portions of Governor's May 9, 2016, Executive Order B-37-16. Among other things, the Executive Order calls for, 1) setting new water use targets based partly on strengthened standards for water lost through leaks, and 2) directing water suppliers to accelerate data collection, improve water system management, and prioritize capital projects to reduce water waste. It remains unclear at this time what new requirements or additional legislation may arise from this process. Nevertheless, the WSO project just completed significantly advances the entire Department's understanding of water losses on the distribution system, provides direction on specific ways to reduce those losses, and puts the City in good shape to respond to the upcoming reporting requirements of SB 555 next year.

*City of Santa Cruz*

Audit Period: 2014

# WATER AUDIT

# &

# WATER LOSS CONTROL PROGRAM

PROGRAM REPORT

AUGUST 2016

WSO

August 24, 2016

Dear Santa Cruz Staff,

Over the past year, Water Systems Optimization and the City of Santa Cruz have partnered to complete a water audit, examine utility data management practices, assess leakage losses, and design proactive and targeted water loss control strategies. Water Systems Optimization is now proud to deliver this Program Report to document the goals, methods, and outcomes of the Water Audit and Water Loss Control Program. This Program Report communicates the most important concepts and findings and is intended to be accessible to all levels of utility management and operations.

Water Systems Optimization also compiled an Analytic Report to accompany this Program Report. The Analytic Report – a separate document – walks the reader through the methodology, data sources, analyses, and itemized findings relevant to the Water Audit and Water Loss Control Program. Water Systems Optimization intends for the Analytic Report to serve as a "customized water auditing manual" that Santa Cruz can reference when compiling future water audits and endeavoring to maintain an economically-efficient water loss profile. Additionally, the lower-priority data management findings and recommendations are detailed in the Analytic Report.

It has been a pleasure to work with Santa Cruz staff over the past year. Our work has benefitted from the enthusiasm and initiative demonstrated by employees in all departments. We are inspired to see how staff commitment translates to effective system management. Through the water audit, Component Analysis of Real Losses, and pilot leak detection, Water Systems Optimization has determined that Santa Cruz's distribution network is operating close to an Economic Level of Leakage. Water Systems Optimization hopes that the results of the Water Audit and Water Loss Control Program empower Santa Cruz to maintain its performance, continue to hone data management systems and practices, and capture snapshots of system efficiency with greater accuracy.

Should you have any questions about the information and findings contained in these reports, please do not hesitate to reach out. We're always excited to talk about water loss control!

Sincerely,

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## List of Acronyms and Abbreviations

**AWWA**: American Water Works Association
**CARL**: Current Annual Real Losses
**CCF**: hundred cubic feet
**CIP**: Capital Improvement Program
**gal**: gallons
**gpm:** gallons per minute
**ILI:** Infrastructure Leakage Index
**MG**: million gallons
**PSI**: pounds per square inch
**SCADA**: Supervisory Control and Data Acquisition system
**UARL**: Unavoidable Annual Real Losses
**WSO**: Water Systems Optimization

# 1 GOALS

**Water Systems Optimization (WSO) partnered with the City of Santa Cruz ("Santa Cruz") to conduct a thorough water audit and develop a water loss control program.** The project had four goals:

1. Complete a comprehensive water audit.
2. Establish internal mechanisms to ensure consistency and reliability of water auditing year-to-year.
3. Conduct a Component Analysis of Real Losses.
4. Design a cost-effective water loss control program and recommend improvements in data management.

Water audits and component analyses usually study a 12-month period. Therefore, **WSO and Santa Cruz selected calendar year 2014 (January 1, 2014 to December 31, 2014) as the audit period.**

# 2 METHODS

In the Water Audit and Water Loss Control Program project, **WSO and Santa Cruz completed four primary investigations of system efficiency and data management practices**:

1. American Water Works Association (AWWA) water audit
2. Component Analysis of Real Losses and leak detection pilot
3. Field tests of instrument accuracy
4. Economic analyses of water loss control activities

Each of these project activities is described on the following pages.

## Water Audit

To identify the volumes of Real Loss and Apparent Loss in Santa Cruz's system, WSO completed an American Water Works Association (AWWA) water audit. **Water auditing aims to accomplish three objectives:**

1. **Account for all volumetric inputs and outputs** in a system during an audit period to derive volumes of water loss.
2. **Study the reliability and accuracy of audit data sources** to document the introduction of potential uncertainty and correct for known errors, where possible.
3. **Communicate system efficiency** with a suite of calculated performance indicators.

A water balance is the primary tool used to complete a water audit. A standard water balance is presented in Figure 1 below. Each column represents an equal volume. In a water balance, a volume of water introduced into a distribution system is broken down into component volumes based on how the water is consumed, or alternatively, lost. Water balancing permits all water to be quantified either by measurement or estimation, and as a result no water is "unaccounted for."

<table>
<tr><td rowspan="9">Water from Own Sources</td><td rowspan="12">System Input Volume</td><td colspan="4">Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td rowspan="11">Water Supplied</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="9">Nonrevenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="7">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="4">Real Losses</td><td>Leakage on Mains</td></tr>
<tr><td rowspan="3">Water Imported</td><td>Leakage on Service Connections</td></tr>
<tr><td>Leakage on Appurtenances</td></tr>
<tr><td>Leakage and Overflow at Storage Tanks</td></tr>
</table>

Figure 1: Standard AWWA Water Balance

Completing a water audit results in an understanding of a utility's water loss profile. Water Losses can be divided into two distinct forms: Apparent Losses and Real Losses.

**Apparent Losses are the volumes of water that are successfully delivered to customers but not measured or recorded accurately**. Often referred to as "paper losses," Apparent Losses come in three distinct forms: customer metering inaccuracies, unauthorized consumption, and systematic data handling errors. Recovering Apparent Losses increases revenue but does not change the volume a utility must produce to meet demand.

**Real Losses are physical losses like leaks, breaks, and overflows**. Recovering Real Losses reduces the volume of water that a utility must produce. As a result, increasing system efficiency by reducing Real Losses can serve as an effective conservation measure. Additionally, conservation through Real Loss reduction is often more cost-effective than demand-side conservation measures since a utility will not experience a reduction in revenue corresponding to decreased customer demand.

To complete Santa Cruz's water audit, WSO used AWWA Free Water Audit Software (version 5.0). AWWA software is considered the industry best-practice tool for water auditing. The software requests inputs that capture audit-period volumes, describe infrastructure and cost parameters, and document data reliability. The software then calculates standard performance indicators and an overall data validity score.

## Component Analysis of Real Losses

A water audit determines the total volume of Real Losses that occurred in a system during a given audit period, but auditing by itself does not provide the detailed insight into leakage necessary for water loss control program design. Therefore, in order to cost-effectively manage water losses, it is important to complete a Component Analysis of Real Losses in addition to a water audit.

**A Component Analysis of Real Losses disaggregates the total volume of Real Loss into distinct sub-volumes of leakage based on the intervention technologies that would most effectively address the leakage.** The component volumes of Real Loss investigated with a Component Analysis are:

- **Reported Leakage**: leakage brought to the utility's attention by staff and customers and best addressed by improving location and repair times
- **Unreported Leakage**: leakage discovered through proactive leak detection and best controlled through leak detection at an optimal survey frequency
    - **Hidden Losses**: leakage that *could* be discovered through proactive leak detection but has not yet been identified; best controlled through leak detection at an optimal survey frequency
- **Background Leakage**: leakage occurring at such low flow rates as to be acoustically undetectable and best controlled through pressure optimization

To complete a Component Analysis of Real Losses, WSO and Santa Cruz modeled Santa Cruz's Background Leakage, investigated Reported Leakage by examining records of leak repair, attributed remaining Real Losses to ongoing Unreported Leakage in the form of Hidden Losses, and corroborated the estimation of Hidden Losses with a pilot leak detection study.

## Field Investigations of Instrument Accuracy

Water auditing and Component Analysis of Real Losses are analytical exercises whose results directly depend on the quality of input data. To study the reliability and accuracy of key instruments informing the water audit, WSO and Santa Cruz:

1. **Tested Graham Hill Water Treatment Plant influent meters** to verify the accuracy of the volume of Water Supplied.
2. **Tested a sample of 75 customer meters and analyzed 214 previous tests** to estimate the volume of Apparent Losses due to customer metering inaccuracy.

## Economic Analyses of Water Loss Control Activities

**Water loss control is the practice of assessing water distribution efficiency, evaluating the economic parameters of system management, and then acting to reduce water losses to an economically-efficient level.**

Effective water loss control offers a host of benefits to a utility, including:

- Water conservation
- Increased revenue
- Reduced operating costs
- Reduced liability
- Improved credibility with stakeholders
- Proactive engagement with infrastructure management

For a water loss control program to be effective, it must be informed and targeted. Therefore, water auditing and Component Analysis of Real Losses are essential first steps in water loss control program design.

### *Apparent Loss Recovery*

Apparent Losses are primarily incurred through customer meter under-registration, as meters tend to decline in registration accuracy as throughput accumulates. Therefore, **meter replacement can recover Apparent Losses and associated revenue.** However, it is important to balance the potential for increased revenue with the costs of meter replacement. As a result, Apparent Loss recovery programs focus on targeting replacement of those meters that under-register beyond a cost-effective threshold.

***Random* and *representative* meter test data is necessary to identify the particular meter populations for which replacement offers a positive return on initial investment.** In the absence of meter test data, Apparent Losses can be valued to provide approximate insight into the scale of Apparent Loss recovery potential, but focused interventions cannot be planned. Should the potential for Apparent Loss recovery seem significant, a utility can study the performance of suspected meter groups with a targeted meter testing program.

### *Real Loss Recovery*

**Real Losses are addressed through three short- to medium-term interventions: pressure optimization, proactive leak detection, and improved leak repair times** (see Figure 2 on the next page). Each water loss intervention aims to reduce the volume of leakage to an economically-optimized level. For most utilities, this Economic Level of Leakage lies between the technical minimum (Unavoidable Annual Real Losses) and Current Annual Real Losses.

Pipeline and other asset replacement also reduces Real Losses, but because this intervention strategy is longer-term and capitally intensive, analysis of asset replacement was not included in the scope of this project. Nonetheless, it is important to acknowledge that Santa Cruz currently replaces assets through its Capital

Improvement Program (CIP) and standard operating budget. Santa Cruz has allocated $3,750,000 in the CIP for water main replacement by city staff and contractors between 2017 and 2019. The Water Main Replacement Plan aims to ensure a safe and reliable supply of water and prioritize the replacement of infrastructure that has the highest likelihood and greatest potential impact of failure. Since 2002, Santa Cruz has replaced 1.5 miles of water main annually on average. Santa Cruz engineers report that to maintain an effective replacement schedule, the recent rate of replacement will need to double to an average rate of 3.0 miles annually. Increasing the rate of main replacement will serve the dual purposes of maintaining the reliability and integrity of supply while also reducing volumes of Real Loss.

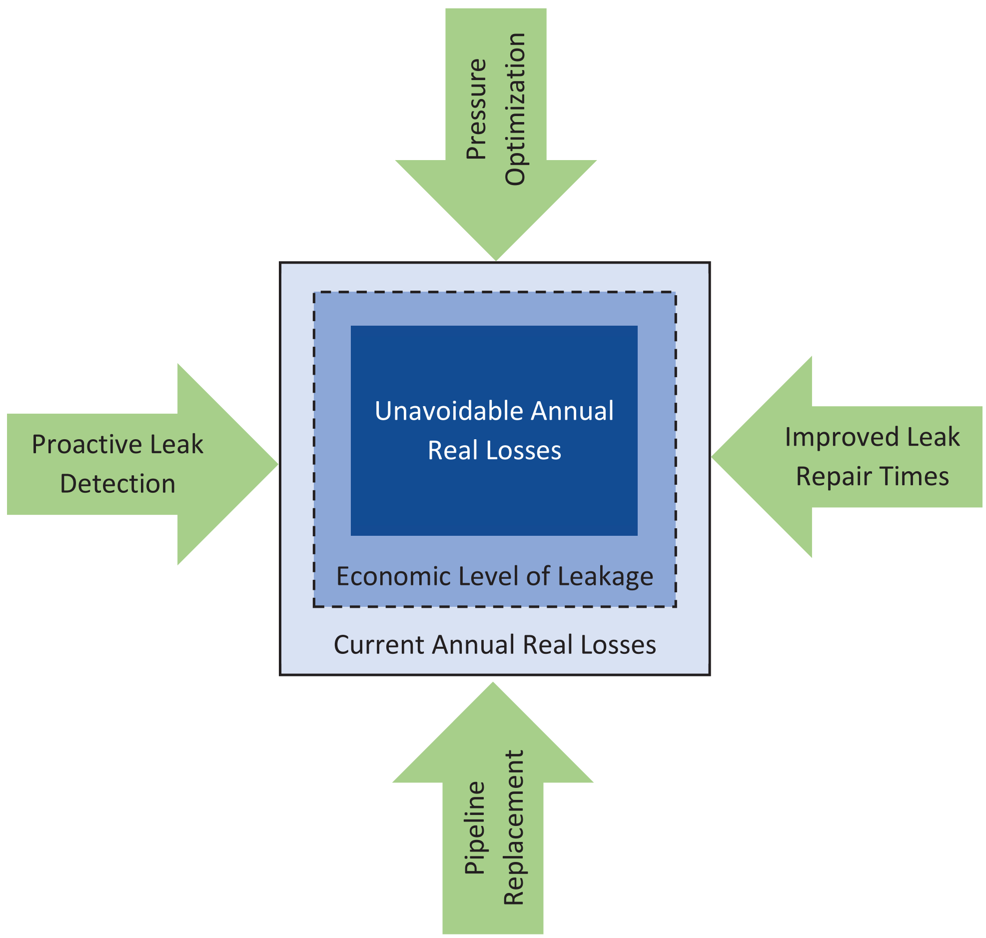


Figure 2: Real Loss Intervention Strategies

**Pressure optimization reduces the volume lost to all three types of leakage** – Background Leakage, Reported Leakage, and Unreported Leakage – by reducing leak frequency and flow rates.

**Proactive leak detection recovers Unreported Leakage**, leakage that has not yet been discovered but is acoustically detectable. A proactive leak detection program is cost-effectively designed to match the expense and frequency of surveying to the value of Unreported Leakage a utility expects to recover. Periodic surveying at an economically-optimized frequency additionally allows a utility to clear the backlog of leakage accumulated prior to proactive leak detection and then study the occurrence of new leakage in the system. An effective leak detection program maintains distribution efficiency at the Economic Level of Leakage.

**Improved leak repair times reduce Reported Leakage** by more quickly containing leaks. In evaluating shortening leak repair times, the cost of additional repair capacity is compared to the value of Reported Leakage a utility expects to recover.

# 3 OUTCOMES

Through the water audit, Component Analysis of Real Losses, field investigations of instrument accuracy, and economic evaluation of water loss control, WSO and Santa Cruz achieved the following outcomes:

1. **The water audit, Component Analysis of Real Losses, and pilot leak detection all indicate that Santa Cruz experienced low levels of leakage during 2014.**
2. Santa Cruz staff are knowledgeable in water audit methodology and have demonstrated their ability to compile thorough, reliable water audits. To reinforce Santa Cruz's own auditing protocols, **WSO recommends a series of data management practices and instrumentation testing procedures that will improve the accuracy and consistency of future audits.**
3. Santa Cruz's archived leak repair records did not allow for a robust Component Analysis of Real Losses because the total count of leaks, leak durations, and infrastructure information were not captured in available data. **WSO recommends repair data management practices that Santa Cruz staff should adapt to the constraints of the work order system to inform future Component Analyses of Real Losses.**
4. The results of customer meter accuracy testing suggest that Santa Cruz receives revenue for almost all of the water it delivers. **WSO recommends that Santa Cruz reinstigate a formal random small meter testing program and targeted large meter testing to maintain customer meter accuracy and revenue generation.**
5. Santa Cruz's 2014 volume of Real Losses matched the system's Economic Level of Leakage. Additionally, the pilot leak detection survey indicated that the volume of Unreported Leakage is too low for proactive leak detection to be cost-effective at this point in time. Therefore, WSO does not recommend the enactment of any new water loss control activities. Instead, **WSO recommends that Santa Cruz maintain current water loss control efforts and monitor system losses annually. Should the volume of Real Losses increase past an economically-efficient level, WSO recommends that Santa Cruz reevaluate the costs and benefits of system-wide proactive leak detection.**

   Additionally, proactive leak detection can serve as an effective tool in Santa Cruz's monitoring of system losses. Surveying a small portion of the system periodically for leaks can confirm efficient performance, as this exercise did during the 2014 water audit project. Furthermore, leak detection can provide insight into the evolution of leakage in Santa Cruz's distribution network.

## Goal 1: Complete a Comprehensive Water Audit

Santa Cruz's 2014 water balance is presented below in Figure 3.

The water audit determined a 2014 Water Supplied volume of 2,603 MG. Of this total, 2,344 MG was Revenue Water. Therefore, the remaining 259 MG was Non-Revenue Water.

<table>
<tr><td rowspan="8">Water from Treatment Plant<br>2,416 MG</td><td rowspan="11">Water Supplied<br>2,603 MG</td><td rowspan="4">Authorized Consumption<br>2,355 MG</td><td rowspan="2">Billed Authorized Consumption<br>2,344 MG</td><td>Billed Metered Consumption<br>2,343 MG</td><td rowspan="2">Revenue Water<br>2,344 MG</td></tr>
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<tr><td>Leakage and Overflow at Storage Tanks</td></tr>
</table>

Figure 3: 2014 Water Balance

Using the water balance, basic infrastructure information, and a handful cost parameters, the AWWA water audit software calculated a suite of standard performance indicators, displayed in Table 1 on the following page.

Table 1: 2014 Performance Indicators

| | 2014 | UNITS |
|---|---|---|
| ***FINANCIAL PERFORMANCE INDICATORS*** | | |
| Non-Revenue as percent by volume of Water Supplied | **9.9%** | |
| Non-Revenue as percent by cost of operating system | **1.4%** | |
| annual cost of Apparent Losses | **$256,200** | *valued at customer retail unit cost* |
| annual cost of Real Losses | **$111,000** | *valued at variable production cost* |
| ***OPERATIONAL EFFICIENCY PERFORMANCE INDICATORS*** | | |
| Apparent Losses per service connection per day | **5.3** | gal / conn / day |
| Real Losses per service connection per day | **22.5** | gal / conn / day |
| Real Losses per service connection per day per PSI of pressure | **0.3** | gal / conn / day / PSI |
| Unavoidable Annual Real Losses (UARL) | **163** | MG / yr |
| Current Annual Real Losses (CARL) | **201** | MG / yr |
| Infrastructure Leakage Index (CARL/UARL) | **1.2** | |
| ***DATA VALIDITY PERFORMANCE INDICATOR*** | | |
| Data Validity Score | **74** | *weighted overall score out of 100* |

To assess performance, WSO recommends that Santa Cruz consider all performance indicators together, with a particular emphasis on Apparent Losses per service connection per day, Real Losses per service connection per day, and the Infrastructure Leakage Index (ILI).

Santa Cruz's water audit results indicate that the system is performing efficiently. WSO interprets Santa Cruz's 2014 performance indicators as follows:

- **The ILI value of 1.2 indicates that Santa Cruz's distribution infrastructure leaked *1.2 times* the system's technical minimum volume of Real Losses during 2014.** Achieving the technical minimum volume of leakage – an ILI of 1.0 – is rarely cost-effective. Rather than pursue an ILI of 1.0, WSO recommends that Santa Cruz continue to monitor annual Real Losses to maintain an ILI around 1.2.
- **Real Losses of 22.5 gallons per service connection per day denotes an efficiently-performing system when compared to statewide water audit data.** Water Research Foundation project 4372B examined a multi-year dataset of water audits (63 California utilities included) and determined that the top-performing 20% of California utilities lose less than 25 gallons per service connection per day. The 4372B data was not validated and should therefore be interpreted cautiously. Nonetheless, Real Losses between 20 and 25 gallons per day demonstrate low levels of leakage.
- **Apparent Losses of 5.3 gallons per service connection per day suggests that Santa Cruz is receiving revenue for almost all of the water it delivers.** However, given Santa Cruz's customer retail unit cost and the annual cost of Apparent Losses, studying and then targeting improvement of the accuracy of customer meters – particularly large meters – could recover additional revenue without incurring undue expense.
- **An overall Data Validity Score of 74 communicates that Santa Cruz's water audit data is reliable enough to serve as the foundation of an informed water loss control program, but room for data improvements remains.** A data validity score above 50 suggests that water audit data is sufficiently reliable for a utility to begin water loss control program design, but a program should be orchestrated to collect additional data so that interventions can be refined as better data becomes available.

## Goal 2: Establish Internal Auditing Mechanisms to Promote Consistency and Reliability

WSO and Santa Cruz staff collaborated to complete the 2014 water audit so that future audits are conducted with similar procedures and staff engagement**. Systematically analyzing data and consistently interpreting audit methodology ensures that results are comparable year-to-year.** By employing standard water auditing procedures, Santa Cruz can more confidently attribute changes in performance to actual system conditions, rather than inconsistencies in data or audit procedures.

**WSO observed that Santa Cruz staff are up-to-date on auditing best practices, take pride in their system's efficient performance, and readily engage with recommended procedural improvements.** In compiling the 2014 water audit, WSO and Santa Cruz staff highlighted the following practices to improve and standardize future water audits:

Table 2: Audit Procedure Improvements

| SUBJECT | DESCRIPTION |
|---|---|
| **Influent meter accuracy** | Volumetrically test influent meters at the Graham Hill Water Treatment plant at least annually using the test procedure that WSO and Santa Cruz developed and honed during the spring of 2016. |
| **Plant service meter** | Do not incorporate the bi-directional plant service meter in the Water Supplied volume because water registered by the plant service meter actually circulates in a large closed loop. |
| **Plant consumption** | Do not use a portion of plant service meter registration to estimate treatment plant consumption. Instead, consult with treatment plant staff to determine a more appropriate method of plant consumption estimation. |
| **Production data source** | Until SCADA data reliability is improved, use summaries of production volumes compiled by treatment plant staff instead of raw SCADA data to calculate Water Supplied. |
| **Billing data validation** | Validate billing data annually by counting the number of audit-period account numbers and bills, tracking the prevalence of skipped reads and estimations, and pro-rating billed volumes. |
| **Customer meter accuracy** | Reinstitute random and representative testing of small customer meters, implement a large meter testing schedule, and analyze test results to incorporate volume- and time-weighting in the determination of accuracy. |

## Goal 3: Conduct a Component Analysis of Real Losses

To divide the total volume of Real Losses into actionable component volumes, WSO and Santa Cruz performed a Component Analysis of Real Losses. WSO also conducted a pilot leak detection survey to validate the low level of Real Losses estimated by the top-down water audit.

**The total volume of Real Losses, 199 MG, was determined in the water audit. The total volume of Real Losses was then divided into component volumes using a combination of repair record analysis and modeling.**

Figure 4 provides the results of the Component Analysis, and each leakage volume is described below. **WSO encourages Santa Cruz to interpret the results of the Component Analysis cautiously.** Though WSO modeled the volume of Background Leakage using standard parameters, the remaining Real Losses could not be confidently divided into Reported Leakage and Unreported Leakage due to uncertainty in the retrospective repair records. Therefore, **WSO recommends that Santa Cruz view the volume of Reported Leakage, Unreported Leakage, and Hidden Losses in aggregate as a single volume of "Detectable Leakage"** (shown in shades of blue in Figure 4).

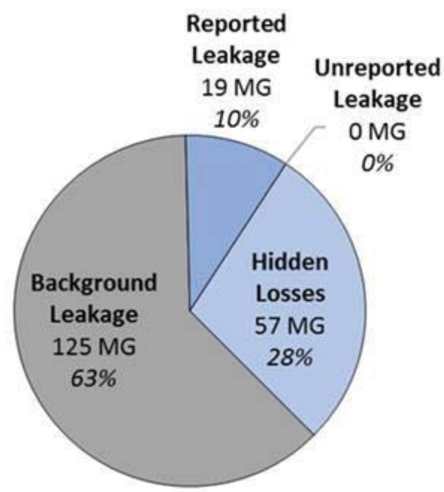


Figure 4: Component Analysis of Real Losses Results

### *Background Leakage*

WSO modeled Santa Cruz's Background Leakage using infrastructure data and an average system pressure of 87 PSI. As expected, **Background Leakage – leakage that is acoustically undetectable and runs continuously at low flow rates – composes the majority of Santa Cruz's leakage volume.** For 2014, Background Leakage was modeled to be 125 MG, approximately 63% of total Real Losses.

### *Reported Leakage*

WSO examined Santa Cruz's archived repair records to estimate the volume of Reported Leakage (leakage brought to Santa Cruz's attention and repaired during the audit period)**. Using repair records in Component**

**Analysis requires that records capture infrastructure type, infrastructure size, and leak duration on a per-failure basis.** Additionally, records must be selected to exclusively represent leakage events and not incorporate flushing and repairs unrelated to water loss.

**Santa Cruz's 2014 repair records were difficult to filter for water loss-related events, and leak type and duration were not consistently documented.** Additionally, the two distinct data sources available to summarize 2014 repair activity did not agree in the count of leaks repaired, as communicated in Table 3.

Table 3: Repair Activity by Data Source

| DATA SOURCE | MAIN BREAKS REPAIRED | SERVICE LINE BREAKS REPAIRED |
|---|---|---|
| summary report of annual repair activity | 37 | 190 |
| work orders | 76 | 35 |

Santa Cruz reported that the work orders may have captured both leak repair and operational activity (Unbilled Unmetered Authorized Consumption), so WSO chose to model Reported Leakage using the summary report of annual repair activity, assumed flow rates, and assumed leak durations.

Though modeling Reported Leakage with uncertain summary data and general parameters instead of detailed repair records produces inexact results, WSO expects that Santa Cruz will be able to perform more robust Component Analyses of Real Losses in future years once improved repair information is available.

WSO and Santa Cruz have engaged with the work order management system and current utility procedures to improve data collection for Component Analysis of Real Losses. **WSO recommends that Santa Cruz adjust the work order management system and repair documentation process to capture the following observations, using a *single work order per failure*:**

- Date and time of leak report initiation
- Source of leak report (e.g. customer service, engineering, field operations)
- Leak location
- Time of leak containment
- Infrastructure type and size
- Occurence of water loss (a yes/no field indicating whether water was lost to leakage, to distinguish leakage losses from water used for operational activities)
- Severity of break (distinct levels indicating priority and extent of loss, with corresponding definitions)
- Cost of repair

### *Pilot Leak Detection*

As indicated in Figure 4, the Component Analysis of Real Losses determined that the majority of Santa Cruz's leakage volume is attributable to Background Leakage running continuously at acoustically undetectable flow rates. Furthermore, the water balance and performance indicators suggest that Santa Cruz currently experiences low levels of leakage.

**To corroborate the findings of the Component Analysis and water audit, WSO performed a pilot leak detection survey of 100 miles of mains (37% of all Santa Cruz mains).** WSO and Santa Cruz staff selected three geographic transects to survey, highlighted in Figure 5, to investigate a variety of pressure conditions, soil types, and pipe age and materials.

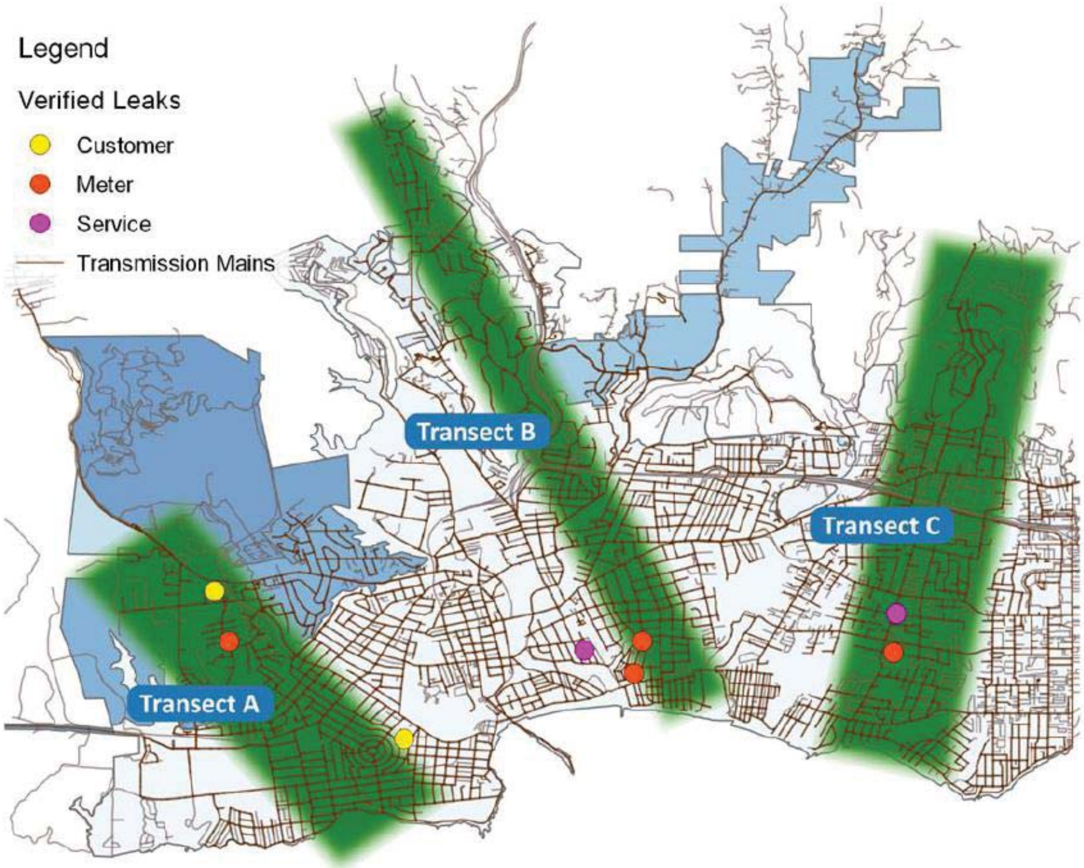


Figure 5: Leak Detection Survey Transects and Results

The leak detection survey discovered six city-side leaks, documented in Table 4, and an additional two customer-side leaks.

Table 4: Leaks Detected

| LEAK TYPE | COUNT | TOTAL ESTIMATED FLOW (gpm) | ANNUAL VOLUME RECOVERED (MG) |
|---|---|---|---|
| meter | 4 | 2.6 | 1.4 |
| service | 2 | 3.5 | 1.8 |
| **TOTAL** | **6** | **6.1** | **3.2** |

**The results of the pilot leak detection survey corroborate the water audit and Component Anaylsis. Santa Cruz's system currently experiences low levels of leakage, and the majority of the leakage that does occur is acoustically-undetectable Background Leakage.**

## Goal 4: Design a Water Loss Control Program and Recommend Improvements in Data Management

Santa Cruz and WSO completed the water audit, Component Analysis of Real Losses, pilot leak detection, and meter tests to establish the foundational information necessary for water loss control program design. Each form of water loss – Real Loss and Apparent Loss – is addressed using distinct tools that recover leakage and promote ongoing water loss monitoring.

### *Real Loss Recovery*

**The water balance, Component Analysis of Real Losses, and pilot leak detection work all indicate that Santa Cruz is operating approximately at the Economic Level of Leakage.** In this situation, pursuing the recovery of Real Losses would cost more than the value of the leakage recovered. Therefore, WSO recommends that Santa Cruz continue to monitor system leakage and intervene if leakage increases. Future interventions should incorporate pressure optimization, improved leak repair times, and proactive leak detection at levels that match the magnitude of losses. Additionally, WSO recommends that Santa Cruz consider performing leak detection of a small and representative portion of the system periodically to corroborate water audit findings, as was conducted for the 2014 water audit.

Furthermore, **higher confidence in the water balance will allow Santa Cruz to act when economically justified**. The largest uncertainty in the 2014 water balance is the accuracy of the Water Supplied volume. To explore the accuracy of the meters informing the Water Supplied volume, WSO and Santa Cruz performed a series of volumetric tests. The precision of the tests were affected by the following conditions:

- Estimation of necessary withdrawals from and supplements to the reference volume due to the water treatment process
- Disagreement of redundant instruments measuring the reference volume

**These test factors allowed WSO and Santa Cruz to conclude that the Graham Hill Water Treatment Plant influent meters register with accuracy close to 100%, but their exact deviance from 100% is not clear even after the series of volumetric accuracy tests.** For treatment plant operations, approximate understanding of the accuracy of the influent meters is sufficient. However, for the water balance, even small inaccuracies in the Water Supplied volume have significant impacts on the derivation of Real Losses. Therefore, **WSO recommends that Santa Cruz continue to test the accuracy of the influent meters, refine estimates and instrumentation in subsequent tests, and consider the installation of a single effluent meter after the treatment process.**

### *Apparent Loss Recovery*

The majority of Santa Cruz's Apparent Losses are attributable to customer meter under-registration. To determine the volume lost to meter inaccuracy and then evaluate meter testing and replacement opportunities, Santa Cruz performed 75 accuracy tests on meters 1" and larger and provided the test results of 214 5/8" meter tests conducted during 2014. Test results are presented in Table 5.

Table 5: Customer Meter Test Results

| SIZE | TESTS | AVERAGE TEST RESULT | CONFIDENCE INTERVAL (±) |
|---|---|---|---|
| 5/8” | 214 | 99.7% | 0.7% |
| 3/4" | 0 | - | - |
| 1” | 34 | 96.3% | 5.6% |
| 1 1/2" | 11 | 98.1% | 2.0% |
| 2” | 17 | 96.3% | 7.8% |
| 3” | 6 | 101.1% | 2.0% |
| 4” | 3 | 95.1% | 8.7% |
| 6” | 2 | 91.4% | 2.0% |
| 8” | 0 | - | - |
| 10” | 2 | 97.7% | 2.6% |
| **TOTAL** | **289** | **98.9%** | **0.9%** |

In using the customer meter accuracy test results to consider Apparent Loss recovery, **it is necessary to appreciate the following qualifications:**

- **The meter test sample was small** when compared to Santa Cruz’s total customer meter stock of about 24,000 meters.
- **Though meters were randomly selected for testing, the overall composition of the test sample is not perfectly representative of Santa Cruz’s meter stock.** The 5/8” tests were conducted to examine the accuracy of Santa Cruz’s older meters, so the accuracy of newer meters is not well represented in the test results. Additionally, no 3/4" or 8” meters were tested.
- Each meter was tested at three flow rates, as recommended by AWWA. Small meter flow rates were weighted using industry-standard time and volume distributions to produce a single average accuracy result for each test. In contrast, large meter flow rates were not weighted; instead, the accuracy result of each test was the simple average of each flow rate’s accuracy. **For test results to describe the interplay of flow rate-dependent accuracy and consumption patterns unique to Santa Cruz’s customers, assumptions about flow rate and time distribution ought to be studied**.

To determine Santa Cruz’s Apparent Loss volume, test results were applied to registered consumption by *meter size* for meters 3/4" and larger and by *meter installation year* for 5/8” meters.

Most 5/8” meter *tests* were conducted on older meters (installed before 2000), and tests of older meters tended to indicate under-registration. In contrast, tests of newer 5/8” meters tended to indicate over-registration, and most 5/8” meters *in the meter stock* were installed during or after 2000. As a result, the 5/8” meter tests, though random, were not representative of the age distribution of the meter stock. This relationship is displayed in Figure 6.

Therefore, **even though the average 5/8” test result suggested under-registration, the total 5/8” meter population was actually estimated to have over-registered slightly during 2014.**

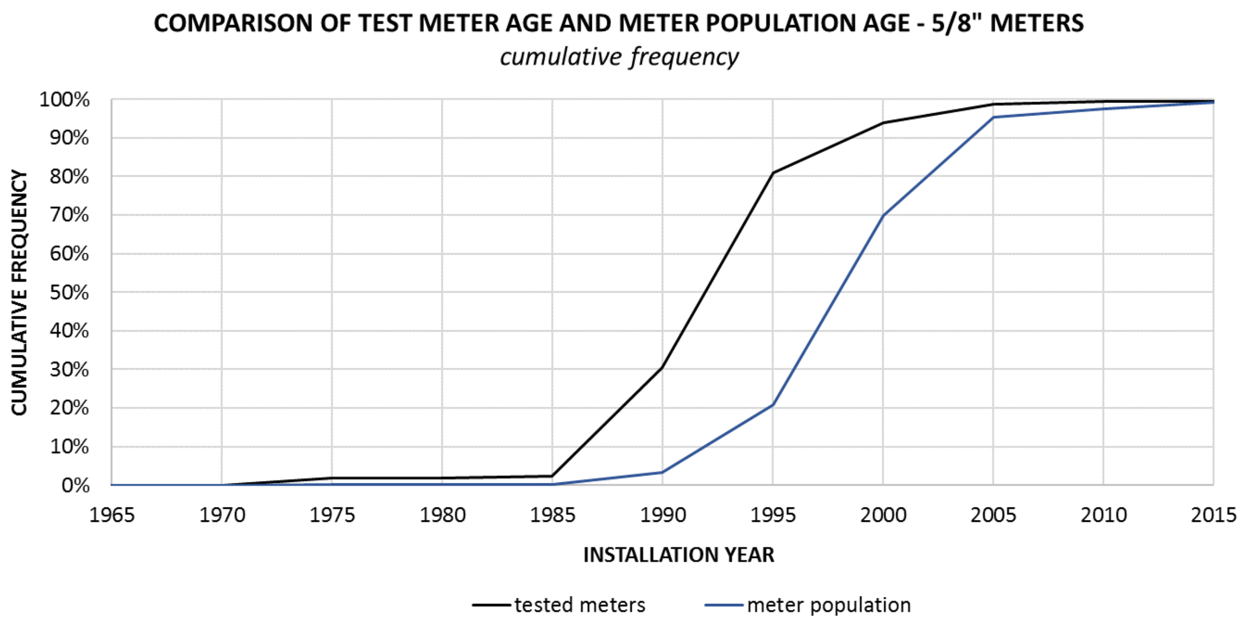


Figure 6: Comparison of Test Meter Age and Meter Stock Age

The results of Apparent Loss analysis are presented in Table 6. **A customer retail unit cost of $4.04 per hundred cubic feet (CCF) was used to value Apparent Losses.** No test data was available for 3/4" and 8" meters, so the average large-meter test result was applied to consumption registered by these meter sizes.

Table 6: Apparent Losses and Associated Revenue Losses

| SIZE | COUNT OF METERS | CONSUMPTION (CCF) | APPARENT LOSSES (CCF) | VALUE OF APPARENT LOSSES | % OF TOTAL |
|---|---|---|---|---|---|
| 5/8" | 21,683 | 1,524,302 | – 1,636 | – $6,608 | – 12% |
| 3/4" | 348 | 29,098 | 956 | $3,862 | 2% |
| 1" | 1,386 | 267,240 | 10,201 | $41,212 | 19% |
| 1 1/2" | 468 | 268,729 | 5,165 | $20,867 | 9% |
| 2" | 405 | 484,876 | 18,571 | $75,027 | 34% |
| 3" | 47 | 170,813 | – 1,854 | – $7,489 | – 3% |
| 4" | 26 | 141,593 | 7,324 | $29,590 | 13% |
| 6" | 13 | 142,839 | 13,522 | $54,630 | 25% |
| 8" | 4 | 2,014 | 66 | $267 | 0% |
| 10" | 3 | 100,580 | 2,392 | $9,663 | 4% |
| unknown | 2 | 313 | 10 | $42 | 0% |
| **TOTAL** | **24,385** | **3,132,397** | **54,719** | **$221,063** | **100%** |

**To gain greater insight into the performance of the meter population, WSO recommends that Santa Cruz continue to test customer meters.** A number of 5/8" meters, *selected randomly and representatively*, should be tested to monitor the accuracy of the 5/8"meter population as it ages. The more meters Santa Cruz is able to test, the better, although staff and financial capacity must be incorporated in determining the scope of meter testing. As as starting point, WSO suggests that Santa Cruz aim to test at least 100 small customer meters annually.

The large meters that see the most consumption should be tested periodically to allow Santa Cruz to intervene when their accuracy – and therefore their ability to generate revenue – deteriorates past acceptable limits. WSO modeled the costs under-registration and maintenance and has identified 22 key large meters that should be prioritized in a large meter testing program. Additionally, meter test results should be tracked in a master document so that the deterioration of each meter can be observed through time and test schedules refined accordingly.

*City of Santa Cruz Water Loss Control Program*

Audit Period: 2014

# WATER AUDIT

# &

# WATER LOSS CONTROL PROGRAM

ANALYTIC REPORT

AUGUST 2016

WSO

WSO

August 24, 2016

Dear Santa Cruz Staff,

Over the past year, Water Systems Optimization and the City of Santa Cruz have partnered to complete a water audit, examine utility data management practices, assess leakage losses, and design proactive and targeted water loss control strategies. Water Systems Optimization is now proud to deliver this Analytic Report to document the methodology, data sources, analyses, and itemized findings relevant to the Water Audit and Water Loss Control Program. This Analytic Report is intended to serve as a customized "water auditing manual" that Santa Cruz can reference when compiling future water audits and endeavoring to maintain an economically-efficient water loss profile.

Water Systems Optimization also summarized the project in a Program Report that accompanies this Analytic Report. The Program Report – a separate documents – briefly outlines the goals, methods, and outcomes of the full Water Audit and Water Loss Control Program. The Program Report communicates the most important concepts and findings and is intended to be accessiblt to all levels of utility management and operations.

It has been a pleasure to work with Santa Cruz staff over the past year. Our work has benefitted from the enthusiasm and initiative demonstrated by employees in all departments. We are inspired to see how staff commitment translates to effective system management. Through the water audit, Component Analysis of Real Losses, and pilot leak detection, Water Systems Optimization has determined that Santa Cruz's distribution network is operating close to an Economic Level of Leakage. Water Systems Optimization hopes that the results of the Water Audit and Water Loss Control Program empower Santa Cruz to maintain its performance, continue to hone data management systems and practices, and capture snapshots of system efficiency with greater accuracy.

Should you have any questions about the information and findings contained in these reports, please do not hesitate to reach out. We're always excited to talk about water loss control!

Sincerely,

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**AP**: audit period
**AWWA**: American Water Works Association
**BABE**: Break and Background Estimate
**BMAC**: Billed Metered Authorized Consumption
**BUAC**: Billed Unmetered Authorized Consumption
**CARL**: Current Annual Real Losses
**CCF**: hundred cubic feet
**conn**: service connection
**EBMUD**: East Bay Municipal Water District
**gal**: gallons
**GDC:** gross daily consumption
**GHWTP**: Graham Hill Water Treatment Plant
**GIS**: Geographic Information System
**gpm**: gallons per minute
**ICF**: Infrastructure Condition Factor
**ILI**: Infrastructure Leakage Index
**IRR**: Internal Rate of Return
**IWA**: International Water Association
**MG**: million gallons
**MGD**: million gallons per day
**ml**: milliliters
**NC:** Newell Creek
**NRW**: Non-Revenue Water
**NPV**: Net Present Value
**PSI**: pounds per square inch
**SCADA**: Supervisory Control and Data Acquisition system
**SIV**: System Input Volume
**SLR**: San Lorenzo River
**UARL**: Unavoidable Annual Real Losses
**UMAC**: Unbilled Metered Authorized Consumption
**UUAC**: Unbilled Unmetered Authorized Consumption
**WSO**: Water Systems Optimization
**WTP**: water treatment plant

# EXECUTIVE SUMMARY

## Project Background

**Water Systems Optimization (WSO) partnered with the City of Santa Cruz ("Santa Cruz") to conduct a thorough water audit and develop a water loss control program.** The Water Audit and Water Loss Control Program had four goals:

1. Complete a comprehensive water audit.
2. Establish internal mechanisms to ensure consistency and reliability of water auditing year-to-year.
3. Conduct a Component Analysis of Real Losses.
4. Design a cost-effective water loss control program and recommend improvements in data management.

Water audits and Component Analyses usually study a 12-month period. Therefore, **WSO and Santa Cruz selected calendar year 2014 (January 1, 2014 to December 31, 2014) as the audit period.**

## Summary of Volumetric Findings

Santa Cruz's water balance is presented in Figure ES.1 on the following page. Each volume in the water balance was individually calculated using all available data and examined for data integrity.

<table>
<tr><td rowspan="8">Surface Water from Treatment Plant<br>2,416 MG</td><td rowspan="11">Water Supplied<br>2,603 MG</td><td rowspan="4">Authorized Consumption<br>2,355 MG</td><td rowspan="2">Billed Authorized Consumption<br>2,344 MG</td><td>Billed Metered Consumption<br>2,343 MG</td><td rowspan="2">Revenue Water<br>2,344 MG</td></tr>
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<tr><td>Leakage and Overflow at Storage Tanks</td></tr>
</table>

Figure ES.1: 2014 Water Balance

Definitions of water balance volumes and their application to Santa Cruz's system are provided below.

- **Water Supplied** is the sum of all *potable* inputs into the distribution system. For Santa Cruz, Water Supplied is composed of calculated potable effluent leaving the Graham Hill Water Treatment Plant, potable water produced and treated at the Beltz Wells and Beltz Well 12, and an adjustment for the change in stored volume during the 2014 audit period.

- **Authorized Consumption** is the volume of water used by registered consumers, including residential customers; industrial, commercial, and irrigation users; and the utility itself. Water used for firefighting and infrastructure maintenance (e.g. distribution main flushing) is also considered Authorized Consumption. Authorization of use can be explicit or implicit. Authorized Consumption is categorized as billed or unbilled and metered or unmetered. Santa Cruz's Authorized Consumption is primarily captured in the billing database, with a few supplemental estimates tracking unmetered and unbilled consumption.

- **Apparent Losses** are the volumes of water that are successfully delivered to customers but not measured or recorded accurately. Often referred to as "paper losses," Apparent Losses come in three distinct forms: customer metering inaccuracies, unauthorized consumption, and systematic data handling errors.

- **Real Losses** are physical losses such as leaks, breaks, and overflows. Mathematically, Real Losses are what remain after Authorized Consumption and Apparent Losses have been subtracted from Water Supplied. Real Losses can also be modeled "bottom-up" using a component analysis of Real Losses. This modeling approach estimates the annual volume of Real Losses by examining the numerous leakage events during the year and estimating each leak's Real Loss volume. To arrive at a volume lost to each leak, repair documentation and modeling assumptions are employed to determine leak flow rate and leak duration.

- **Revenue Water** is the component of Authorized Consumption that generates revenue, primarily Billed Metered Authorized Consumption.
- **Non-Revenue Water** is water that does not generate revenue and consists of Real Losses, Apparent Losses, and Unbilled Authorized Consumption.

## Water Balance Validation

**WSO carefully examined the validity of contributing data sources to ensure that the water balance is as reliable as possible.** Additionally, all water balance volumes are subject to inherent error in measurement and estimation, so volumes are assigned a data validity score based on meter accuracy, the reliability of contributing data sources, and the rigor of data tracking practices.

The primary analyses involved in validating each water balance volume are briefly described below in Table ES.1. Throughout data compilation and analysis, WSO engaged with Santa Cruz staff to document data generation and tracking protocols in order to identify the potential for introduction of volumetric errors. WSO's findings prompted the data management recommendations discussed in this report.

Table ES.1: Key Volume Validations

| VOLUME | VALIDATION |
|---|---|
| Water Supplied | • treatment plant influent SCADA data analyzed for consistency and completeness<br>• well production totals reviewed<br>• influent meters tested for volumetric accuracy<br>• internal production summaries examined for potential omission or double-counting |
| Authorized Consumption | • billing database analyzed for consistency, completeness, boundary sensitivity, and abnormal records<br>• bills apportioned to align production and consumption<br>• inventory of unbilled and unmetered consumption performed, estimates examined |
| Apparent Losses | • sample of meters tested for volumetric accuracy<br>• small and large meter test results extrapolated to all customer meters to estimate meter stock accuracy |
| Component Analysis of Real Losses | • leak repair work orders examined<br>• preliminary Component Analysis completed<br>• pilot leak detection performed to corroborate analytic derivations of Real Losses |

**To improve the validity of future water audits, WSO recommends that Santa Cruz continue to study the accuracy of treatment plant influent meters, install an effluent meter at the GHWTP treatment plant, reinstitute a customer meter testing program, and perform periodic pilot leak detection.** Full recommendations are listed at the end of the executive summary.

## Performance Indicators

Once a water balance has been populated, a series of performance indicators can be calculated that capture water distribution efficiency. These **standard AWWA performance indicators allow utilities to meaningfully track their Water Losses from year to year, and a select few indicators allow utilities to compare their performance to peer utilities**. Santa Cruz's 2014 performance indicators are presented in Table ES.2.

WSO recommends that performance indicators be evaluated as a suite, as no single performance indicator communicates a complete picture of efficiency. Additionally, WSO urges Santa Cruz to employ percentage figures cautiously (e.g. Non-Revenue Water as a percent by volume of Water Supplied) because percentages are heavily influenced by their denominator. In the case of Non-Revenue Water as a percent by volume of Water Supplied, Water Supplied is the denominator and inevitably varies from year to year. Given this variability, simple percentages are not robust indicators of Water Losses. More consistent indicators – like Real Losses per service connection per day and the Infrastructure Leakage Index – are the preferred metrics of operational efficiency.

Table ES.2: 2014 Performance Indicators

| | 2014 | UNITS |
|---|---|---|
| ***FINANCIAL PERFORMANCE INDICATORS*** | | |
| Non-Revenue as percent by volume of Water Supplied | **9.9%** | |
| Non-Revenue as percent by cost of operating system | **1.4%** | |
| annual cost of Apparent Losses | **$256,200** | *valued at customer retail unit cost* |
| annual cost of Real Losses | **$111,000** | *valued at variable production cost* |
| ***OPERATIONAL EFFICIENCY PERFORMANCE INDICATORS*** | | |
| Apparent Losses per service connection per day | **5.3** | gal / conn / day |
| Real Losses per service connection per day | **22.5** | gal / conn / day |
| Real Losses per service connection per day per PSI of pressure | **0.3** | gal / conn / day / PSI |
| Unavoidable Annual Real Losses (UARL) | **163** | MG / yr |
| Current Annual Real Losses (CARL) | **201** | MG / yr |
| Infrastructure Leakage Index (CARL/UARL) | **1.2** | |
| ***DATA VALIDITY PERFORMANCE INDICATOR*** | | |
| Data Validity Score | **74** | *weighted overall score out of 100* |

Santa Cruz's water audit results indicate that the system is performing efficiently. WSO interprets Santa Cruz's 2014 performance indicators as follows:

- **The ILI value of 1.2 indicates that Santa Cruz's distribution infrastructure leaked *1.2 times* the system's technical minimum volume of Real Losses during 2014.** Achieving the technical minimum volume of leakage – an ILI of 1.0 – is rarely cost-effective. Rather than pursue an ILI of 1.0, WSO recommends that Santa Cruz continue to monitor annual Real Losses to maintain an ILI around 1.2. For additional information about the ILI, see Appendix M.

- **Real Losses of 22.5 gallons per service connection per day denotes an efficiently-performing system when compared to statewide water audit data.** Water Research Foundation project 4372B examined a large dataset of water audits and determined that the top-performing 20% of California utilities lose less than 25 gallons per service connection per day. The 4372B data was not validated and should therefore be interpreted cautiously. Nonetheless, Real Losses between 20 and 25 gallons per day demonstrate low levels of leakage.
- **Apparent Losses of 5.3 gallons per service connection per day suggests that Santa Cruz is receiving revenue for almost all of the water it delivers.** However, given Santa Cruz's customer retail unit cost and the annual cost of Apparent Losses, studying and then targeting improvement of the accuracy of customer meters – particularly large meters – could recover additional revenue without incurring undue expense.
- **An overall Data Validity Score of 74 communicates that Santa Cruz's water audit data is reliable enough to serve as the foundation of an informed water loss control program, but room for data improvements remains.** A data validity score above 50 suggests that water audit data is sufficiently reliable for a utility to begin water loss control program design, but a program should be orchestrated to collect additional data so that interventions can be refined as better data becomes available. WSO has provided the rationale for Santa Cruz's 2014 Data Validity Score in Appendix K.

### *Comparison to State Dataset*

WSO recently examined water audits submitted to the California Urban Water Conservation Council in fulfillment of Best Management Practice 1.2. In total, 68 utilities were included in the California set of water audits. Please note that some California utilities that submitted audits are not included in this dataset due to unrealistic audit submissions.

Analysis of this data set determined that **the median California utility loses 36.6 gallons per service connection per day to Real Losses and 7.0 gallons per service connection per day to Apparent Losses**, using 2012 as the study year. Santa Cruz's normalized Real Losses volume of 22.5 gallons per connection per day is about 40% less than the calculated median in California. Additionally, **the median California utility reports an ILI of 2.1**, compared to Santa Cruz's ILI of 1.2. Please note that the audits analyzed to produce these median values were self-reported and therefore have not been validated. As a result, these performance indicator statistics should be viewed cautiously, as suggestive of the potential magnitude of Water Losses seen by California utilities but not indicative of exact values.

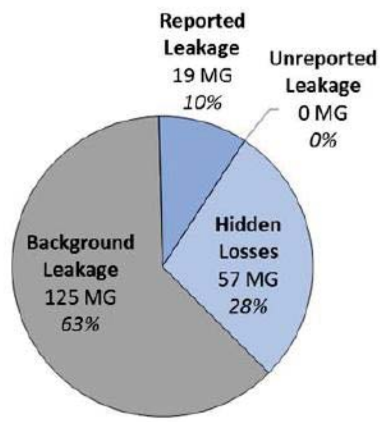
## Component Analysis of Real Losses

In order to intervene against Real Losses, the total volume of Real Losses must first be divided into component volumes based on how Santa Cruz interacts with the leakage. Knowing where and in what form leakage occurs allows intervention strategies to be more effectively and locally applied. **In order to break down Real Losses**

**into distinct leakage volumes, WSO performed a component analysis of Real Losses.** The results of the component analysis are presented in Figure ES.3.

The available 2014 repair data did not allow WSO to confidently calculate the volume of Reported Leakage. Therefore, WSO encourages Santa Cruz to view the volumes of Reported Leakage, Unreported Leakage, and Hidden Losses together as a single volume of "Detectable Leakage" (shown in blue in Figure ES.3).

Figure ES.3: Component Analysis of Real Losses Volumes




## Intervention Strategies

**Each Real Loss component volume responds to specific intervention strategies**. The standard tools for Real Loss control are presented in Figure ES.6.

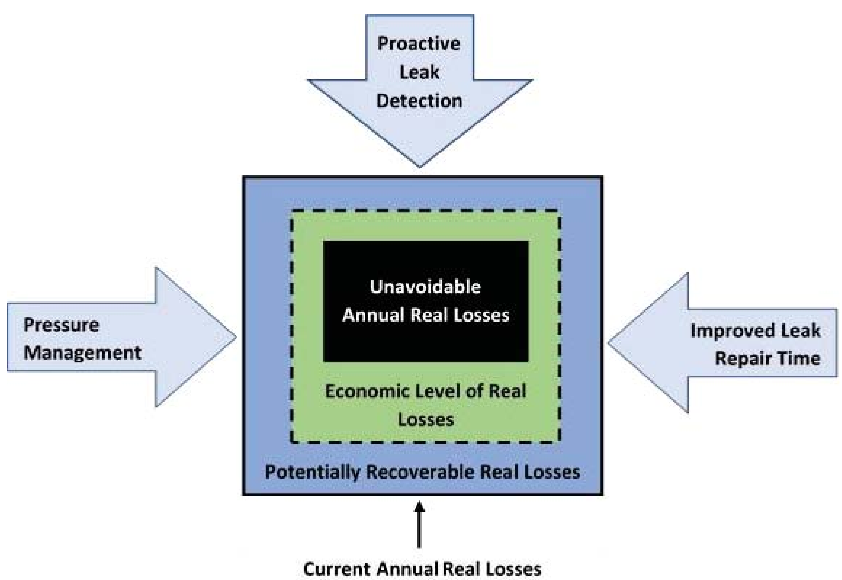



Figure ES.6: Real Loss Intervention Tools

Pressure management reduces all Real Loss component volumes and is the only way to lessen the volume lost to Background Leakage in the short to medium term. Proactive leak detection addresses Hidden Losses, the volume of leakage that is undiscovered and ongoing in the system but makes enough noise to be found through acoustic leak detection. Improved leak repair times reduce Real Losses due to Reported Leakage and discovered Unreported Leakage by reducing the amount of time for which leaks are permitted to run.

**Santa Cruz's volume of Real Losses approximately matches the system's Economic Level of Leakage, given the costs of producing water and intervening against Real Losses**. Therefore, WSO recommends that Santa Cruz continue Real Loss monitoring efforts through annual water auditing, Component Analysis of Real Losses, and pilot leak detection.

## Compiled Recommendations

**WSO recommends that Santa Cruz pursue the following opportunities to improve distribution efficiency and data collection and management.** Enacting these recommendations will improve the accuracy and ease of future water audits and Component Analyses of Real Losses. Recommendations are presented by relevant water balance volume but are otherwise unordered. The recommendations that WSO considers to be most important are highlighted in blue. Descriptions of each recommendation are provided in the body of this report (organized by relevant volume) and in a separate document pertaining exclusively to recommendations.

### *Water Supplied*

1. Trust the summaries of production produced by treatment plant staff over raw SCADA data.
2. Investigate the archival of null values and gaps in the SCADA historian.
3. Be careful using Wonderware reporting and retrieval functions to create production summaries.
4. Revisit the assumption that plant consumption can be derived from plant domestic service.
5. Continue volumetric accuracy testing of the NC and SLR influent meters on an annual basis.
6. Interpret influent meter test results cautiously.
7. Investigate discrepancies in water level measurements captured by the hanging pressure transducer, the hatch-installed pressure transducer, and the SCADA historian.
8. Explore the difference in influent meter flow rates captured by the data logger and by the SCADA historian.
9. Consult treatment plant staff on instrumentation reliability and test interpretation.
10. Consider the benefits of installing and regularly testing an effluent meter on the treatment plant's finished water line.

*Authorized Consumption*

1. Include a Boolean (true/false) field in the EDEN billing database to quickly and easily filter Billed Metered Authorized Consumption-relevant records.
2. Perform the validation checks listed in the Analytic Report when completing an annual audit.

*Apparent Losses*

1. Implement ongoing random and representative small meter testing, to the extent operationally and financially possible.
2. Instigate a large meter testing program that balances revenue lost to meter inaccuracy with the costs of meter testing and replacement.
3. Inform future meter replacement programs with the economic analyses presented in the Analytic Report.
4. Perform a consumption profiling study in order to customize the volumetric weighting factors applied in meter accuracy calculations.

*Water Balance*

1. Perform an annual water audit and repeat the analyses described in the Analytic Report.
2. Focus on improving the reliability of data, using the Data Validity Scoring system as a guide but focusing resources on the particular areas where uncertainty and error are most significantly introduced.

*Component Analysis of Real Losses*

1. Track all repairs in the work order system using a single work order per failure.
2. Program and then use the work order system to capture information necessary for a Component Analysis of Real Loses.
3. Perform future Component Analyses of Real Losses using the modeling parameters outlined in the Analytic Report.

*Leak Detection*

1. Continue periodic pilot leak detection to track leakage and confirm the results of future water audits and Component Analyses.

# 1 Project Background

## 1.1 Goals

**Water Systems Optimization (WSO) partnered with the City of Santa Cruz ("Santa Cruz") to conduct a thorough water audit and develop a water loss control program.** The Water Audit and Water Loss Control Program had four goals:

1. Complete a comprehensive water audit.
2. Establish internal mechanisms to ensure consistency and reliability of water auditing year-to-year.
3. Conduct a Component Analysis of Real Losses.
4. Design a cost-effective water loss control program and recommend improvements in data management.

Water audits and Component Analyses usually study a 12-month period. Therefore, **WSO and Santa Cruz selected calendar year 2014 (January 1, 2014 to December 31, 2014) as the audit period.**

## 1.2 Methods

Water loss control requires an in-depth, reliable understanding of a utility's unique water loss profile. Therefore, before devising targeted water loss intervention strategies, WSO first determined the types and magnitudes of water loss that occurred in Santa Cruz's system during the 2014 audit period. WSO investigated system efficiency and data reliability through four methods:

1. American Water Works Association (AWWA) water audit
2. Component Analysis of Real Losses and leak detection pilot
3. Field tests of instrument accuracy
4. Economic analyses of water loss control activities

### 1.2.1 *AWWA Water Audit*

Water auditing pursuant to AWWA methodology aims to accomplish three objectives:

1. **Account for all volumetric inputs and outputs** in a system during an audit period to derive volumes of water loss.
2. **Study the reliability and accuracy of audit data sources** to document the introduction of potential uncertainty and correct for known errors, where possible.
3. **Communicate system efficiency** with a suite of calculated performance indicators.

A water balance is the primary tool used to complete a water audit. **A water balance is a mathematical summary of all inputs, withdrawals, and losses for a water distribution system.** In a water balance, a volume of water inputted into a distribution system is broken down into component volumes based on how it is consumed or, alternatively, lost. Water balance methodology requires that *all* water be quantified either by measurement or estimation, and as a result no water is "unaccounted for."

A standard water balance is presented below in Figure 1. All complete columns represent equal volumes of water and are therefore "balanced." Note that this water balance is not to scale; the volume of each box does not correspond to the volume of that component. Highlighted in blue are the component volumes that contribute to water losses and non-revenue water, the volumes that WSO's recommendations aim to quantify with greater certainty and reduce.

<table>
<tr><td rowspan="3">Water from Own Sources</td><td rowspan="12">System Input Volume</td><td colspan="4">Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td rowspan="11">Water Supplied</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="9">Water Imported</td><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="9">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="7">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Customer Metering Inaccuracies</td></tr>
<tr><td>Unauthorized Consumption</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="4">Real Losses</td><td>Reported Leakage</td></tr>
<tr><td>Unreported Leakage</td></tr>
<tr><td>Background Leakage</td></tr>
<tr><td>Hidden Losses</td></tr>
</table>

Figure 1: Standard AWWA Water Balance

### 1.2.2 *Component Analysis of Real Losses and Leak Detection Pilot*

A water audit determines the total volume of Real Losses that occurred in a system during a given audit period, but auditing by itself does not provide the detailed insight into leakage necessary for water loss control program design. Therefore, in order to cost-effectively manage water losses, it is important to complete a Component Analysis of Real Losses in addition to a water audit.

**A Component Analysis of Real Losses disaggregates the total volume of Real Loss into distinct sub-volumes of leakage based on the intervention technologies that would most effectively address the leakage.** The component volumes of Real Loss investigated with a Component Analysis are:

- **Reported Leakage**: leakage brought to the utility's attention by staff and customers and best addressed by improving location and repair times
- **Unreported Leakage**: leakage discovered through proactive leak detection and best controlled through leak detection at an optimal survey frequency
- **Background Leakage**: leakage occurring at such low flow rates as to be acoustically undetectable and best controlled through pressure optimization

Both water auditing and Component Analysis of Real Losses are analytic exercises that study archived data to determine a system's Real Loss profile. Upon completing a Component Analysis, **it is important to validate the top-down results with field observations of leakage obtained through pilot leak detection.**

### 1.2.3 *Field Investigations of Instrument Accuracy*

The results of data-driven water loss analysis depend directly on the quality of input data. Therefore, **it is important to validate water audit findings by studying the reliability and accuracy of key instruments.** It is particularly important to understand the performance of system input meters and the customer meter population. Both types of instruments can be volumetrically tested to hone an understanding of their accuracy.

### 1.2.4 *Economic Analysis of Water Loss Control Activities*

**Water loss control is the practice of assessing water distribution efficiency, evaluating the economic parameters of system management, and then acting to reduce water losses to an economically-efficient level.**

Effective water loss control offers a host of benefits to a utility, including:

- Water conservation
- Increased revenue
- Reduced operating costs
- Reduced liability
- Improved credibility with stakeholders
- Proactive engagement with infrastructure management

**Apparent Losses and Real Losses are addressed through distinct intervention strategies.** Each intervention strategy aims to reduce the volume of loss to an economically-optimized level and then track changes in the water loss profile.

Real Losses are recovered through pressure optimization, proactive leak detection, improved leak response times, and targeted infrastructure replacement. Apparent Losses are recovered through strategic customer meter management, rigorous data management practices, and investigations of water theft.

# 2 Water Supplied

## 2.1 Introduction

To begin a water balance, the System Input Volume (SIV) must be calculated. **SIV is the sum of all potable inputs into the distribution system, ordinarily composed of water from wells, treatment plant operation, and bulk water imports.** SIV includes all water sources that a utility owns plus those that it purchases.

Once SIV is known, the volume of Water Exported is subtracted to determine Water Supplied. Water Supplied informs many of the performance indicators calculated in an AWWA water audit, as it is the volume distributed to customers through a utility's own infrastructure and is therefore subject to various forms of water loss.

| | | | | | | |
|---|---|---|---|---|---|---|
| Water from Own Sources | System Input Volume | Water Exported | | | | Revenue Water |
| | | Water Supplied | Authorized Consumption | Billed Authorized Consumption | Billed Metered Consumption | |
| | | | | | Billed Unmetered Consumption | |
| Water Imported | | | | Unbilled Authorized Consumption | Unbilled Metered Consumption | Non-Revenue Water |
| | | | | | Unbilled Unmetered Consumption | |
| | | | Water Losses | Apparent Losses | Customer Metering Inaccuracies | |
| | | | | | Unauthorized Consumption | |
| | | | | | Systematic Data Handling Errors | |
| | | | | Real Losses | *Reported Leakage* | |
| | | | | | *Unreported Leakage* | |
| | | | | | *Background Leakage* | |
| | | | | | *Hidden Losses* | |

Figure 2: Water Balance, System Input Volume Highlighted

In Santa Cruz's case, SIV and Water Supplied are equivalent, since no water is exported.

**Water Supplied is the basis for the entire water balance because known consumption volumes are subtracted from Water Supplied to determine Water Losses**. As a result, WSO carefully examined the validity of contributing data sources when quantifying Water Supplied. Data validity is captured in American Water Works Association Free Water Audit Software that documents Santa Cruz's complete audit and performance indicators.

The contents of this chapter are as follows:

- Section 2.2 – Production Background

- Section 2.3 – Data Sources
- Section 2.4 – Water Supplied Volume Determination
- Section 2.5 – Influent Meter Testing
- Section 2.6 – Recommendations

## 2.2 Production Background

The City of Santa Cruz produces raw water from four sources:

- North Coast (three coastal streams and one spring)
- San Lorenzo River and Tait Wells
- Loch Lomond Reservoir
- Beltz/Live Oak Wells

Santa Cruz relies entirely on rainfall, surface water, and groundwater infiltration. Santa Cruz does not import any water from or export any water to neighboring agencies.

Water produced at the Beltz Wells is treated on-site. Water produced at the original Beltz wells is treated at at the Beltz Water Treatment Plant. Water produced at Beltz Well 12 is treated separately.

Water from the other three sources (North Coast, San Lorenzo River, and Loch Lomond Reservoir) is transported to the Graham Hill Water Treatment Plant (GHWTP) for treatment. Water enters GHWTP through two raw-water influent meters.

The Newell Creek (NC) influent meter registers water sourced from Loch Lomond. The San Lorenzo River (SLR) influent meter registers water transmitted from the Coast Pump Station, which in turn receives water from North Coast, the San Lorenzo River, and the Tait Wells. This arrangement is schematically illustrated in Figure 3.

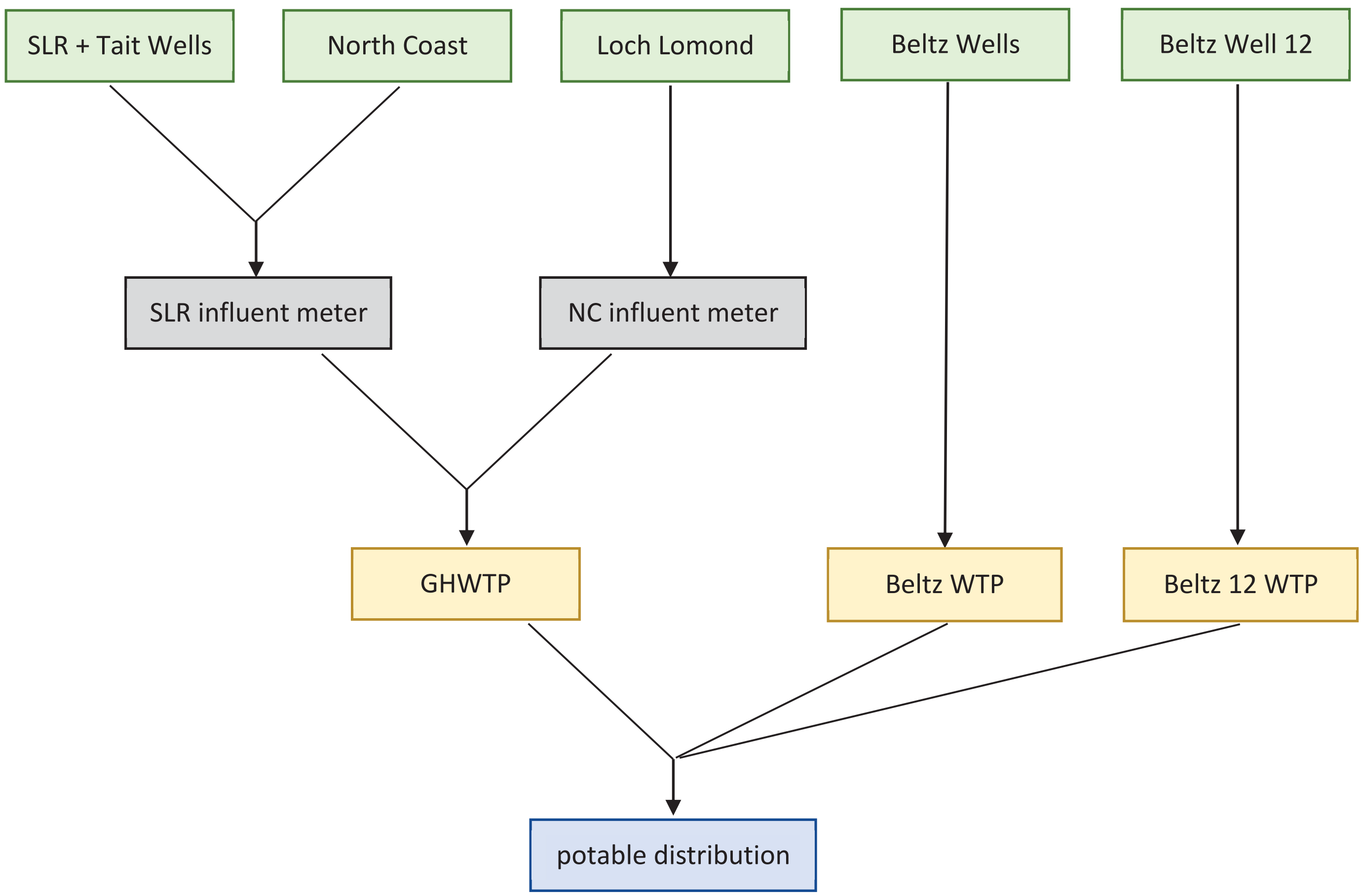



Figure 3: Schematic of Production, Treatment, and Metering

Raw water that enters GHWTP is treated before entering the distribution system. The treatment process results in minor water loss, illustrated in Figure 4. Dashed lines in Figure 4 indicate transmission of *unmetered* water. Of note is the fact that the plant's output to the distribution system is mostly unmetered. Water pumped to the Pasatiempo zone is metered, but water sent to the Gravity and Carbonera Zones is unmetered.

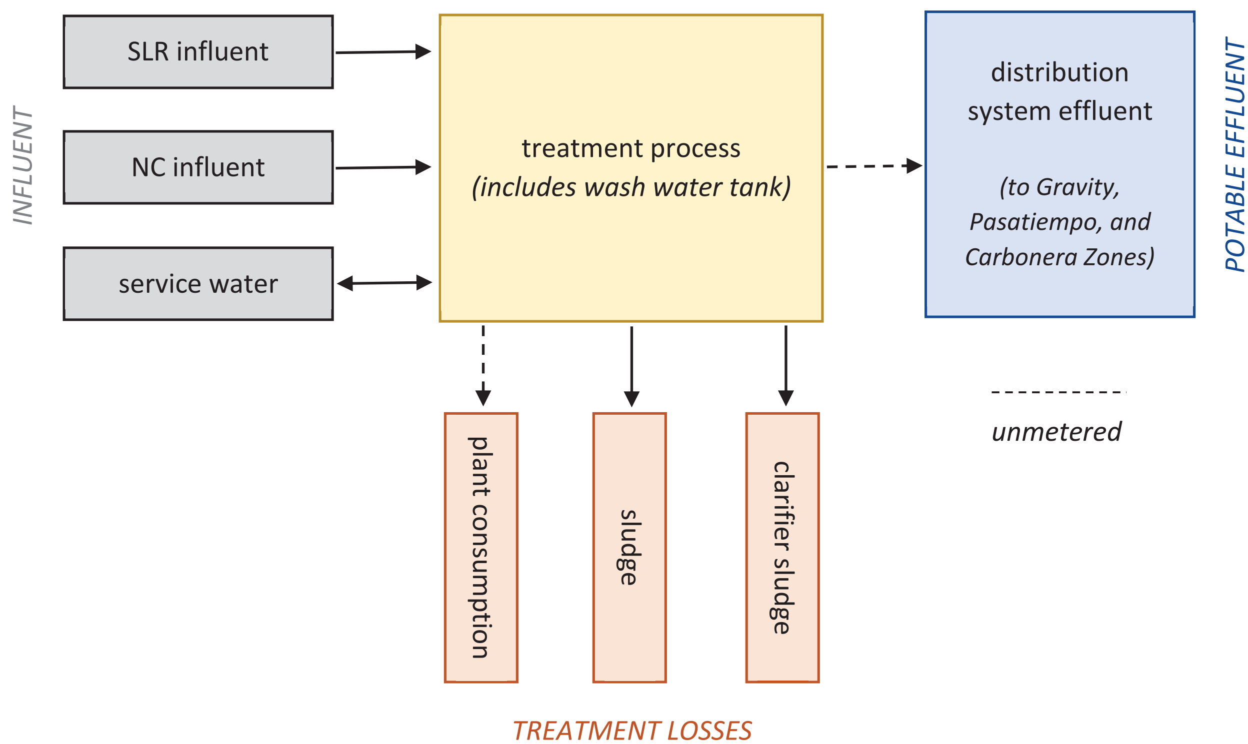



Figure 4: Schematic of GHWTP

The service water meter measures domestic water service bi-directionally into and out of the plant.

Included in unmetered plant consumption is water used in plant bathrooms, sinks, irrigation, and water quality analysis (e.g. turbidity meters, chemical feed water).

To calculate total potable effluent, treatment losses are subtracted from total influent.

## 2.3 Data Sources

In order to thoroughly validate the production volume, WSO collected production data from a variety of sources. **By comparing raw data to SCADA reports and Santa Cruz's own internal production summaries, WSO aimed to identify discrepancies in reported production volumes and any potential introduction of error.**

### 2.3.1 *Key Meters*

Because the water audit is limited to potable water, the determination of SIV was informed by data from meters closest to the point of entry of potable water into the distribution system. Key meters are listed in Table 1 with their SCADA retrieval tags. SCADA only records flow rates, not totalized volumes.

Table 1: Key SIV Meters

| METER NAME | SCADA TAG | SIZE | MANUFACTURER AND MODEL | TYPE |
|---|---|---|---|---|
| SLR influent at GHWTP | SLR Flow MGD at WTP | 18” | Fischer Porter 10D1435A | electromagnetic |
| NC influent at GHWTP | NC Flow MGD at WTP | 18” | Fischer Porter 10D1435A | electromagnetic |
| Domestic Service at GHWTP | Service Water Flow MGD WTP | 6” | McCrometer Ultra Mag UM06-06 | electromagnetic |
| Clarifier Sludge at GHWTP | Clarifier Sludge Flow GPM | 2” | Fischer Porter D1475 | electromagnetic |
| Other Sludge at GHWTP | Sludge Flow GPM | 3” | McCrometer UM06-03 | electromagnetic |
| Beltz Wells finished flow | *not on SCADA* | 6” | McCrometer UM06-06 | electromagnetic |
| Beltz Well 12 | *not on SCADA* | 2”, 6” | McCrometer | |

Santa Cruz has not historically tested the volumetric accuracy of these key meters. However, **to consider meter accuracy for the 2014 water audit, the SLR and NC influent meters were volumetrically tested**. The exact accuracy of the SLR and NC meters could not be determined through the volumetric test, but the tests did determine that the influent meters register close to 100% and within an acceptable range of accuracy for plant operations. The tests are described in detail in Section 2.5.

### 2.3.2 *Santa Cruz Internal Tracking*

Santa Cruz staff provided WSO with their internal production tracking method that has informed past water audits. To calculate SIV for the water audit, Santa Cruz summarizes treated water production on a monthly basis. Inflow to GHWTP and finished flow from the Beltz Wells is totaled, and then GHWTP outflow, consumptive use, and water quality testing volumes are subtracted. This is outlined in Figure 5.

Internal production tracking for the purposes of the water audit (distinct from tracking for plant operation) has not incorporated itemized volumes of chemical feed water, GHWTP service pump delivery, nephelometric turbidity analysis, and lab sink consumption during regular operation. However, these plant uses are considered by plant operators in their accounting of treatment plant volumes.

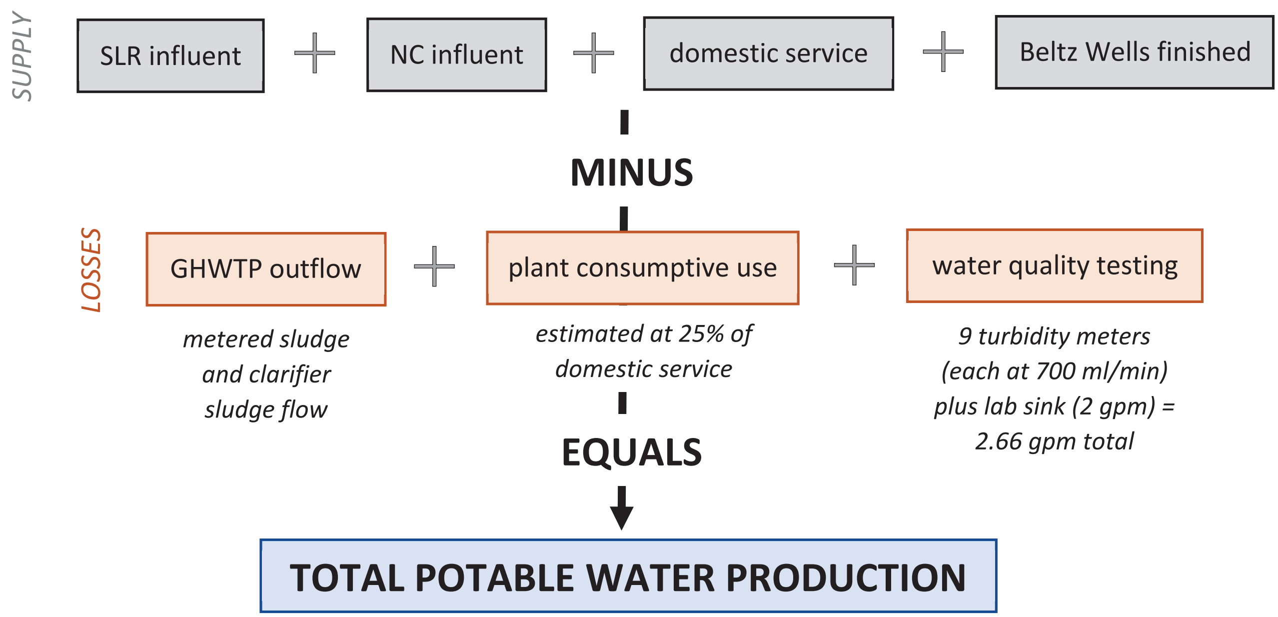



Figure 5: Schematic of Santa Cruz Internal Production Tracking

Monthly summary volumes of treatment plant production and losses are produced and reviewed by treatment plant staff and SCADA technicians. Santa Cruz staff report difficulty with the consistency of the reporting system in recent years after a transition from the previous reporting program to new Wonderware software.

Every couple of days, a state-certified water treatment operator appraises Wonderware production summaries and confirms reproducibility of production totals to check for potential errors. Production is summarized by accessing data with the Wonderware historical viewer using a best-fit retrieval mode. When the technician finds suspect values, he investigates by reviewing Wonderware trending and operator reads at record flow (recorded every two hours). Any gaps in data are filled in using operator read sheets. Reviewed and adjusted production data is captured in monthly spreadsheets (titled “2014 Monthly Production Reports” in this document).

### 2.3.3 *Comparison of Raw Data and Summary Data*

WSO investigated the various sources of production data available. Four primary data sources were examined:

- **SCADA historian exports** – export of raw data at intervals equivalent to the SCADA scan/collection frequency
- **SCADA Wonderware reports** – export of data at one-minute intervals, constructed with historian data and best-fit retrieval functions
- **Manual Gross Daily Consumption Input** – summary document listing plant production rates (MGD), well production, and reservoir levels to estimate gross daily consumption
- **2014 Monthly Production reports** – daily production summary compiled by treatment plant staff on a monthly basis (see Section 2.3.2 for details)

SCADA production data directly exported in a near-raw form, either through the historian or Wonderware, contained data gaps that made it impractical to use raw data alone to summarize production. After review, WSO determined that Santa Cruz's protocol for filling in production data gaps is appropriate and thorough. As a result, WSO employed the tabulations of production volumes provided by GHWTP staff to determine SIV and Water Supplied.

However, in order to explore the potential for introduction of error into production summaries, WSO compared raw data to summary data. In the comparisons, WSO juxtaposed the summary data in the 2014 Monthly Production reports with data from the Wonderware reports (minute intervals) for the SLR influent meter and the NC influent meter. The 2014 audit period totals for each data source are presented in Table 2 and in the following sections.

Table 2: Comparison of 2014 Monthly Production and SCADA Totals

| METER | 2014 MONTHLY PRODUCTION (MG) | SCADA WONDERWARE (MG) | DIFFERENCE (MG) |
|---|---|---|---|
| SLR @ WTP | 2,077 | 2,024 | 53 |
| NC @ WTP | 356 | 312 | 44 |
| **TOTAL** | **2,433** | **2,336** | **97** |

WSO does not at this time have an explanation for the gaps in SCADA data, given that the zeroes and null values could have been introduced by:

- Primary instrumentation (influent meters)
- Data conversion and transmission to SCADA
- Data archival
- Data retrieval

*SLR Influent Meter*

Over the course of the 2014 audit period, the treatment plant staff's 2014 Monthly Production summary recorded 53 MG more production than the SCADA Wonderware report (2,077 MG versus 2,024 MG). The majority of this difference in consumption results from a gap in the SCADA Wonderware data lasting from February 19th to February 25th. Santa Cruz treatment plant staff report that data did not properly archive during this time period, resulting in null values stored in Wonderware. An additional minor gap in SCADA data occurred on April 1st.

Figure 6 compares SCADA data (light blue) and the 2014 Monthly Production summary (black). Additional volume captured by the monthly production summary reports but not in the SCADA data is displayed in black. As previously mentioned, WSO has chosen to use the 2014 Monthly Production summary in calculating SLR influent volume, given the gaps present in SCADA data and the reasonable correction procedures employed by treatment plant staff.

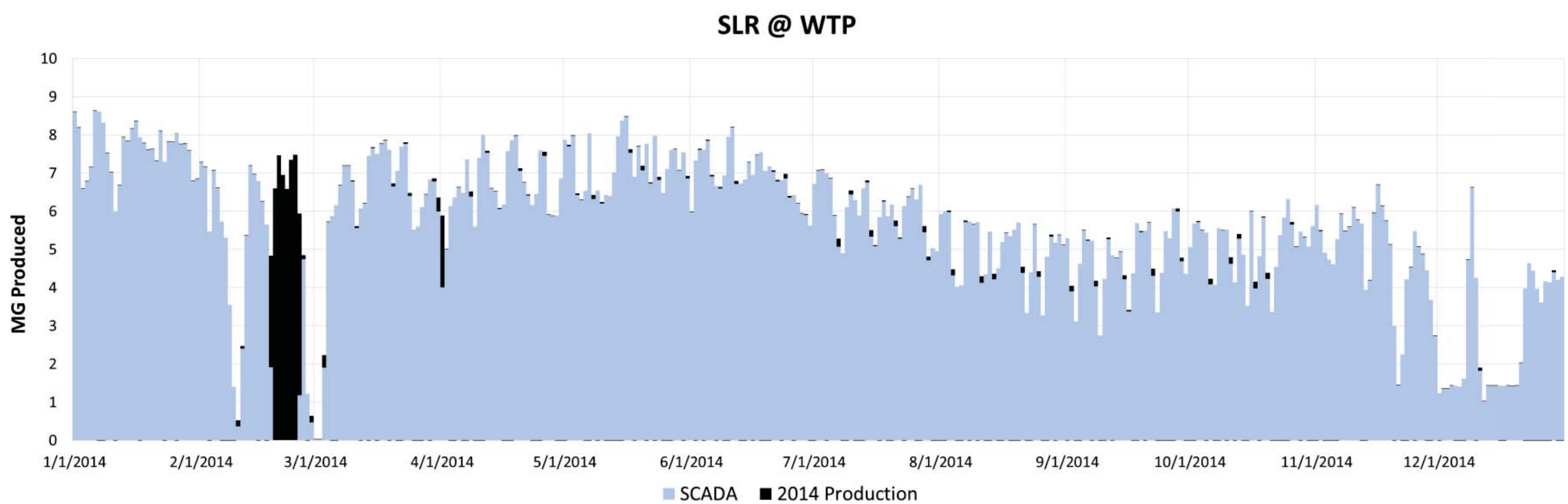



Figure 6: Difference in SLR Production Captured by SCADA and 2014 Production Summary

*NC Influent Meter*

Over the course of the 2014 audit period, treatment plant staff's 2014 Monthly Summary recorded 44 MG more influent through the NC meter than the SCADA Wonderware report (356 MG vs. 312 MG). Treatment plant staff corrected frequent zeroes and nulls values in the SCADA data, captured by in Figure 7 the difference between SCADA volumes (light blue) and 2014 Production volumes (black). Zeroes and null values were more prevalent in NC SCADA data than in SLR SCADA data. Overall, the NC influent meter discrepancies are more distributed; unlike the significant SLR SCADA data gap in February 2014, the NC SCADA data saw more discrete, frequent adjustments throughout the year.

As previously mentioned, WSO has chosen to use the 2014 Monthly Production summary in calculating NC influent volume, given the gaps present in SCADA data and the reasonable correction procedures employed by treatment plant staff.

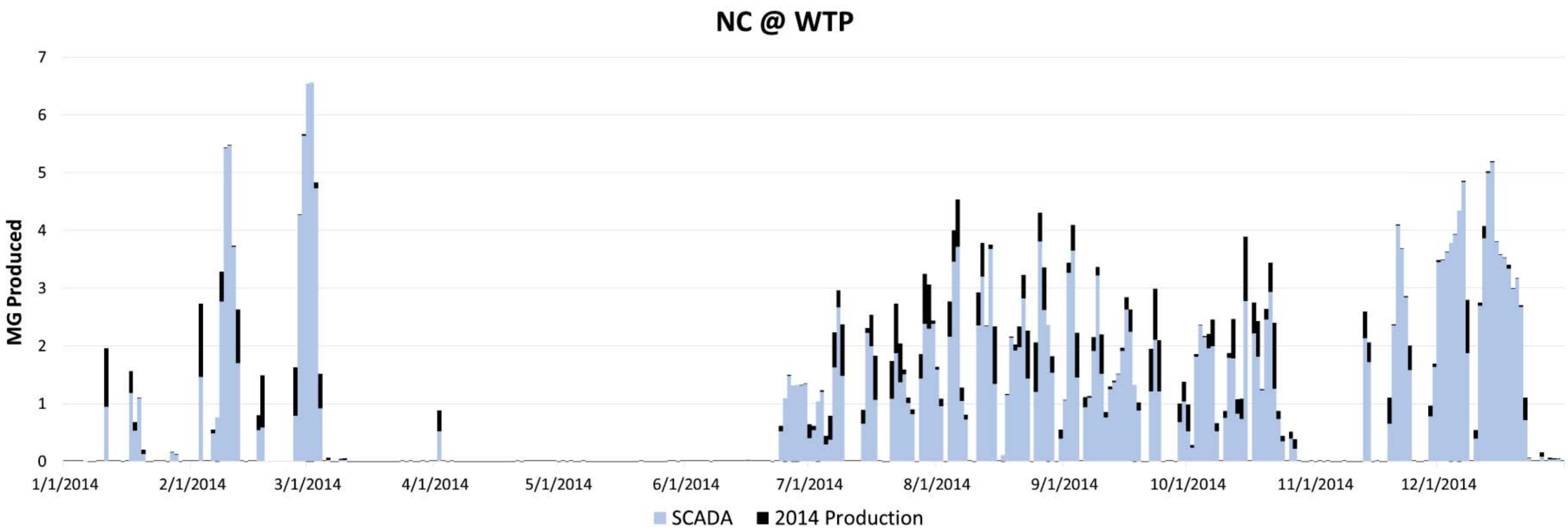



Figure 7: Difference in NC Production Captured by SCADA and 2014 Production Summary

### 2.3.4 *Summary of Data Sources*

**The data sources that WSO employed in the final calculations of SIV and Water Supplied are listed in Table 4**. Additionally, volumes are categorized as inputs (contributing to total SIV) or losses (detracting from total SIV, most commonly as losses in the treatment process).

WSO's calculations of SIV vary slightly from Santa Cruz's (outlined in Section 2.3.2). Santa Cruz estimates plant consumption as 25% of domestic service, a value that for 2014 is actually a positive contribution to SIV rather than a detraction. Therefore, WSO chose to estimate plant consumption on a daily per-capita basis and extrapolate this figure to capture annual consumption.

Santa Cruz staff report that this calculation of plant consumption can be refined to better reflect plant operations. Therefore, WSO considers this volume to be a reasonable stand-in that Santa Cruz can revisit in future audits.

Table 3: Estimation of Plant Consumption

| | FIGURE | NUMBER | NOTES |
|---|---|---|---|
| A | estimated daily per-capita use | 100 gallons | USGS daily per capita figure |
| B | treatment plant employees | 10 | number of employees working on an average day |
| C | estimated daily plant consumption | 1000 gallons | A x B |
| | **estimated annual plant consumption** | **365,000 gallons** | **C x 365** |

Additionally, Santa Cruz formerly considered the domestic service meter an input to the treatment plant. In this arrangement, water flowing into the plant through the domestic service meter is considered a gain, whereas water flowing out of the plant is categorized as a loss. However, given that water flowing through the domestic service meter enters or exits the plant *after* the treatment process, the volume is already incorporated in the total effluent volume. Therefore, if Santa Cruz does not account for water passed through the domestic service meter both in the Water Supplied volume and again as a consumption volume (therefore allocating the correction portion of the total input volume to this authorized use), water passed through the domestic service meter is not appropriately accounted for and runs the risk of double-counting.

Therefore, WSO has chosen to exclude the domestic service meter from calculations of System Input Volume, as domestic service throughput is essentially a closed loop and should not be double-counted.

Finally, it is important to consider the change in storage throughout the distribution system over the course of the audit period when calculating System Input Volume. If the volume of system storage decreases, this introduces additional input into the distribution system and should therefore be considered an increase in System Input Volume. Conversely, if the volume in storage increases, this volume should be subtracted from System Input Volume as it does not enter the distribution system.

Table 4: Data Sources Informing SIV and Water Supplied

| | VOLUME | DATA SOURCE | INPUT OR LOSS? |
|---|---|---|---|
| *treatment plant* | SLR Influent | 2014 Monthly Production | input |
| | NC Influent | 2014 Monthly Production | input |
| | Plant Consumption | *estimate – see Table 3* | loss |
| | Water Quality Testing | *estimate – flow rate x time (see page 30)* | loss |
| | Clarifier Sludge | SCADA Wonderware export | loss |
| | Sludge | SCADA Wonderware export | loss |
| *ground-water* | Beltz Wells | Manual GDC Input | input |
| | Beltz 12 | Manual GDC Input | input |
| | change in storage | Manual GDC Input | loss if decrease<br>input if increase |

## 2.4 Water Supplied Volume Determination

**WSO determined Santa Cruz's 2014 volume of Water Supplied to be 2,603 MG**. This volume is broken down into component volumes in Table 5. In contrast to Santa Cruz's internal tracking protocol, WSO estimated plant consumption using a daily per-capita estimate of water consumption and excluded the domestic service meter to avoid double-counting this volume in the water balance process.

Table 5: 2014 Water Supplied Component Volumes

| WATER SUPPLIED COMPONENT | VOLUME (MG) | % OF TOTAL |
|---|---|---|
| SLR Influent | 2,077 | 79.8% |
| NC Influent | 356 | 13.7% |
| Plant Consumption | –0.4 | 0.0% |
| Water Quality Testing | –2 | –0.1% |
| Clarifier Sludge | –13 | –0.5% |
| Sludge | –1 | 0.0% |
| *TOTAL FROM TREATMENT PLANT* | *2,417* | 92.9% |
| Beltz Wells | 181 | 7.0% |
| Beltz 12 | 6 | 0.2% |
| *TOTAL FROM WELLS* | *187* | 7.2% |
| *TOTAL CHANGE IN STORAGE* | *–1* | 0.0% |
| **TOTAL WATER SUPPLIED** | **2,603** | 100.0% |

Santa Cruz observed an expected trend of increased production during summer months, though staff report that this trend was muted during 2014 compared to previous years due to drought and associated customer conservation. Maximum production occurred in July, while minimum production occurred in December (see Figure 8 on the next page). Beltz Well 12 came online at the end of the audit period and only contributed to SIV for the month of December. Figure 8 does not incorporate plant losses due to plant consumption, water quality testing, or sludge volumes.

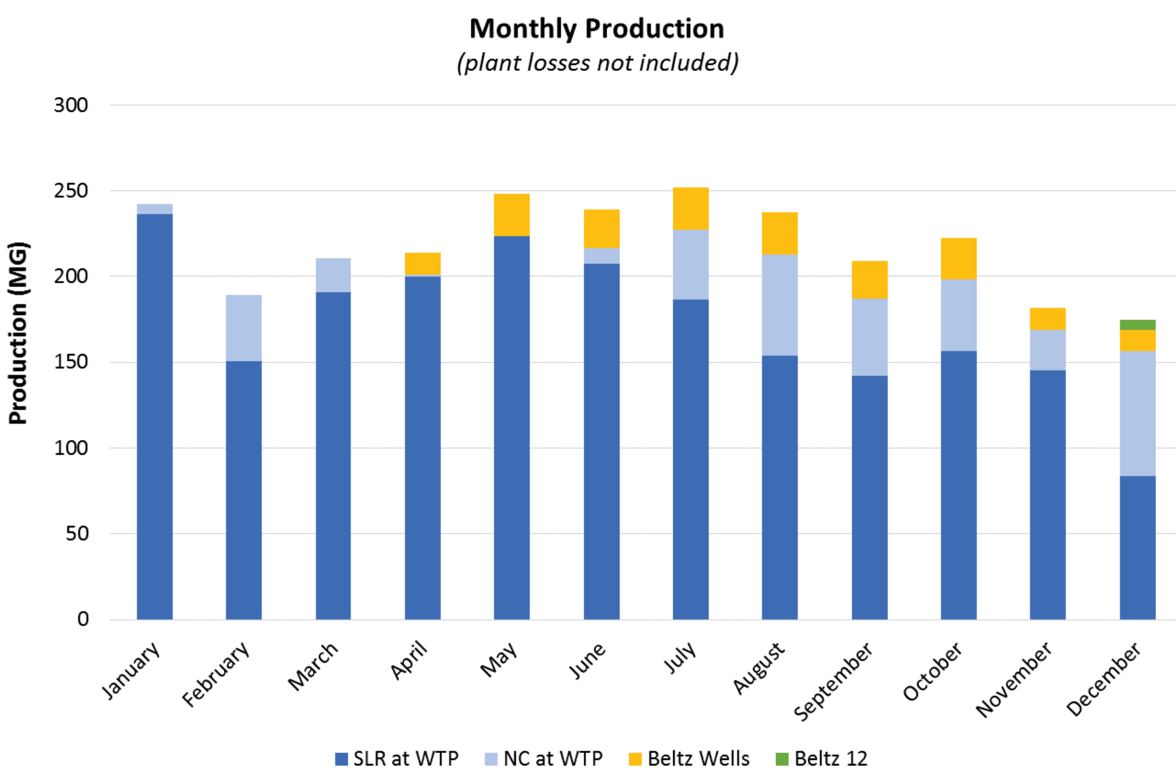



Figure 8: Monthly Production

For a graphical presentation of daily production by source, see Appendix A.

## 2.5 Influent Meter Testing

Water balance methodology recommends that the accuracy of meters be evaluated in order to:

- correct production volumes, if appropriate
- assign defensible margins of error to production volumes
- grade the validity of production data

Prior to this water audit, Santa Cruz did not systematically test key production meters. Therefore, Santa Cruz chose to pilot volumetric accuracy testing of two primary metering assets, the SLR and NC influent meters at the Graham Hill Water Treatment Plant. The tests had three main goals:

- establish an internal protocol for volumetric testing of influent meters
- examine the data sources used in defining a reference volume
- study the accuracy of influent meters as compared to a reference volume

The following sections describe volumetric meter testing protocols, Santa Cruz's test process and data streams, and final test results.

### 2.5.1 *Volumetric Meter Accuracy Testing*

**Volumetric meter accuracy is assessed by comparing a known volume of water passed through a meter to the volume registered by the mete**r. To independently quantify the volume of water passed through a meter during a test, the dimensions of a reservoir upstream or downstream of the meter are combined with the change in reservoir level to produce a known volume (the "reference volume"). As a result, the accuracy of the volumetric test depends upon the accuracy of the reservoir level change measurement. Santa Cruz's influent meter volumetric test protocol is outlined in Appendix B.

**Testing the volumetric accuracy of Santa's Cruz influent meters is complicated by the treatment process**. Both the SLR meter and the NC meter measure raw water prior to treatment. However, the reservoir used to calculate a test reference volume is the finished water tank located after the treatment process. Therefore, the test must incorporate volumetric gains and losses from the treatment process in the reference volume calculation.

Additionally, care must be taken to align the volume of water passed through the influent meter with the volume of water reaching the finished water tank. Though it is assumed that one gallon of influent produces a corresponding gallon of effluent, the treatment process introduces the potential for a time lag. Therefore, **the test must be run for sufficient time to ensure that the reference volume is large enough to dilute measurement uncertainty and achieve a prolonged operational steady state that makes comparison of influent and effluent volumes productive.**

### 2.5.2 *Test Flow Rate Selection*

Meters are constructed to register in specific flow ranges that depend on the meter size, measurement technology, and manufacturer specifications. **Meter accuracy varies with flow rate, even in a meter's ideal flow rate range, so it recommended that a meter is tested at more than one flow rate in the range the meter typically sees.**

*SLR Influent Meter*

The SLR meter sees the majority of inflow to the GHWTP. Over the course of 2014, daily flow rate through the SLR meter ranged from 0 MGD to 8.6 MGD with an average of 5.5 MGD and a median of 5.9 MGD. Average daily flow rates for 2014 are displayed in Figure 9, as are test flows.

To design an ideal test process and investigate the accuracy of the SLR meter, the treatment plant staff conducted two tests of the SLR meter. The first test ran at approximately 6.0 MGD and consisted of water sourced entirely from the San Lorenzo River. The second test ran at 6.1 MGD and consisted of a blend of Coast and San Lorenzo River water. Both tests approximated the median flow rate seen during the 2014 audit period.

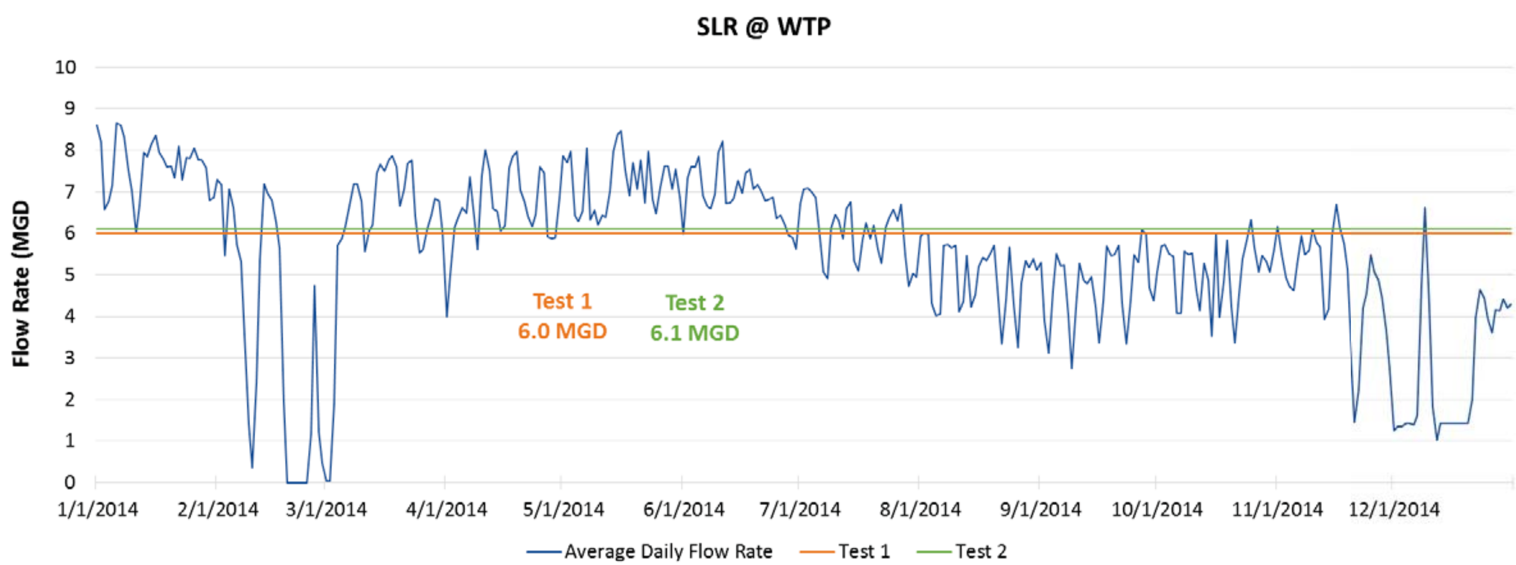



Figure 9: SLR Meter Average Daily Flow Rate and Test Flow Rates

*NC Influent Meter*

The NC meter sees a minority of inflow to the GHWTP. Over the course of 2014, daily flow rate through the NC meter ranged from 0 MGD to 6.6 MGD. Average flow rate was less than 0.1 MGD (essentially 0 MGD) on 207 days in the 365-day audit period. Flow rates of less than 0.1 MGD can indicate NC pipeline pressure relief during Felton diversion pumping or SCADA “noise.” For the days that flow rate was significant (in WSO’s analysis, greater than 0.1 MGD), average flow rate was 2.0 MGD and median flow rate was 1.6 MGD. Average daily flow rates for 2014 are displayed in Figure 10, as are test flows.

GHWTP staff chose to test the SLR meter at 2.0 MGD (thereby capturing the average flow rate seen when the meter is actively measuring influent) and 3.8 MGD (thereby investigating the accuracy of common peak flows).

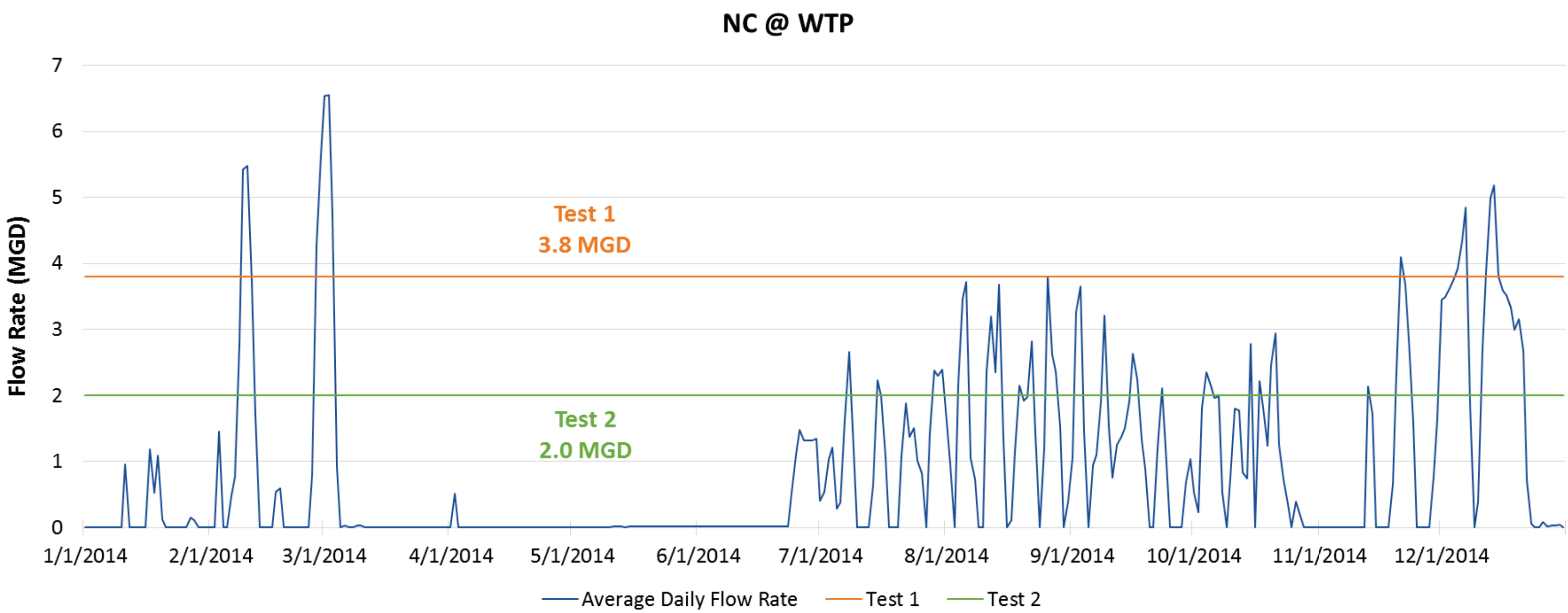



Figure 10: NC Meter Average Daily Flow Rate and Test Flow Rates

### 2.5.3 *Test Data Sources*

To capture test data at a high frequency, back up data archival functions, and investigate the transfer of data from original instrument to SCADA reporting, Santa Cruz staff installed a series of data loggers and programmed redundant measurement of test data. The technologies capturing each test data type are listed in Table 6.

Table 6: Data Sources Available for Test Analysis

| VOLUME or INSTRUMENT | DATA SOURCE | DATA TYPE | UNIT | RECORDING FREQUENCY |
|---|---|---|---|---|
| ***TEST VOLUME*** | | | | |
| influent meter | data logger | flow rate | MGD | 5 seconds |
| influent meter | SCADA historical viewer | flow rate | MGD | SCADA scan frequency |
| ***REFERENCE VOLUME*** | | | | |
| finished water tank | data logger – hanging pressure transducer | water level | feet | 1 minute |
| finished water tank | data logger – hatch-installed pressure transducer | water level | feet | 5 seconds |
| finished water tank | SCADA historical viewer | water level | feet | SCADA scan frequency |
| finished water tank | as-built diagrams, supplemented by divers | dimensions | feet | – |
| ***GAINS AND LOSSES*** | | | | |
| losses from plant* | flow rate estimates and measurements | flow rate | gpm | – |
| gains to plant* | flow rate estimates and measurements | flow rate | gpm | – |

* Santa Cruz staff estimated plant gains and losses by taking flow rate samples of each gain and loss. Gains included chemical feed carrier water and chemical inputs to the plant. Losses included lab sinks, turbidimeters, and chemical analyzers.

#### *Test Volume*

**The test volume is the volume registered by the influent meter, either the Newell Creek meter or the San Lorenzo River meter.** This volume can be derived from one of two data sources:

- Data logger attached to the influent meter
- SCADA historical viewer accessing flow rate data collected by SCADA

WSO observed that volumes calculated using data logger data are consistently lower than volumes calculated using SCADA historical viewer data, by approximately 0.5% on average. This contrasts with the 2014 audit period, where treatment plant staff reports of consumption captured *higher* volumes than SCADA data, due to data gaps in the historian.

#### *Reference Volume*

**The reference volume is the increase in volume observed in the finished water tank during the test.** To calculate this volume, the change in water tank level is paired with tank dimensions.

WSO received as-built diagrams of the finished water tank. The accuracy of the as-built diagrams was confirmed by a team of divers hired by Santa Cruz. The diameter of the tank was determined to be five-eighths of an inch wider than indicated on the diagrams; otherwise, all recorded dimensions were deemed accurate. Using the as-built diagrams supplemented by information from the divers, WSO calculated the average volume-per-height in the finished water tank to be 33,137 gal/ft.

WSO also created a volume-per-foot spreadsheet calculator for the finished water tank. This spreadsheet is provided in Appendix C for Santa Cruz's future use. In analyzing the influent meter tests, WSO chose to use the average volume per foot rather than the detailed spreadsheet because WSO was unable to connect the zero-points of the levels readers to the absolute height of water in the tank. Instead, the relative water level change was paired with the average volume per foot in the tank to produce a reference volume.

The water level necessary for determining the reference volume can be derived from one of three sources:

- Data logger attached to the hanging pressure transducer (hanging from the ceiling of the tank and laying on the tank floor)
- Data logger attached to the hatch-installed pressure transducer (installed at ground level a few feet above the floor of the tank)
- SCADA historical viewer accessing level data collected by SCADA from the hatch-installed pressure transducer

Santa Cruz staff discussed the reliability of instrumentation in measuring the absolute height and the relative height of the water level. Staff report that the hatch-installed pressure transducer is likely the most reliable instrument, given its superior quality and the integrity of its installation and configuration. However, WSO will present results using all data sources to acknowledge the possible range of results and encourage future investigation into test instrumentation.

WSO observed that the data logger on the hanging pressure transducer recorded consistently lower changes in height than the hatch-installed pressure transducer (both captured by the data logger and by SCADA). On average, the hanging pressure transducer change in height was 3.5% lower than the change in height recorded by the hatch-installed pressure transducer data logger.

Additionally, the change in height recorded by the hatch-installed pressure transducer through the data logger and through the SCADA historical viewer differed for each test. Though there appears to be no pattern to this difference, its absolute value was on average 0.3%.

Also incorporated in the calculation of reference volumes were losses and gains from the treatment process. Each test included a net gain ranging from 7.7 gpm to 10.5 gpm.

### 2.5.4 *Test Results*

To conduct each test, the treatment plant was operated in a steady-state mode with a period of warm up and cool down before and after each test. WSO selected a steady-state time slice to analyze for each test.

Given the variety of data sources available to describe the tests, WSO calculated two test volumes and three reference volumes for each test. WSO is unable at this time to recommend the use of one instrument over another in analyzing test results, so all results are presented below. The results presented in Table 7 through Table 14 are summary figures; the detailed results of each test can be found in Appendix D.

Table 7: Test Results – NC 2.0 MGD, Data Logger as Test Volume

| NC 2.0 MGD – DATA LOGGER | | 12/29/2015, 2:00pm – 6:00pm |
|---|---|---|
| **TEST VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | |
| data logger – NC Meter | 327,134 | |
| **REFERENCE VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | **TEST RESULT** |
| data logger – hatch-installed pressure transducer | 322,097 | 101.6% |
| SCADA historical viewer – hatch-installed pressure transducer | 323,223 | 101.2% |
| data logger – hanging pressure transducer | 311,095 | 105.2% |

Table 8: Test Results – NC 2.0 MGD, SCADA as Test Volume

| NC 2.0 MGD – SCADA | | 12/29/2015, 2:00pm – 6:00pm |
|---|---|---|
| **TEST VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | |
| SCADA historical viewer – NC Meter | 329,078 | |
| **REFERENCE VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | **TEST RESULT** |
| data logger – hatch-installed pressure transducer | 322,097 | 102.2% |
| SCADA historical viewer – hatch-installed pressure transducer | 323,223 | 101.8% |
| data logger – hanging pressure transducer | 311,095 | 105.8% |

Table 9: Test Results – NC 3.8 MGD, Data Logger as Test Volume

| NC 3.8 MGD – DATA LOGGER | | 12/23/2015, 10:30am – 1:45pm |
|---|---|---|
| **TEST VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | |
| data logger – NC Meter | 510,697 | |
| **REFERENCE VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | **TEST RESULT** |
| data logger – hatch-installed pressure transducer | 510,180 | 100.1% |
| SCADA historical viewer – hatch-installed pressure transducer | 508,987 | 100.3% |
| data logger – hanging pressure transducer | 492,498 | 103.7% |

Table 10: Test Results - NC 3.8 MGD, SCADA as Test Volume

| NC 3.8 MGD – SCADA | 12/23/2015, 10:30am – 1:45pm | |
|---|---|---|
| **TEST VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | |
| SCADA historical viewer – NC Meter | 511,942 | |
| **REFERENCE VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | **TEST RESULT** |
| data logger – hatch-installed pressure transducer | 510,180 | 100.3% |
| SCADA historical viewer – hatch-installed pressure transducer | 508,987 | 100.6% |
| data logger – hanging pressure transducer | 492,498 | 103.9% |

Table 11: Test Results - SLR 6.0 MGD, Data Logger as Test Volume

| SLR 6.0 MGD – DATA LOGGER | 2/11/2016, 9:45am – 12:15pm | |
|---|---|---|
| **TEST VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | |
| data logger – SLR Meter | 621,746 | |
| **REFERENCE VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | **TEST RESULT** |
| data logger – hatch-installed pressure transducer | 634,187 | 98.0% |
| SCADA historical viewer – hatch-installed pressure transducer | 634,399 | 98.0% |
| data logger – hanging pressure transducer | 612,019 | 101.6% |

Table 12: Test Results - SLR 6.0 MGD, SCADA as Test Volume

| SLR 6.0 MGD – SCADA | 2/11/2016, 9:45am – 12:15pm | |
|---|---|---|
| **TEST VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | |
| SCADA historical viewer – SLR Meter | 626,055 | |
| **REFERENCE VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | **TEST RESULT** |
| data logger – hatch-installed pressure transducer | 634,187 | 98.7% |
| SCADA historical viewer – hatch-installed pressure transducer | 634,399 | 98.7% |
| data logger – hanging pressure transducer | 612,019 | 102.3% |

Table 13: Test Results - SLR 6.1 MGD, Data Logger as Test Volume

| SLR 6.1 MGD – DATA LOGGER | | 2/25/2016, 9:30am – 11:25am |
|---|---|---|
| **TEST VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | |
| data logger – SLR Meter | 485,446 | |
| **REFERENCE VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | **TEST RESULT** |
| data logger – hatch-installed pressure transducer | 492,989 | 98.5% |
| SCADA historical viewer – hatch-installed pressure transducer | 490,603 | 98.9% |
| data logger – hanging pressure transducer | 474,930 | 102.2% |

Table 14: Test Results - SLR 6.1 MGD, SCADA as Test Volume

| SLR 6.1 MGD – SCADA | | 2/25/2016, 9:30am – 11:25am |
|---|---|---|
| **TEST VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | |
| SCADA historical viewer – SLR Meter | 488,940 | |
| **REFERENCE VOLUME** | | |
| **DATA SOURCE** | **VOLUME (gal)** | **TEST RESULT** |
| data logger – hatch-installed pressure transducer | 492,989 | 99.2% |
| SCADA historical viewer – hatch-installed pressure transducer | 490,603 | 99.7% |
| data logger – hanging pressure transducer | 474,930 | 102.9% |

*Interpretation of Test Results*

Figures on the following pages graphically present influent meter accuracy test results. The test results indicate that the SLR meter hovers around 100% accuracy, while the NC meter might display a slight bias toward over-registration. However, these statements should be interpreted cautiously, given the following:

- The data sources selected to inform test analysis can change the result of the test.
- The estimation of gains and losses, though appropriate and thoroughly documented by Santa Cruz staff, nonetheless introduces uncertainty into test results.
- The inherent measurement uncertainty of test instruments has not been considered in this analysis of test results.
- The treatment process (and therefore a potential time lag) exists between the test volume and the reference volume. In theory one gallon of influent into the plant should produce an immediate and corresponding gallon of effluent (assuming there is no intermediate storage of water in the plant).

However, this is an unverified assumption and could be investigated to improve confidence in applying test results.

- Given available information, WSO does not yet recommended the preferential application of one test interpretation over any other for the purposes of the water audit. However, Santa Cruz staff report a higher degree of confidence in the reliability of the hatch-installed pressure transducer and could investigate the outcomes of using test data from the hatch-installed pressure transducer in future work.

**Using GHWTP influent meter tests to adjust the Water Supplied volume is unadvised at this point, since the results of the tests indicate accuracy close to 100% but the exact deviation from 100% is still unknown.** Nonetheless, the tests indicate that both influent meters are likely performing within an acceptable accuracy range, though the particular application of the meters will determine their specific acceptable accuracy range.

Test results are presented in a pair of graphs on the following pages. WSO has chosen to consider both the data logger and SCADA system when determining the test volumes that passed through the meters. The data logger provides the most direct measurement of influent volume and therefore influent meter accuracy. However, Santa Cruz uses SCADA to access production data, so the SCADA system's overlay on the results of the meter accuracy tests also provides relevant information about influent meter performance.

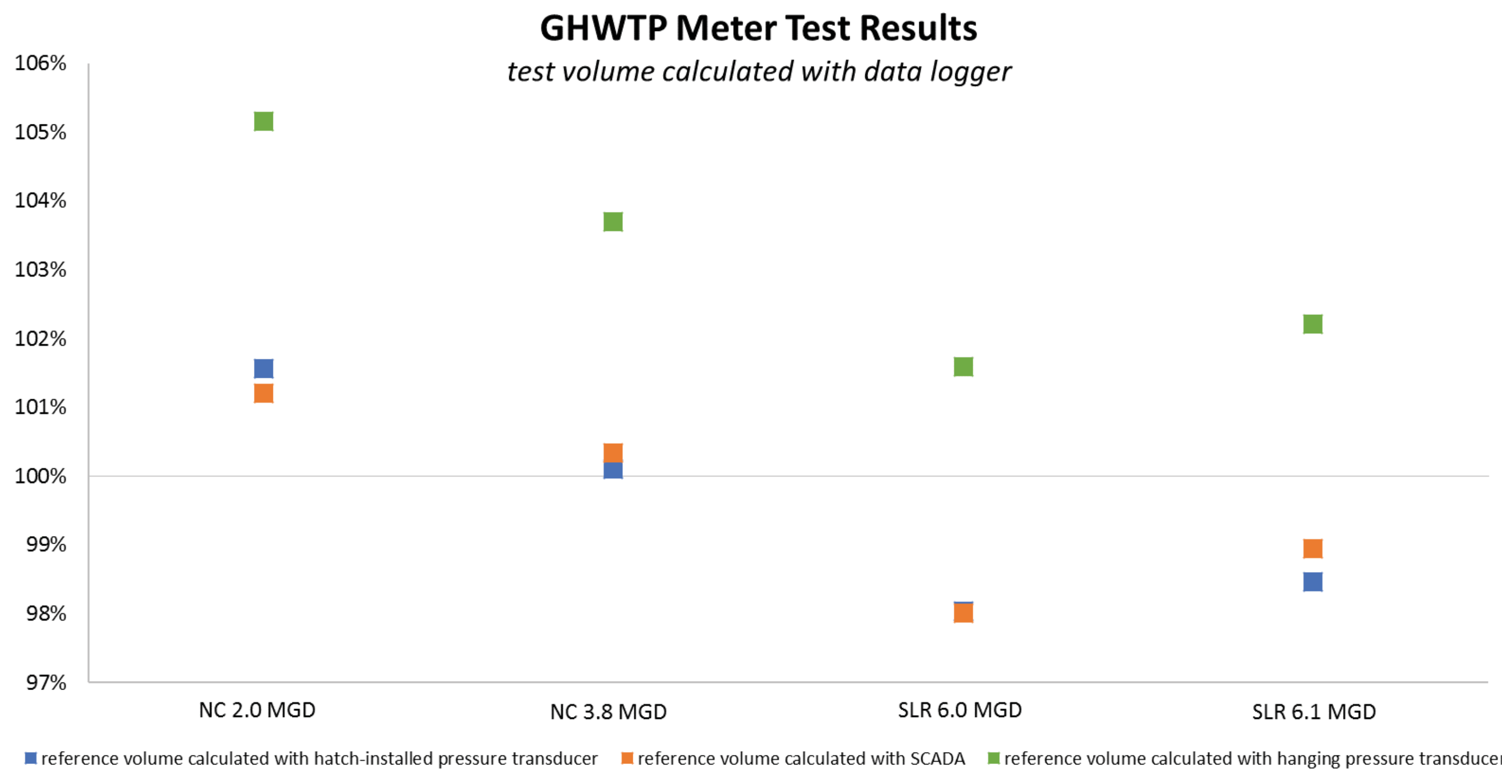



Figure 11: GHWTP Influent Meter Test Results – Test Volume Calculated with Data Logger

In Figure 11, results calculated with reference volumes drawn from the hatch-installed pressure transducer are represented by blue markers. Results calculated with reference volumes drawn from the SCADA historical viewer are represented by orange markers. Results calculated with reference volumes drawn from the hanging pressure transducer are represented by green markers.

When the test volume is calculated using the data logger, the NC meter appears to slightly over-register at both test flows. Contrastingly, the SLR meter results can be interpreted as indicating either slight under-registration or slight over-registration, depending on which data source informs the calculation of the reference volume.

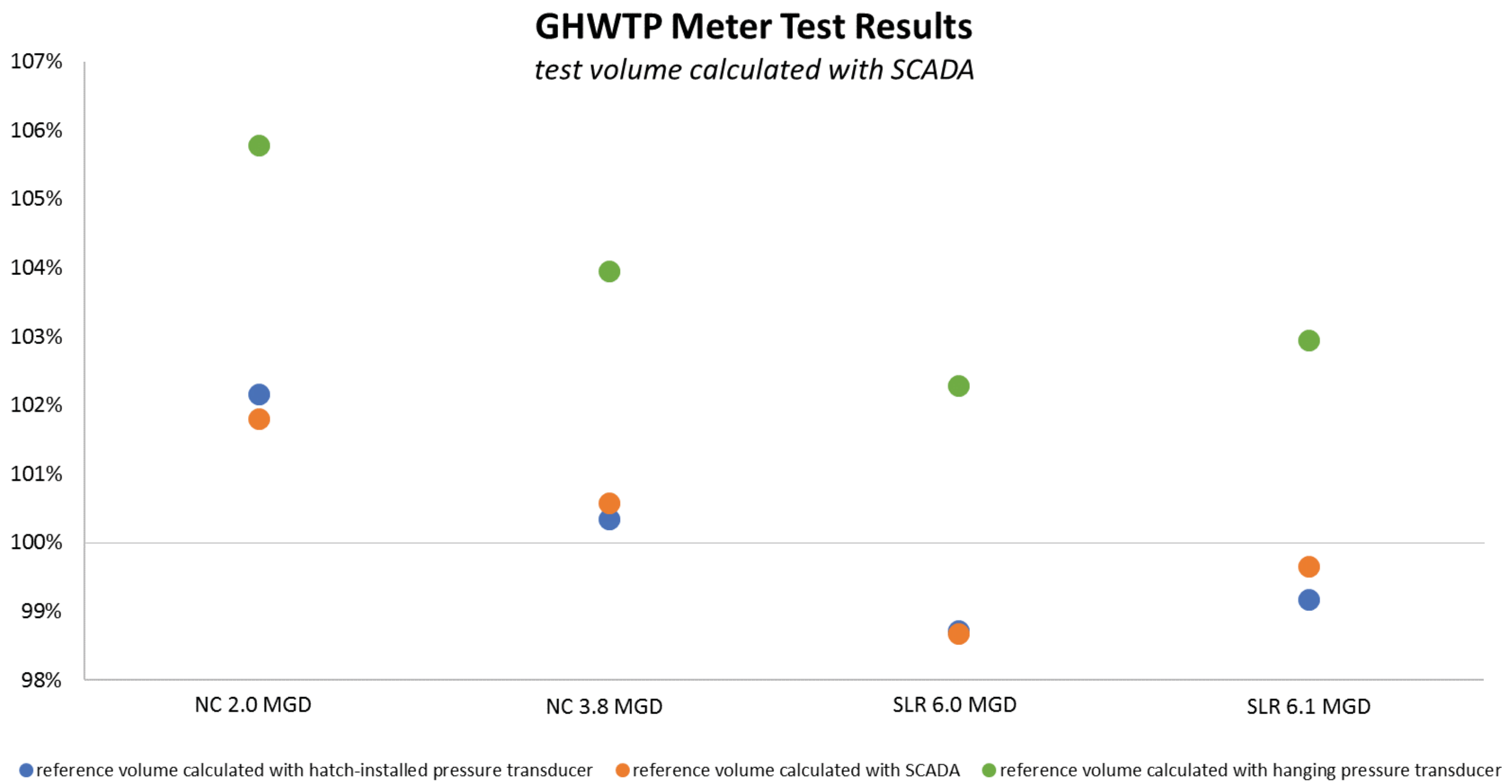



Figure 12: GHWTP Influent Meter Test Results – Test Volume Calculated with SCADA

In Figure 12, results calculated with reference volumes drawn from the hatch-installed pressure transducer are represented by blue markers. Results calculated with reference volumes drawn from the SCADA historical viewer are represented by orange markers. Results calculated with reference volumes drawn from the hanging pressure transducer are represented by green markers.

When the test volume is calculated using the SCADA system, the NC meter appears to slightly over-register at both test flows. Contrastingly, the SLR meter results can be interpreted as indicating either slight under-registration or slight over-registration, depending on which data source informs the calculation of the reference volume. There results mimic those on the previous page (test  volume calculated using the data logger), though their exact values differ slightly.

## 2.6 Recommendations

### 2.6.1 *System Input Volume Accounting*

- **Trust the summaries of production produced by treatment plant staff over raw SCADA data.** The frequency of gaps and nulls values in the SCADA historian makes raw data unreliable for the time being. The protocols that treatment plant staff employ in calculating production volumes are as thorough as possible given the current SCADA inconsistencies.
- **Investigate the archival of null values and gaps in the SCADA historian.** In theory, the SCADA historian and associated Wonderware reports should capture flow information continuously. However, gaps in the historian data during 2014 caused SCADA to miss an estimated 97 MG of production during the audit period. Gaps observed in the SCADA historian indicate an issue somewhere in the transfer of data from metering instrument to database archival. It would be worthwhile for Santa Cruz to identify the source of this data production or storage error so that future summaries of Water Supplied can be validated with raw data.
- **Be careful using Wonderware reporting and retrieval functions to create production summaries.** Accessing data through retrieval functions like best-fit and time-interval manipulation can subtly alter data points. While alterations in data caused by retrieval functions are minor, they can add up over the course of a year-long audit period. For the water balance, unmanipulated raw data is the best source of information (given the caveat that gaps in the historian data make using raw data difficult). However, in using raw data it is important to remember that data points are collected at SCADA scan frequency, not in consistent time intervals. As a result, it is better to weight flow rates by the time intervals they capture, rather than take a simple average of flow rates, to calculate volumes. Of course, this practice depends on a more reliable understanding of communication between SCADA and the historian.
- **Revisit the assumption that plant consumption can be derived from plant domestic service.** During 2014, plant domestic service was negative – indicating water leaving the plant – and the corresponding estimation of plant consumption was positive – indicating a contribution to Water Supplied, rather than a detraction. This is contrary to the fact that plant consumption is actually consumption, rather than supply. Given this scenario, Santa Cruz should consider other methods of estimating plant consumption.

### 2.6.2 *Influent Meter Testing*

- **Continue volumetric accuracy testing the NC and SLR influent meters on an annual basis.** While the tests are not yet informative enough to adjust production volumes, a focus on fine-tuning of test protocols, refinement of estimations, and investigation of data sources and instrument accuracy may allow Santa Cruz to quantify the accuracy of production meters in the future. Additionally, year-to-year tracking of trends in meter accuracy will allow Santa Cruz to monitor key production assets.
- **Interpret influent meter test results cautiously.** Because test results vary significantly depending on the selection of instruments used, and there is not yet a reason to prefer one instrument over any other, the 2016 influent meter accuracy tests did not provide an exact understanding of influent meter accuracy. Therefore, influent meter test results should not be used to adjust production volumes for the 2014 water audit. However, if Santa Cruz selects a single test set-up to track meter accuracy and takes

stock of the types and magnitudes of uncertainty in that test set-up, future test results can be used to adjust the volume of Water Supplied.

- **Investigate discrepancies in water level measurements captured by the hanging pressure transducer, the hatch-installed pressure transducer, and the SCADA historian.** Because both transducers measure the same datum, they should approximately agree. However, an average difference of 3.5% of calculated height change was observed in all four tests. Furthermore, though the SCADA historian data is derived from the hatch-installed pressure transducer, the values recorded in SCADA do not align with pressure transducer data logger output as closely as would be expected. Until Santa Cruz establishes which instrument is best to capture finished water tank level or the three data sources agree, it will be difficult to interpret test results. Santa Cruz staff have indicated that the hatch-installed pressure transducer may be the best source of test data, an assertion that can be investigated in future tests.
- **Explore the difference in influent meter flow rates captured by the data logger and by the SCADA historian.** The historian captured 0.5% more volume on average than the data logger. Some aspect of the data transmission process introduces this additional flow rate (and therefore volume), and investigating this discrepancy may assist Santa Cruz in more fully understanding the strengths and limitations of the SCADA system.
- **Consult treatment plant staff on instrumentation reliability and test interpretation.** WSO's interaction with data sources and test results was intentionally removed from treatment plant staff's anecdotal information to promote neutral analysis and full consideration of all available data sources. Now that initial test analysis is complete, the treatment plant staff's experience and insight will be important to include in interpreting test results and refining future tests.

### 2.6.3 *Effluent Meter Consideration*

- **Consider the benefits of installing and regularly testing an effluent meter on the treatment plant's finished water line.** When assessing water losses, the importance of the input volume measurement cannot be overstated because the input volume is the foundation of the water audit. Installing a single effluent meter at the Graham Hill Water Treatment Plant would simplify and improve this critical measurement. Ideally the meter would be installed near a reservoir or tank to allow for direct volumetric testing.

# 3 AUTHORIZED CONSUMPTION

## 3.1 Introduction

**Authorized Consumption is the volume of water used by registered consumers, including residential customers; industrial, commercial, and irrigation users; and the utility itself.** Water used for firefighting and infrastructure maintenance (e.g. distribution main flushing) is also considered Authorized Consumption. Authorization of use can be explicit or implicit. In order to subdivide Authorized Consumption into component volumes, **consumption is categorized as billed or unbilled and metered or unmetered,** as highlighted in Figure 13.

<table>
<tr><td rowspan="3">Water from Own Sources</td><td rowspan="12">System Input Volume</td><td colspan="4">Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td rowspan="11">Water Supplied</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="9">Water Imported</td><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="9">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="7">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Customer Metering Inaccuracies</td></tr>
<tr><td>Unauthorized Consumption</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="4">Real Losses</td><td>Reported Leakage</td></tr>
<tr><td>Unreported Leakage</td></tr>
<tr><td>Background Leakage</td></tr>
<tr><td>Hidden Losses</td></tr>
</table>

Figure 13: Water Balance, Authorized Consumption Highlighted

Chapter 3 documents Authorized Consumption as follows:

- Section 3.2 – Billed Metered Authorized Consumption
- Section 3.3 – Billed Unmetered Authorized Consumption
- Section 3.4 – Unbilled Metered Authorized Consumption
- Section 3.5 – Unbilled Unmetered Authorized Consumption
- Section 3.6 – Summary of Authorized Consumption and margins of error

Once quantified, **Authorized Consumption is subtracted from System Input Volume to calculate Water Losses**.

## 3.2 Billed Metered Authorized Consumption

Billed Metered Authorized Consumption (BMAC) is the volume of Authorized Consumption that is metered and generates revenue. The following sections describe the data contributing to BMAC calculation; the process of validating BMAC data; and the BMAC volume, both totaled and broken down by account type, service type, and meter size.

### 3.2.1 *Data Source*

WSO received billing data extracted from Santa Cruz's EDEN system. The export included all bills issued between September 1, 2013 and April 30, 2015 to provide enough data to perform lag time analysis (see Section 3.2.3). The fields captured in the billing data are listed and described below in Table 15.

Table 15: Billing Fields Received in Export

| FIELD | EXAMPLE | DESCRIPTION |
|---|---|---|
| Service Location ID | 18780 | unique ID identifying the service connection; does not change when the associated account number changes |
| Account Number | 071-03790-014 | unique ID identifying the account; independent of the service location |
| Meter Number | 59220502 | meter serial number |
| Meter Size | 58 | code indicating meter size |
| Meter Use | water | utility inventory device type |
| Manufacturer | RK | meter manufacturer |
| Account Type | res-sf | account type for rate assignment and tracking |
| Jurisdiction | out | designation of location in Santa Cruz proper or outside city limits (e.g. North Coast) |
| Dwelling Units | 1 | number of units served by the meter |
| Bill Date | 1/27/2014 | date bill was issued |
| Read Date | 1/17/2014 | date meter was read |
| Consumption | 11 | billed consumption in hundred cubic feet (CCF) |
| Bill Days | 59 | days captured since the previous bill; bills are monthly or bimonthly |
| Pressure Zone | U | |

### 3.2.2 *Accounts Excluded from BMAC Calculation*

**Santa Cruz's BMAC volume is composed of all *potable* water consumption billed through the standard billing system.** However, a single billing system is used to handle both raw water and potable water customers, and it also tracks a handful of unbilled accounts. Therefore, **raw water customers and unbilled customers must be actively excluded from BMAC analysis**.

*Raw Water Accounts*

All accounts beginning with the number "199" consume raw water and are therefore excluded from analysis. Additionally, the "404" accounts listed below also consume raw water and are excluded.

- 404-01075-011
- 404-01100-011
- 404-02300-011
- 404-02600-001

A summary of the raw-water account numbers and consumption excluded from analysis is provided below in Table 16.

Table 16: Raw Water Summary

| ACCOUNT TYPE | NUMBER OF ACCOUNTS | AUDIT PERIOD CONSUMPTION (CCF) |
|---|---|---|
| 199 | 25 | 29,360 |
| 404 | 4 | 568 |
| **ALL RAW ACCOUNTS** | **29** | **29,928** |

*Unbilled Potable Accounts*

An additional three "404" accounts consume potable water but have been grandfathered into Santa Cruz's system and are unbilled. These account numbers, listed below, will be discussed in Section 3.4 on Unbilled Metered Authorized Consumption.

- 404-01000-011
- 404-02100-011
- 404-02200-011

### 3.2.3 *Billing Data Validation*

Once the project team verified that all raw water and potable unbilled accounts were excluded from the billing data, we began the process of billing data validation. **Validation verifies that billing data is complete and reliable and acknowledges any potential inaccuracies.**

WSO's validation process consisted of three steps, listed and described below. *Please note that throughout the validation process, WSO handled bills by read date, not bill/post date.*

1. **Lag time analysis** confirms that the delay between consumption and meter reading data collection does not adversely affect BMAC calculation. If a significant impact exists, audit period records may not accurately capture the consumption that occurred during the audit period and therefore make the comparison of Water Supplied and Authorized Consumption inconclusive.

To verify that bill lag time does not have an effect on consumption, WSO calculated the total consumption that occurred during the year-long audit period. WSO then compared this consumption total to the consumption totals of alternate year-long audit periods shifted by a month or two from the original audit period. Lag time analysis is particularly important for consumption that is billed bimonthly, as was the case for a minority of Santa Cruz accounts at the beginning of the audit period. For the results of the lag time analysis, see Section 0.

2. **Counts of account numbers and audit period records** indicate whether the data export WSO received encompasses all audit period billing data. Approximately the same number of bills should be generated each month, so any months with bill counts deviating significantly from average should be investigated. Additionally, because Santa Cruz bills on a monthly basis, most accounts should have twelve bills over the course of the audit period. However, some accounts were billed bimonthly at the beginning of the audit period and transitioned to monthly billing by April of 2014. This initial bimonthly billing is reflected in the counts of account numbers and audit period records; see Section 0 for additional detail.
3. The prevalence of **skipped reads and estimated consumption volumes** is also explored to acknowledge their effect on consumption. See Section 0 for a discussion of skipped and estimated reads

Each of the three validation steps is presented in detail in the following sections.

*Lag Time Analysis*

**Lag time analysis confirms that the time difference between actual consumption and eventual monthly or bimonthly meter reading does not affect the audit period BMAC total**. If shifting the year-long audit period by a month or two months does not significantly change the consumption volume, WSO can confidently state that lag time does not matter in determining audit period consumption. Table 17 below provides the audit period consumption total and the consumption totals of contiguous 12-month periods.

Table 17: Lag Time Analysis

| RANGE START | RANGE END | CONSUMPTION (CCF) | % DIFFERENCE FROM AUDIT PERIOD |
|---|---|---|---|
| October 2013 | September 2014 | 3,519,390 | 8.8% |
| November 2013 | October 2014 | 3,454,251 | 6.8% |
| December 2013 | November 2014 | 3,278,158 | 1.4% |
| **January 2014** | **December 2014** | **3,233,337** | **0.0%** |
| February 2014 | January 2015 | 3,109,507 | -3.8% |
| March 2014 | February 2015 | 3,096,913 | -4.2% |
| April 2014 | March 2015 | 3,038,554 | -6.0% |

Figure 14 and Figure 15 display lag time analysis graphically. WSO's examination of lag time indicates that **the delay between consumption and meter reading has a significant effect on audit period consumption.** The consumption seen in alternate audit periods differs from the actual audit period total by more than 1.0%, the threshold at which WSO decides to apportion billed consumption.

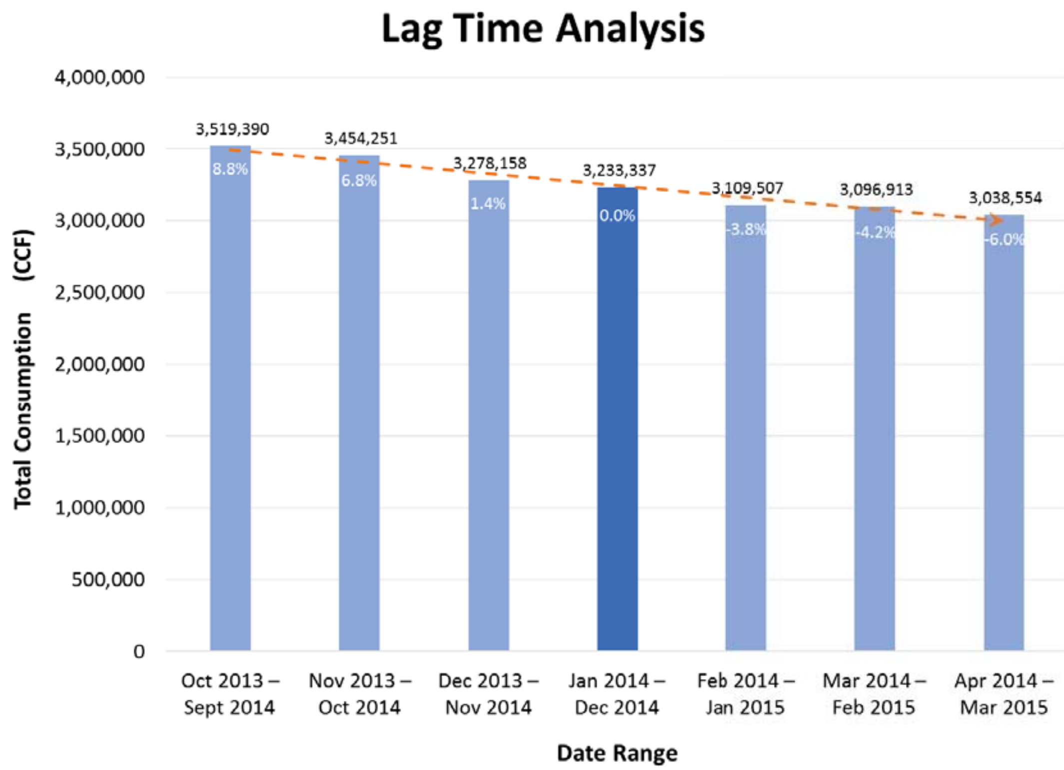



Figure 14: Lag Time Analysis

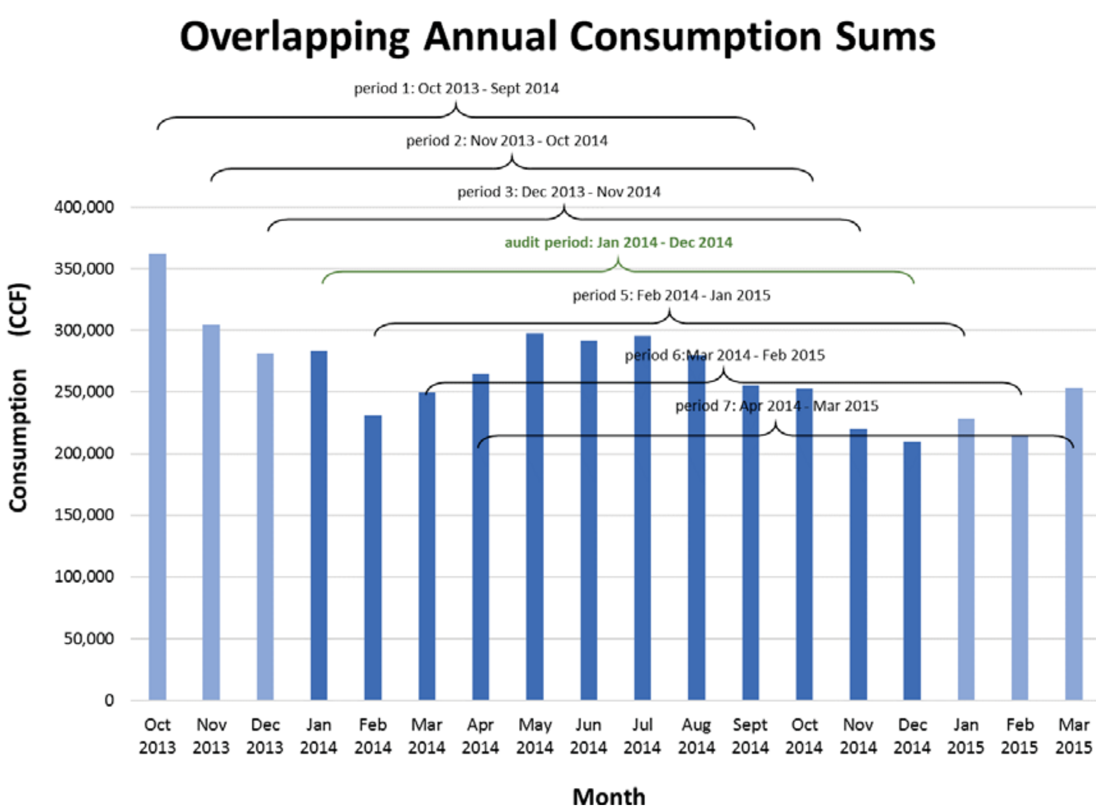



Figure 15: Overlapping Annual Consumption Sums

**A portion of the deviation observed between the audit period and alternate years may be attributable to effective customer conservation**. The year-long consumption totals decrease consistently with each month shift (demonstrated by the linear trend line in Figure 14), suggesting that decreasing customer consumption may confound lag time analysis. Nonetheless, **WSO has chosen to apportion consumption in order to decrease the effect of the lag between production and consumption**. The apportioning process is described in a following section.

*Record, Account, and Location Counts*

**To confirm that the billing database export contained all audit period data, WSO counted the number of records, accounts, and locations read per month.**

Table 18 presents counts of records, accounts, and locations by read month (*not* necessarily the same as bill month). Figure 16 displays the monthly counts of records graphically. At the beginning of the audit period, Santa Cruz read most accounts on a monthly basis but some accounts were read once every two months. In March of 2014, the meter reading schedule transitioned to a monthly read for all accounts. This change in meter read frequency is observable in Figure 16. After March of 2014, an average of 24,829 records were generated each month (marked by the orange line in Figure 16).

The monthly number of records is always greater than the number of accounts, which is in turn greater than the number of locations. This indicates that new accounts are created each month and that some accounts receive multiple bills each month. The prevalence of multiple bills is further explored on the following page.

Table 18: Counts of Records, Accounts, and Locations by Read Month

| YEAR | MONTH | COUNT OF RECORDS | COUNT OF ACCOUNTS | COUNT OF LOCATIONS |
|---|---|---|---|---|
| 2013 | September | 22,784 | 22,288 | 22,173 |
| | October | 18,828 | 18,419 | 18,365 |
| | November | 22,507 | 22,225 | 22,182 |
| | December | 18,868 | 18,384 | 18,326 |
| **2014** | **January** | **22,441** | **22,234** | **22,174** |
| | **February** | **18,606** | **18,374** | **18,347** |
| | **March** | **24,643** | **24,321** | **24,262** |
| | **April** | **24,705** | **24,336** | **24,270** |
| | **May** | **24,759** | **24,326** | **24,276** |
| | **June** | **24,950** | **24,403** | **24,304** |
| | **July** | **25,052** | **24,453** | **24,301** |
| | **August** | **25,007** | **24,438** | **24,323** |
| | **September** | **25,066** | **24,476** | **24,308** |
| | **October** | **24,882** | **24,414** | **24,331** |
| | **November** | **24,698** | **24,375** | **24,331** |
| | **December** | **24,758** | **24,393** | **24,344** |
| 2015 | January | 24,698 | 24,382 | 24,319 |
| | February | 24,827 | 24,339 | 24,301 |
| | March | 25,039 | 24,378 | 24,329 |
| | April | 24,521 | 24,310 | 24,281 |
| | **ALL MONTHS** | **471,639** | **29,258** | **24,429** |
| | *Audit Period Only* | *289,567* | *27,296* | *24,401* |

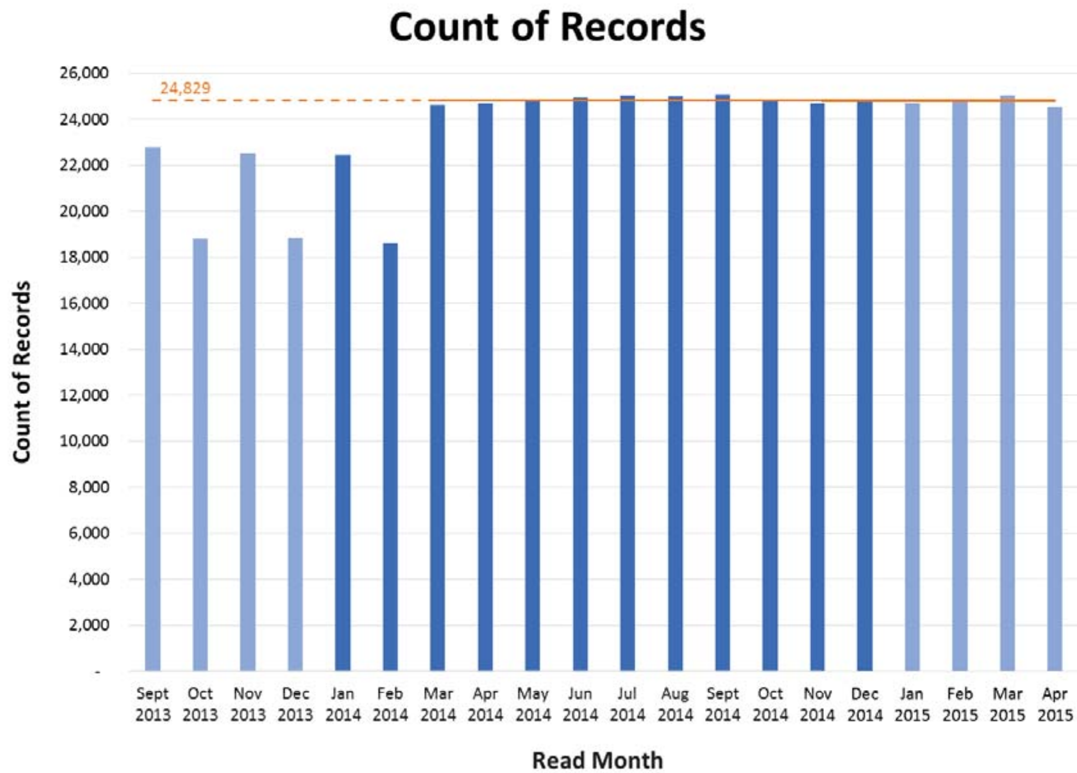



Figure 16: Count of Records by Read Month

**24,401 locations associated with 27,286 unique account numbers were billed during the audit period**. An average of 24,131 records were generated each month during the audit period. This number is lower than the counts of locations and account numbers because of the effect of bimonthly billing during the first quarter of the audit period. As mentioned previously and indicated by the orange line in Figure 16, once all reads had transitioned to a monthly schedule, an average of 24,829 records were generated each month.

**The consistency of the record, account, and location counts from month to month suggests that the data WSO received is complete**. After checking monthly bill counts, examining the number of records per account can serve as an additional check on the completeness of billing data. Should a majority of accounts have fewer than 12 associated bills during the audit period, data completeness should be further interrogated.

76.8% of accounts were billed 11 or 12 times during the audit period, indicating that most accounts received the appropriate number of bills during 2014 (depending on the initial monthly or bimonthly schedule). 18.1% of accounts received fewer than 11 bills, likely attributable to accounts opening or closing during the audit period. A minority of accounts – only 5.2% - received more than 12 bills during 2014. This information is displayed in Table 19. **WSO's analysis of the number of records generated for each account indicates that the billing data is complete.**

Table 19: Count of Standard Bills per Account during the Audit Period

| NUMBER OF BILLS | NUMBER OF ACCOUNTS | % OF TOTAL ACCOUNTS |
|---|---|---|
| 1 | 415 | 18.1% |
| 2 | 558 | |
| 3 | 565 | |
| 4 | 621 | |
| 5 | 451 | |
| 6 | 551 | |
| 7 | 595 | |
| 8 | 417 | |
| 9 | 435 | |
| 10 | 322 | |
| **11** | **7,019** | **76.8%** |
| **12** | **13,939** | |
| 13 | 677 | 5.2% |
| 14 | 640 | |
| 15 | 43 | |
| 16 | 43 | |
| 17 | 2 | |
| 18 | 2 | |
| 19 | 1 | |
| **TOTAL** | **27,296** | **100.0%** |

*Skipped and Estimated Accounts*

**To determine whether skipped and estimated accounts could have an effect on BMAC calculation, WSO requested correction and estimation protocol from Santa Cruz staff.** Staff reports that adjustments to consumption fall into one of two categories: new meter installation and multi-family paired ("multi-multi") meters.

When field staff replace a meter, it is protocol to record the final register reading on the pulled meter so that consumption is correctly billed. If field staff replace a meter but do not record the register reading, it may appear that the customer consumed an abnormally large volume of water, enough to reset the meter register. To address this possibility, billing staff consistently review consumption data for anomalous reads and correct those that they find using the account's historical consumption. Staff report that this sort of correction happens very rarely.

In "multi-multi" metering situations, two meters measure consumption billed to a single multi-family property. When rationing is imposed, the meters are treated as a single unit so that volumetric allotments are equitably billed. Under this practice, the consumption registered by both meters is *totaled* and then *averaged* per meter in ordered to be fairly billed. This does not affect total consumption, only the specific consumption attributed to each meter, and therefore does not affect total BMAC calculation. Additionally, staff do not change the meter reads stored in EDEN, only the billed consumption volume. This minimizes the potential for introduction of erroneous data.

Finally, Santa Cruz occasionally must estimate consumption in the case of a missed meter read and looming billing deadline. In such a circumstance, staff estimates consumption based on account history. Then, the next meter read corrects any error in estimation. Staff report that this happens very infrequently; in 2014, only 221 estimates were made, accounting for less than one-tenth of one percent of all reads. Additionally, all estimates are tracked in EDEN with a yes/no field.

Based on this understanding of billing protocols, **WSO has determined the effect of skipped, estimated, and corrected reads on BMAC calculation to be negligible.**

### 3.2.4 *BMAC Volume and Breakdowns*

*Bill Apportioning*

At the beginning of the audit period, Santa Cruz read some accounts once every two months. In March of 2014, the meter reading schedule transitioned to a monthly read for all accounts. The initial bimonthly reads and the results of the lag time analysis (Section 0) make apportioning of consumption important to ensure that BMAC reflects *only* consumption that occurred during the audit period. **Apportioning proportionally allocates consumption to each audit period month, using average daily consumption values from each bill.** Appendix E provides a step-by-step example of apportioning. *WSO apportions bills individually, rather than apportioning total route or monthly consumption volumes.*

In order to apportion bills, the number of days that a bill represents must be known. Santa Cruz's billing database contains a field that provides the number of billable days captured by each record. To verify the number of billable days, WSO also assigned each bill a previous read date based on the read date of previous record associated with the account. After confirming the number of billable days represented by each record, average daily consumption was determined using the number of billable days and billed consumption. Finally, consumption was allocated to each month based on the number of days captured by the bill and average daily consumption. This process of **apportioning makes sure that bills overlapping the audit period bounds are properly included in BMAC analysis and that BMAC temporally aligns with Water Supplied.** An example of bi-monthly apportioning is presented in Table 20.

Table 20: Example Calculation of Apportioning One Bill's Consumption by Calendar Month

| | | | |
|---|---|---|---|
| **Previous Read Date** | | March 23, 2007 | |
| **Read Date** | | May 23, 2007 | |
| **Consumption (CCF)** | | 66 | CCF |
| **Days Between Reads** | | 61 | days |
| **Average Consumption Per Day** | | 1.082 | CCF/day |
| **Consumption Apportioned to March** *(8 days in March within the billing period)* | = 8 days x 1.082 CCF/day | **8.66** | **CCF** |
| **Consumption Apportioned to April** *(30 days in April within the billing period)* | = 30 days x 1.082 CCF/day | **32.46** | **CCF** |
| **Consumption Apportioned to May** *(23 days in May within the billing period)* | =23 days x 1.082 CCF/day | **24.89** | **CCF** |

Apportioning consumption reduces monthly variability, as displayed in Figure 17 during the months preceding the audit period. **Additionally, apportioning slightly changes the consumption volume determined to have occurred during the audit period from an unapportioned total of 3,233,337 CCF (2,418.7 MG) to an apportioned total of 3,132,397 CCF (2,343.2 MG)**. The majority of this decrease in audit period consumption is due to consumption read during January 2014 being assigned to December 2013 and therefore not included in the audit period sum (see Figure 17).

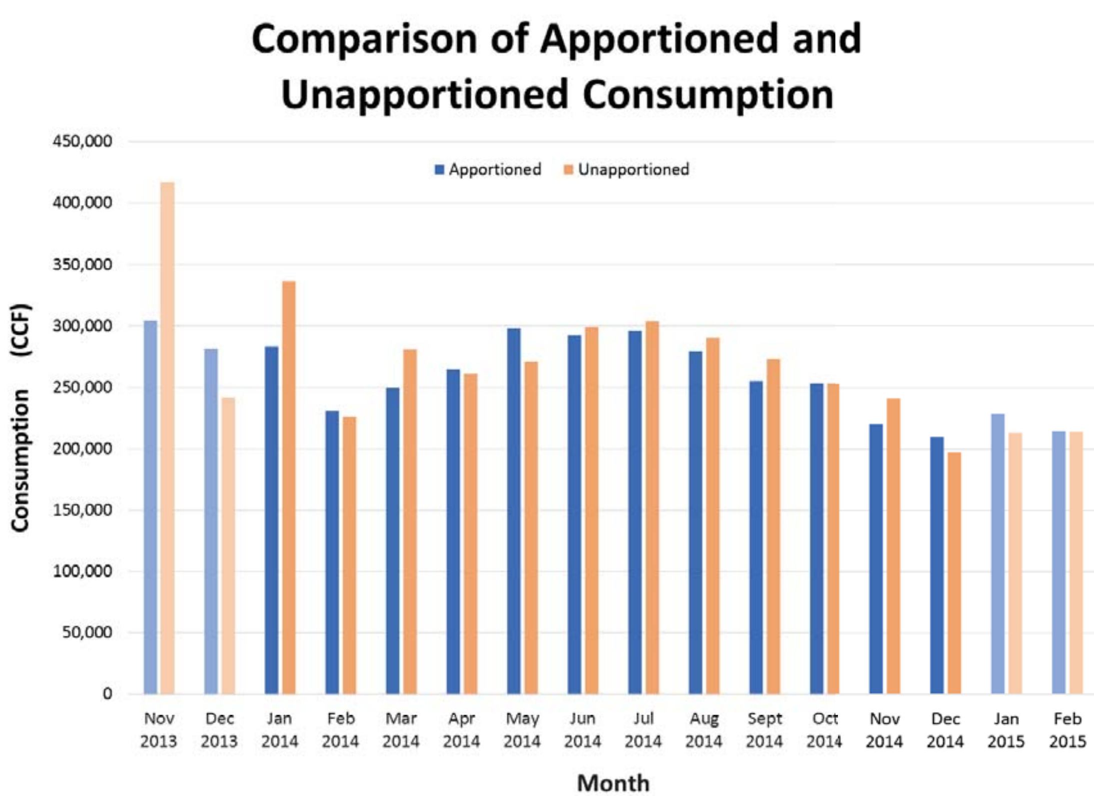



Figure 17: Comparison of Monthly Apportioned and Unapportioned Consumption

*BMAC Total*

Table 21 provides monthly consumption after billing data validation and apportioning. **Santa Cruz's total audit period BMAC was 3,132,397 CCF (2,343.2 MG).**

Table 21: Apportioned Monthly Consumption

| MONTH | CONSUMPTION (CCF) |
|---|---|
| January | 283,550 |
| February | 230,793 |
| March | 249,401 |
| April | 264,962 |
| May | 297,894 |
| June | 291,959 |
| July | 295,841 |
| August | 279,727 |
| September | 255,217 |
| October | 253,137 |
| November | 220,061 |
| December | 209,856 |
| **TOTAL** | **3,132,397** |

Santa Cruz staff independently summarized monthly consumption for California Urban Water Conservation Council Best Management Practice 1.2 reporting. To calculate monthly consumption sums, Santa Cruz staff used EDEN monthly sales reports to determine total consumption by read cycle, pro-rated consumption by cycle, and then subtracted North Coast raw water consumption to isolate audit-period potable consumption. Through this process, Santa Cruz staff determined audit-period consumption to be 2,343.34 MG. This is greater than WSO's apportioned consumption total by only 0.14 MG. This nominal difference was likely introduced by the slight difference in apportioning process (individual bills by read date or groups of bills by cycle).

*BMAC by Account Type*

**Santa Cruz's potable BMAC is sorted by account type into 14 categories.** Residential accounts consume 62.9% of BMAC, businesses consume 21.6%, irrigation consumes 5.5%, and miscellaneous categories consume the remaining 10.0%. Table 22 breaks BMAC down by account type.

Table 22: BMAC by Account Type

| ACCOUNT TYPE | COUNT OF LOCATIONS | CONSUMPTION (CCF) | AVERAGE CONSUMPTION (CCF/meter/day) | % OF TOTAL CONSUMPTION |
|---|---|---|---|---|
| business – general | 1,703 | 523,005 | 0.84 | 16.7% |
| business – hotel | 86 | 102,858 | 3.28 | 3.3% |
| business – restaurant | 107 | 51,449 | 1.32 | 1.6% |
| construction | 32 | 612 | 0.05 | 0.0% |
| interdepartmental | 214 | 40,193 | 0.51 | 1.3% |
| industrial | 39 | 63,138 | 4.44 | 2.0% |
| irrigation – business | 261 | 52,490 | 0.55 | 1.7% |
| irrigation – golf | 6 | 94,386 | 43.10 | 3.0% |
| irrigation – North Coast | 1 | 0 | 0.00 | 0.0% |
| irrigation - residential | 202 | 24,088 | 0.33 | 0.8% |
| residential – multi-family | 2,743 | 766,957 | 0.77 | 24.5% |
| residential – single-family | 18,987 | 1,202,677 | 0.17 | 38.4% |
| UCSC | 11 | 209,166 | 52.10 | 6.7% |
| "unmetered" | 9 | 1,377 | 0.42 | 0.0% |
| **ALL ACCOUNT TYPES** | **24,401** | **3,132,397** | **0.35** | **100.0%** |

The "unmetered" account type is actually metered and catalogues consumption seen at bulk water stations and on construction meters.

*BMAC by Meter Size*

Santa Cruz delivers water to customers through meters ranging in size from 5/8" to 10". 5/8" meters register a plurality of consumption (48.7%), followed by 2" meters (15.5%). Santa Cruz has one account listed as having a 5/9" meter, which WSO believes to be an error in documentation. Another account does not have a meter size assigned to it. Figure 18 provides a visual breakdown of consumption by meter size.

Table 23: BMAC by Meter Size

| METER SIZE | COUNT OF LOCATIONS | CONSUMPTION (CCF) | AVERAGE CONSUMPTION (CCF/meter/day) | % OF TOTAL CONSUMPTION |
|---|---|---|---|---|
| 5/8" | 21,798 | 1,524,302 | 0.19 | 48.7% |
| 3/4" | 281 | 29,098 | 0.28 | 0.9% |
| 1" | 1,380 | 267,240 | 0.53 | 8.5% |
| 1 1/2" | 459 | 268,729 | 1.60 | 8.6% |
| 2" | 390 | 484,876 | 3.41 | 15.5% |
| 3" | 51 | 170,813 | 9.18 | 5.5% |
| 4" | 24 | 141,593 | 16.16 | 4.5% |
| 6" | 11 | 142,839 | 35.58 | 4.6% |
| 8" | 3 | 2,014 | 1.84 | 0.1% |
| 10" | 3 | 100,580 | 91.85 | 3.2% |
| NULL | 1 | 313 | 0.86 | 0.0% |
| **ALL METERS** | **24,401** | **3,132,397** | **0.35** | **100.0%** |

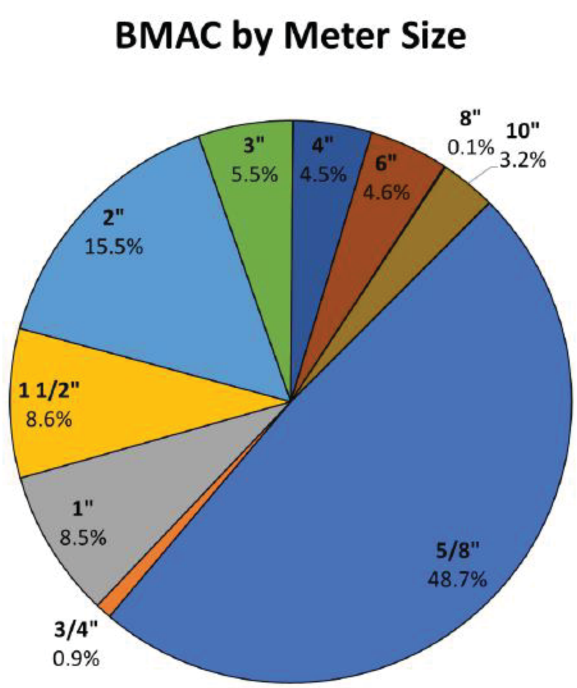



Figure 18: Percentage of BMAC by Meter Size

*BMAC by Jurisdiction*

Santa Cruz delivers water to four jurisdictions: "in" city limits, "out" (outside) of city limits, North Coast, and Capitola. The amount of water consumed by each jurisdiction is recorded in Table 24. Most water is consumed in the City of Santa Cruz (63.7%), followed by accounts outside the City of Santa Cruz (34.2%).

Table 24: BMAC by Jurisdiction

| JURISDICTION | COUNT OF LOCATIONS | CONSUMPTION (CCF) | % OF TOTAL CONSUMPTION |
|---|---|---|---|
| Capitola | 236 | 57,091 | 1.8% |
| Santa Cruz City | 15,842 | 1,995,485 | 63.7% |
| North Coast | 45 | 7,931 | 0.3% |
| NULL | 2 | 24 | 0.0% |
| County | 8,276 | 1,071,866 | 34.2% |
| **ALL JURISDICTIONS** | **24,401** | **3,132,397** | **100.0%** |

## 3.3 Billed Unmetered Authorized Consumption

Santa Cruz tracks Billed Unmetered Authorized Consumption (BUAC) used for three primary purposes:

- street sweeping
- storm drain and sewer flushing
- sanitation district sewer flushing

During the 2014 audit period, no consumption for street sweeping was reported, even though street sweeping occurred. Therefore, the 2014 street sweeping volume is categorized as Unbilled Unmetered Authorized Consumption because this volume was not billed.

Monthly BUAC attributed to flushing operations is provided in Table 25 below. Flushing volumes were estimated by multiplying the number of times a tank of known volume was filled by the tank's volume.

Table 25: Monthly Billed Unmetered Authorized Consumption

| MONTH | STORM DRAIN AND SEWER FLUSHING (gal) | SANITATION DISTRICT SEWER FLUSHING (gal) | TOTAL (gal) |
|---|---|---|---|
| January | 40,000 | 0 | **40,000** |
| February | 74,436 | 7,050 | **81,486** |
| March | 96,900 | 2,600 | **99,500** |
| April | 64,400 | 0 | **64,400** |
| May | 86,558 | 1,700 | **88,258** |
| June | 70,698 | 2,000 | **72,698** |
| July | 74,732 | 7,625 | **82,357** |
| August | 64,340 | 3,300 | **67,640** |
| September | 68,960 | 3,000 | **71,960** |
| October | 66,468 | 1,000 | **67,468** |
| November | 48,095 | 0 | **48,095** |
| December | 59,175 | 0 | **59,175** |
| **TOTAL** | **814,762** | **28,275** | **843,037** |

**Santa Cruz's BUAC volume for 2014 totaled 843,037 gallons (0.8 MG).**

## 3.4 Unbilled Metered Authorized Consumption

Santa Cruz supplies water for six primary Unbilled Metered Authorized Consumption (UMAC) uses:

- Graham Hill Water Treatment Plant
- North Coast Recirculation Station
- water main replacement and extension
- corporation yard fire service (all hydrant uses, including fire service training)
- street tree watering
- legacy "404" unbilled potable water accounts

The Graham Hill Water Treatment Plant did not see any net consumption during 2014 on the bi-directional meter that measures internal plant water uses. The other five UMAC volumes are broken down by month in Table 26.

Table 26: Monthly Unbilled Metered Authorized Consumption

| MONTH | NORTH COAST RECIRCULATION (gal) | MAIN REPLACEMENT & EXTENSION (gal) | CORPORATION YARD (gal) | TREE WATERING (gal) | 404 ACCOUNTS (gal) | TOTAL (gal) |
|---|---|---|---|---|---|---|
| January | 674,000 | 22,446 | 26,928 | 0 | 43,384 | **766,758** |
| February | 2,000 | 0 | 1,496 | 0 | 45,628 | **49,124** |
| March | 214,000 | 0 | 1,496 | 0 | 40,392 | **255,888** |
| April | 692,000 | 0 | 11,220 | 0 | 44,132 | **747,352** |
| May | 689,000 | 9,849 | 26,180 | 3,000 | 30,668 | **758,697** |
| June | 781,000 | 32,245 | 5,984 | 2,400 | 70,312 | **891,941** |
| July | 666,000 | 0 | 2,244 | 2,400 | 94,248 | **764,892** |
| August | 856,000 | 6,829 | 0 | 3,000 | 81,532 | **947,361** |
| September | 390,000 | 0 | 7,480 | 2,400 | 86,020 | **485,900** |
| October | 652,000 | 30,502 | 2,244 | 3,000 | 76,296 | **764,042** |
| November | 555,000 | 0 | 3,740 | 0 | 47,124 | **605,864** |
| December | 91,000 | 19,320 | 14,960 | 0 | 46,376 | **171,656** |
| **TOTAL** | **6,262,000** | **121,191** | **103,972** | **16,200** | **706,112** | **7,209,475** |

**Santa Cruz's UMAC volume for 2014 totaled 7,209,475 gallons (7.2 MG).**

## 3.5 Unbilled Unmetered Authorized Consumption

Unbilled Unmetered Authorized Consumption (UUAC) is the estimated volume of water taken unmetered from the system and from which no revenue is generated. For Santa Cruz, five uses are categorized as Unbilled Unmetered Authorized Consumption:

- annual system flushing
- repair activity (flushing for service connections breaks, main breaks, etc.)
- tank maintenance
- City of Santa Cruz unmetered fire department use (both fire suppression and training)
- Central Fire District use (both fire suppression and training)

Minimal system flushing and no tank maintenance was performed in 2014 due to drought-induced water rationing. Additionally, both the City of Santa Cruz Fire District and Central Fire District did not record consumption estimates during 2014. In the absence of fire district data, WSO has chosen to *not* estimate these UUAC volumes and instead consider the total UUAC volume to have a wide margin of error.

Santa Cruz staff performing field repairs estimate and record water used during each repair**. This process of estimation sometimes incorporates water loss estimations in addition to the authorized water consumption used in the process of repair**. WSO will investigate this further as part of the Component Analysis of Real Losses, during which WSO will examine repair records and the process that generates them.

Because estimates of Santa Cruz's UUAC are available, WSO has chosen *not* to employ the AWWA default estimate of 1.25% of total Water Supplied. Instead, the volumes provided in Table 27 will serve as the audit period UUAC.

Table 27: Monthly Unbilled Unmetered Authorized Consumption

| MONTH | ANNUAL FLUSHING (gal) | REPAIRS (gal) | TOTAL (gal) |
|---|---|---|---|
| January | 167,285 | 344,150 | 511,435 |
| February | 0 | 257,775 | 257,775 |
| March | 0 | 134,750 | 134,750 |
| April | 0 | 277,390 | 277,390 |
| May | 0 | 200,000 | 200,000 |
| June | 0 | 157,600 | 157,600 |
| July | 0 | 849,130 | 849,130 |
| August | 0 | 178,500 | 178,500 |
| September | 0 | 149,220 | 149,220 |
| October | 0 | 359,140 | 359,140 |
| November | 0 | 262,450 | 262,450 |
| December | 0 | 327,410 | 327,410 |
| **TOTAL** | **167,285** | **3,497,515** | **3,664,800** |

**Santa Cruz's UUAC volume for 2014 totaled 3,664,800 gallons (3.7 MG).**

## 3.6 Authorized Consumption Summary

**During 2014, Santa Cruz's authorized consumption volume was 2,356.1 MG**. The majority of this volume (99.5%) was consumed by billed, metered customers. Table 28 below provides a summary of Authorized Consumption broken down by metering and billing status.

Table 28: Authorized Consumption Summary

| AUTHORIZED CONSUMPTION CATEGORY | DESCRIPTION | VOLUME (CCF) | VOLUME (MG) | % OF CONSUMPTION TOTAL |
|---|---|---|---|---|
| Billed Metered | accounts in EDEN billing database | 3,132,397 | **2,343.2** | 99.5% |
| Billed Unmetered | flushing | 1,127 | **0.8** | 0.0% |
| Unbilled Metered | North Coast recirculation, main replacement, corporation yard, tree watering, potable 404 accounts, increase in stored volume | 9,638 | **7.2** | 0.3% |
| Unbilled Unmetered | system flushing estimates | 4,899 | **3.7** | 0.2% |
| **TOTAL** | | **3,148,061** | **2,354.9** | **100.0%** |

## 3.7 Recommendations

- **Include a Boolean (true/false) field in the EDEN billing database to quickly and easily filter BMAC-relevant records.** To minimize the likelihood of accidentally including raw water or unbilled consumption in BMAC totals, a yes/no field indicating status as a BMAC account should be added to EDEN and employed in future consumption analyses. When the field is checked "yes," the water for the account is potable and revenue-generating and therefore should be incorporated in audit totals of Billed Metered Authorized Consumption. When the field is not checked, the water for the account is not potable or is not revenue-generating and should therefore be excluded from audits totals of Billed Metered Authorized Consumption.

- **Perform the validation checks listed Section 3.2.3 when completing an annual audit.** These validation checks confirm that billing data is complete and reliable at a macroscopic level. Santa Cruz currently checks lag time and apportions consumption by reading route. Performing the additional checks outlined in this report will confirm data validity more thoroughly.

# 4 Apparent Losses

## 4.1 Introduction

**According to the AWWA M36 water auditing manual, Apparent Losses are the water losses that occur when water is successfully delivered to customers but is not measured or recorded accurately.** As a results, Apparent Losses fail to generate revenue for a utility, even though water has reached its destination after the distribution process. Often referred to as "paper losses," Apparent Losses come in three distinct forms, outlined below and in Figure 19.

- **customer metering inaccuracies** that result in *less water registered* by meters *than actually passes through* the meters
- **unauthorized consumption** (theft) that results in consumption that is neither registered nor billed
- **systematic data handling errors** like accounting omissions, errant computer programming, erroneous data entry, and financial bill manipulations that result in inaccurate records of consumption

<table>
<tr><td rowspan="3">Water from Own Sources</td><td rowspan="12">System Input Volume</td><td colspan="4">Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td rowspan="11">Water Supplied</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="9">Water Imported</td><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="9">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="7">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Customer Metering Inaccuracies</td></tr>
<tr><td>Unauthorized Consumption</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="4">Real Losses</td><td>Reported Leakage</td></tr>
<tr><td>Unreported Leakage</td></tr>
<tr><td>Background Leakage</td></tr>
<tr><td>Hidden Losses</td></tr>
</table>

Figure 19: Water Balance, Apparent Losses Highlighted

**Apparent Losses are valued at customer retail cost, so reclaiming Apparent Losses can offer opportunity for significant revenue recovery**. Additionally, thorough investigation of Apparent Losses often reveals opportunities to improve operational practices like meter reading, customer billing, account management, and meter testing and replacement.

Chapter 4 will address Apparent Losses as follows:

- Section 4.2 – Customer Metering Inaccuracies
- Section 4.3 – Unauthorized Consumption
- Section 4.4 – Systematic Data Handling Errors
- Section 4.5 – Summary of Apparent Losses
- Section 4.6 – Recommendations

Once quantified, **Apparent Losses are subtracted from Water Losses to determine Real Losses**. As a result, accuracy of the Apparent Loss volume is especially important. The relationship between Real Losses and Apparent Losses is zero-sum: under-estimation of Apparent Losses will result in an equal over-estimation of Real Losses.

## 4.2 Customer Metering Inaccuracies

**All meter populations feature a certain degree of inaccuracy in registering customer consumption volumes.** Inaccuracies typically result from under-registration due to inappropriate meter sizing and meter wear-and-tear, thereby producing an Apparent Loss volume. Meter over-registration is also possible. However, over-registration is much less common than under-registration, especially for smaller mechanical meters (as opposed to larger electromagnetic and Venturi meters).

In order to quantify Apparent Losses due to customer metering error, the accuracy of the meter population must be estimated. **Individual meter accuracy is measured by volumetric testing, the practice of comparing a known volume of water passed through a meter to the volume registered by the meter.** Meter testing protocol differs for small and large meters, so these two meter populations were considered separately for Santa Cruz's water audit. Additionally, Santa Cruz conducted 5/8" meter testing in 2014, so WSO and Santa Cruz chose to focus testing resources on meters 1 1/2" and larger for this water audit project.

In order to estimate Apparent Losses due to customer metering inaccuracies,

1. A sample of large meters (1 1/2" and greater) was tested for volumetric accuracy.
2. A test results database composed of large meter tests and 5/8" meter tests (from 2014) was composed and analyzed for average accuracy by meter size.
3. Testing and analytical results were extrapolated to the entire meter stock by meter size (and install year, in the case of 5/8" meters).
4. Meter stock accuracy was paired with consumption volumes to determine Apparent Losses.

**The potential for error resulting from the sampling and extrapolation method is acknowledged by the calculation of a 95% confidence interval.** Were the sampling process to be repeated multiple times and a 95% confidence interval calculated for each sample accuracy average, 95% of the resultant confidence intervals would capture the true population average accuracy.

The following sections describe the test samples, test results, and Apparent Loss calculations for small meters (5/8”) and large meters (3/4” and greater).

### 4.2.1 *Small Meters*

*Meter Stock and Meter Tests*

Santa Cruz’s 5/8” meter stock consists of about 21,680 meters. During the 2014 audit period, 5/8” meter registered 1,504,302 CCF, approximately 49% of total consumption registered by all meter sizes.

Santa Cruz conducted tests of 5/8” meters during 2014 to investigate the relationship between meter age and accuracy. In order to extrapolate the 5/8” tests to the entire 5/8” meter stock, WSO chose to stratify the 5/8” meter population by meter age, using 5-year buckets.

To determine the total count of active 5/8” meters, Santa Cruz staff ran an EDEN report that tallied the number of meters by install year. Though the report was run in 2016, Santa Cruz has not significantly changed the composition of its meter population since 2014. Therefore, WSO considers the 2016 report to adequately approximate the 2014 meter stock. The 2016 EDEN report of 5/8” meters by meter age is summarized in Table 29. The count of 2014 tests by meter age is also provided.

Table 29: 5/8” Meter Tests and Total Population

| SIZE | INSTALL RANGE | COUNT OF METERS | % OF TOTAL COUNT | COUNT OF TESTS | % OF TOTAL TESTS |
|---|---|---|---|---|---|
| 5/8” | 1965 – 1969 | 1 | 0% | - | - |
| 5/8” | 1970 – 1974 | - | - | - | - |
| 5/8” | 1975 – 1979 | 15 | 0% | 4 | 2% |
| 5/8” | 1980 – 1984 | 6 | 0% | - | - |
| 5/8” | 1985 – 1989 | 12 | 0% | 1 | 0% |
| 5/8” | 1990 – 1994 | 680 | 3% | 60 | 28% |
| 5/8” | 1995 – 1999 | 3,829 | 18% | 108 | 50% |
| 5/8” | 2000 – 2004 | 10,583 | 49% | 28 | 13% |
| 5/8” | 2005 – 2009 | 5,557 | 26% | 10 | 5% |
| 5/8” | 2010 – 2014 | 669 | 3% | 2 | 1% |
| 5/8” | 2015 - present | 141 | 1% | - | - |
| 5/8” | unknown | 190 | 1% | 1 | 0% |
| **ALL 5/8”** | | **21,683** | **100%** | **214** | **100%** |

**The 5/8”meters that were tested were randomly selected, but the sample was designed to represent the older meters in Santa Cruz’s meter stock, not the meter stock as a whole.** Therefore, the accuracy of new meters – particularly those installed after 2005 – is not well-captured in the 5/8” meter tests. The difference in the age composition of the test sample and the entire 5/8” meter stock is highlighted in Figure 20, which provides a cumulative frequency curve based on the installation year. The median test meter was installed in 1992, compared to the median stock meter installed in 1998.

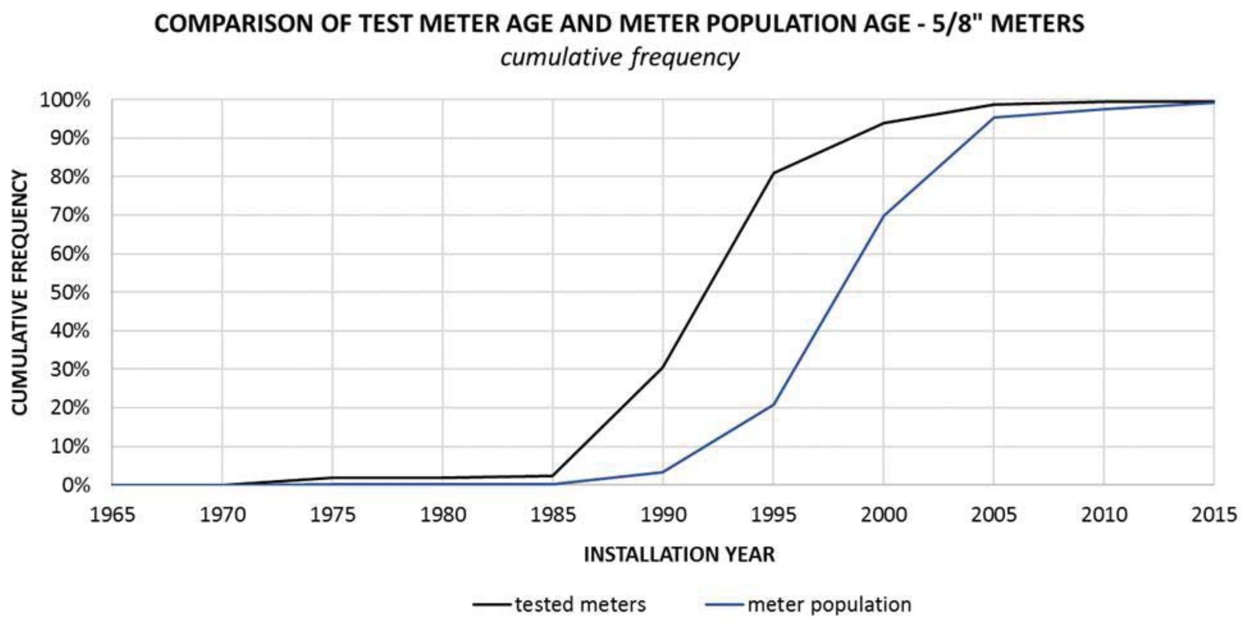



Figure 20: Comparison of 5/8” Meter Age in Test Sample and Meter Stock

*Test Procedure*

**To determine small meter accuracy, meters were volumetrically tested using the test method outlined in AWWA Manual M36**. AWWA methodology stipulates that small meters be tested at three flow rates. The three flow rates – low, medium, and high – are standardized by meter size to capture the common range of flow rates that each meter size experiences. Test flow rates are provided in Table 30.

Once meter accuracy at each flow rate is known, weighting factors are assigned to each flow rate to determine average accuracy. The weighting factors are derived from the proportion of water consumed at each specific flow rate compared to the total volume consumed at all flow rates.

Table 30: 5/8” Meter Test Flow Rates and Weighting Factors

| FLOW CATEGORY | FLOW RATE (gpm) | TIME ASSUMPTION | WEIGHTING FACTOR |
|---|---|---|---|
| Low | 0.25 | 15% | 1% |
| Medium | 2 | 70% | 38% |
| High | 15 | 15% | 61% |

The weighting factors endorsed by AWWA assume that small meters register 15% of the time at low flows, 70% at medium flows, and 15% at high flows. This time distribution paired with the standardized flow rates produces volumetric weighting factors that are used to calculate average meter accuracy. Volumetric weighting is preferred to simple time weighting because it acknowledges the interaction between flow rate and time in producing recorded volume. For example, while it is assumed that a 5/8” meter operates 15% of the time at low flows, it only records about 1% of total volume at low flows.

To tailor weighting factors to Santa Cruz's actual consumption patterns instead of employing AWWA assumptions, Santa Cruz could log residential consumption patterns for a statistically significant and representative sample of customers. Such a study would align the flow-rate time distribution used to weight accuracy with Santa Cruz's unique customer consumption profiles, thereby improving the accuracy of weighting factors and the ultimate calculation of Apparent Losses. See Appendix F for an example of a consumption profiling project conducted by the East Bay Municipal Utility District (EBMUD) that informed test weighting factors.

*Test Results*

Table 31 provides test results for 5/8" meters by meter size, after the process of time-and-volume weighting. Additionally, standard confidence intervals are provided to indicate the degree of uncertainty inherent in the test results. Confidence intervals cannot be calculated for sample groups where only one test was conducted.

Table 31: 5/8" Meter Test Results

| INSTALL RANGE | POPULATION | TESTS | AVERAGE ACCURACY | CONFIDENCE INTERVAL (±) |
|---|---|---|---|---|
| 1965 – 1969 | 1 | - | | |
| 1970 – 1974 | - | - | | |
| 1975 – 1979 | 15 | 4 | 99.5% | 2.0% |
| 1980 – 1984 | 6 | - | | |
| 1985 – 1989 | 12 | 1 | 99.4% | N/A |
| 1990 – 1994 | 680 | 60 | 99.0% | 2.1% |
| 1995 – 1999 | 3,829 | 108 | 99.9% | 0.6% |
| 2000 – 2004 | 10,583 | 28 | 100.1% | 0.3% |
| 2005 – 2009 | 5,557 | 10 | 100.3% | 0.6% |
| 2010 – 2014 | 669 | 2 | 100.7% | 2.3% |
| 2015 - present | 141 | - | | |
| unknown | 190 | 1 | 100.2% | N/A |
| **ALL 5/8"** | **21,683** | **214** | **99.7%** | **0.7%** |

**Because the meter test sample was not representative, the average figure of 99.7% accuracy describes the average *test result* but the not the average performance of a 5/8" meter.** Instead, WSO wishes to highlight more general trends. Even meters installed as long ago as 1975 appear to be working with AWWA specifications (100% ± 1.5%). Additionally, older meters appear to slightly under-register, whereas newer meters may nominally over-register.

**The range of test results and the limited number of tests performed are communicated by the confidence intervals**. A wider confidence interval indicates that results should be interpreted cautiously and conclusions about meter stock accuracy should be qualified by a high degree of uncertainty.

AWWA has established basic standards for acceptable small meter inaccuracy at each flow rate (low, medium, and high). These accuracy thresholds are presented below in Table 32.

Table 32: AWWA Small Meter Accuracy Recommendations by Flow Rate

| LOW FLOW | MEDIUM FLOW | HIGH FLOW |
|---|---|---|
| 95.0% – 100.0% | 98.5% – 101.5% | 98.5% – 101.5% |

Of the 214 5/8" meters tested, only 4 meters (2%) do not pass the AWWA accuracy standards at any flow rate. 142 meters (66%) failed to meet AWWA thresholds for at least one flow rate, and the low-flow rate was most commonly failed. Figure 21 below provides a summary of pass rates by flow rate, and Figure 22 summarizes pass rates at all flow rates.

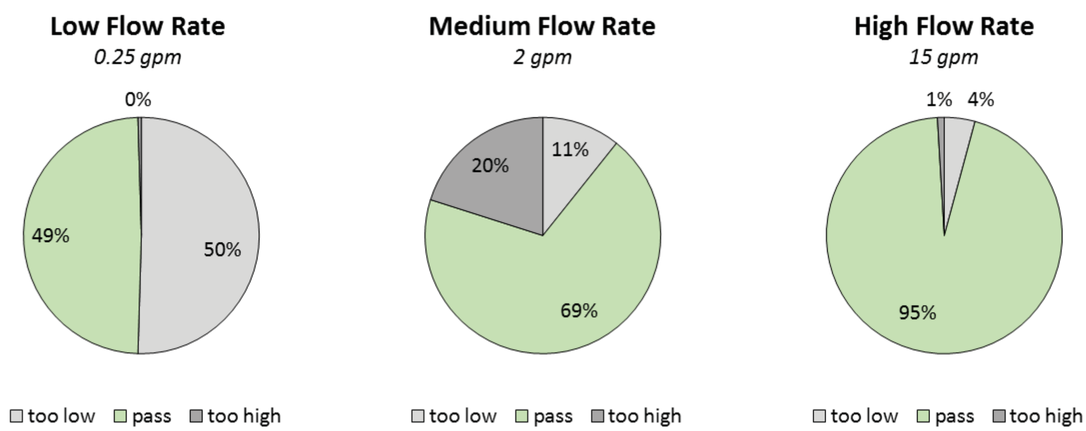



Figure 21: Meters Passing AWWA Accuracy Threshold by Flow Rate

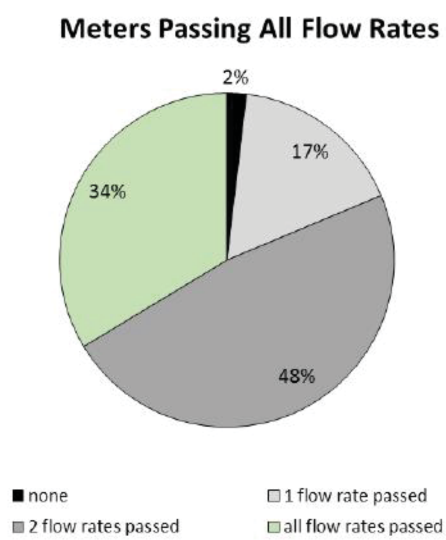



Figure 22: Meters Passing AWWA Accuracy Threshold for all Flow Rates

*Apparent Losses*

Once the average accuracy of each age group has been calculated using test results, the Apparent Loss volume can be determined for each age group. For ages not tested, the average accuracy of all tested 5/8" meters is used. Apparent Losses are calculated using the following formula.

$$\text{Apparent Losses} = \left(\frac{V}{A}\right) - V$$

where *V* is the volume registered by the meter (consumption)

*A* is the accuracy as a decimal value

**When accuracy test results are paired with consumption, Santa Cruz's 5/8" meter stock registered with a weighted average accuracy of 100.1% during the audit period, resulting in an Apparent Loss volume of –1,636 CCF (–1.2 MG).** A negative Apparent Loss figure indicates "Apparent Gain" – more water registered than was delivered.

Table 33 provides a summary of the Apparent Losses attributed to each 5/8" age group. Italicized average accuracy figures indicate the usage of average test accuracy values in the absence of age group tests. **Meter age and consumption information could not be connected using the billing data, so all meters were assumed to register equal volumes during 2014**. Therefore, total 5/8" consumption was proportionally allocated across all age groups by the count of meters in each age group.

Table 33: Small Meter Apparent Losses by Size-Make Group

| INSTALL RANGE | CONSUMPTION (CCF) | COUNT OF TESTS | AVERAGE ACCURACY | APPARENT LOSS (CCF) |
|---|---|---|---|---|
| 1965 – 1969 | 70 | - | *99.7%* | *0* |
| 1975 – 1979 | 1,049 | 4 | 99.5% | 5 |
| 1980 – 1984 | 420 | - | *99.7%* | *1* |
| 1985 – 1989 | 839 | 1 | 99.4% | 5 |
| 1990 – 1994 | 47,551 | 60 | 99.0% | 493 |
| 1995 – 1999 | 267,756 | 108 | 99.9% | 319 |
| 2000 – 2004 | 740,054 | 28 | 100.1% | – 912 |
| 2005 – 2009 | 388,593 | 10 | 100.3% | – 1,242 |
| 2010 – 2014 | 46,782 | 2 | 100.7% | – 304 |
| 2015 - present | 9,860 | - | *99.7%* | *32* |
| unknown | 21,328 | 1 | 100.2% | – 33 |
| **ALL 5/8"** | **1,524,302** | **214** | **100.1%** | **– 1,636** |

**Even though the average 5/8" test result suggested under-registration, the total 5/8" meter population was actually estimated to have over-registered slightly during 2014.** Most 5/8" meter *tests* were conducted on older meters (installed before 2000), and tests of older meters tended to indicate under-registration. In contrast, tests of newer 5/8" meters tended to indicate over-registration, and most 5/8" meters *in the meter stock* were installed during or after 2000. As a result, the 5/8" meter tests, though random, were not representative of the age distribution of the meter stock.

### 4.2.2 *Large Meters*

This section details the calculation of Apparent Loss for large meters, meters 3/4"and greater in diameter. Large meter accuracy was investigated by randomly testing a number of meters in each meter size group.

*Meter Stock and Meter Tests*

Santa Cruz's large meter stock consists of about 2,700 meters that are 3/4" and larger, listed by size in Table 34. These meters registered 1,608,095 CCF during the audit period, accounting for 51% of total registered consumption. As was the case with 5/8" meters, the count of large meters by size was drawn from a 2016 EDEN report determined to be an adequate proxy for the 2014 meter stock.

Table 34: Large Meter Stock Composition and Consumption

| SIZE | COUNT OF METERS | % OF TOTAL COUNT | COUNT OF TESTS | % OF TOTAL TESTS |
|---|---|---|---|---|
| 3/4" | 348 | 13% | - | - |
| 1" | 1,386 | 51% | 34 | 45% |
| 1 1/2" | 468 | 17% | 11 | 15% |
| 2" | 405 | 15% | 17 | 23% |
| 3" | 47 | 2% | 6 | 8% |
| 4" | 26 | 1% | 3 | 4% |
| 6" | 13 | 0% | 2 | 3% |
| 8" | 4 | 0% | - | - |
| 10" | 3 | 0% | 2 | 3% |
| unknown | 2 | 0% | - | - |
| **ALL LARGE METERS** | **2,702** | **100%** | **75** | **100%** |

Large meters were randomly selected for testing. Size groups with more meters were generally allocated more tests.

*Test Procedure*

**To determine large meter accuracy, meters were volumetrically tested using the test method outlined in AWWA Manual M36**. AWWA methodology stipulates that large meters be tested at three flow rates. AWWA recommends low, medium, and high flow rates by meter size, but large meter flow rates can be adjusted to capture the unique operating conditions of each meter.

Test flow rates are provided in Table 35.

Table 35: Large Meter Test Flow Rates

| SIZE | LOW FLOW (gpm) | MEDIUM FLOW (gpm) | HIGH FLOW (gpm) |
|---|---|---|---|
| 1” | 0.75 | 4 | 40 |
| 1 1/2” | 1.5 | 8 | 50 |
| 2” | 0.75 or 2 | 12 or 15 | 50 or 100 |
| 3” | 0.75 or 8 | 15 | 150 |
| 4” | 0.75 | 25 | 200 |
| 6” | 1.5 | 35 | 200 or 370 |
| 10” | 35 | 120 | 400 |

In contrast to 5/8” meter test analysis, large meter flow rates and accuracy results are not time- and volume-weighted to determine a single accuracy figure. Instead, the simple average of all three flow-rate results is taken. Large meters tend to register a wide range of consumption patterns, so no single time distribution can be responsibly applied to large meter test results.

To be able to weight flow-rate results instead of taking a simple average, Santa Cruz could investigate the consumption patterns unique to key large meters by logging flow rates for a study period. The details of such an investigation are outlined in Appendix G alongside an examination of large-meter right-sizing.

*Test Results*

Table 36 provides test results for large meters by meter size. Additionally, standard confidence intervals are provided to indicate the degree of uncertainty inherent in the test results.

Table 36: Large Meter Test Results

| SIZE | POPULATION | TESTS | AVERAGE ACCURACY | CONFIDENCE INTERVAL (±) |
|---|---|---|---|---|
| 3/4” | 348 | - | | |
| 1” | 1,386 | 34 | 96.3% | 5.6% |
| 1 1/2” | 468 | 11 | 98.1% | 2.0% |
| 2” | 405 | 17 | 96.3% | 7.8% |
| 3” | 47 | 6 | 101.1% | 2.0% |
| 4” | 26 | 3 | 95.1% | 8.7% |
| 6” | 13 | 2 | 91.4% | 2.0% |
| 8” | 4 | - | | |
| 10” | 3 | 2 | 97.7% | 2.6% |
| unknown | 2 | - | | |
| **ALL LARGE METERS** | **2,702** | **75** | **96.8%** | **1.8%** |

**In contrast to the 5/8” meter tests, most large meter tests indicate performance outside AWWA recommended accuracy ranges.** Discussion of AWWA accuracy thresholds is provided below.

**The range of test results and the limited number of tests performed are communicated by the confidence intervals**. A wider confidence interval indicates that results should be interpreted cautiously and conclusions about meter stock accuracy should be qualified by a high degree of uncertainty.

AWWA has established basic standards for acceptable large meter inaccuracy at each flow rate (low, medium, and high). These accuracy thresholds are presented below in Table 32.

Table 37: AWWA Large Meter Accuracy Recommendations by Flow Rate

| LOW FLOW | MEDIUM FLOW | HIGH FLOW |
|---|---|---|
| 95.0% – 100.0% | 98.5% – 101.5% | 98.5% – 101.5% |

Of the 75 large meters tested, 8 meters (11%) do not pass the AWWA accuracy standards at any flow rate. 57 meters (76%) failed to meet AWWA thresholds for at least one flow rate, and the low flow rate was most commonly failed. Figure 23 below provides a summary of pass rates by flow rate, and Figure 24 summarizes pass rates at all flow rates.

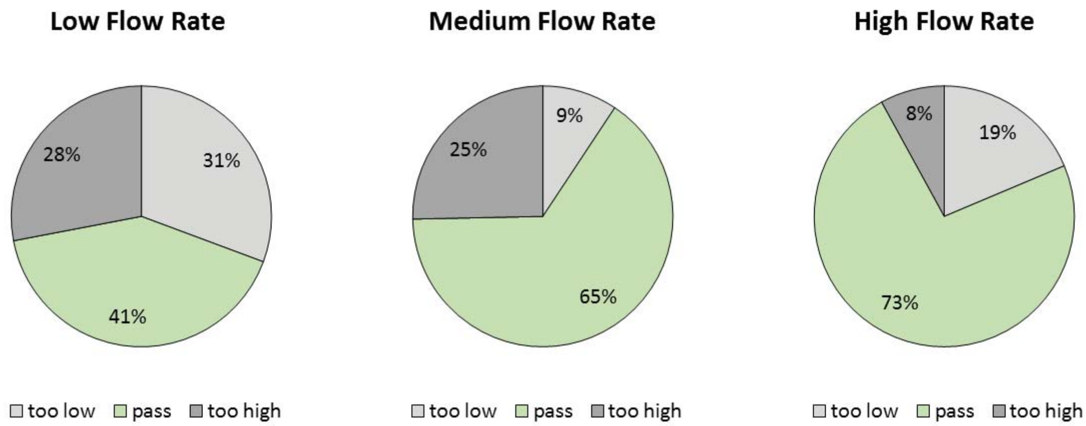



Figure 23: Meters Passing AWWA Accuracy Threshold by Flow Rate

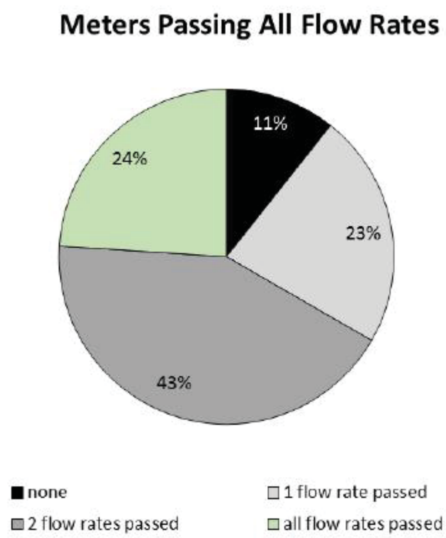



Figure 24: Meters Passing AWWA Accuracy Threshold for all Flow Rates

*Apparent Losses*

Once the average accuracy of each size group has been calculated using test results, the Apparent Loss volume can be determined for each size group. For sizes not tested, the average accuracy of all tested large meters is used. Apparent Losses are calculated using the following formula.

$$\text{Apparent Losses} = \left(\frac{V}{A}\right) - V$$

where *V* is the volume registered by the meter (consumption)

*A* is the accuracy as a decimal value

**When accuracy test results are paired with consumption, Santa Cruz's large meter stock registered with a weighted average accuracy of 96.6% during the audit period, resulting in an Apparent Loss volume of 56,354 CCF (42.2 MG).**

Table 33 provides a summary of the Apparent Losses attributed to each large meter size group. Italicized average accuracy figures indicate the usage of average test accuracy values in the absence of size group tests.

Table 38: Small Meter Apparent Losses by Size-Make Group

| SIZE | TOTAL CONSUMPTION (CCF) | AVERAGE CONSUMPTION PER METER (CCF) | COUNT OF TESTS | AVERAGE ACCURACY | APPARENT LOSS (CCF) |
|---|---|---|---|---|---|
| 3/4" | 29,098 | 83.6 | - | *96.8%* | *956* |
| 1" | 267,240 | 192.8 | 34 | 96.3% | 10,201 |
| 1 1/2" | 268,729 | 574.2 | 11 | 98.1% | 5,165 |
| 2" | 484,876 | 1,197.2 | 17 | 96.3% | 18,571 |
| 3" | 170,813 | 3,634.3 | 6 | 101.1% | –1,854 |
| 4" | 141,593 | 5,445.9 | 3 | 95.1% | 7,324 |
| 6" | 142,839 | 10,987.6 | 2 | 91.4% | 13,522 |
| 8" | 2,014 | 503.5 | - | *96.8%* | *66* |
| 10" | 100,580 | 33,526.7 | 2 | 97.7% | 2,392 |
| unknown | 313 | 156.5 | - | *96.8%* | *10* |
| **ALL LARGE METERS** | **1,608,095** | **595.1** | **75** | **96.6%** | **56,354** |

Inaccuracy in the 2" and 6" meter groups contributed most significantly to total large meter Apparent Losses.

*Summary*

**Customer metering inaccuracies resulted in 54,719 CCF (40.9 MG) of Apparent Loss during the 2014 audit period.** A summary of Apparent Losses by meter size is given in Table 39. To value Apparent Losses, WSO used a customer retail unit cost of $4.04/CCF.

Table 39: Summary of Customer Meter Apparent Losses

| SIZE | APPARENT LOSSES (CCF) | VALUE OF APPARENT LOSSES | % OF METER APPARENT LOSSES |
|---|---|---|---|
| 5/8” | –1,636 | – $6,608 | –3% |
| 3/4” | 956 | $3,862 | 2% |
| 1” | 10,201 | $41,212 | 19% |
| 1 1/2” | 5,165 | $20,867 | 9% |
| 2” | 18,571 | $75,027 | 34% |
| 3” | –1,854 | – $7,489 | –3% |
| 4” | 7,324 | $29,590 | 13% |
| 6” | 13,522 | $54,630 | 25% |
| 8” | 66 | $267 | 0% |
| 10” | 2,392 | $9,663 | 4% |
| unknown | 10 | $42 | 0% |
| **ALL METERS** | **54,719** | **$221,063** | **100.0%** |

### 4.2.3 *Economically Efficient Level of Customer Metering Inaccuracies*

To determine the appropriate level of intervention against Apparent Losses, **WSO examined the economics of meter replacement based on meter size**. Evaluation of meter replacement compares revenue savings in improved registration to the upfront costs of purchasing and installing a new meter. Additionally, meter replacement programs can be orchestrated to specifically target problematic meter groups based on lost revenue, rather than replacing meters purely by age or geography.

WSO intends for this analysis to serve as an example calculation of the economically efficient level of customer metering inaccuracies, should Santa Cruz choose to pursue future meter replacement.

*Analytical Parameters*

Evaluating meter replacement requires the input of three key parameter values, listed below:

- **Value of water (per unit)** – this is usually the average customer retail unit cost
- **Cost of meter replacement** – this is composed of both the cost of the new meter and the cost of labor to install the new meter
- **Length of payback period** – this informs the calculation of the Net Present Value (NPV) and determines the bounds of Santa Cruz’s financial analysis

For this analysis, **Apparent Losses are valued at an average customer retail cost of $4.04 per CCF**. Customer retail cost was calculated by dividing the total volume of water sold to customers during the audit period by the total revenue generated from customer bills during the same period. Fixed and flat fees were not incorporated because they do not depend on meter accuracy.

**Meter replacement costs, composed of the cost of a new meter, the cost of replacement labor, and the credit received for meter recycling, are listed below in Table 40 by meter size**.

Table 40: Meter Replacement Costs

| SIZE | NEW METER COST* | MXU/RADIO COST | LABOR COST | CREDIT | TOTAL COST |
|---|---|---|---|---|---|
| 5/8" | $108 | $110 | $20 | $3.75 | $234.25 |
| 3/4" | $131 | $110 | $20 | $5.50 | $255.50 |
| 1" | $164 | $110 | $20 | $8 | $286 |
| 1 1/2" | $313 | $110 | $60 | $18 | $465 |
| 2" | $469 | $110 | $80 | $25 | $634 |
| 3" | $745 | $110 | $80 | $75 | $860 |
| 4" | $1,090 | $110 | $120 | $75 | $1,245 |
| 6" | $2,567 | $110 | $120 | $75 | $2,722 |
| 8” | $3,199** | $110 | $140** | $75 | $3,524 |
| 10” | $3,831 | $110 | $160 | $75 | $4,026 |

*New meter cost reflects the purchase cost of a Badger disc meter. Other types of meters – for example, Sensus compound meters – may have different price points and should be individually considered based on customer needs.

**Replacement costs not provided. WSO chose to substitute an average of 6” and 10” categorical costs.

Finally, **the length of the payback period is 10 years**. In order for this analysis to be conservative in its assumptions, for each year during this 10-year period savings diminish slightly based on the assumption that a new meter's accuracy decreases with use. WSO assumes that meter accuracy deteriorates 0.1% per year. Santa Cruz can adjust these analytical parameters in future analyses to inform calculations that are more conservative or more aggressive.

*Example Evaluation: 2” Meters*

The following tables outline an example evaluation of meter replacement. In this case, 2” meters are considered. Table 41 provides the meter stock information, consumption total, and test results for this meter size.

Table 41: Test Results and Apparent Loss Total for 2” Meters

| | | |
|---|---|---|
| METER STOCK | size | 2” |
| | count | 405 |
| TEST RESULTS | sample size tested | 17 |
| | average accuracy | 96.3% |
| | confidence limit of average accuracy | ±8.7% |
| AUDIT PERIOD VOLUMES | Billed Metered Authorized Consumption | 484,876 CCF |
| | Apparent Losses | 18,571 CCF |

In order to convert Apparent Losses to a value of lost revenue, the average customer retail unit cost is applied. In this analysis, retail cost is $4.04 per CCF. This calculation is provided below in Table 42.

Table 42: Lost Revenue Calculation for 2” Meters

| PRICE | APPARENT LOSSES | LOST REVENUE |
|---|---|---|
| $4.04 / CCF | 18,571 CCF | $75,027 |

Lost revenue due to under-registration is estimated to be $75,027 for 2” meters. However, were Santa Cruz to replace this entire group of meters, not all of the lost revenue would be recovered because new meters also under-register slightly and incur Apparent Losses. For this analysis, WSO assumes that new meters under-register by 0.5%, as this is a common manufacturer’s quote for the accuracy of new meters. To determine increased earnings in the form recovered revenue, the new meters’ revenue loss much be compared to the replaced meters’ revenue loss, as shown in Table 43.

Table 43: Increased Earnings Calculation for 2” Meters

| | |
|---|---|
| old meter lost revenue (A) | $75,027 |
| apparent losses for new meters<br>*(assuming 0.5% under-registration)* | 2,517 CCF |
| retail cost | $4.04 / CCF |
| lost revenue for new meters (B) | $10,170 |
| **INCREASE IN WATER EARNINGS (A-B)** | **$64,857** |

Increased earnings are then compared to the cost of meter replacement. Meter replacement cost is calculated by multiplying the count of meters by the cost of replacing a meter, as outlined in Table 44. Meter replacement costs were previously provided in Table 40 on page 81.

Table 44: Cost of Replacement for 2” Meters

| | |
|---|---|
| cost of one 2” meter<br>*(including labor, credit, and unit exchange)* | $634 |
| count of meters | 405 |
| **TOTAL COST OF REPLACEMENT** | **$256,770** |

Finally, to properly weigh the benefits (increased revenue due to more accurate registration) against replacement costs, WSO performed a 10-year Net Present Value (NPV) calculation. Table 45 presents ten years of increased earnings. As previously stated, each year savings are assumed to diminish slightly as meter registration worsens with wear. In this analysis, a 0.1% annual decrease in meter accuracy is applied. The Internal Rate of Return (IRR) is also presented in Table 45.

Table 45: Net Present Value and Internal Rate of Return Calculation

| INITIAL INVESTMENT | | $256,770 |
|---|---|---|
| INCREASED EARNINGS | year 1 | $64,857 |
| | year 2 | $62,823 |
| | year 3 | $60,789 |
| | year 4 | $58,756 |
| | year 5 | $56,722 |
| | year 6 | $54,688 |
| | year 7 | $52,654 |
| | year 8 | $50,620 |
| | year 9 | $48,586 |
| | year 10 | $46,552 |
| | **total increased earnings** | **$557,047** |
| **NET PRESENT VALUE** | | **$179,663** |
| **INTERNAL RATE OF RETURN** | | **19%** |

In the case of 2” meters, replacement of all meters to recover revenue could be a cost-effective proposition. Using a 10-year payback period, both the NPV and the IRR are positive, indicating a potentially worthwhile investment.

Of course, the reliability of this economic analysis of replacement hinges on the accuracy of the meter tests in representing the performance of all 2” meters. Given the wide confidence interval on the test results – a confidence interval that includes 100% registration – WSO recommends that Santa Cruz test additional meters before considering wholesale replacement.

In order to refine economic analysis of meter replacement, understand meter performance and revenue generation, and inform the water audit, **it important for Santa Cruz to annually test a random and representative sample of 5/8” meters and maintain a testing schedule for large meters**. When meter accuracy tracking is paired with economic analysis, meter size groups can be targeted for cost-effective replacement when performance deteriorates past an acceptable threshold.

*Summary of Meter Replacement Analysis*

WSO performed the economic analysis of meter replacement described above for all meter sizes. The analysis is provided in Appendix H. The calculations suggest that replacement of some meter size groups could be cost-effective. However, many of the test results have wide confidence intervals, indicating that Santa Cruz should perform more meter tests before considering replacement. Once more data has been gathered, the economic analysis of replacement can be refined. Therefore, WSO has chosen to not present the results of small meter replacement economic analysis in the body of this report, given that the results require additional test information in order to be useful. Instead, **the preliminary economic analysis is provided in Appendix H and can be updated when meter accuracy, particularly large meter accuracy, has been investigated more thoroughly.**

## 4.3 Unauthorized Consumption

In water distribution systems, unauthorized consumption may occur through:

- misuse of fire hydrants and fire-fighting systems in unmetered fire lines
- buried, vandalized, or bypassed consumption meters
- illegal connections
- unauthorized use on closed accounts

In most cases, unauthorized consumption is not measured, and the utility may not have sufficient data to make reasonable estimates of this volume. As a result, the AWWA recommends assuming a default value of 0.25% of Water Supplied as the volume of unauthorized consumption.

**For Santa Cruz's 2014 water audit, the estimated unauthorized consumption volume is 6.5 MG,** calculated using the default value in the audit software of 0.25% of Water Supplied.

## 4.4 Systematic Data Handling Errors

Systematic data handling errors like accounting omissions, errant computer programming, erroneous data entry, and financial bill manipulations can result in inaccurate records of consumption, thereby introducing Apparent Losses. WSO has examined Santa Cruz's consumption data handling procedures and determined that there is minimal potential for the introduction of error. As a result, **Apparent Losses due to data handling errors are 0.0 MG for the 2014 audit period.**

## 4.5 Apparent Losses Summary

**Santa Cruz's total Apparent Losses during 2014 are estimated to be 47.4 MG, broken down in Table 46.**

Table 46: Summary of Apparent Losses

| TYPE | VOLUME (MG) |
|---|---|
| customer metering inaccuracies | 40.9 |
| unauthorized consumption | 6.5 |
| systematic data handling errors | 0.0 |
| **TOTAL APPARENT LOSSES** | **47.4** |

Santa Cruz's total Water Losses, calculated by subtracting Authorized Consumption from Water Supplied, are estimated to be 248.1 MG. Therefore, **Apparent Losses compose 19% of total Water Losses**. The remaining 200.7 MG of Water Losses are Real Losses (water lost to leakage). This Real Loss volume will be disaggregated in the Component Analysis of Real Losses described in Section 6.

## 4.6 Recommendations

Santa Cruz's meter test sample was stratified by meter size into two broad groups: small meters (5/8") and large meters (3/4" and larger). The 5/8" meter test sample was biased to study the accuracy of older meters. The large meter test sample was representative but did not examine 3/4" meters.

To continue to study the accuracy of the customer meter stock, better align tests with the composition of the meter stock, and maintain key revenue-generating meters**, WSO recommends that Santa Cruz formalize a meter test program**. The meter test program will incorporate random and representative testing of small meters and targeted, scheduled testing of large meters.

The meter test program will serve three goals:

1. Assess overall meter inaccuracy and the resulting Apparent Losses for the water audit.
2. Inform future meter replacement with an understanding of meter performance.
3. Maintain the accuracy and revenue-generation potential of key large meters.

### 4.6.1 *Small Meter Testing*

A small meter testing program assesses the overall accuracy of a small meter population by testing a random and representative sample of meters. The larger the sample size, the more confidently the results can be used to describe the performance of the entire meter stock. Therefore, **WSO recommends that Santa Cruz test as many small meters annually as institutionally and financially realistic.**

Small meter testing should be stratified by size. Additional test groupings can also be considered, but adding further levels of stratification necessitates that more meters are tested to minimize the potential for error introduced by small sample sizes.

Santa Cruz tested 214 meters in the 2014 5/8" meter test effort. In future years, Santa Cruz should aim to test at least 100 meters annually. To provide a sense of sample breakdown, WSO built a 100-meter test scenario, outlined in Table 47. If Santa Cruz wishes to test additional meters, the test sample breakdown outlined in Table 47 can be multipled to create a larger sample. For example, a 200-meter test sample would test 120 5/8" meters and 10 3/4" meters.

Table 47: Small Meter Test Sample – 100 Meter Tests Scenario

| METER SIZE | 2014 COUNT | 2014 CONSUMPTION (CCF) | ANNUAL TESTS |
|---|---|---|---|
| 5/8" | 21,798 | 1,524,302 | 60 |
| 3/4" | 281 | 29,098 | 5 |
| 1" | 1,380 | 267,240 | 10 |
| 1 1/2" | 459 | 268,729 | 10 |
| 2" | 390 | 484,876 | 20 |
| **TOTAL** | **24,308** | **2,574,245** | **100** |

Though meters larger than 5/8” compose only a small fraction of the total number of small meters, they record proportionally more consumption. Therefore, **WSO recommends that Santa Cruz incorporate the consumption recorded by each meter size group in designing a representative test sample, not just the count of meters in each size group.**

Once a test sample has been designed, it is essential that meters are selected randomly for testing. **WSO recommends that Santa Cruz use a randomizing function to select test meters**, taking care to avoid testing meters out of convenience (e.g. meters pulled during operations or replacement programs).

Small meters should be tested in accordance with AWWA methodology by testing at a low, medium, and high flow rate and then using time and volume weighting factors to determine the meters’ overall accuracy. The results weighting process is outlined in Section 4.2.1. Additionally, WSO has created a results tracking template for Santa Cruz, provided in Appendix I.

### 4.6.2 *Large Meter Testing*

*Large Meter Population*

**Large meter testing programs prioritize meters that generate the most revenue for a utility, since any under-registration will have a noticeable impact on utility income.** Each large meter is assigned a test frequency that balances the risk of under-registration with the cost to test and replace the meter. **Regular meter testing and replacement should minimize the average cost of revenue losses and replacement costs by attending to meters at a customized and optimized frequency.**

For this analysis, **large meters are considered to be meters that are 3” and greater**. This differs from the size stratification employed in the 2014 water audit, in which large meters were identified as meters 3/4” and larger. However, designing invididual test schedules for meters between 3/4” and 2” in size is not feasible, given the number of meters such an exercise would incorporate. Instead, WSO chose to focus on the 91 meters 3” and larger that were active during the 2014 audit period.

**Approximately 10% of Santa Cruz’s large meters – only 9 meters – were responsible for generating more than 50% of Santa Cruz’s large meter revenue in 2014**. (see Figure 25). In fact, these 9 large meters were responsible for 9% of Santa Cruz’s *total* revenue in 2014. Attending to the accuracy of these meters, as well as other key revenue-generating large meters, can strategically recover lost revenue without significant effort or investment.

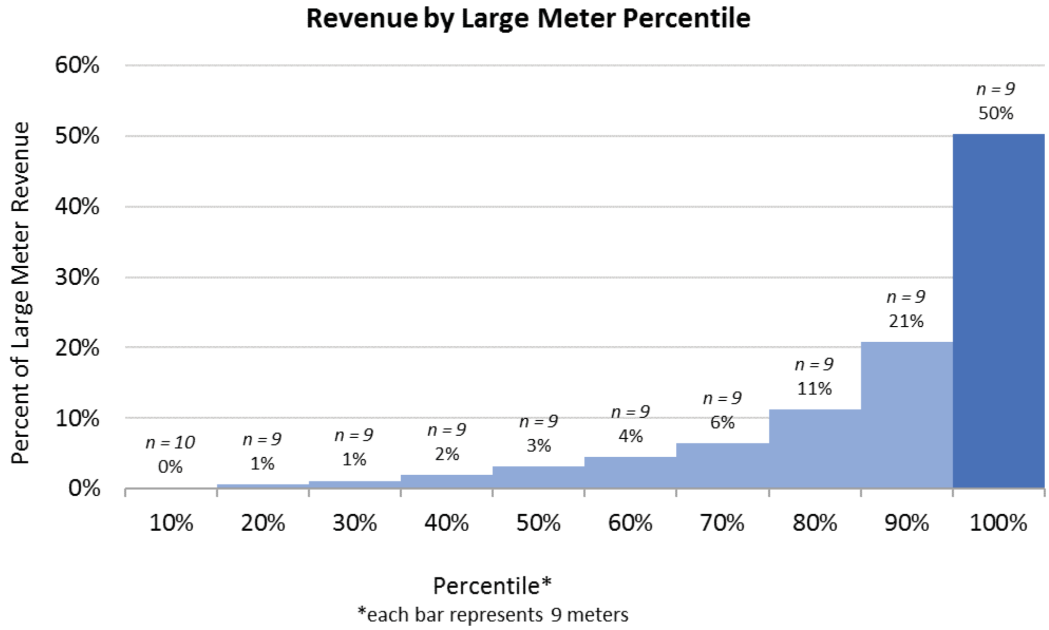



Figure 25: Large Meter Revenue Generation

*Analysis*

**The ideal frequency of meter testing and replacement depends on a meter's inaccuracy and resulting revenue loss, as well as meter replacement costs**. Metering inaccuracy is impacted by a variety of factors, including throughput volume, meter age, meter technology, water quality, and consumption patterns. As a result, the exact antecedent conditions of meter deterioration and subsequent rate of deterioration is currently unknown for Santa Cruz's large meters. However, Santa Cruz can assess the typical decline of its meters through a periodic large meter testing program.

Without specific information on large meter decline, **WSO modeled meter deterioration and economic replacement intervals.** Higher degrees of inaccuracy and faster rates of deterioration result in greater revenue loss and therefore prompt more frequent testing and repair. An example of economic testing and replacement analysis is provided below.

Table 48: Initial Parameters of Large Meter Replacement Economics

| | INITIAL PARAMETERS | | |
|---|---|---|---|
| A | **Meter Serial Number** | 73131861 | |
| B | **Meter Size** | 3" | |
| C | **Average Monthly Throughput** | 2,087 | CCF (from billing data, *adjusted for initial accuracy*) |
| D | **Billing Rate** | $4.04 | per CCF |
| E | **Test and Replacement Cost** | $1,205 | |
| F | **Assumed Initial Accuracy** | 98.0% | |
| G | **Monthly Accuracy Deterioration** | 0.1% | |

1. A three-inch meter currently registers with 98%  accuracy (F). For meter 73131861 (A), this accuracy figure is an estimate. For other Santa Cruz meters, the initial accuracy of a meter is captured by recent large meter tests.

2. The meter sees 2,087 CCF of throughput (C) in an average month. This figure was determined using annual billing data and adjusting the billed volume updated to account for the 2% initial inaccuracy.

3. The meter's accuracy deteriorates 0.1% per month (G). The rate of deterioration for this meter is assumed; however, having two or more meter tests for a single meter can allow for the calculation of an average rate of deterioration.

4. The meter costs $1,205 to test and replace (E).

5. The meter will accumulate missed volume and corresponding revenue as it ages and its performance deteriorates. The accumulation of missed revenue with deteriorating performance is provided in Table 49 on the following page. Additionally, the meter will eventually have to be tested and replaced, and so the test and replacement cost must be incorporated in economic analysis of the meter's ideal replacement schedule.

6. At some point, the *average monthly cost* of operating the meter will be at a minimum. The average monthly cost is the accumulated missed revenue plus the cost of replacement divided by the number of months the meter has been registering. This *minimum average monthly cost* indicates the number of months after which Santa Cruz should replace the meter, given that Santa Cruz will presumably operate a meter at this location in perpetuity. For a graph representation of minimum average monthly cost, see Figure 26 on page 90.

7. For meter 73131861, the monthly cost of ownership is at a minimum when the meter is replaced after 16 months. This calculation is highlighted in green in Table 49.

Table 49: Determining Average Monthly Cost for Deteriorating Large Meter

| MONTH | ACCUMULATED THROUGHPUT | INITIAL INACCURACY | ACCUMULATED DETERIORATION | ENDING INACCURACY | ACCUMULATED MISSED VOLUME (CCF) | ACCUMULATED LOST REVENUE | TOTAL ACCUMULATED COST | AVERAGE MONTHLY COST |
|---|---|---|---|---|---|---|---|---|
| | *average monthly throughput x months* | *100% - initial accuracy* | *rate of deterioration x months* | *initial accuracy + accumulated deterioration* | *(initial inaccuracy x accumulated throughput) + (0.5 x accumulated deterioration x accumulated throughput)* | *accumulated missed volume x billing rate* | *accumulated lost revenue + testing and replacement cost* | *total accumulated cost / months* |
| 1 | 2,087 | 2.0% | 0.1% | 2.1% | 43 | $173 | $1,198 | $1,197.85 |
| 2 | 4,174 | 2.0% | 0.2% | 2.2% | 88 | $354 | $1,379 | $689.57 |
| 3 | 6,261 | 2.0% | 0.3% | 2.3% | 135 | $544 | $1,569 | $522.95 |
| 4 | 8,348 | 2.0% | 0.4% | 2.4% | 184 | $742 | $1,767 | $441.75 |
| 5 | 10,435 | 2.0% | 0.5% | 2.5% | 235 | $949 | $1,974 | $394.71 |
| 6 | 12,522 | 2.0% | 0.6% | 2.6% | 288 | $1,164 | $2,189 | $364.76 |
| 7 | 14,609 | 2.0% | 0.7% | 2.7% | 343 | $1,387 | $2,412 | $344.57 |
| 8 | 16,696 | 2.0% | 0.8% | 2.8% | 401 | $1,619 | $2,644 | $330.49 |
| 9 | 18,783 | 2.0% | 0.9% | 2.9% | 460 | $1,859 | $2,884 | $320.46 |
| 10 | 20,870 | 2.0% | 1.0% | 3.0% | 522 | $2,108 | $3,133 | $313.29 |
| 11 | 22,958 | 2.0% | 1.1% | 3.1% | 585 | $2,365 | $3,390 | $308.19 |
| 12 | 25,045 | 2.0% | 1.2% | 3.2% | 651 | $2,631 | $3,656 | $304.64 |
| 13 | 27,132 | 2.0% | 1.3% | 3.3% | 719 | $2,905 | $3,930 | $302.29 |
| 14 | 29,219 | 2.0% | 1.4% | 3.4% | 789 | $3,187 | $4,212 | $300.87 |
| 15 | 31,306 | 2.0% | 1.5% | 3.5% | 861 | $3,478 | $4,503 | $300.20 |
| 16 | 33,393 | 2.0% | 1.6% | 3.6% | 935 | $3,777 | $4,802 | $300.15 |
| 17 | 35,480 | 2.0% | 1.7% | 3.7% | 1,011 | $4,085 | $5,110 | $300.60 |
| 18 | 37,567 | 2.0% | 1.8% | 3.8% | 1,089 | $4,401 | $5,426 | $301.46 |
| 19 | 39,654 | 2.0% | 1.9% | 3.9% | 1,170 | $4,726 | $5,751 | $302.68 |
| 20 | 41,741 | 2.0% | 2.0% | 4.0% | 1,252 | $5,059 | $6,084 | $304.20 |
| 21 | 43,828 | 2.0% | 2.1% | 4.1% | 1,337 | $5,400 | $6,425 | $305.98 |
| 22 | 45,915 | 2.0% | 2.2% | 4.2% | 1,423 | $5,750 | $6,775 | $307.97 |
| 23 | 48,002 | 2.0% | 2.3% | 4.3% | 1,512 | $6,109 | $7,134 | $310.16 |
| 24 | 50,089 | 2.0% | 2.4% | 4.4% | 1,603 | $6,476 | $7,501 | $312.52 |

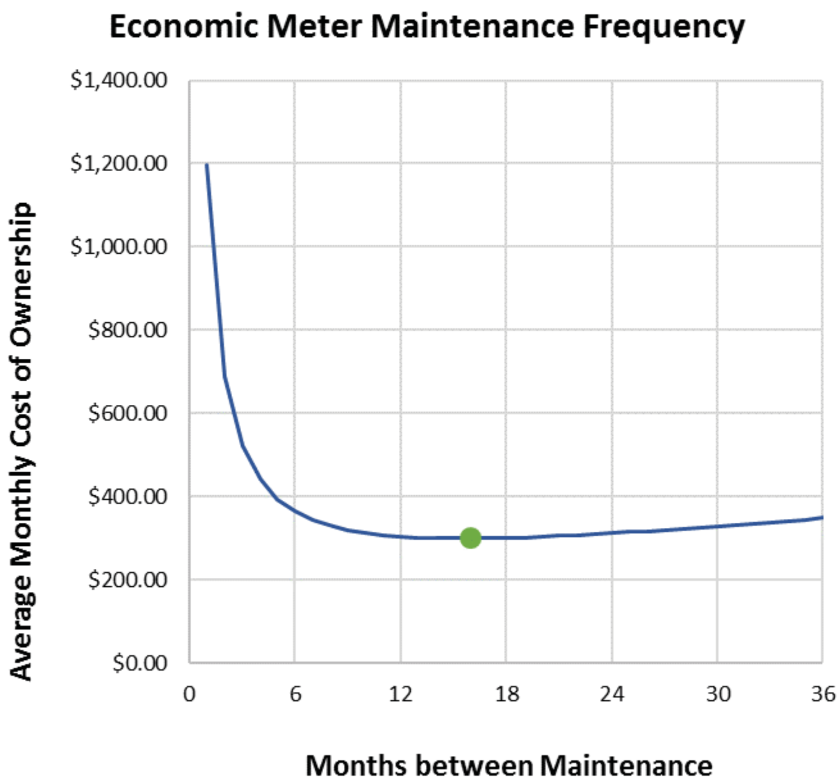



Figure 26: Average Monthly Cost of Large Meter Ownership

WSO performed this economic analysis of ideal replacement schedule for Santa Cruz's 91 large meters (bigger than 3"). In this analysis, WSO assumed the following:

- An initial accuracy calculated using large meter test results, if available
- An initial accuracy of 98%, if large meter results were not available for the meter
- A monthly accuracy deterioration of 0.1%, resulting in an annual deterioration of 1.2%
- An average billing rate of $4.04 per CCF

The large meter replacement analysis is provided in detail in Appendix J. The economic analysis of meter replacement suggests that Santa Cruz should periodically test a subset of all large meters (see Table 50).

Table 50: Summary of Replacement Frequency Analysis

<table>
<tr><th>TEST AND REPLACE FREQUENCY</th><th>COUNT OF METERS</th><th></th></tr>
<tr><td>after 18 months</td><td>3</td><td rowspan="4">22 meters</td></tr>
<tr><td>after 24 months</td><td>11</td></tr>
<tr><td>after 30 months</td><td>2</td></tr>
<tr><td>after 36 months</td><td>6</td></tr>
<tr><td>longer period than 36 months</td><td>69</td><td></td></tr>
</table>

**It is important to note that this analysis depends on an understanding a meter's initial performance and its rate of deterioration.** Nonetheless, the meters identified in this analysis and listed in Appendix J should be tested periodically to maintain their accuracy and revenue generation potential, even if the tests are not conducted on the exact schedule produced by the replacement analysis.

Santa Cruz can refine this large meter analysis as additional test data becomes available and the rate of deterioration of large meters is better understood. Therefore, **WSO recommends that Santa Cruz begin a large meter testing program by testing the meters identified in this analysis and then refining the test schedule to maintain meter accuracy without incurring undue expense.**

### 4.6.3 *Summary*

The recommendations listed below aim to gain more insight into meter accuracy, better estimate Apparent Losses, and maintain efficient revenue generation.

- **Implement ongoing random and representative small meter testing, to the extent operationally and financially possible**. In order for small meter accuracy to be understood and tracked, small meters (2" and smaller) should be tested following AWWA-recommended test protocol. This involves testing small meters at specific low, medium, and high flows and then using time and volume distributions to produce a weighted average accuracy. Additionally, a representative and significant number of meters must be tested in order for test results to be extrapolated to the entire meter stock.
- **Instigate a large meter testing program that balances revenue lost to meter inaccuracy with the costs of meter testing and replacement**. Under such a program, meters 3" and larger would be assigned individual maintenance (test and replace) frequencies ranging from once every six months to once every five years. Test schedules would aim to maintain the accuracy of key revenue-generating meters based on the risk of revenue loss resulting from under-registration and the cost to replace the meters. Once the large meter testing program is underway, initial test results should be tracked and used to refine the test schedule by incorporating an understanding of initial meter accuracy and the rate of meter decline.
- **Inform future meter replacement programs with the economic analyses presented in this report.** Analyzing meter replacement by comparing lost revenue to replacement costs empowers Santa Cruz to intervene only when the benefits outweight the costs. Additionally, meter replacement can target certain meter groups like size, manufacturer, and install year, if meter test data allows for such stratification. This type of tailored meter replacement is preferred over replacement due to age or anecdotal performance alone.
- **Perform a consumption profiling study (see Appendices F and G for examples) in order to customize the volumetric weighting factors applied in meter accuracy calculations.** Using tailored weighting factors will minimize the potential for inaccuracy in Apparent Loss estimations and economic analysis. Consumption profiling is helpful in determining the weighting factors for small meter accuracy and optimal test flow rates for large meters.

# 5 Water Balance

## 5.1 Introduction

**A water balance is a mathematical summary of all inputs, withdrawals, and losses for a water distribution system.** In a water balance, a volume of water inputted into a distribution system is broken down into component volumes based on how it is consumed or, alternatively, lost. Water balance methodology requires that *all* water be quantified either by measurement or estimation, and as a result no water is "unaccounted for."

The 2014 water balance is presented in Figure 27 on the following page. All complete columns represent equal volumes of water and are therefore "balanced." Note that this water balance is not to scale; the volume of each box is not proportional to the volume of that component. Highlighted in blue are the component volumes that contribute to Water Losses and Non-Revenue Water, the volumes that programmatic recommendations aims to verify and reduce.

To populate the water balance, WSO calculated Water Supplied, Authorized Consumption, and Apparent Losses. The three previous chapters in this report document the data collection, analysis, and recommendations pertaining to each key volume. Once these three volumes were calculated and validated, WSO derived the volume of Real Losses by subtracting Authorized Consumption and Apparent Losses from Water Supplied.

In order for the determinations of water balance volumes to be accurate, the validity of contributing data sources must be a primary focus of a thorough water audit. To describe data validity, **the project team assigned data validity scores to each water balance volume**. Appendix K provides a description of data validity scoring and explains Santa Cruz's scores.

**Santa Cruz's 2014 AWWA Free Water Audit Software water balance is attached to this document as Appendix L.**

The outline of this section is:

- Section 5.3 – System and Financial Data
- Section 5.4 – Performance Indicators
- Section 5.5 – Discussion
- Section 5.6 - Recommendations

## 5.2 2014 Water Balance

| | | | | | |
|---|---|---|---|---|---|
| Water from Treatment Plant 2,416 MG | Water Supplied 2,603 MG | Authorized Consumption 2,355 MG | Billed Authorized Consumption 2,344 MG | Billed Metered Consumption 2,343 MG | Revenue Water 2,344 MG |
| | | | | Billed Unmetered Consumption 1 MG | |
| | | | Unbilled Authorized Consumption 11 MG | Unbilled Metered Consumption 7 MG | Nonrevenue Water 259 MG |
| | | | | Unbilled Unmetered Consumption 4 MG | |
| | | Water Losses 248 MG | Apparent Losses 47 MG | Unauthorized Consumption 6 MG | |
| | | | | Customer Metering Inaccuracies 41 MG | |
| | | | | Systematic Data Handling Errors 0 MG | |
| | | | Real Losses 201 MG | Leakage on Mains | |
| Water from Wells 187 MG | | | | Leakage on Service Connections | |
| | | | | Leakage on Appurtenances | |
| | | | | Leakage and Overflow at Storage Tanks | |

Figure 27: Complete 2014 Water Balance

**Calculated using AWWA water balance methodology, Santa Cruz's 2014 volume of Water Losses was 248 MG.** Of this volume, 47 MG were Apparent Losses and 201 MG were Real Losses.

Real Losses can also be investigated with a "bottom-up" component analysis. Component analysis divides the total volume of Real Losses into reported leakage, unreported leakage, and background leakage, depending on how Santa Cruz interacts with the leakage. Chapter 6 describes the Component Analysis of Real Losses breakdown. Comparing the water balance calculation of Real Losses with the component analysis of Real Losses provides insight into the volume of Hidden Losses, the leakage running undetected in Santa Cruz's system that could be uncovered with proactive leak detection.

## 5.3 System and Financial Data

AWWA water balance methodology provides a handful of standardized performance indicators used to capture and compare system efficiency. The performance indicators are informed by water balance volumes, system data, and financial data. The system and financial data used to calculate Santa Cruz's 2014 performance indicators is documented in Table 51.

Table 51: System and Financial Data

| | FY13-14 | UNITS |
|---|---|---|
| ***SYSTEM DATA*** | | |
| length of mains | 271.2 | miles |
| active and inactive service connections | 24,429 | service connections |
| service connection density | 90 | connections/mile |
| average length of customer service line | 0 | feet |
| average operating pressure | 87.1 | PSI |
| ***FINANCIAL DATA*** | | |
| total annual cost of operating potable water system | $27,512,944 | |
| customer retail unit cost | $4.04 | $/CCF |
| variable production cost | $553 | $/MG |

To calculate the **length of mains**, WSO used a treated water mains inventory from 2015. The inventory provided lengths of pipe by size and material. The inventory listed 264.0 miles of main, ranging in diameter from 1" to 42" and incorportating asbestos concrete, cast iron, ductile iron, steel, galvanized steel, plastic, and unknown materials.

The mains inventory also separately listed the length of fire hydrants laterals, which totaled 7.2 miles. Therefore, after incorportaing hydrant laterals, Santa Cruz's total length of mains was 271.2 miles.

Santa Cruz staff reported the total **count of active and inactive service connections**. The figure includes service, combination, and designated fire service laterals, both active and inactive, to account for the total pressurized infrastucture in the system.

Santa Cruz reports that customer meters are typically located at the curbstop, so the **average length of a customer service line** past the curbstop is 0 feet.

To calculate **average operating pressure**, WSO weighted static pressures by the count of service connections in each pressure or operational zone. Santa Cruz furnished static pressure, service connections, and zone data for this calculation.

The **total annual cost of operating the system** includes expenses incurred in operations, maintenance and long-term system upkeep. These costs were reported by Santa Cruz staff for fiscal year 2014.

**Customer retail unit cost** was calculated by diviging the total volume of water sold in 2014 by revenues from volumetric sales, thereby excluding flat fees and connection charges. This resulted in an average customer retail unit cost of $4.04 per CCF, slightly higher than Santa Cruz's inside-city, single-family residential second tier and uniform (non-SFR) tier. Both tiers have a retail cost of $4.00 per CCF.

**Variable production cost** was calculated by totaling power and chemical costs incurred in 2014 during water treatment and transmission and then dividing by total volume produced. This produced a variable production cost of $553 per MG.

## 5.4 Performance Indicators

The system and financial data are used to calculate performance indicators that benchmark water loss performance and assign monetary value to water losses. Santa Cruz's performance indicators are provided in Table 52.

Table 52: Performance Indicators

| | 2014 | UNITS |
|---|---|---|
| ***FINANCIAL PERFORMANCE INDICATORS*** | | |
| Non-Revenue as percent by volume of Water Supplied | **9.9%** | |
| Non-Revenue as percent by cost of operating system | **1.4%** | |
| annual cost of Apparent Losses | **$256,200** | *valued at customer retail unit cost* |
| annual cost of Real Losses | **$111,000** | *valued at variable production cost* |
| ***OPERATIONAL EFFICIENCY PERFORMANCE INDICATORS*** | | |
| Apparent Losses per service connection per day | **5.3** | gal / conn / day |
| Real Losses per service connection per day | **22.5** | gal / conn / day |
| Real Losses per service connection per day per PSI of pressure | **0.3** | gal / conn / day / PSI |
| Unavoidable Annual Real Losses (UARL) | **163** | MG / yr |
| Current Annual Real Losses (CARL) | **201** | MG / yr |
| Infrastructure Leakage Index (CARL/UARL) | **1.2** | |
| ***DATA VALIDITY PERFORMANCE INDICATOR*** | | |
| Data Validity Score | **74** | *weighted overall score out of 100* |

## 5.5 Discussion

To assess performance, WSO recommends that Santa Cruz consider all performance indicators together, with a particular emphasis on Apparent Losses per service connection per day, Real Losses per service connection per day, and the Infrastructure Leakage Index (ILI).

Santa Cruz's water audit results indicate that the system is performing efficiently. WSO interprets Santa Cruz's 2014 performance indicators as follows:

- **The ILI value of 1.2 indicates that Santa Cruz's distribution infrastructure leaked *1.2 times* the system's technical minimum volume of Real Losses during 2014.** Achieving the technical minimum volume of leakage – an ILI of 1.0 – is rarely cost-effective. Rather than pursue an ILI of 1.0, WSO recommends that Santa Cruz continue to monitor annual Real Losses to maintain an ILI around 1.2. For additional information about the ILI, see Appendix M.
- **Real Losses of 22.5 gallons per service connection per day denotes an efficiently-performing system when compared to statewide water audit data.** Water Research Foundation project 4372B examined a large dataset of water audits and determined that the top-performing 20% of California utilities lose less than 25 gallons per service connection per day. The 4372B data was not validated and should therefore be interpreted cautiously. Nonetheless, Real Losses between 20 and 25 gallons per day demonstrate low levels of leakage.

- **Apparent Losses of 5.3 gallons per service connection per day suggests that Santa Cruz is receiving revenue for almost all of the water it delivers.** However, given Santa Cruz's customer retail unit cost and the annual cost of Apparent Losses, studying and then targeting improvement of the accuracy of customer meters – particularly large meters – could recover additional revenue without incurring undue expense.
- **An overall Data Validity Score of 74 communicates that Santa Cruz's water audit data is reliable enough to serve as the foundation of an informed water loss control program, but room for data improvements remains.** A data validity score above 50 suggests that water audit data is sufficiently reliable for a utility to begin water loss control program design, but a program should be orchestrated to collect additional data so that interventions can be refined as better data becomes available. WSO has provided the rationale for Santa Cruz's 2014 Data Validity Score in Appendix K.

## 5.6 Recommendations

To maintain consistency of analysis and continue to refine the water auditing process, WSO recommends the following:

- **Perform an annual water audit and repeat the analyses described in this report.** Using the same data sources, data treatments, and validation techniques from year to year permits Santa Cruz to track changes in system efficiency, since changes in performance indicators will likely reflect actual system conditions rather than the results of different analytic approaches.
- **Focus on improving the reliability of data, using the Data Validity Scoring system as a guide but focusing resources on the particular areas where uncertainty and error are most significantly introduced.** WSO recommends that Santa Cruz work to improve data quality by examining the instruments and data management systems that inform the audit, instead of using the Data Validity Scoring system as a strict guide. The scoring matrix is intended to be general and apply to a wide range of systems, so it cannot always serve as a customized data improvement road map. Instead, the scoring matrix is useful in highlighting the importance of instrument testing, data review, and occasional third-party confirmation. Santa Cruz's goal should not be a Data Validity Score of 100, since achieving such a high score tends to require investment past a point of diminishing returns. Rather, Santa Cruz should aim to thoroughly understand the accuracy of key system instruments, appreciate the overlay of SCADA and software packages on primary measurement, and minimize error introduced through human interaction with data.

# 6 Component Analysis of Real Losses

## 6.1 Introduction

To populate the 2014 water balance, WSO calculated Water Supplied, Authorized Consumption, and Apparent Losses. Chapters 2, 3, and 4 document the data collection, analysis, and recommendations pertaining to each key volume. Once these three volumes had been calculated and validated, WSO derived the total volume of Real Losses by subtracting Authorized Consumption and Apparent Losses from Water Supplied.

Next, **in order to disaggregate the total volume of Real Losses into distinct leakage volumes, WSO performed a Component Analysis of Real Losses**. A Component Analysis of Real Losses uses water audit data, modeling parameters, and records of leak detection and leak repair to break Real Losses into component volumes of leakage based on the intervention strategies that would best address the leakage. This chapter attends to the Component Analysis with the following structure:

- Section 6.2 – Component Analysis Background
- Section 6.3 – 2014 Component Analysis
- Section 6.4 – Discussion
- Section 6.5 - Recommendations

## 6.2 Component Analysis Background

Break and Background Estimate (BABE) Component Analysis, a systematic approach to modeling Real Losses, was developed during the UK National Leakage Initiative between 1991 and 1993. The model recognizes that the annual volume of Real Losses consists of numerous leakage events where the volume lost to each leak is a function of that leak's flow rate and duration before repair.

Component Analysis additionally recognizes that distinct forms and magnitudes of leakage are best addressed through distinct interventions.

### 6.2.1 *Types of Leakage*

BABE component analysis divides leakage into three categories: Reported Leakage, Unreported Leakage, and Background Leakage. Each of these categories has the typical characteristics outlined in Table 53 and Figure 28.

Table 53: Component Analysis Categories of Leakage

| LEAKAGE TYPE | DISCOVERY | FLOW RATE | DURATION | INTERVENTION |
|---|---|---|---|---|
| **Reported** | generally surfaces; reported to utility by customers and staff | varied, but generally high flow rates | relatively short duration, function of leak repair practices | shorter repair times pressure optimization |
| **Unreported** | unsurfaced but discovered through proactice leak detection | varied but sufficient to be acoustically detectable; generally mid-range flow rates | duration is a function of proactive leak detection policy | proactive leak detection and repair pressure optimization |
| **Hidden** *Type of Unreported Leakage* | unsurfaced *and* undiscovered, but could be discovered through proactive leak detection | varied but sufficient to be acoustically detectable; generally mid-range flow rates | duration is a function of proactive leak detection policy | proactive leak detection and repair pressure optimization |
| **Background** | undetectable | acoustically undetectable, low flow rates (e.g. seeps and drips at joints and fittings) | ongoing | pressure optimization infrastructure replacement |

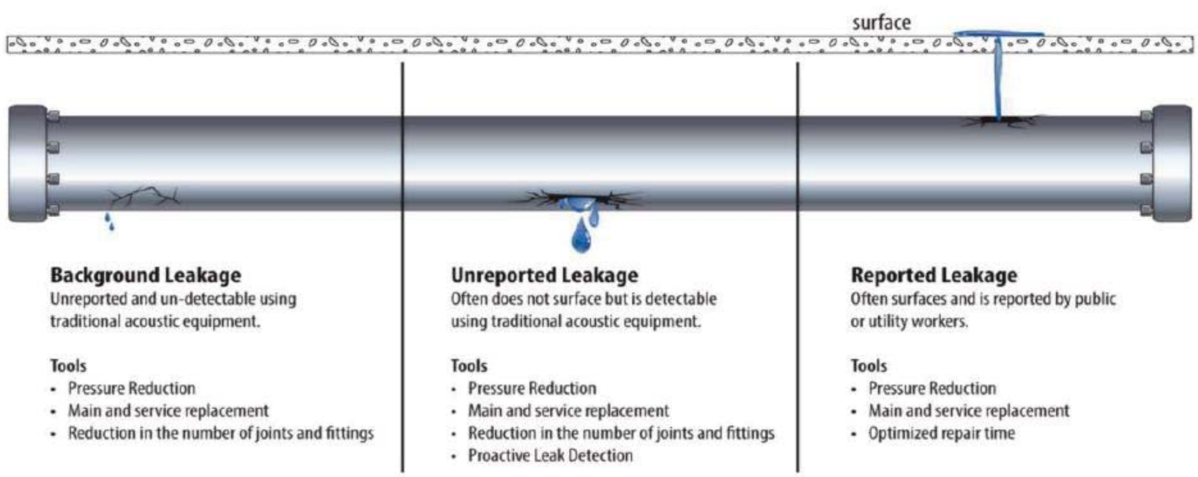



Figure 28: Component Analysis Categories of Leakage[1]

As these definitions indicate, **leakage is categorized by how Santa Cruz interacts with it.** Santa Cruz is made aware of Reported Leakage by both customers and utility personnel during standard operations. In contrast, Unreported Leakage is *only* discovered through proactive acoustic leak detection. Hidden Losses could be detected through proactive leak detection but have not yet been discovered. Background Leakage cannot be sonically detected and is best managed through pressure optimization.

[1] Source: Hodgins, Maureen et al. "Water Loss Control." *Advances in Water Research*, Vol. 24, No. 3 (2014): 6-11.

### 6.2.2 *Leak Flow Rate*

**The rate at which a leak flows in part determines the volume of water lost.** Leak flow rates can be measured or estimated during repair. However, unless a clear protocol for leak flow measurement and documentation exists, estimations of flow rate can vary widely in their accuracy and consistency and are difficult to confirm. In the absence of reliable flow rate data, industry-standard flow rate assumptions are employed. **Flow rate assumptions are based on the type of leak (Reported, Unreported, or Background), the type of infrastructure, and the size of the infrastructure.** The leak flow rates used in Santa Cruz's Component Analysis are discussed in Section 6.3.2.

### 6.2.3 *Leak Duration*

**To determine the volume lost to each instance of leakage, the leak flow rate must be paired with a leak run time.** According to the BABE methodology, the length of time for which a failure runs is divided into two time components: awareness time and response time (which is the sum of location time and repair time). The duration of each is separately estimated, as summarized below and in Figure 29.

- **Awareness duration:** the length of time between a leak first occurring – whether it is reported or unreported – and the time when Santa Cruz first becomes aware that the leak exists, though not necessarily aware of its exact location. For reported leaks and breaks, this duration is usually very short, while for unreported leaks and breaks, it is a function of the proactive leakage control program.
- **Response duration:** the time it takes Santa Cruz to find and stop the leak flow after becoming aware of its existence. Response duration is also referred to as location and repair duration, as it is composed of the amount of time it takes Santa Cruz to correlate, unearth, and repair a leak.

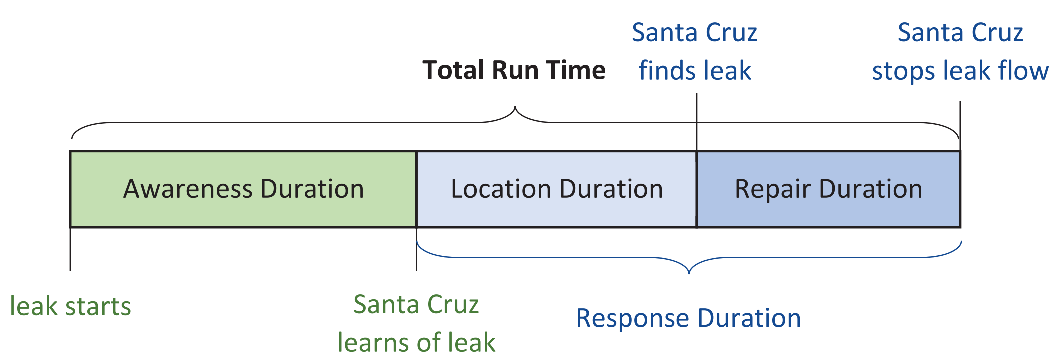



Figure 29: Leak Duration Diagram

**By knowing the number of reported and unreported breaks, their average leak flow rates, and their awareness and location and repair times, it is possible to calculate the volume of water lost due to known leakage.**

### 6.2.4 *Hidden Losses*

Component Analysis of Real Losses determines the volume of leakage that Santa Cruz *interacted with* and *lost to Background Leakage* in a given audit period. A water balance calculates the *total* volume of Real Losses that occurred during the audit period. Therefore, subtracting the component volumes of Real Losses (Reported Leakage, Unreported Leakage, and Background Leakage) from the total volume of Real Losses determined with a water balance estimates the volume of Hidden Losses. **Hidden Losses is the leakage that ran continuously and undetected during the audit period but that could have been discovered through acoustic leak detection.** Recommendations for water loss control often focus on the economics of recovering Hidden Losses because this volume can be both significant and cost-effective to reclaim.

## 6.3 2014 Component Analysis

WSO performed a Component Analysis for the 2014 audit period using available data and modeling parameters. This Component Analysis broke down Real Losses as laid out in Table 54.

Table 54: 2014 Component Analysis Results

| LEAKAGE COMPONENT | VOLUME (MG) | % OF TOTAL REAL LOSSES |
|---|---|---|
| Reported Leakage | 19 | 10% |
| Unreported Leakage | 0 | 0% |
| Background Leakage | 125 | 62% |
| Hidden Losses | 57 | 28% |
| **TOTAL REAL LOSSES** | **201** | **100%** |

**The following sections describe the data sources, assumptions, and modeling parameters informing the component analysis.** Each Component Analysis volume – Reported Leakage, Unreported Leakage, and Background Leakage – is independently calculated. The complete component analysis and the derivation of Hidden Losses are summarized in Section 6.3.5. **Santa Cruz's 2014 Component Analysis software model is provided in Appendix O.**

### 6.3.1 *Data Sources*

*Reported Leakage*

**Santa Cruz had two data sources available to describe 2014 repair activity.**

The first data source, referred to as "summary data," was an Excel spreadsheet maintained by the former head of field operations that tabulated annual repairs on service connections and mains.

The second data source, referred to as "work orders," consisted of monthly work order system reports. Each report listed field activity for the month, capturing the date of activity, location, infrastructure information, and estimations of water use or water loss. Some of the work order line items recorded water lost to leakage, while others recorded water used for operational purposes (e.g. dead-end flushing). Leakage losses and operational water use could not be easily and reliably distinguished in the work order summary reporrts.

Furthermore, in the latter half of 2014, Santa Cruz transitioned from an Access-based work order system to a CMMS system. Each data management platform captured slightly different observations, as laid out in Table 55.

Table 55: Data Recorded in Work Orders

| ACCESS | CMMS |
|---|---|
| work order number | work order number |
| date | |
| address | address |
| | water loss cause |
| line size | |
| hydrant number | |
| flow | flow |
| time | time |
| total gallons | total gallons |

**The two data sources – the summary data and the work orders – did not agree in the total count of repairs.** The discrepancies in total repairs are provided in Table 56.

Table 56: Repair Activity by Data Source

| DATA SOURCE | MAIN BREAKS REPAIRED | SERVICE LINE BREAKS REPAIRED |
|---|---|---|
| summary data | 37 | 190 |
| work orders | 76 | 35 |

Santa Cruz staff report that the summary data likely contains the most accurate count of repairs because the work order system was not consistently used during 2014, and some work orders pertain to operational activity rather than water loss. Therefore, **to model Reported Leakage, WSO used the summary data that describes 2014 repairs instead of the work orders.**

WSO digitized and tabulated the 2014 pdf work orders in order to study the leakage they captured. These digitized work orders are provided for Santa Cruz's use in Appendix N.

*Unreported Leakage*

**Because Santa Cruz did not conduct proactive leak detection during the 2014 audit period, no data capturing Unreported Leakage was requested.**

*Background Leakage*

**To calculate Background Leakage, WSO used the system data (miles of main, count of service connections, and average operating pressure) that populated the water audit.** See Section 5.3 for these figures.

### 6.3.2 *Reported Leakage*

*Reported Leak Duration*

Neither the work order reports nor the summary data consistently provided the time stamps necessary to calculate leak durations. The summary data did not give timestamps, only dates. The work order listed durations often pertained to repair and flushing activity, not leak runtime. Therefore, WSO assumed a total duration of 2 days for main breaks and 3 days for service connection breaks. Each leak duration was composed of the awareness and response time listed in Table 57 below.

Table 57: Awareness and Response Duration Assumptions

| INFRASTRUCTURE TYPE | AWARENESS DURATION (days) | RESPONSE DURATION (days) | TOTAL DURATION (days) |
|---|---|---|---|
| mains | 1 | 1 | 2 |
| service connections | 2 | 1 | 3 |

**In future Component Analyses, Santa Cruz should use the unique duration of each repair in combination with standard assumptions of awareness duration to determine total leak runtimes.**

*Reported Leak Flow Rate*

The summary data only listed the total count of repairs; no information describing flow rates or main size was supplied. Additionally, flow rates provided in work orders often pertained to repair activity, rather than the flow rate of the leak itself.

In the absence of flow rate or infrastructure size, **WSO assumed an industry-standard flow rate of 114.5 gpm for main breaks**, a flow rate typical of breaks on mains between 6” and 10” in diameter when system operating pressure is 87 PSI.

**WSO assumed an industry-standard flow rate of 8.6 gpm for service breaks**, a flow rate typical of breaks on service connections when system operating pressure is 87 PSI.

For additional detail on leak durations and flow rates in the Component Analysis model, WSO encourages Santa Cruz to reference Water Research Foundation Study 4372A: *Real Loss Component Analysis – A Tool for Economic Water Loss Control*.

Table 58: Reported Leak Flow Rate Assumptions

| INFRASTRUCTURE TYPE | FLOW RATE (gpm) |
|---|---|
| mains | 114.5 |
| service connections | 8.6 |

*Reported Leak Summary*

**To determine the total volume of Reported Leakage, WSO determined the total volume lost to each leak by multiplying its duration by its flow rate. Then, WSO totaled the volume lost to each leak to produce a total Reported Leakage volume.** This process is outlined below in Table 59.

Table 59: Reported Leakage Calculation

| INFRASTRUCTURE TYPE | DURATION (days) | FLOW RATE (gpm) | LOSS PER EVENT (MG) | TOTAL EVENTS | TOTAL LEAKAGE (MG) |
|---|---|---|---|---|---|
| mains | 2 | 114.5 | 0.33 | 37 | 12.2 |
| service connections | 3 | 8.6 | 0.04 | 190 | 7.1 |
| **TOTAL** | | | **0.09** | **227** | **19.3** |

WSO calculated that Santa Cruz lost 19.3 MG to Reported Leakage during 2014. However, WSO emphasizes that Reported Leakage was primarily determined by modeling. Furthermore, the only input derived from Santa Cruz's own data, the total count of failures, was also uncertain. Therefore, Santa Cruz should view this calculation of Reported Leakage as a guide for future calculations but not view the total Reported Leakage volume as definitive.

### 6.3.3 *Unreported Leakage*

Santa Cruz did not perform any proactive leak detection during 2014. Therefore, **the volume categorized as water lost to Unreported Leakage (leakage found through proactive leak detection during the audit period) was 0.0 MG.**

### 6.3.4 *Background Leakage*

Background Leakage is acoustically undetectable. Therefore, **Background Leakage is modeled using an annual leakage allowance dependent on system infrastructure and operating pressure.** The parameters of the Background Leakage calculation for 2014 are given in Table 60.

WSO chose an Infrastructure Condition Factor (ICF) of 1.0. The ICF acknowledges the age and condition of Santa Cruz's infrastructure. An ICF of 1.0 indicates that system infrastructure is in good condition and less than 50 years old, on average. Furthermore, the ICF is used as a linear multiplier for the volume of Background Leakage. Therefore, the selection of an ICF greater than 1.0 would proportionally increase Santa Cruz's total Background

Leakage volume. Given Santa Cruz's total leakage volume, failure frequencies, and staff reports of general infrastructure condition, WSO considers an ICF of 1.0 to be appropriate.

Additionally, the relationship between pressure and leakage in the Background Leakage calculation is assumed to be exponential, using an "N1" exponent of 1.5 to adjust leak flow rates modeled at 70.0 PSI for an actual operating pressure of 87.1 PSI.

The count of service connections includes both active and inactive connections.

Finally, because all of Santa Cruz's storage reservoirs are above ground and well-maintained, WSO assumed that reservoirs do not leak at a level that should be acknowledged in the Component Analysis.

**Santa Cruz's 2014 Background Leakage volume was modeled to be 124.6 MG.**

Table 60: Parameters of Background Leakage Calculation

| TYPE | QUANTITY | BACKGROUND LEAKAGE ALLOWANCE | ICF | PRESSURE (PSI) | TOTAL BACKGROUND LEAKAGE (MG) |
|---|---|---|---|---|---|
| main pipe | 271.2 miles | 2.870 gal/mile/day/PSI | 1.0 | 87.1 | 27.6 |
| service connection | 24,429 connections | 0.112 gal/conn/day/PSI | 1.0 | 87.1 | 97.0 |
| **TOTAL** | **-** | **-** | **1.0** | **87.1** | **124.6** |

### 6.3.5 *FY13-14 Component Analysis Summary*

Table 61 and Figure 30 summarize Santa Cruz's Component Analysis volumes. The total Real Loss volume was determined using a top-down AWWA water balance. To calculate Hidden Losses, the volumes of Reported Leakage, Unreported Leakage, and Background Leakage were subtracted from total Real Losses.

| LEAKAGE COMPONENT | VOLUME (MG) | % OF TOTAL REAL LOSSES |
|---|---|---|
| Reported Leakage | 19 | 10% |
| Unreported Leakage | 0 | 0% |
| Background Leakage | 125 | 62% |
| Hidden Losses | 57 | 28% |
| **TOTAL REAL LOSSES** | **201** | **100%** |

Table 61: FY13-14 Component Analysis Summary

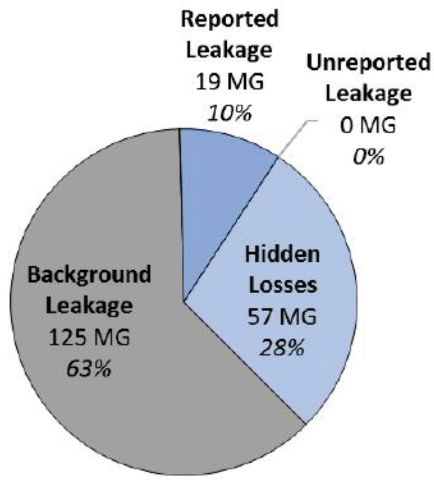



Figure 30: FY13-14 Component Analysis Summary

A few key modeling assumptions informed this component analysis:

- Reported Leakage flow rates were adjusted for Santa Cruz's average operating pressure (87.1 PSI) using an N1 factor of 1.0, indicating a linear relationship between leakage and pressure for this type of leakage.
- Background Leakage flow rates were adjusted for Santa Cruz's average operating pressure (87.1 PSI) with an N1 factor of 1.5, indicating an exponential relationship between leakage and pressure for this type of leakage.
- Background Leakage on mains and service connections was multiplied by an Infrastructure Condition Factor of 1.0 to acknowledge the age of Santa Cruz's infrastructure (less than 50 years old *on average* and in good condition given system age, failure frequency, and total leakage volume).

## 6.4 Discussion

### 6.4.1 *Reported Break Frequencies*

**Break frequency can be a useful metric for comparing systems and determining optimal performance. Additionally, comparing reported break frequency to industry standards can validate the Component Analysis.**

Break frequencies for mains (in terms of breaks per 100 miles per year) and for service connections (in terms of breaks per 1,000 connections per year) are discussed in the following sections.

*Main Breaks*

Figure 31 juxtaposes Santa Cruz's reported main break frequency with two industry-standard reported break frequencies: the break frequency of an *average* system and the break frequency of an *optimized* system.

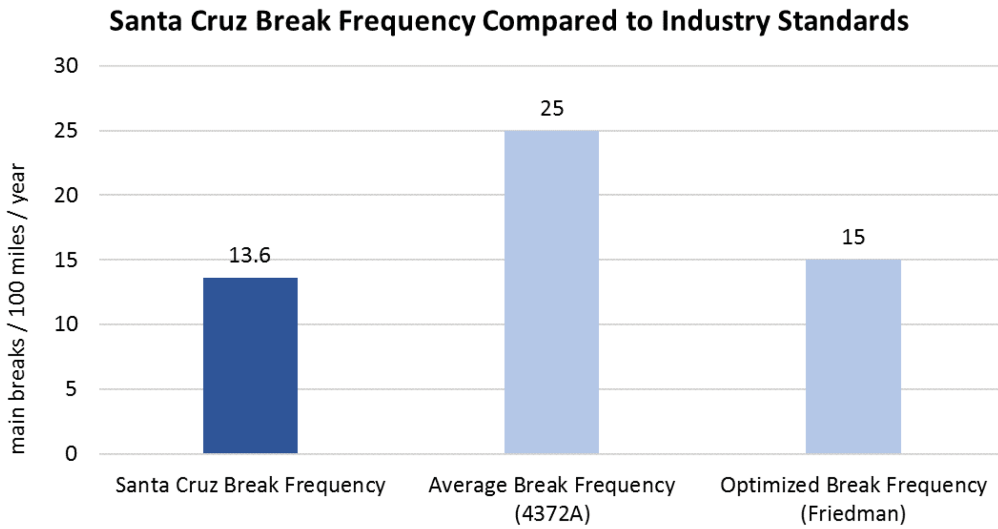



Figure 31: Comparison of Santa Cruz Main Break Frequency to Industry Standards

The average break frequency in Figure 31 is drawn from Water Research Foundation project 4372A: Real Loss Component Analysis – A Tool for Economic Water Loss Control. As part of this research, WSO studied average break frequencies at water utilities throughout North America and found that the average break frequency of all utilities studied was 25 reported breaks per 100 miles of main per year.

The optimized break frequency in Figure 31 was determined in Water Research Foundation project 4109: Criteria for Optimized Distribution Systems by Friedman et al.[2] This study published benchmarks that indicate that a distribution system is well-managed and established a break frequency of 15 reported breaks per 100 miles of main per year as a reasonable target for optimized systems.

**Santa Cruz's reported break frequency of 13.6 breaks per 100 miles of main per year is slightly lower than the optimized break frequency.** As a result, WSO wonders whether the summary of main breaks truly captured all events during the audit period.

*Service Connection Breaks*

WSO compared Santa Cruz's service connection reported break frequency to the Unavoidable Annual Real Losses component for service connection failures. The American Water Works Association has created a formula to determine the theoretical minimum level of leakage for a system, the Unavoidable Annual Real Losses (UARL). This formula allows for a certain level of leakage for each infrastructure type, dependent on system characteristics. The UARL service connection break frequency allowance is 2.25 break per 1,000 service connections per year**. Santa Cruz's service connection reported break rate is 7.8 breaks per 1,000 connections per year, about 3.5 times the technical minimum** (see Figure 32).

[2] Friedman, M., G. Kirmeyer, and J. Lemieux. 2010. *Criteria for Optimized Distribution Systems.* Denver, Colo.: Water Research Foundation.

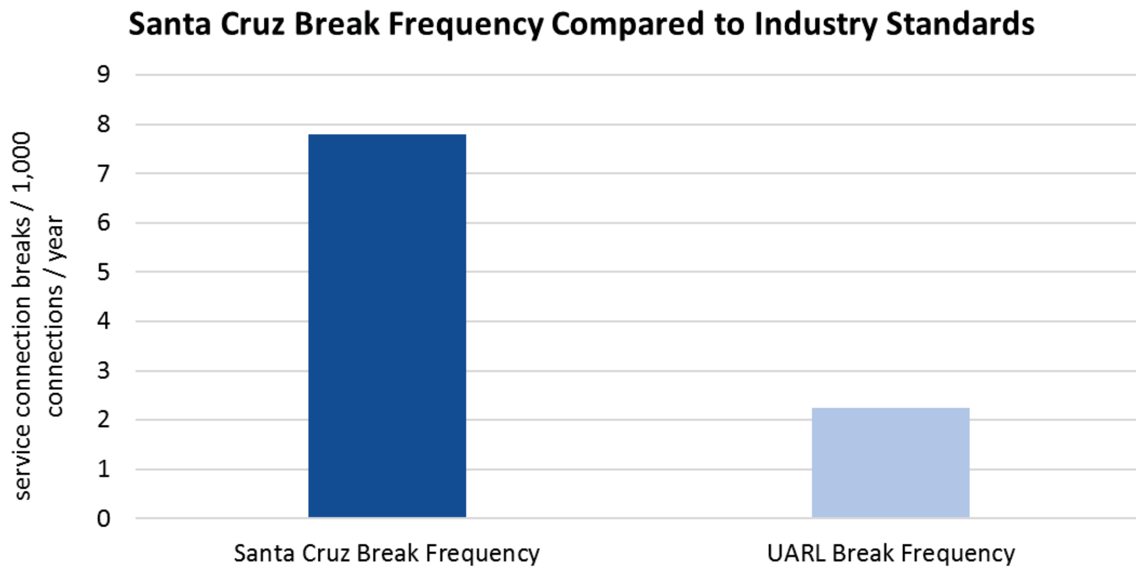



Figure 32: Comparison of Santa Cruz Service Connection Break Frequency to UARL Technical Minimum

## 6.5 Recommendations

In order to improve the conclusions that can be drawn from future Component Analyses and intervene against Real Losses using reliable data, WSO recommends the following:

- **Track all repairs in the work order system using a single work order per failure**. Using a single work order per failure will reduce the likelihood that breaks will be excluded from or double-counted in Component Analysis. Santa Cruz should document all activity related to a repair in one work order, rather than generating a work order for each repair activity.
- **Program and then use the work order system to capture the following information at a minimum**:
    - Time of leak report initiation (when Santa Cruz learned of the leak's existence)
    - Source of leak report (e.g. customer service, field operations, engineering)
    - Time of leak containment
    - Infrastructure type and size
    - Failure or problem type
    - Occurrence of water loss (a yes/no field indicating whether water was lost to leakage, to distinguish leakage losses from water used for operational activities)
    - Severity of break (distinct descriptive levels indicating priority and extent of loss, with corresponding standardized definitions; definitions of severity should *only* pertain to flow rate or water loss ranges, not expense of repair or liability)

  These fields will allow Santa Cruz to determine leak location and reponse time, filter repair data for water loss events, and model leak flow rates.

- **Perform future Component Analyses of Real Losses using the modeling parameters outlined in this report.** By making the same assumptions about the ICF and N1 pressure exponent, Santa Cruz can compare Component Analysis results year-to-year.

# 7 LEAK DETECTION

## 7.1 Introduction

The Component Analysis of Real Losses determined that the majority of Santa Cruz's leakage volume is attributable to Background Leakage running continuously at acoustically undetectable flow rates. Futhermore, the water balance and performance indicators suggest that Santa Cruz currently experiences low levels of leakage.

**To corroborate the findings of the water audit and Component Analysis, WSO performed a pilot comprehensive leak detection survey of 100 miles of mains (37% of all Santa Cruz mains).**

This section describes leak detection as follows:

- Section 7.2 – Survey Background
- Section 7.3 – Leak Confirmation Process
- Section 7.4 – Leaks Identified
- Section 7.5 – Analysis
- Section 7.6 – Summary
- Section 7.7 - Recommendations

## 7.2 Survey Background

### 7.2.1 *Geography*

WSO completed a pilot leak detection survey of the City of Santa Cruz's distribution system**. WSO comprehensively surveyed three transects of the distribution network, covering a total of 100.0 miles of mains,** between February 8th and February 21st, 2016. The three transects were chosen to sample representative pressure, pipe materials, and infrastructure conditions in the Santa Cruz service area. Overall, 37% of the system was surveyed in the pilot leak detection effort.

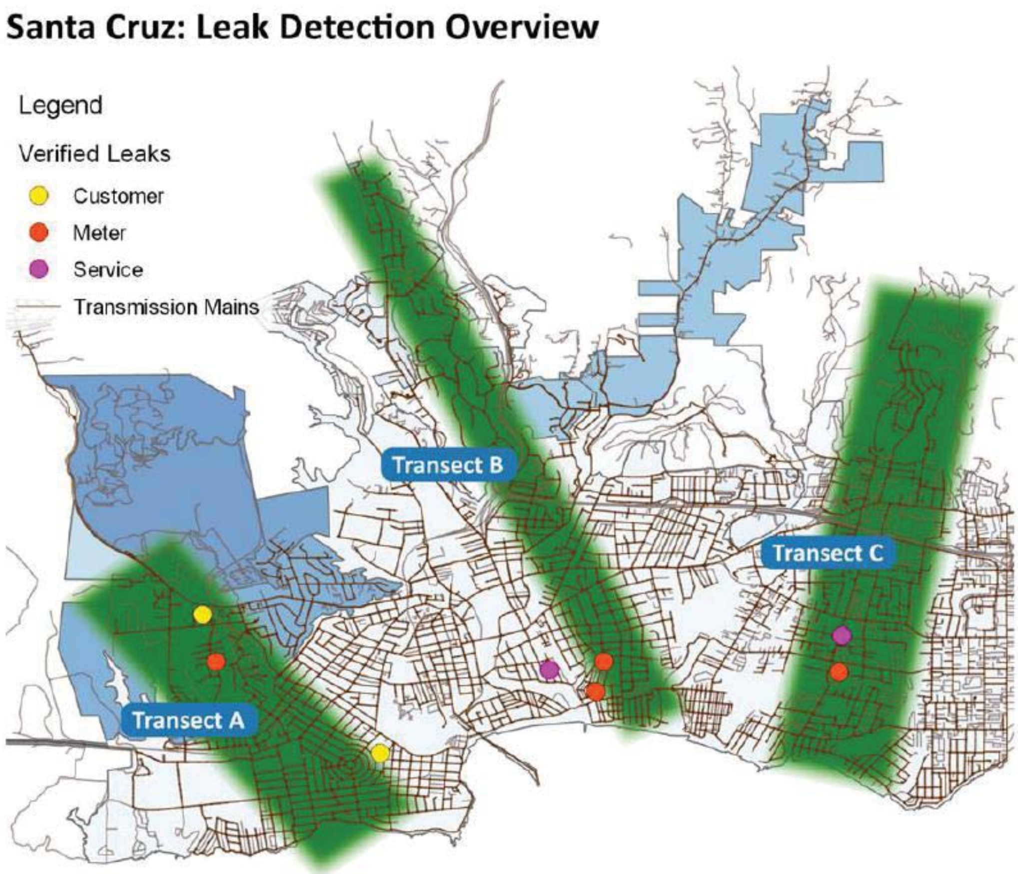



Figure 33: Map of Leak Detection Transects

### 7.2.2 *Technology*

Acoustic leak detection, though procedurally simple, is an effective way to discover leakage. Acoustic leak detection amplifies noise at various points of connection through a system's infrastructures so that surveyors can idenfity unsurfaced leaks.

Leak detection can be general or thorough, depending on the location of leaks and level of detail that a utility wishes to investigate.[3]

- **General Survey:** this survey method is often referred to as a "valve and hydrant survey." In a general survey, technicians listen exclusibely to fire hydrants and valves to detect leaks. Service connections are not sounded. Fire hydrants are often selected at approximately constant intervals to provide even geographic coverage. In a general survey, geophones and leak noise correlators are usually only used to pinpoint a leak. Though general surveying is fast, service connection leaks often go undetected, especially if the area consists primarily of non-metallic pipe.

[3] Water Loss Control, Second Edition; Thornton, Sturm & Kunkel, 2008.

- **Comprehensive Survey:** this survey method listens to all available fittings on mains *and* service connections. Geophones are used to sound above mains in case contact points are far apart from each other. Once a leak sound is detected, geophones and leak noise correlators can be used for pinpointing the leak. Even though comprehensive surveying is more time-consuming than general surveying, it is the most effective way to identify all detectable leaks in the system, including service connection leaks.

WSO's leak detection work throughout North America and research conducted for the Water Research Foundation (formerly the American Water Works Association Research Foundation) has clearly highlighted that **a comprehensive survey is necessary to detect all unreported hidden leaks in a distribution network.**[4]

Santa Cruz's leak detection survey was therefore comprehensive and conducted using a Fluid Conservation System (FCS) L-Mic sonic leak detection probe and a FCS ACCUCOR 3000 digital leak noise correlator. **WSO made direct contact with all accessible distribution system appurtenances in the areas surveyed, including customer meters, fire hydrants, blow-off valves and backflow preventers.**

## 7.3 Leak Confirmation Process

When WSO detected a potential leak, WSO technicians noted the location of the leak in a tracking tool. Then, WSO technicians returned to the potential leak location at a different time to confirm the leak.

Upon confirming a leak noise's persistance, WSO requested that Santa Cruz's leak specialist verified the leak. The findings in this report are based on the final outcome of joint leak verification. Figure 34 shows the workflow for leak detection, confirmation by the city, and ultimate leak repair.

Leak locations were recorded using a standardized leak report to streamline leak repair and analysis of findings. After documentation of leak location, leak flow rates were estimated based either on the visible appearance of the leaks or the intensity of the noise produced by non-visible leaks.

[4] Leakage Management Technologies, AWWA Research Foundation, 2007. p 60.

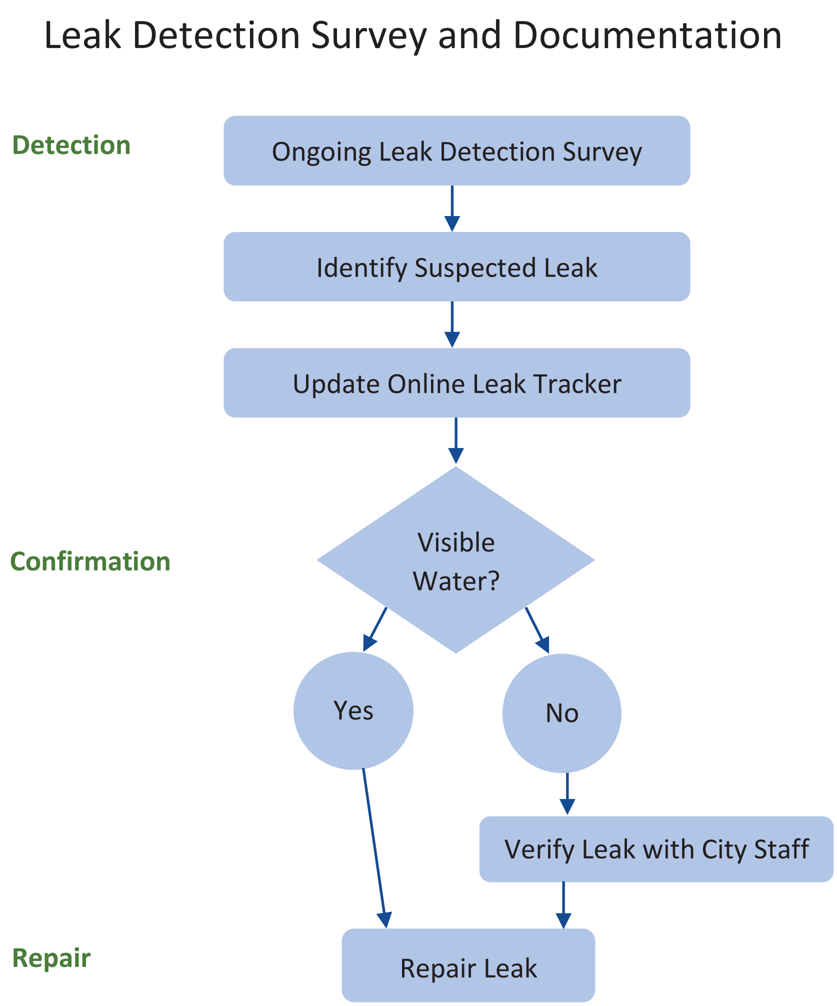



Figure 34: Leak Detection, Confirmation, and Repair Process

## 7.4 Leaks Identified

WSO identified a total of **6 city-side leaks**. Four of the city-side leaks were on customer meters; the other two leaks were on service connections (see Table 62). The six leaks were estimated to cumulatively generate 6.1 gpm in leakage. The absence of main breaks, and the very low number of service leaks found, suggests that the distribution system has relatively low levels of real losses.

| LEAK TYPE | COUNT | PERCENT OF TOTAL COUNT | CUMULATIVE ESTIMATED FLOW (GPM) | PERCENT OF TOTAL ESTIMATED FLOW | VOLUME RECOVERED PER YEAR (MG) |
|---|---|---|---|---|---|
| meter | 4 | 67% | 2.6 | 43% | 1.4 |
| service | 2 | 33% | 3.5 | 57% | 1.8 |
| **TOTAL** | **6** | **100%** | **6.1** | **100%** | **3.2** |

Table 62: City-Side Leaks

An additional two customer side leaks were identified, estimated to cumulatively generate 1 gpm (see Table 63). While customer leaks are not considered Real Losses within the AWWA water audit methodology because customer side leaks are metered and billed, they represent an additional form of water savings realized through leak detection. The total savings attributed to repaired customer leaks assumes that customer leaks would otherwise have run for 30 days (one bill period) prior to recognition by customers or utility staff.

| COUNT | ESTIMATED FLOW (GPM) | VOLUME RECOVERED (MG) |
|---|---|---|
| 2 | 1 | 0.04 |

Table 63: Customer-Side Leaks

## 7.5 Analysis

### 7.5.1 *Volumetric Savings*

As a best estimate, Santa Cruz can expect to **annually recover 3.2 MG per year** (presented in Table 64). An additional 0.04 MG of savings will be realized through proactive discovery of customer-side leaks.

| CATEGORY | BEST ESTIMATE |
|---|---|
| recoverable leakage (gpm) | 6.1 |
| recoverable leakage (MG per year) | 3.2 |

Table 64: Volumetric Savings of City Side Leaks

### 7.5.2 *Financial Savings & Cost-Effectiveness*

*Marginal Cost of Water*

Undetected, ongoing leakage produces a direct cost to Santa Cruz. Leakage losses are valued at production cost, since Santa Cruz must produce additional water to cover the leakage volume. Production cost was determined to be $553 per MG, the same figure used for variable production cost in the water audit.

Please note that this valuation of water does not incorporate other less-direct costs, like the avoidance of liability for leak damage and the potential for ongoing leaks to grow in magnitude.

**The best estimate of 3.2 MG in annual recoverable city-side leakage translates to $1,709 in annual savings** (see Table 65), assuming variable production cost of water and constancy of leak flow rate. Assuming flow rates remain constant is a conservative assumption because leak flow rates typically increase over time. It is important to note that the savings below reflect *annual* savings, but without knowing how long the leaks would otherwise run undetected, it is not possible to project the actual accruement of savings for a definite period of time.

| LEAK TYPE | COUNT | ANNUAL VOLUME RECOVERED (MG) | ANNUAL SAVINGS |
|---|---|---|---|
| meter | 4 | 1.4 | $746 |
| service | 2 | 1.8 | $959 |
| **TOTAL** | **6** | **3.2** | **$1,705** |

Table 65: Annual Recovered Savings (Variable Production Cost)

Assuming the marginal cost of water and leak flow rates remain constant over the next twenty years, **the cost of the leak detection survey has a payback time of seventeen years**, as shown in Table 66**.**

| | |
|---|---|
| Miles Surveyed | 100 |
| Cost of Leak Detection per Mile | $300 |
| Total Cost of Leak Detection | $30,000 |
| Annual Savings (at variable production cost of water) | $1,705 |
| **SIMPLE PAYBACK TIME (years)** | **17.6** |

Table 66: Leak Detection Payback Period

### 7.5.3 *Retail Cost of Water*

Another way to evaluate the financial performance of the leak detection survey is to compare it to alternative forms of water conservation. Customer demand conservation programs, such as toilet rebate programs, come at the expense of utility revenues, since lower customer demand means less billed consumption. Recovery of system leakage before the customer meter, on the other hand, does not reduce retail revenues, since leakage is not billed to customers in the first place.

If Santa Cruz were to save the amount of water recovered through leak detection instead through demand-side conservation strategies, decreased water sales would represent an opportunity cost to the utility. For this reason, WSO presents below an additional scenario that values water at average retail cost, $4.04/CCF. WSO applied this rate universally, regardless of the location of leakage.

**Had Santa Cruz saved 3.2 MG annually using demand side conservation measures, Santa Cruz would incur an annual hidden cost of $17,282 in the form of decreased water sales.** Note that this reflects variable costs only and does not include other fixed costs associated with demand side reduction like the cost of providing free low-flow water fixtures to customers.

As described in Table 67, the best estimate of 3.2 MG in savings represents a retail value of $17,282. Therefore, if this supply reduction were achieved through customer demand conservation, it would come at an estimated cost of $17,282 in decreased revenues.

| LEAK TYPE | COUNT | ANNUAL VOLUME RECOVERED (MG) | ANNUAL SAVINGS |
|---|---|---|---|
| meter | 4 | 1.4 | $7,561 |
| service | 2 | 1.8 | $9,721 |
| **TOTAL** | **6** | **3.2** | **$17,282** |

Table 67: Annual Recovered Savings (Retail Unit Cost)

Assuming verification and repair of leaks, and the retail cost of water and leak flow rates noted previously, **the cost of the leak detection survey has a payback time of 3.1 years as shown in Table 68.**

| | |
|---|---|
| Miles Surveyed | 100 |
| Cost of Leak Detection per Mile | $300 |
| Total Cost of Leak Detection | $30,000 |
| Annual Savings (at variable production cost of water) | $17,282 |
| **SIMPLE PAYBACK TIME (years)** | **1.7** |

Table 68: Cost-Effectiveness of Leak Detection at Retail Cost of Water

## 7.6 Summary

1. WSO identified **8 leaks**, comprised of four meter leaks and two service connection leaks, and two customer side leaks. The city-side leaks are estimated to cumulatively generate **6.1 gpm** in leakage.
2. Upon repair of City-side leaks, Santa Cruz can expect to **annually recover a best estimate of 3.2 MG**.
3. At the *variable production cost* of water (the cost to provide water), the 3.2 MG in city-side leakage translates to an **estimated annual savings of $1,709.** At the *retail cost* of water (the cost of water to customers), the volume translates to an **estimated annual savings of $17,282**.
4. The project has an **expected simple payback time of 17.6 years** at the *variable production cost*. At the *retail cost*, **the expected payback time is 1.7 years.**
5. WSO identified **two additional customer-side leaks** that are estimated to cumulatively generate **1 gpm** in leakage. Upon repair of these leaks, Santa Cruz can expect to **annually recover a best estimate of 0.04 MG.** While repair of customer leaks does not generate financial savings to the City because the water

feedings this leakage are metered and billed, Santa Cruz would nonetheless realize the associated water savings.

The leak detection effort is projected to pay itself back in 17.6 years if assessed at the variable production cost of water or 1.7 years if assessed at retail cost. It must be acknowledged that this basic method for evaluating cost-effectiveness does not take into account the following benefits:

- Amelioration of regulatory burdens associated with drought conditions, including improved ability to meet demand reduction targets
- Reduced wear-and-tear on infrastructure as a result of proactive leakage management, which contributes to avoided infrastructure replacement and other costs associated with responding to larger break events
- Improvements in the quality of customer service by preventing future breaks of greater magnitude

## 7.7 Recommendations

The pilot leak detection survey and the Component Analysis of Real Losses indicate that Santa Cruz system currently experiences low levels of leakage. Furthermore, both activities suggest that the majority of the leakage volume is attributable to background leakage, leakage that cannot be acoustically detected and that is best addressed through pressure management.

Therefore, **WSO does not recommend that Santa Cruz implement a full-system leak detection program at this time.** Full-system leak detection is not economically efficient for Santa Cruz right now, since the costs of surveying would greatly exceed the value of water recovered. Santa Cruz is alread operating close to an Economic Level of Leakage, the threshold at which the costs of active leakage control approximately match the value of water recovered.

Instead, **WSO recommends that Santa Cruz continue periodic pilot leak detection.** Limited but regular leak detection will:

- Monitor the system for developing leakage
- Investigate zones of the system not covered by this pilot survey
- Identify areas and pipe materials that require more frequent surveying
- Corroborate the results of future water audits and Component Analyses

The extent of a leak monitoring program depends on Santa Cruz's capacity. As a starting point, WSO recommends that Santa Cruz consider a program that surveys the system in its entirety over the next 5 years. Under such a program, 20% of the system (about 54 miles) would be surveyed each year.

After completing the initial survey, Santa Cruz will have cleared the system of leaks and can then study the evolution of new leakage. A second survey, conducted with the same schedule as the first survey, will identify the areas that develop new leaks most quickly and allow Santa Cruz to estimate its unique Rate of Rise of Leakage.

# 8 Compiled Recommendations

## 8.1 Water Supplied

### 8.1.1 *System Input Volume Accounting*

- **Trust the summaries of production produced by treatment plant staff over raw SCADA data.** The frequency of gaps and nulls values in the SCADA historian makes raw data unreliable for the time being. The protocols that treatment plant staff employ in calculating production volumes are as thorough as possible given the current SCADA inconsistencies.

- **Investigate the archival of null values and gaps in the SCADA historian.** In theory, the SCADA historian and associated Wonderware reports should capture flow information continuously. However, gaps in the historian data during 2014 caused SCADA to miss an estimated 97 MG of production during the audit period. Gaps observed in the SCADA historian indicate an issue somewhere in the transfer of data from metering instrument to database archival. It would be worthwhile for Santa Cruz to identify the source of this data production or storage error so that future summaries of Water Supplied can be validated with raw data.

- **Be careful using Wonderware reporting and retrieval functions to create production summaries.** Accessing data through retrieval functions like best-fit and time-interval manipulation can subtly alter data points. While alterations in data caused by retrieval functions are minor, they can add up over the course of a year-long audit period. For the water balance, unmanipulated raw data is the best source of information (given the caveat that gaps in the historian data make using raw data difficult). However, in using raw data it is important to remember that data points are collected at SCADA scan frequency, not in consistent time intervals. As a result, it is better to weight flow rates by the time intervals they capture, rather than take a simple average of flow rates, to calculate volumes. Of course, this practice depends on a more reliable understanding of communication between SCADA and the historian.

- **Revisit the assumption that plant consumption can be derived from plant domestic service.** During 2014, plant domestic service was negative – indicating water leaving the plant – and the corresponding estimation of plant consumption was positive – indicating a contribution to Water Supplied, rather than a detraction. This is contrary to the fact that that plant consumption is actually consumption, rather than supply. Given this scenario, Santa Cruz should consider other methods of estimating plant consumption.

### 8.1.2 *Influent Meter Testing*

- **Continue volumetric accuracy testing the NC and SLR influent meters on an annual basis.** While the tests are not yet informative enough to adjust production volumes, a focus on fine-tuning of test protocols, refinement of estimations, and investigation of data sources and instrument accuracy may allow Santa Cruz to quantify the accuracy of production meters in the future. Additionally, year-to-year tracking of trends in meter accuracy will allow Santa Cruz to monitor key production assets.

- **Interpret influent meter test results cautiously.** Because test results vary significantly depending on the selection of instruments used, and there is not yet a reason to prefer one instrument over any other, the 2016 influent meter accuracy tests did not provide an exact understanding of influent meter accuracy. Therefore, influent meter test results should not be used to adjust production volumes for the 2014 water audit. However, if Santa Cruz selects a single test set-up to track meter accuracy and takes stock of the types and magnitudes of uncertainty in that test set-up, future test results can be used to adjust the volume of Water Supplied.

- **Investigate discrepancies in water level measurements captured by the hanging pressure transducer, the hatch-installed pressure transducer, and the SCADA historian.** Because both transducers measure the same datum, they should approximately agree. However, an average difference of 3.5% of calculated height change was observed in all four tests. Furthermore, though the SCADA historian data is derived from the hatch-installed pressure transducer, the values recorded in SCADA do not align with pressure transducer data logger output as closely as would be expected. Until Santa Cruz establishes which instrument is best to capture finished water tank level or the three data sources agree, it will be difficult to interpret test results. Santa Cruz staff have indicated that the hatch-installed pressure transducer may be the best source of test data, an assertion that can be investigated in future tests.
- **Explore the difference in influent meter flow rates captured by the data logger and by the SCADA historian.** The historian captured 0.5% more volume on average than the data logger. Some aspect of the data transmission process introduces this additional flow rate (and therefore volume), and investigating this discrepancy may assist Santa Cruz in more fully understanding the strengths and limitations of the SCADA system.
- **Consult treatment plant staff on instrumentation reliability and test interpretation.** WSO's interaction with data sources and test results was intentionally removed from treatment plant staff's anecdotal information to promote neutral analysis and full consideration of all available data sources. Now that initial test analysis is complete, the treatment plant staff's experience and insight will be important to include in interpreting test results and refining future tests.

### 8.1.3 *Effluent Meter Consideration*

- **Consider the benefits of installing and regularly testing an effluent meter on the treatment plant's finished water line.** When assessing water losses, the importance of the input volume measurement cannot be overstated because the input volume is the foundation of the water audit. Installing a single effluent meter at the Graham Hill Water Treatment Plant would simplify and improve this critical measurement. Ideally the meter would be installed near a reservoir or tank to allow for direct volumetric testing.

## 8.2 Authorized Consumption

- **Include a Boolean (true/false) field in the EDEN billing database to quickly and easily filter BMAC-relevant records.** To minimize the likelihood of accidentally including raw water or unbilled consumption in BMAC totals, a yes/no field indicating status as a BMAC account should be added to EDEN and employed in future consumption analyses. When the field is checked "yes," the water for the account is potable and revenue-generating and therefore should be incorporated in audit totals of Billed Metered Authorized Consumption. When the field is not checked, the water for the account is not potable or is not revenue-generating and should therefore be excluded from audits totals of Billed Metered Authorized Consumption.

- **Perform the validation checks listed Section 3.2.3 when completing an annual audit.** These validation checks confirm that billing data is complete and reliable at a macroscopic level. Santa Cruz currently checks lag time and apportions consumption by reading route. Performing the additional checks outlined in this report will confirm data validity more thoroughly.

## 8.3 Apparent Losses

- **Implement ongoing random and representative small meter testing, to the extent operationally and financially possible**. In order for small meter accuracy to be understood and tracked, small meters (2” and smaller) should be tested following AWWA-recommended test protocol. This involves testing small meters at specific low, medium, and high flows and then using time and volume distributions to produce a weighted average accuracy. Additionally, a representative and significant number of meters must be tested in order for test results to be extrapolated to the entire meter stock.
- **Instigate a large meter testing program that balances revenue lost to meter inaccuracy with the costs of meter testing and replacement**. Under such a program, meters 3” and larger would be assigned individual maintenance (test and replace) frequencies ranging from once every six months to once every five years. Test schedules would aim to maintain the accuracy of key revenue-generating meters based on the risk of revenue loss resulting from under-registration and the cost to replace the meters. Once the large meter testing program is underway, initial test results should be tracked and used to refine the test schedule by incorporating an understanding of initial meter accuracy and the rate of meter decline.
- **Inform future meter replacement programs with the economic analyses presented in this report.** Analyzing meter replacement by comparing lost revenue to replacement costs empowers Santa Cruz to intervene only when the benefits outweight the costs. Additionally, meter replacement can target certain meter groups like size, manufacturer, and install year, if meter test data allows for such stratification. This type of tailored meter replacement is preferred over replacement due to age or anecdotal performance alone.
- **Perform a consumption profiling study (see Appendices F and G for examples) in order to customize the volumetric weighting factors applied in meter accuracy calculations.** Using tailored weighting factors will minimize the potential for inaccuracy in Apparent Loss estimations and economic analysis. Consumption profiling is helpful in determining the weighting factors for small meter accuracy and optimal test flow rates for large meters.

## 8.4 Water Balance

- **Perform an annual water audit and repeat the analyses described in this report.** Using the same data sources, data treatments, and validation techniques from year to year permits Santa Cruz to track changes in system efficiency, since changes in performance indicators will likely reflect actual system conditions rather than the results of different analytic approaches.
- **Focus on improving the reliability of data, using the Data Validity Scoring system as a guide but focusing resources on the particular areas where uncertainty and error are most significantly introduced.** WSO recommends that Santa Cruz work to improve data quality by examining the

instruments and data management systems that inform the audit, instead of using the Data Validity Scoring system as a strict guide. The scoring matrix is intended to be general and apply to a wide range of systems, so it cannot always serve as a customized data improvement road map. Instead, the scoring matrix is useful in highlighting the importance of instrument testing, data review, and occasional third-party confirmation. Santa Cruz's goal should not be a Data Validity Score of 100, since achieving such a high score tends to require investment past a point of diminishing returns. Rather, Santa Cruz should aim to thoroughly understand the accuracy of key system instruments, appreciate the overlay of SCADA and software packages on primary measurement, and minimize error introduced through human interaction with data.

## 8.5 Component Analysis of Real Losses

- **Track all repairs in the work order system using a single work order per failure**. Using a single work order per failure will reduce the likelihood that breaks will be excluded from or double-counted in Component Analysis. Santa Cruz should document all activity related to a repair in one work order, rather than generating a work order for each repair activity.
- **Program and then use the work order system to capture the following information at a minimum**:
    - Time of leak report initiation (when Santa Cruz learned of the leak's existence)
    - Source of leak report (e.g. customer service, field operations, engineering)
    - Time of leak containment
    - Infrastructure type and size
    - Failure or problem type
    - Occurrence of water loss (a yes/no field indicating whether water was lost to leakage, to distinguish leakage losses from water used for operational activities)
    - Severity of break (distinct descriptive levels indicating priority and extent of loss, with corresponding standardized definitions; definitions of severity should *only* pertain to flow rate or water loss ranges, not expense of repair or liability)

  These fields will allow Santa Cruz to determine leak location and reponse time, filter repair data for water loss events, and model leak flow rates.
- **Perform future Component Analyses of Real Losses using the modeling parameters outlined in this report.** By making the same assumptions about the ICF and N1 pressure exponent, Santa Cruz can compare Component Analysis results year-to-year.

## 8.6 Leak Detection

- **Continue periodic pilot leak detection to track leakage and confirm the results of future water audits and Component Analyses.** The extent of a leak monitoring program depends on Santa Cruz's capacity.

As a starting point, WSO recommends that Santa Cruz consider a program that surveys the system in its entirety over the next 5 years. Under such a program, 20% of the system (about 54 miles) would be surveyed each year.

After completing the initial survey, Santa Cruz will have cleared the system of leaks and can then study the evolution of new leakage. A second survey, conducted with the same schedule as the first survey, will identify the areas that develop new leaks most quickly and allow Santa Cruz to estimate its unique Rate of Rise of Leakage.

# APPENDICES

# APPENDIX A: DAILY PRODUCTION BY SOURCE

Figure 35 presents a daily breakdown of production by source. Production was highest during summer months and lowest during winter months, as expected. However, production varied widely on a day-to-day basis.

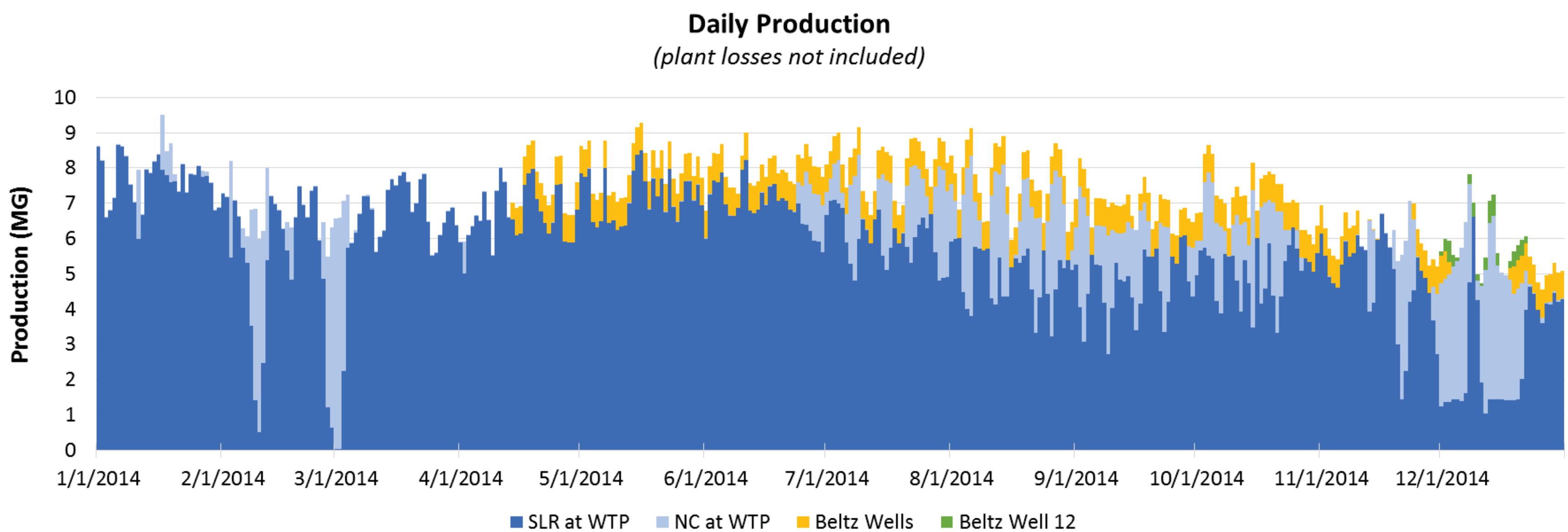



Figure 35: 2014 Daily Production by Source

# APPENDIX B: INFLUENT METER TEST PROCEDURE

The table below lists the planning and steps necessary for conducting a volumetric accuracy test of the San Lorenzo River (SLR) and Newell Creek (NC) influent electromagnetic flow meters at the Graham Hill Water Treatment Plant (GHWTP). The test protocol is based on comparing the rate of storage gain in the GHWTP Finished Water Tank (FWT) to the rate of flow registered through the influent meter over a steady-state time interval. To realize all influent flow as storage gain in the FWT requires the GHWTP to be isolated from the potable distribution system and the internal volume of the GHWTP to remain constant over the course of the test. Additionally, water inputs and withdrawals during the treatment process must be minimized and quantified to the extent possible over the span of the test to allow for an accuracte calculation of a reference volume.

| TASK & DESCRIPTION | DATA/SETUP REQUIRED |
|---|---|
| **PREPARATION** | |
| **WEEK BEFORE TEST: PLAN.** | |
| *Conduct a planning meeting to decide which meter to test and the target test flow rate. Schedule the test with Operations Sections (Production, Distribution, etc.)* | • Assess weather and watershed conditions in selecting an influent meter to test.<br>• Determine the time frame of the test based on target test flow rate and FWT capacity. |
| **DAY BEFORE TEST: INSTALL TEST EQUIPMENT.** | |
| *Install equipment needed for meter test and check to ensure proper functioning.* | • Confirm the installation of the hatch-installed pressure transducer; check that transducer is appropriately zeroed and communicating with SCADA.<br>• Connect a data logger to the hatch-installed pressure transducer and program the logger for an acceptable sampling and archival frequency. A level measurement should be archived at least once every fifteen seconds. |
| **DAY OF THE TEST: CONFIGURE THE TREATMENT PLANT FOR VOLUMETRIC TESTING.** | |
| *Prior to the start of the volumetric test, configure GHWTP to minimize changes in the internal plant volume during the test, minimize water inputs not registered through the influent test meters, and minimize water withdrawals not realized as effluent production in the FWT.* | • List all treatment inputs and withdrawals that will be running during the test (e.g. chemical feed carrier water, turbidimeters).<br>• Measure or estimate the flow rates of all treatment inputs and withdrawals that will affect the ultimate calculation of the reference volume. |
| **TESTING** | |
| **1. DRAIN AND ISOLATE THE FINISHED WATER TANK.** | |
| *Lower the Finished Water Tank (FWT) level to allow for the maximum change in water level. Isolate the FWT so that there is no withdrawal during the test, ensuring that the only cause of water level change will be volume passed through the tested meter.* | • Sufficiently drain the FWT, *but do not drain the FWT past the level that the hatch-installed transducer can register.*<br>• Take other reservoirs offline to isolate the FWT for the duration of the test.<br>• Close valves to isolate the GHWTP from the potable distribution system, forcing all production into the FWT but not into the distribution system. |

| TASK & DESCRIPTION | DATA/SETUP REQUIRED |
|---|---|
| **2. RUN THE METER SELECTED FOR TESTING.** | |
| *The meter selected for testing should see throughput for the determined test duration. It's important that the test volume is significant to minimize the effects of reading resolution on both the meter and the level reader. With this in mind, the test duration is informed by the flow rate and the Finished Water Tank dimensions.* | • Adjust flow through the test meter to achieve the specified test flow rate.<br>• Confirm that the other influent meter – the meter *not* being tested – is not receiving throughput.<br>• Note the general start time of the test.<br>• Run the test long enough to achieve a significant change in reservoir volume. |
| **3. RETURN THE PLANT TO NORMAL OPERATIONS ONCE A SUFFICIENT VOLUME HAS ACCUMULATED IN THE FWT.** | |
| *Once the reference volume is sufficient to minimize the effect of measurement uncertainty, return the plant to normal operating conditions.* | • Watch the level in the FWT using SCADA and conclude the test when the FWT level is deemed to be sufficient.<br>• Note the general stop time of the test.<br>• Return the plant to normal operating conditions. |
| **ANALYZING** | |
| **4. EXPORT TEST DATA FROM THE SCADA HISTORIAN.** | |
| *To allow for the test to be analyzed, export data from the SCADA historian into flat files.* | • Export SCADA historian files of influent meter flow rate and hatch-installed transducer FWT level. Pull all data from an hour before the test start time to an hour after the test stop time. Be sure to minimize the application of data retrieval functions (e.g. best fit, interpolation) by selecting all historian data "as-is," collected at time intervals reflecting SCADA scan frequency.<br>• Pull level data from the hatch-installed pressure transducer.<br>• Confirm that all exported data includes timestamps. |
| **5. IDENTIFY TIME INTERVAL FOR ANALYSIS.** | |
| *Select a time interval for analysis during which plant operations achieved steady-state conditions. The time interval must be long enough to minimize the effects of measurement uncertainty.* | • Identify a steady-state period during the test.<br>• Select an analysis start time.<br>• Select an analysis stop time. |
| **6. CALCULATE THE TEST VOLUME.** | |
| *Calculate the volume of water that passed through the influent meter during the analysis interval.* | • Using SCADA data capturing the influent meter flow rate during the test interval, calculate the test volume pertaining to the analysis time interval.<br>• Be careful to incorporate the time intervals between data points. If they are not equal (i.e. intervals reflect SCADA scan frequency, not a consistent interval like every 5 seconds), you cannot use a simple average flow rate from the time interval. Instead, weight the length of time represented by each data point in determining an average test flow rate. |
| **7. CALCULATE THE REFERENCE VOLUME.** | |

| TASK & DESCRIPTION | DATA/SETUP REQUIRED |
|---|---|
| *Calculate the volume of water that arrived in the FWT during the analysis interval, being sure to incorporate gains and losses due to the treatment process.* | • Compare data logger data to SCADA data for the hatch-installed pressure transducer to confirm approximate agreement.<br>• Calculate the volume that arrived in the FWT during the analysis interval using levels readings captured by the hatch-installed pressure transducer data logger.<br>• Calculate the volume of water added during the treatment process through plant gains using flow rate estimates and the length of time represented by the analysis interval.<br>• Calculate the volume of water subtracted during the treatment process through plant losses using flow rate estimates and the length of time represented by the analysis interval.<br>• Determine the net gain volume by subtracting losses from gains.<br>• Subtract the volume of net gain from the FWT volume to determine the reference volume. |
| **8. COMPARE THE REFERENCE VOLUME AND THE TEST VOLUME TO DETERMINE INFLUENT METER ACCURACY.** | |
| *Determine the accuracy of the influent meter compared to the reference volume.* | • Divide the test volume by the reference volume to determine influent meter accuracy out of 100% at the test flow rate. |

# APPENDIX C: FINISHED WATER TANK VOLUME CALCULATIONS

Calculations of the volume of water in the Finished Water Tank by water level is provided in an attached Excel spreadsheet titled "Appendix C – Finished Water Tank Volume Calculations."

The level of the Finished Water Tank must be calculated for two distinct geometries of the tank. The base of the tank, up to 13 feet, has vertical walls, so the volumetric calculation is that of a cylinder.

The upper portion of the tank, above 13 feet, has slightly inclined walls. Therefore, above 13 ft of water level height, the volumetric calculation is that of a cone. However, the bottom portion of the cone (the volume of the cone below the start of the inclined walls) must be subtracted from the overall conical volume to determine the additional volume introduced above 13 feet (see Figure 36).

Lastly, two vertical pipes run the full length of the FWT. The tank's center column has a square cross-section, and the tank's overflow pipe has a circular cross-section. The volume occupied by each pipe must be subtracted from all FWT volume calculations.

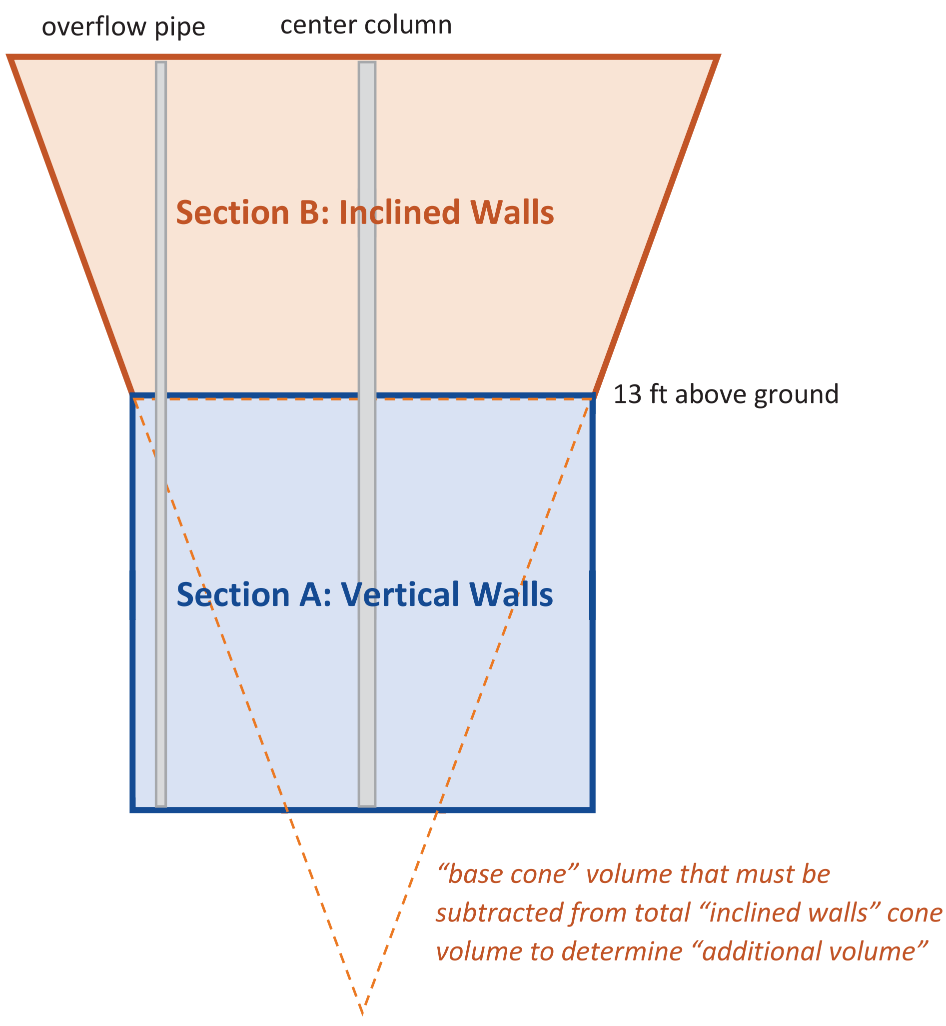



Figure 36: Exaggerated Schematic of Finished Water Tank

# APPENDIX D: DETAILED INFLUENT METER TEST RESULTS

Provided as  Microsoft Excel attachment titled  “Appendix D – Detailed Influent Meter Test Results.xlsx.

# APPENDIX E: APPORTIONMENT

The determination of BMAC utilizes billing database records of consumption. As a result, it is important to test the assumption that a bill generated in a two-month period represents the consumption only of those months. This would be the case if all accounts were consistently billed monthly on the last day of each bi-monthly bill period. Instead, Santa Cruz generates bills over the course of multiple days in each bill period. Therefore, a bill generated in the middle of January will represent some consumption from January, all consumption from December, and consumption from some of November. Apportionment allows consumption to be allocated to each month, rather than assuming that the month of the bill date is also the month of the consumption represented by the bill. The following example outlines the method employed for apportioning a bi-monthly bill.

Table 69: Example Calculation of Apportioning One Bill's Consumption by Calendar Month

| | | | |
|---|---|---|---|
| **Previous Read Date** | | March 23, 2007 | |
| **Read Date** | | May 23, 2007 | |
| **Consumption (CCF)** | | 66 | CCF |
| **Days Between Reads** | | 61 | days |
| **Average Consumption Per Day** | | 1.082 | CCF/day |
| **Consumption Apportioned to March**<br>*(8 days in March within the billing period)* | = 8 days x 1.082 CCF/day | **8.66** | **CCF** |
| **Consumption Apportioned to April**<br>*(30 days in April within the billing period)* | = 30 days x 1.082 CCF/day | **32.46** | **CCF** |
| **Consumption Apportioned to May**<br>*(23 days in May within the billing period)* | =23 days x 1.082 CCF/day | **24.89** | **CCF** |

This process is then applied to all bills within the audit period to apportion all consumption by month, as outlined in Table 70. Consumption within a bill period is averaged to determine daily consumption, and then consumption is apportioned to each month by multiplying the daily average by the number of days in the month. Apportioning consumption by calendar month improves the correlation between System Input Volume and consumption.

Table 70: Example for Apportioning Audit Period Consumption by Calendar Month

| PREVIOUS READ DATE | READ DATE | USAGE | JAN 2014 | FEB 2014 | MAR 2014 | APR 2014 | MAY 2014 | JUN 2014 | JUL 2014 | AUG 2014 | SEPT 2014 | OCT 2014 | NOV 2014 | DEC 2014 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22-Nov-13 | 24-Jan-14 | 25 | 10 | | | | | | | | | | | | **10** |
| 24-Jan-14 | 23-Mar-14 | 33 | 4 | 16 | 13 | | | | | | | | | | **33** |
| 23-Mar-14 | 23-May-14 | 66 | | | 9 | 32 | 25 | | | | | | | | **66** |
| 23-May-14 | 24-Jul-14 | 92 | | | | | 12 | 45 | 36 | | | | | | **92** |
| 24-Jul-14 | 24-Sept-14 | 75 | | | | | | | 8 | 38 | 29 | | | | **75** |
| 24-Sept-14 | 26-Nov-14 | 48 | | | | | | | | | 5 | 24 | 20 | | **48** |
| 26-Nov-14 | 23-Jan-15 | 16 | | | | | | | | | | | 1 | 9 | **10** |
| **TOTAL** | | **355** | **14** | **16** | **22** | **32** | **37** | **45** | **44** | **38** | **34** | **24** | **21** | **9** | **333** |

# APPENDIX F: SMALL METER FLOW PROFILING

Consumption trends particular to a utility's consumer base can be paired with meter accuracy tests to improve Apparent Loss calculations. Logging and evaluating high-frequency consumption data for small customer meters allows for better test result weighting by tailoring the volume recorded in each flow range to a utility's unique consumption profile.

The East Bay Municipal Utility District (EBMUD – Oakland) is in the process of documenting their particular consumption trends in order to more exactly calculate volume-based accuracy. To accomplish this, flow rate data was logged at one-minute intervals for 117 meters over the course of 12 days. The total consumption registered at each flow range was tabulated for each meter, allowing for an understanding of what percentage of consumption occurs in each flow range. Table 71 shows the results of this study, outlining the percentage of consumption recorded in each of the three different flow ranges. It is important to note that this study is still in its early stages. EBMUD plans to investigate additional seasonal demand patterns and increase the testing sample size to achieve statistical significance.

Table 71: EBMUD Preliminary Study Results - Consumption Distribution by Flow Range

| FLOW RATE RANGE | % OF VOLUME RECORDED – EBMUD SAMPLE | % OF VOLUME RECORDED – AWWA STANDARD |
|---|---|---|
| ≤ 1 GPM (AWWA Low Flow Rate Range) | 13% | 1% |
| 1 > GPM ≤ 10 (AWWA Medium Flow Rate Range) | 57% | 38% |
| > 10 GPM (AWWA High Flow Rate Range) | 30% | 61% |

Comparing these results to the volume-based weighting outlined in Table 71 (which uses the AWWA recommended time distribution to calculate a volume weighting of approximately 1% at low flow, 38% at medium flow, and at 61% high flow), much more volume occurs at medium and low flow rates for EBMUD than the AWWA guidelines would suggest.

As these weighting factors are particular to EBMUD's consumption patterns, WSO recommends that Santa Cruz pursue a similar study by logging flow rate data at high-frequency intervals to understand the distribution of consumption by flow rate for small-meter customers. This will enhance the analysis of any further small meter tests, allowing the application of volume weighting factors that reflect Santa Cruz's specific consumption trends.

# APPENDIX G: LARGE METER FLOW PROFILING

## G.1 Example of Meter Profiling: TRO Avenue of the Arts LP

This appendix contains an example of a large meter consumption profiling analysis completed for the Philadelphia Water Department.

The meter examined at the TRO Avenue of the Arts LP is a 3-inch Badger Recordall Turbine. On Tuesday, January 24, 2012, a meter-master unit and a data logger were installed for consumption profile logging at 20-second intervals (see Figure 37).

Figure 37: Meter-Master Installation and Data Logger – TRO Ave of the Arts

Table 72 provides information about the TRO Ave of the Arts meter and the results of the consumption profiling conducted over the course of a week in January.

Table 72: TRO Avenue of the Arts LP – Consumption Profiling Results

| | |
|---|---|
| **Address** | 1340 Chestnut St, 19107 (Art Institute of Philadelphia Building) |
| **Billing Account Number** | XXXXXXXXXXXXXXXXXXXXXX |
| **Avg. Monthly Consumption** | 4,697 HCF |
| **Meter Size** | 3 inches |
| **Meter Number** | 0750833 |
| **Meter Type** | Badger Recordall Turbine |
| **Start Logging** | January 24, 2012 – 03:31 pm |
| **End Logging** | January 31, 2012 – 11:52 am |
| **Total Volume Passed** | 96,513 cubic feet (721,922 gallons) |
| **Average Flow Rate** | 73.2 gpm |
| **Maximum Flow Rate** | 138 gpm |
| **Minimum Flow Rate** | 0.00 gpm |

Figure 38 depicts the consumption profile (1-min average) for the first two days of the meter profile logging between January 24 and January 26 for the TRO Ave for the Arts.

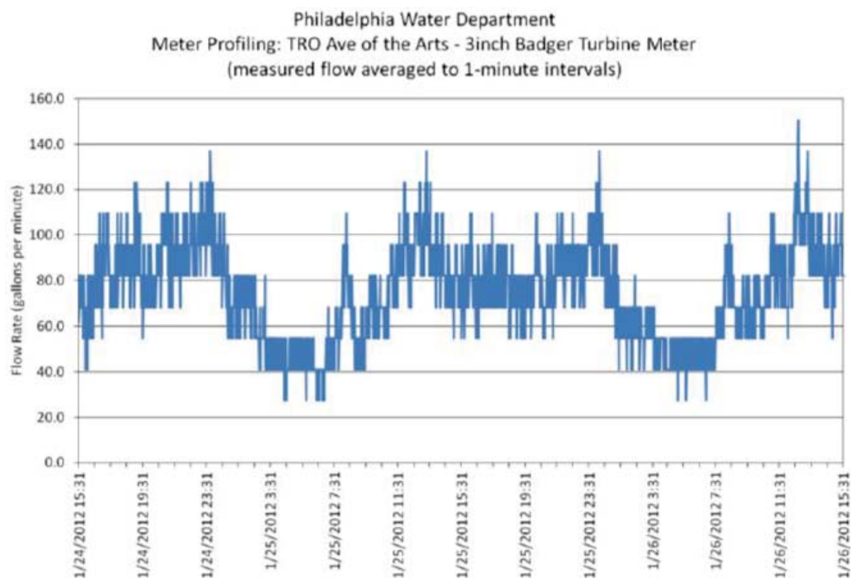



Figure 38: One Minute Average Consumption Volumes at TRO Ave of the Arts

Figure 39 depicts the consumption profile (15-min average) that was recorded between January 24 and January 31 for the TRO Ave of the Arts.

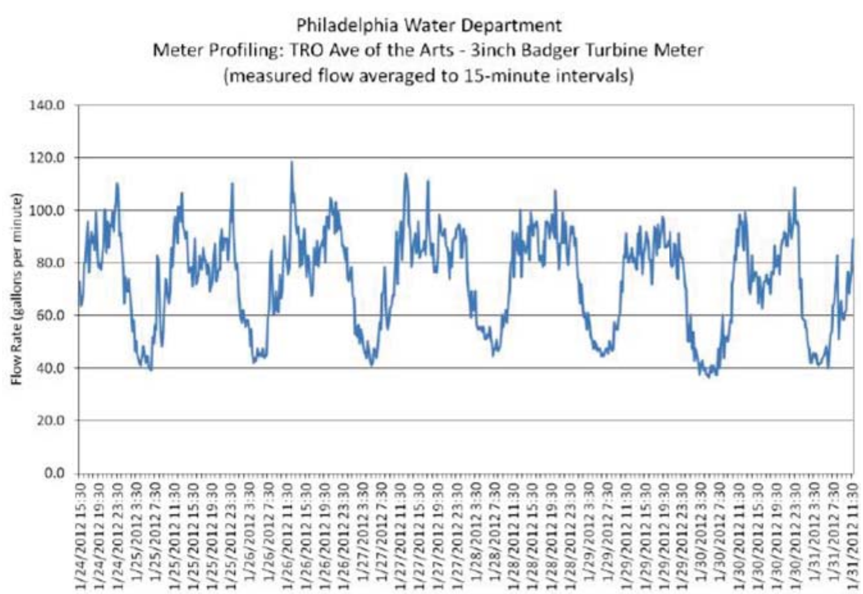



Figure 39: 15 Minute Average Consumption Volumes at TRO Ave of the Arts

Figure 40 depicts the consumption profile (1-hour average) that was recorded between January 24 and January 31 for the TRO Ave of the Arts.

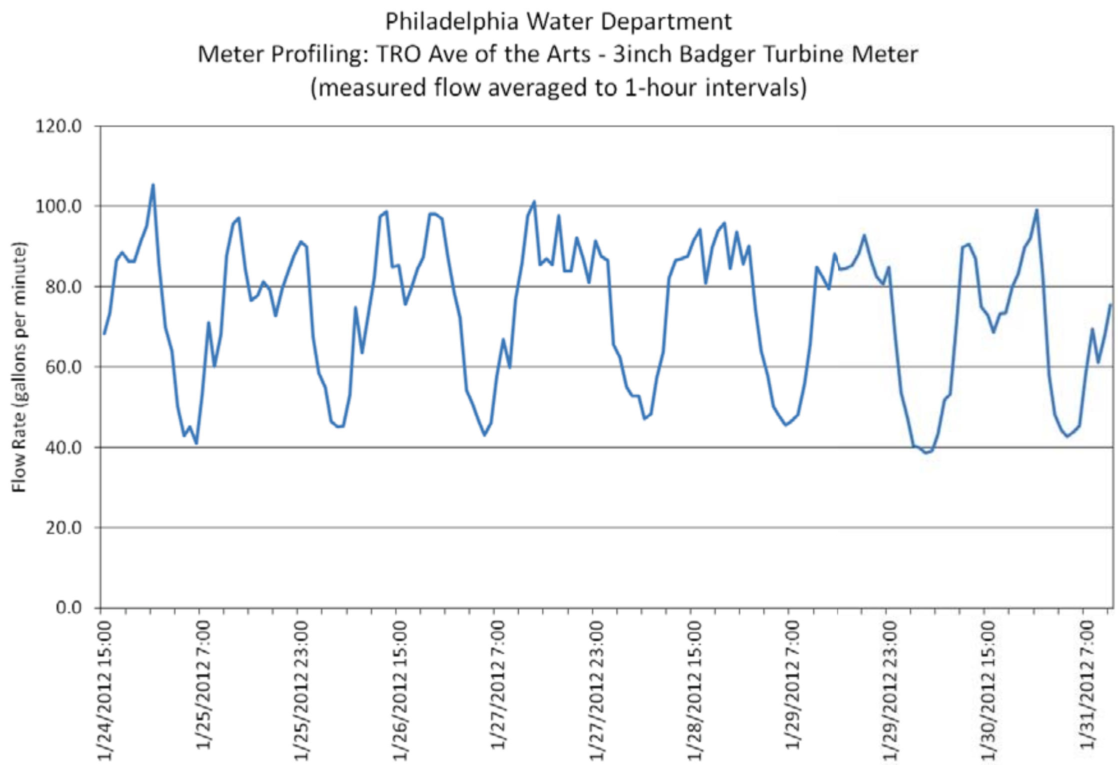



Figure 40: One Hour Average Consumption Volumes at TRO Ave of the Arts

The recommended flow range for a 3-inch Badger Recordall Turbine meter is between 5 gpm and 550 gpm (normal flow limits), and the recommended low flow limit is 4 gpm for this size meter. The data recorded indicates that the TRO Ave of the Arts meter is operating within the recommended flow range. The recorded data indicates that there is constant demand within the lower bounds of the recommended flow range for this site. This suggests that a measurement range from 5 gpm to 550 gpm is not completely necessary. A single-jet meter with high accuracy at lower flow rates would be a more appropriate choice for this location.

## G.2 Portion of Time Spent at Different Flow Rates

The flow data recorded provides the opportunity to analyze how much time the current meter is operating at various flow rates. The analysis looked at how often the flow is zero, how often the flow is below the normal flow rate (less than 5 gpm), how often the meter is operating within the normal flow range (5 gpm to 550 gpm), and how often flow rates greater than the maximum recommended flow rate (550 gpm) occur. The accuracy of a meter is higher when operating in the recommended flow range than when operating outside of the recommended flow range.

Next an analysis was performed to determine how often an alternative meter, in this case a 3-inch Actaris single-jet meter, would operate at zero flow, operate below its recommended flow rate (lower than 2.5 gpm) and operate within its recommended flow range (2.5 gpm to 320 gpm).

Figure 41 shows the results of this flow range analysis when applied to the 1-minute average data. It indicates that none of the minute-averaged recorded flows are 0.0 gpm. This analysis also indicates that for both meter types, 100% of recorded flows fall within the meters' recommended normal flow ranges (see Table 72). However, the quoted accuracy (±0.5%) of the Actaris meter is higher within the recommended flow range than the quoted accuracy (±1.5%) of the current meter. Figure 42 depicts the portion of time the current meter spends at various flow rates between zero and 200 gpm, excluding the times zero flow rate was recorded. About 26% of the flow rates recorded were either zero or between 80 gpm and 85 gpm. No flows were recorded above either of the meters' operating ranges.

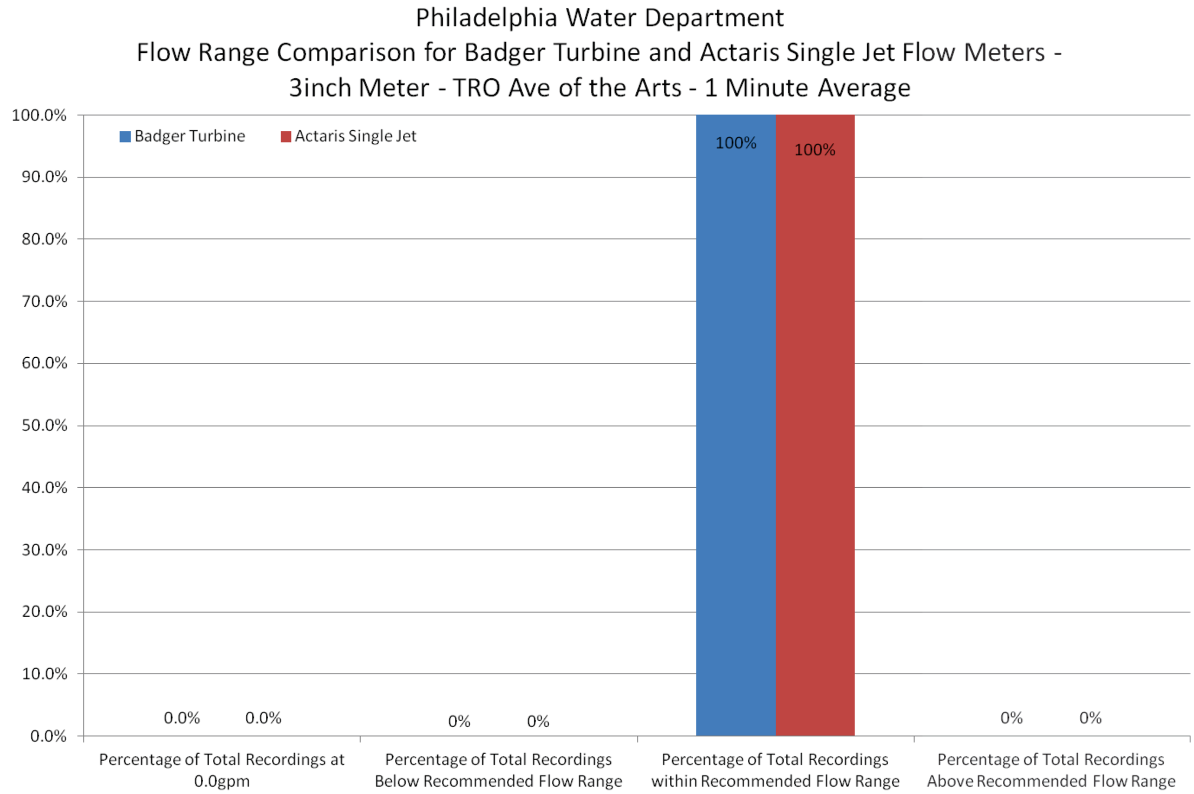



Figure 41: Flow Range Comparison of Current and Alternative Meter – TRO Ave of the Arts

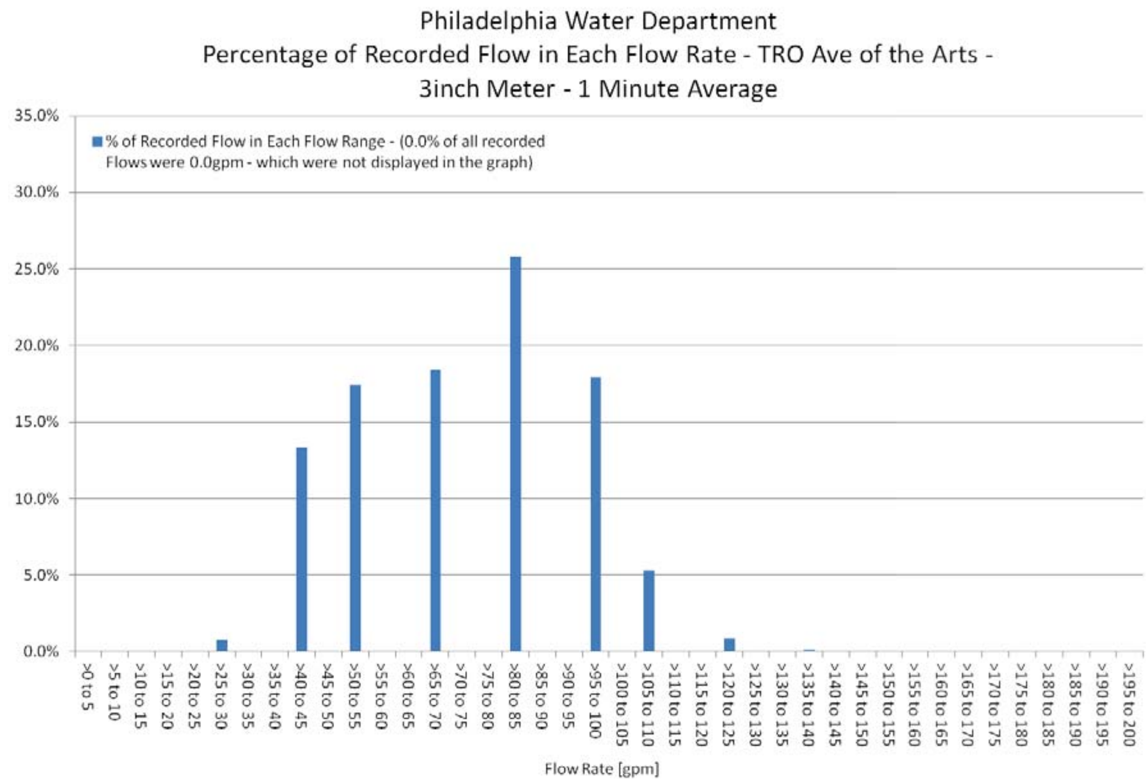



Figure 42: Percentage of Recorded Flow in Each Flow Range – TRO Ave of the Arts

## G.3 Apparent Loss Analysis

Next the recorded data was analyzed to calculate how much volume the current flow meter (Badger Recordall Turbine) recorded at the three strategic flow ranges (below recommended flow range, within recommended flow range, above recommended flow range). Applying the manufacturer's quoted accuracy at these flow ranges allows for calculation of the associated volume of apparent losses (see Table 73). The same approach was used to calculate the theoretical apparent loss volume attributable to an alternative meter (Actaris Single Jet).

Table 73: TRO Ave of the Arts – Apparent Loss Analysis – Current Meter and Alternative Meter

| | **TOTAL VOLUME REGISTERED** | **721,921.48** | **gal** |
|---|---|---|---|
| Actaris | Total Volume Registered Below Normal Flow Range - < 2.5 gpm | - | gal |
| Actaris | Total Volume Registered at Normal Flow Ranges > 2.5 gpm < 320 gpm | 721,921.48 | gal |
| Actaris | Total Volume Registered Above Normal Flow Ranges > 320 gpm | - | gal |
| Badger | Total Volume Registered Below Normal Flow Range - < 5.0 gpm | - | gal |
| Badger | Total Volume Registered at Normal Flow Ranges > 5 gpm < 550 gpm | 721,921.48 | gal |
| Badger | Total Volume Registered Above Normal Flow Ranges > 550 gpm | - | gal |
| | **TOTAL APPARENT LOSS VOLUME (based on manufacturers' accuracy)** | | |
| Actaris | < 2.5 gpm | - | gal |
| Actaris | > 2.5 gpm < 320 gpm | 3,627.75 | gal |
| Actaris | > 320 gpm | - | gal |
| Badger | < 5 gpm | - | gal |
| Badger | > 5 gpm < 550 gpm | 10,993.73 | gal |
| Badger | > 550 gpm | - | gal |

Historical billing data provided by PWD was used to determine the potential annual apparent loss volume for the currently installed meter and an Actaris Single Jet flow meter (see Figure 43).

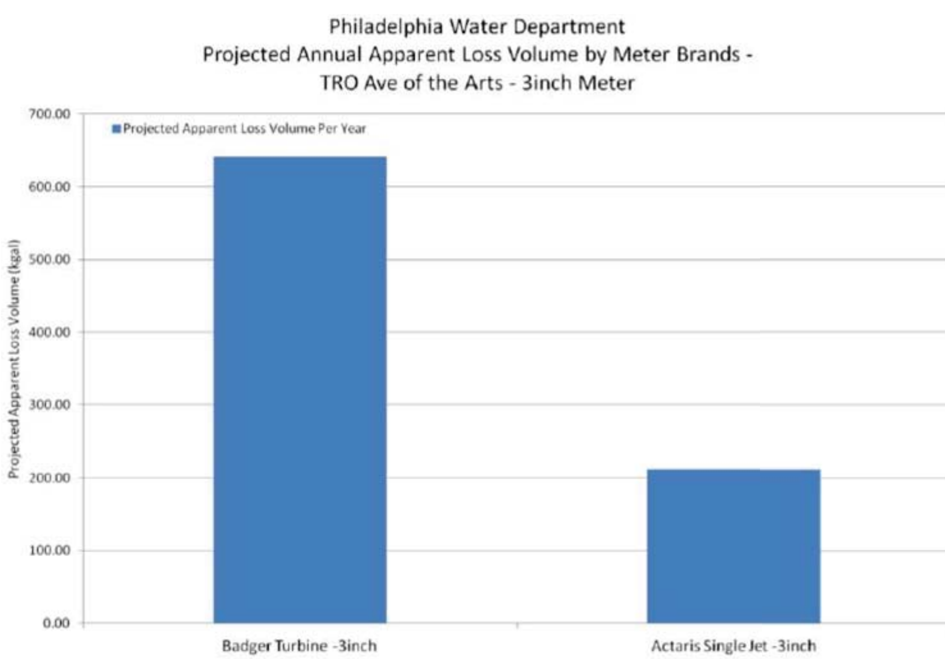



Figure 43: Projected Annual Apparent Loss Volume – TRO Ave of the Arts

Figure 43 demonstrates that the alternate meter (Actaris Single Jet) would reduce the annual volume of apparent losses by about 67%.

## G.4 Cost-Benefit Analysis of Meter Replacement

The costs and benefits of replacing the current meter with an alternate meter were assessed by applying the PWD volumetric charges for water consumption to the calculated volume of apparent losses (see Table 74). At the time of analysis, the PWD volumetric charge for water consumption was approximately $6.08/kgal.

Table 74: TRO Avenue of the Arts LP – Projected Savings through Meter Replacement

| Projected Annual Savings | Volume (kgal/year) | Monetary($/year) |
|---|---|---|
| Badger Total Apparent Losses | 641.88 | $3,900.79 |
| Actaris Total Apparent Losses | 211.81 | $1,287.20 |
| Savings from switching from Badger to Actaris | 430.07 | $2,613.60 |
| Cost of Meter Replacement | | $2,013.76 |
| Resulting Payback Period | | 0.77 years |

The analysis indicates that the volume of apparent losses could be reduced by about 430 kgal/year by replacing the current meter (Badger Recordall Turbine) with an alternate meter (Actaris Single Jet). Based on the current water rate structure in PWD, the reduction in apparent losses would yield an increase in revenue for PWD of about $2,614.

The cost to purchase and install a new 3-inch Actaris meter is $2,013.76. Based upon the monetary value of the apparent loss reduction, this investment would have a payback period of about 0.77 years.

# Appendix H: Apparent Loss and Meter Replacement

Meter test results, test result analysis, Apparent Loss determination, and economics of meter replacement are provided in the Excel spreadsheet titled "Appendix H – Apparent Loss and Meter Replacement.xlsx."

# APPENDIX I: METER TEST RESULTS TRACKING TEMPLATE

A template that Santa Cruz can use to analyze and track test results is provided in the Excel spreadsheet titled "Appendix I – Meter Test Results Tracking Template.xlsx" The first row of the spreadsheet indicates which columns Santa Cruz should enter test results into and which columns provided calculated outputs.

# APPENDIX J: LARGE METER TEST SCHEDULE

The calculations and results of a large meter test schedule analysis are provided in the Excel spreadsheet titled "Appendix J – Large Meter Test Schedule.xlsx." The spreadsheet allows Santa Cruz to test modeling parameters like cost of replacement and rate of deterioration to identify ideal frequency for large meter maintenance.

WSO's preliminary modeling identified 22 meters that Santa Cruz should test to ascertain whether meter maintenance would cost-effectively increase revenue generation. These meters are listed in Table 75. The modeled replacement frequency should be used to prioritize meters for testing, but without additional information about meter accuracy and rate of decline, this number should not be used to actually schedule meter replacement.

Table 75: Key Large Meters to Test

| METER SERIAL | METER SIZE (INCHES) | ACCOUNT TYPE | MODELED REPLACEMENT FREQUENCY (MONTHS) |
|---|---|---|---|
| 71374146 | 3 | indust | 16 |
| 72304472 | 3 | indust | 16 |
| 73131861 | 3 | b-gen | 16 |
| 45843 | 6 | ir-glf | 20 |
| 51616917 | 4 | ir-glf | 21 |
| 63055342 | 10 | ucsc | 21 |
| 51540988 | 4 | b-gen | 22 |
| 1272515 | 10 | ucsc | 22 |
| 68810455 | 4 | ucsc | 23 |
| 74379263 | 4 | ir-glf | 23 |
| 68810453 | 4 | ucsc | 23 |
| 71134912 | 3 | res-mf | 24 |
| 71134913 | 3 | res-mf | 24 |
| 70499107 | 6 | ucsc | 24 |
| 74053985 | 4 | ir-glf | 28 |
| 70045105 | 3 | b-gen | 30 |
| 66435080 | 4 | res-mf | 31 |
| 70398101 | 4 | res-mf | 33 |
| 31263306 | 6 | ucsc | 33 |
| 67250644 | 6 | res-mf | 34 |
| 73204455 | 4 | res-mf | 35 |
| 72304474 | 3 | b-hotl | 36 |

# APPENDIX K: DATA VALIDITY SCORING

***Overall Data Validity Score*: 74**

*Weighted sum normalized to 100*

| DATA INPUT | SCORE | DEFINITION PERTAINING TO SCORE | RATIONALE FOR SCORE |
|---|---|---|---|
| Volume from Own Sources | 7 | Conditions between 6 and 8.<br><br>*Definition for a score of 6:*<br>At least 75% of treated water production sources are metered, or at least 90% of the source flow is derived from metered sources**. Meter accuracy testing and/or electronic calibration of related instrumentation is conducted annually**. Less than 25% of tested meters are found outside of +/- 6% accuracy. | Santa Cruz treats surface water at the Graham Hill Water Treatment Plant and treats well water produced at the Beltz Wells and Beltz Well 12. GHWTP production is calculated using influent meter reads and correcting for the treatment process, as Santa Cruz does not yet have a reliable effluent meter installed.<br>Santa Cruz has initiated a program of influent meter volumetric testing at GHWTP. No testing is yet performed at Beltz treatment sites.<br>For Santa Cruz to achieve a score of 8, *all* key Water Suppled meters (GHWTP and Beltz) will need to be volumetrically tested and calibrated annually. |
| Volume from Own Sources – Master Meter Error Adjustment | 7 | Condtions between 6 and 8.<br><br>*Definition for score of 6:*<br>**Hourly production meter data logged automatically & reviewed on at least a weekly basis**. Data is adjusted to correct gross error when meter/instrumentation equipment malfunction is detected; and/or error is confirmed by meter accuracy testing. Tank/storage facility elevation changes are automatically used in calculating a balanced "Volume from own sources" component, and data gaps in the archived data are corrected on at least a weekly basis. | Santa Cruz maintains a SCADA system that continuously monitors and records water treatment processes. However, the SCADA system archival function occasionally introduces gaps and null values in recorded data. Data is reviewed on at least a weekly basis for consistency and accuracy. The change in storage has been incorporated in the calculation of Volume from Own Sources.<br>For Santa Cruz to achieve a score of 8, all production data will have to be reviewed daily to identify discrepancies and gaps and correct for errors where possible. |
| Water Imported | - | | Santa Cruz does not import any water. |
| Water Imported – Master Meter Error Adjustment | - | | Santa Cruz does not import any water. |
| Water Exported | - | | Santa Cruz does not export any water. |

| DATA INPUT | SCORE | DEFINITION PERTAINING TO SCORE | RATIONALE FOR SCORE |
|---|---|---|---|
| Water Exported – Master Meter Error Adjustment | - | | Santa Cruz does not export any water. |
| Billed Metered Authorized Consumption | 7 | Conditions between 6 and 8.<br><br>*Definition for a score of 6:*<br>At least 90% of customers with volume-based billing from meter reads; consumption for remaining accounts is estimated. Manual customer meter reading gives at least 80% customer meter reading success rate; consumption for accounts with failed reads is estimated. Good customer meter records exist, **but only limited meter accuracy testing is conducted. Regular replacement is conducted for the oldest meters.** Computerized billing records exist with annual auditing of summary statistics conducted by utility personnel. | 100% of billed customers are metered, and meters are read manually. Bills are generated and tracked through a computerized system. Good customer meter records exist, but limited customer meter accuracy testing has been conducted in recent years. Meters are replaced on an age-based schedule, though replacement has been limited because older meters still appear to perform well.<br>For Santa Cruz to qualify for a score of 8, an annual customer meter testing program should be initiated to examine both small meters and large meters. |
| Billed Unmetered Authorized Consumption | 10 | Water utility policy does require metering and volume based billing for all customer accounts. **Less than 2% of billed accounts are unmetered and exist because meter installation is hindered by unusual circumstances**. The goal exists to minimize the number of unmetered accounts to the extent that is economical. **Reliable estimates of consumption are obtained at these accounts via site specific estimation methods**. | Santa Cruz requires that all customers are metered. Only city operations, like street sweeping and sewer flushing, are billed but unmetered. Estimates of use are obtained using truck volumes and number of fills, and tracking processes are rigorous and complete. |
| Unbilled Metered Authorized Consumption | 9 | Conditions between 8 and 10.<br><br>*Definition for a score of 8:*<br>Written policy identifies the types of accounts granted a billing exemption. Customer meter management and meter reading are considered secondary priorities, but **meter reading is conducted at least annually to obtain consumption volumes for the annual water audit**. High level auditing of billing records ensures that a reliable census of such accounts exists. | Unbilled Metered Authorized Consumption consists of water used for six purposes: Graham Hill Water Treatment Plant, North Coast Recirculation Station, water main replacement and extension, corporation yard fire service (all hydrant uses, including fire service training), street tree watering, and legacy "404" unbilled potable water accounts. All uses are metered, and meter reading is conducted annually to track use. However, the accuracy of UMAC meters has not been studied.<br>For Santa Cruz to qualify for a score of 10, UMAC meters should be volumetrically tested to ascertain their accuracy. |

| DATA INPUT | SCORE | DEFINITION PERTAINING TO SCORE | RATIONALE FOR SCORE |
|---|---|---|---|
| Unbilled Unmetered Authorized Consumption | 8 | **Clear policies and good recordkeeping exist for some uses** (ex: water used in periodic testing of unmetered fire connections), but other uses (ex: miscellaneous uses of fire hydrants) have limited oversight. Total consumption is a mix of well quantified use such as from formulae (time running multiplied by typical flow, multiplied by number of events) or temporary meters, and relatively subjective estimates of less regulated use. | Santa Cruz considers five operational uses of water to be Unbilled Unmetered Authorized Consumption: annual system flushing, repair activity (flushing for service connections breaks, main breaks, etc.), tank maintenance, City of Santa Cruz unmetered fire department use (both fire suppression and training), and Central Fire District use (both fire suppression and training). Per-event records of use are well-maintained, but not all events are captured in these records, particularly as related to fire district use.<br>For Santa Cruz to qualify for a score of 10, fire-fighting use should be estimated, and a census of UUAC uses and tracking mechanisms should be performed. |
| Unauthorized Consumption | 5 | Default value of 0.25% of volume of Water Supplied is employed. | In the absence of records of Unauthorized Consumption, WSO chose to use the default value of 0.25% of the volume of Water Supplied. |
| Customer Metering Inaccuracies | 5 | Conditions between 4 and 6.<br><br>*Definition for a score of 4:*<br>Reliable recordkeeping exists; meter information is improving as meters are replaced. **Meter accuracy testing is conducted annually for a small number of meters** (more than just customer requests, but less than 1% of inventory). A limited number of the oldest meters are replaced each year. Inaccuracy volume is largely an estimate, but refined based upon limited testing data. | Santa Cruz tested a sample of 5/8" meters in 2014, but the meter tests primarily investigated the accuracy of older meters and therefore was not truly representative of the 5/8" meter population. Additional large meter tests were also performed in 2016 to better inform the Apparent Loss calculation.<br>For Santa Cruz to qualify for a score of 6, meter testing should become a routine practice and should representatively investigate the accuracy of the entire meter stock. |

| DATA INPUT | SCORE | DEFINITION PERTAINING TO SCORE | RATIONALE FOR SCORE |
|---|---|---|---|
| Systematic Data Handling Errors | 7 | Conditions between 6 and 8.<br><br>*Definition for a score of 6:*<br>Policy and procedures for new account activation and oversight of billing operations is adequate and reviewed periodically. **Computerized billing system is in use with basic reporting available**. Any effect of billing adjustments on measured consumption volumes is well understood. **Internal checks of billing data error conducted annually**. Reasonably accurate quantification of consumption volume lost to billing lapses is obtained. | Santa Cruz uses an EDEN billing system with all the necessary functionalities. Santa Cruz investigated accounts with consecutive zero reads for the 2014 water audit, but such an investigation is not yet routine practice. WSO's billing data validation checks did not uncover any billing lapses, though WSO worked only with raw billing data, rahter than billing data at different stages of summary.<br>For Santa Cruz to qualify for a score of 8, the billing process and database must be routinely checked for zero consumption accounts, and a third party audit of the billing process and system must be conducted at least once every five years. Furthermore, consumption lost to billing lapses will need to be well-quantified. |
| Length of Mains | 8 | Sound written policy and procedures exist for permitting and commissioning new water mains. **Electronic recordkeeping such as a Geographical Information System (GIS) and asset management system are used to store and manage data.** | Santa Cruz tracks mains information using GIS. Pipe material and diameter are logged, though no random field validation is performed. Santa Cruz is in the process of connecting GIS asset information to the repair work order system.<br>For Santa Cruz to qualify for a score of 10, asset information recorded in GIS must be periodically and randomly field-validated. |
| Number of Active and Inactive Service Connections | 8 | Policies and procedures for new account activation and overall billing operations are written, well-structured and reviewed at least biannually. **Well-managed computerized information management system exists and routine**, periodic field checks and internal system audits are conducted. Counts of connections are no more than 2% in error. | Service connections are tracked by service class using asset management technology. Inactive connections are included in summary figures.<br>For Santa Cruz to qualify for a score of 10, the count of inactive service connections must be periodically and randomly field-validated. |
| Average Length of Customer Service Line | 10 | **Customer water meters exist outside of customer buildings next to the curb stop** or boundary separating utility/customer responsibility for service connection piping. | Customer meters are located at the curb stop. |

| DATA INPUT | SCORE | DEFINITION PERTAINING TO SCORE | RATIONALE FOR SCORE |
|---|---|---|---|
| Average Operating Pressure | 5 | Conditions between 4 and 6.<br><br>*Definition for a score of 4:*<br>Effective pressure controls separate different pressure zones; moderate pressure variation across the system, occasional open boundary valves are discovered that breech pressure zones. **Basic telemetry monitoring of the distribution system logs pressure data electronically**. Pressure data gathered by gauges or dataloggers at fire hydrants or buildings when low pressure complaints arise, and during fire flow tests and system flushing. Reliable topographical data exists. **Average pressure is calculated using this mix of data.** | Pressure is measured at key pressure regulation points (e.g. pump stations, pressure reducing valves) and weighted by infrastructure counts on a zonal basis.<br>For Santa Cruz to qualify for a score of 6, Santa Cruz must install loggers and monitor pressure at additional representative sites throughout the system, rather than only at pressure zone boundaries. |
| Total Annual Cost of Operating Water System | 10 | **Reliable electronic, industry-standard cost accounting system in place, with all pertinent water system operating costs tracke**d. Data audited at least annually by utility personnel, and at least once every three years by third-party CPA. | Financial data provided is comprehensive and tracked using industry-standard tools. Data is audited annually by a third-party CPA. |
| Customer Retail Unit Cost | 8 | **Effective water rate structure is in force and is applied reliably in billing operations**. Composite customer rate is determined using a weighted average composite consumption rate, which includes residential, commercial, industrial, institutional (CII), and any other distinct customer classes within the water rate structure. | Santa Cruz's customer retail unit cost is a weighted average of all tiers and was calculated by dividing all volumetric revenue received during the audit period by the volume sold.<br>For Santa Cruz to qualify for a score of 10, the rate structure must be reviewed by a third party knowledgable in M36 water auditing methodology at least once every five years. |
| Variable Production Cost | 7 | Conditions between 6 and 8.<br><br>*Definition for a score of 6:*<br>**Reliable electronic, industry-standard cost accounting system in place, with all pertinent water system operating costs tracked**. Pertinent additional costs beyond power, treatment and water imported purchase costs (if applicable) such as liability, residuals management, wear and tear on equipment, impending expansion of supply, are included in the unit variable production cost, as applicable. The data is audited at least annually by utility personnel. | Industry-standard production cost accounting practices and tools are employed. All relevant costs have been incorporated in the variable production cost. However, variable production cost information has not been audited by a third-party knowledgeable in M36 methodology.<br>For Santa Cruz to qualify for a score of 8, a third-party financial auditor familiar with M36 water auditing methodology must annually examine the derivation of variable production cost and account for all relevant primary and secondard variable costs. |

# APPENDIX L: 2014 WATER AUDIT SOFTWARE

Santa Cruz's 2014 AWWA Free Water Audit Software is provided in the attached Excel spreadsheet titled "Appendix L – 2014 Water Audit Software.xlsx."

# APPENDIX M: THE INFRASTRUCTURE LEAKAGE INDEX

## M.1 Background

All systems leak. This fact is acknowledged by the Infrastructure Leakage Index (ILI), a customized performance indicator used to benchmark and compare Real Loss performance. The ILI is calculated by taking the ratio of Current Annual Real Losses (CARL) to Unavoidable Annual Real Losses (UARL). Mathematically, this relationship is:

$$ILI = \frac{CARL}{UARL}$$

where *ILI* is the Infrastructure Leakage Index

*CARL* is the volume of Current Annual Real Losses

*UARL* is the volume of Unavoidable Annual Real Losses

## M.2 CARL and UARL

The CARL is calculated with a top-down water balance. The water balance process accounts for all inputs and outputs to determine Water Losses. CARL is then deduced by subtracting the volume of Apparent Losses from total Water Losses.

The UARL quantifies the theoretical technical minimum level of leakage a system would experience were all modern leakage control technologies employed to the maximum extent. Though not likely to be cost-effective, such a leakage control program is expected to constrain leakage to a minimum volumetric allowance, dependent on asset type. For a system with customer meters located at the curbstop, the minimum leakage allowances by asset type are:

| | |
|---|---|
| *5.41 gal* | per mile of main pipe per PSI of pressure per day |
| *0.15 gal* | per service connection per PSI of pressure per day |

To calculate these minimum allowances, the International Water Association (IWA) performed a component analysis of Real Losses, assuming well-maintained infrastructure in good condition. Assumptions of break frequencies by asset type were derived from international studies of repair statistics. Leak flow rates were determined using standard pressures and industry modeling practices, and leak run times were set using target durations for intensive, best-management leak repair regimes. These inputs resulted in a volume lost to leakage for each asset category. For additional information on the history of the UARL formula and the data behind the minimum leakage allowances, see Lambert & McKenzie (2002).

Given the minimum leakage allowances, the UARL is calculated using the following formula:

$$UARL = (5.41Lm + 0.15Nc) * P$$

| | |
|---|---|
| where | *UARL* is the volume of Unavoidable Annual Real Losses (gal/day) |
| | *Lm* is the length of main pipe (miles) |
| | *Nc* is the number of active and inactive service connections |
| | *P* is the average system operating pressure (PSI) |

In calculating the ILI using the CARL and UARL, it is important to verify that both values are in the same volume and time units. Of note is the fact that the above formula calculates the UARL in gallons per day.

The UARL (and therefore the ILI) has not been approved for use for very small systems. If at least one of the following conditions is not satisfied, then the UARL is deemed inapplicable:

$$P < 35\ PSI$$

OR

$$(Lm * 32) + Nc < 3000$$

## M.3 Interpretation

As previously mentioned, the ILI is the ratio of current leakage to technical minimum leakage. Therefore, ILI calculations should be interpreted as follows:

| | | |
|---|---|---|
| ILI < 1.0 | leakage is less than the technical minimum | *impossible by definition;*<br>*very difficult to achieve in practice* |
| ILI = 1.0 | leakage is equal to the technical minimum | *improbable, rarely cost-effective* |
| ILI > 1.0 | leakage is greater than the technical minimum | *possible, cost-effectiveness depends* |

## M.4 Common Errors and Formula Review

The ILI depends on the UARL formula. When an ILI of less than 1.0 is calculated, it is natural to question the accuracy or applicability of the UARL formula. Industry experts have offered the following thoughts on the calculation of ILIs less than 1.0 (Lambert 2009):

> *At low ILIs, the top-down deduction of CARL (leakage) is likely have a wide margin of error.* The magnitude of the margin of error can be on the order of ±20%, even for fully metered systems.
>
> *Systematic errors in the water balance can result in an under-estimation of Real Losses.* Common errors include ignorance of production meter inaccuracy and over-estimation of authorized metered consumption, especially if lag-time effects are not taken into account.
>
> *The number of service connections or the average operating pressure can be over-estimated*. Over-estimating either figure will increase the technical minimum leakage allowance (UARL), thereby increasing the denominator of the ILI calculation and decreasing the resulting ILI.

After the introduction of the UARL formula in 1999, three separate research studies (Liemberger & McKenzie, 2005; Koelbl et al 2007; WSAA 2008) independently reviewed the UARL formula to determine if the leakage coefficients ought to be changed. All three reviewers concluded that there is no reason to modify the basic UARL coefficients. The ILI remains a useful performance indicators with the UARL equation in its present form. Any benefits from altering the coefficients would be significantly offset by the confusion caused by the introduction of a new UARL equation (Lambert 2009).

## M.5 References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# APPENDIX N: DIGITIZED WORK ORDERS

Santa Cruz provided work order froms 2014 in scanned PDFs. To be able to tabulate the data captured in the work orders and accompanying handwritten notes, WSO digitized the PDFs. The digitized work orders are provided in the Excel spreadsheet titled "Appendix N – Digitized Work Order.xlsx" for Santa Cruz's use.

# APPENDIX O: 2014 COMPONENT ANALYSIS SOFTWARE

Santa Cruz's 2014 Component Analysis software model is provided the attached Excel spreadsheet titled "Appendix O – 2014 Component Analysis Software.xlsx."

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WATER COMMISSION
INFORMATION REPORT

DATE: 9/8/16

AGENDA OF: September 12, 2016

TO: Water Commission

FROM: Heidi Luckenbach, Deputy Director/Engineering Manager

SUBJECT: Water Supply Augmentation Strategy, Quarterly Work Plan Update

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RECOMMENDATION: Receive information regarding the status of the various components of the Water Supply Augmentation Strategy and provide feedback.

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BACKGROUND: As per the Final Agreements and Recommendations of the Water Supply Advisory Committee (WSAC), the Water Commission shall receive quarterly updates on the status of the various elements of the recommended plan. This is the third quarterly update.

Elements of the Water Supply Augmentation Strategy (WSAS) include In Lieu water transfers with neighboring agencies, Aquifer Storage and Recovery, Recycled Water, and Seawater Desalination. Demand management, via implementation of the Long Term Water Conservation Master Plan, is foundational to the WSAS. The following report provides an update on the various efforts recommended by the Water Supply Advisory Committee (WSAC), accepted by the City Council in late 2015 and recently incorporated into the approved 2015 Urban Water Management Plan as directed by the Council.

DISCUSSION: The Water Department's current Capital Improvement Plan (CIP) is included as Attachment A to show the elements of the WSAS recommendations within the context of the other CIP projects. Progress and status of the various WSAS-related work is described in detail below as well as that of other projects related to but not specifically articulated in the WSAS.

**Demand Management (Conservation and Urban Water Management Plan)**

The top priorities of the Water Conservation Section over the last three months (with valuable assistance from other sections of the Water Department) included the following:

- Completing the 2015 Urban Water Management Plan
- Assisting with the Water Rate Study and Development of Budget Based Irrigation Rates
- Completing the Water Loss Control project

The City Council held a public hearing on the updated plan on August 9, 2016, and adopted the 2015 Urban Water Management Plan (UWMP), as modified by input from the Water Commission, on August 23, 2016. In accordance with the City Council resolution adopting the plan, the Water Supply Advisory Committee's Final Report on Agreements and Recommendations was adopted in its entirety by reference as an element of the City's 2015 UWMP, effectively setting the direction and the process that the City intends to follow to improve its water supply reliability by 2025.

Like the WSAC Final Report on Agreements and Recommendations, the Water Conservation Master Plan was also adopted by reference as part of the UWMP. It now formally sets the direction and integrates demand side programs as envisioned in the WSAC Report. There are two small administrative tasks remaining before the plan will be submitted to the CA Department of Water Resources in about one week.

Development of budget based irrigation rates (No. 3 of 35 programs) has entailed mapping of an additional 128 sites, which is complete. Currently, staff is working with the account holders at these sites to confirm the amount of the irrigated area at each property. Staff is also working with IT to test the new rates on the Utility Billing System. The new rates will take full effect with the November bills and will require a sustained effort by staff until that time. See Attachment B for an excerpt from the final Water Rate study describing the budget based rate structure and for an example of how the rate would apply to a dedicated irrigation account at a typical homeowner association.

Results of the Water Loss Control project (No. 1) will be presented as a separate item at the September 12, 2016, Water Commission meeting.

Finally, staff is pleased to report the recent hiring of a new Environmental Projects Analyst to fill a vacant position. This position will assist with program development, analysis, and ongoing administration.

**In Lieu Water Transfers**

On August 1, 2016, the agreement between the City and Soquel Creek Water District (SqCWD) was finalized. The agreement (provided in Attachment C) outlines the general provisions for transferring water from the City to the SqCWD from the City's Majors Creek and Liddell Springs sources. The goals of this resource management pilot program include collecting information on any physical constraints or limitations, gathering water quality data, and monitoring any response on the groundwater basin to reduced pumping. Several items need to be completed or resolved prior to starting the pilot program.

- System Flushing: It is common practice for agencies to have flushing programs to ensure distribution system water quality standards are maintained. This can be particularly important for agencies seeking to modify standard operating procedures such as the addition of a new water source. Many flushing programs have been stalled due to the past several years of drought. SqCWD is in the process of flushing their distribution system and is setting a target of ~50% of the system that would be receiving the city's surface water; the current status is 7%.
- Operation Plan: The City and District are working together to develop an operations plan that will spell out in more detail the day to day operations of the connection(s). The draft is currently being review by SqCWD staff. The document itself is akin to any Standard Operating Procedure and directs the reader to existing groundwater monitoring plans each agency already has in place for measuring any effects on the basin. It should be noted that this pilot study will likely reveal more about the operational constraints and

any water quality issues rather than produce significant findings on any response in the basin to reduced pumping. Basin recovery will require significantly more effort in terms of volumes of water transferred, the amount of pumping reduced, and duration of the project.

- Water Quality Testing: Given the recent media coverage of water quality issues potentially related to blending of water sources, both agencies are proceeding cautiously to ensure public health and water quality standards are not compromised. The City has implemented a water quality sampling study in its Beltz service area to assess any impacts on water quality of switching between surface and groundwater; a practice implemented for decades in the city service area. Two locations are being sampled, one at 30th and Scriver, and a second at 35th and Portola. Three sets of data have been collected: 5/23/2016 - pre Beltz WTP start up; 6/08/2016 – post Beltz WTP start up; 8/31/2016 – post Beltz WTP start up. There is not enough data as of yet to draw any conclusions.

  In addition, the agencies are working together to perform bench or pilot scale pipe loop testing to further evaluate any potential impacts of this project.

- Permit: To receive water from a new source the District must apply for a modified or amended permit from the State Division of Drinking Water. The District is working on this and the City is providing support as needed.

As stated in the agreement, the pilot study ends on December 31, 2020. In the meantime, any longer term water transfer or exchange project(s) with SqCWD, as well as other neighboring agencies, are being further evaluated.

While recent efforts related to the water purchase agreement have been focused on the District receiving water from the City, on August 30th, staff from both agencies completed a pump test to verify the intertie is able to support 1,000+gpm in both directions. The intertie will be used in the near future to provide the City 1,000 gpm while the Loch Lomond Reservoir is taken offline for maintenance along the pipeline.

**Aquifer Storage and Recovery (ASR) – Phase I Work**

*Status*

- Consultant: Pueblo Water Resources
- Contract Signed: February 2016
- Project Partners: NA
- Engaged Stakeholders: SqCWD, County of Santa Cruz
- Amount Spent: $41,900
- Amount Remaining: $404,500
- Status: On schedule

*Key meetings*

- March 2016: Kick off Meeting with City
- April 2016: Kick off Meeting with Regional Partners (SqCWD, Scotts Valley Water District, County of Santa Cruz)
- June 2016: Clarifying Assumptions Meeting with Staff and Consultants, Part 1

- August 2016: Groundwater Model Coordination Meeting with Kennedy/Jenks
- August 2016: Clarifying Assumptions Meeting with Staff and Consultants, Part 2

Pueblo is currently under contract for Phase 1 of a potentially three phase evaluation process.

- Phase 1 – Paper study/modeling/siting study
- Phase 2 – Pilot study
- Phase 3 – Full Scale Implementation

*Current Tasks (See Attachment D)*

Task 1.1 Existing Well Screening

Work within this task has included the following:

- Request, compilation, and review of existing wells data from all three agencies (i.e., City, SqCWD, and SVWD)
- Development of existing well database
- Development of preliminary existing well ranking criteria
- Preliminary evaluation and ranking of existing wells for Phase 2 pilot testing

This task is approximately 90 % complete. As part of this task, Pueblo will deliver a Technical Memorandum documenting the findings and a recommendation for wells that could be used for pilot testing (one in each service area). Anticipated delivery for the Draft TM is the week of September 12, 2016.

Task 1.2 Site specific injection capacity analyses

After completion of the Existing Well Screening TM, Site-Specific injection capacity analyses will be performed on the recommended wells that are to be used for pilot testing. This task is roughly at 75% complete and has an anticipated DRAFT TM delivery date in the 3$^{rd}$ or 4$^{th}$ week of September.

*Future Items*

Task 1.3 Geochemical Interaction analysis

This task is not scheduled to be completed until Quarter 2 of 2017. Site-specific native groundwater samples will be collected from the wells that have been recommended for pilot testing, along with samples from the GHWTP during the coming diversion/injection season (Nov – Apr). This water quality data, combined with the aquifer mineralogy analyses, will be the inputs to the geochemical interaction model. Work planned or completed under this task includes:

- Completion of a seasonal variability analysis of key parameters
- Currently performing a similar variability analysis based on SLR river flow
- Plan to sample GHWTP this winter/spring
- Plan to sample the 3 existing wells identified in task T1.1
- Plan to submit cuttings samples for mineralogy analysis

Task 1.5 Well Siting Study

The task of performing a Well Siting Study for permanent full-scale ASR wells in each of the three service areas has begun by developing siting criteria and collecting map coverage for both groundwater basis (Santa Margarita and Santa Cruz Mid-County Groundwater Basin/Purisima). Work on this task will accelerate in Quarter 4 of 2016.

*Groundwater Models*

As the Commission is aware, a key component of the ASR study is the completion and use of the groundwater models for the Purisima and the Santa Margarita groundwater basins. The Santa Margarita groundwater model is complete and will be used to understand the potential recharge opportunities in the Santa Margarita primarily beneath the service areas of Scotts Valley Water District and San Lorenzo Valley Water District. The City, in conjunction with Pueblo, is developing a Santa Margarita ASR concept and will work with SVWD and their groundwater modeler to better understand its feasibility.

The Purisima groundwater model continues to be developed by Hydrometrics WRI. There is a Technical Advisory Committee overseeing this work; the TAC had their second meeting on August 24, 2016. The schedule remains on track for completion in fall 2016.

Below is a summary of groundwater modeling alternatives currently being considered for the various agencies beyond the baseline. Overlapping interests will be identified.

| **Requesting Agency** | **Model Runs** |
|---|---|
| MGA | In-lieu recharge/pumping reductions<br>Injection of Advanced Purified Water<br>ASR |
| SqCWD | Injection of Advanced Purified Water with<br>• Climate Change<br>• Particle Tracking |
| City of Santa Cruz | In-lieu Only<br>ASR only<br>In-lieu + ASR<br>IPR |
| County of Santa Cruz | Impact of non-municipal pumping |

*Technical Working Group*

Staff continues to recommend the use of a third-party review team whose job will be to:

- Review and confirm that the scope of work is adequate
- Review, modify, approve the various model scenarios
- Evaluate findings
- Recommend modifications to the study
- Present material in a workshop setting.

While there are ongoing discussions with Hydrometrics, Todd Groundwater (Mike Maley of Todd Groundwater was a key developer of the Santa Margarita groundwater model), and Dr. Andrew Fisher with UCSC, no formal scopes of work or contracts have been established. Recent conversations include finding the nexus of the work being done by SqCWD to understand their groundwater injection project with that of City. This is not a critical path item.

*Issue(s)*

The issue currently being grappled with is establishing a common understanding of what the ASR study needs to be evaluating given the work and assumptions performed for the WSAC and the parallel work being done by SqCWD and SVWD. This item will be discussed further with the Commission at their meeting.

**Recycled Water Feasibility Study (RW)**

*Status*

- Consultant: Kennedy/Jenks Consultants
- Contract Signed: February 2016
- Project Partners: Water and Public Works Departments,
- Engaged Stakeholders: County of Santa Cruz – Water Resources Division, Santa Cruz County Sanitation District, Scotts Valley Water District, Soquel Creek Water District, State of California – SWRCB
- Funding: State of California $75,000; City Public Works, $35,000; Water, remainder
- Amount Spent: $88,625
- Amount Remaining: $397,400
- Schedule: On schedule.

*Key meetings*

- March 2016: Kick off with staff and regional partners (SqCWD, SVWD, County of Santa Cruz) & Driving tour of regional facilities and potential project locations
- June 28, 2016: Alternatives Workshop
- August 29, 2016: Criteria Webinar
- October 2016, Alternatives Webinar Part I
- November 2016: Alternatives Webinar Part II
- December 2016: Scoring and Ranking Workshop
- February 2017: Present Recommended Alternatives

The focus in the last quarter has been to establish a comprehensive list of alternatives to be evaluated and the criteria to be used to evaluate and rank them. Attachment E shows the large list of alternatives established by the project team along with the Basic Guidelines that were used as a preliminary screening tool to narrow the list. Attachment F shows the short list of alternatives and sub-alternatives. Attachment G shows the criteria established by the project team that will be used to short list a few projects that meet the project objectives.

The next steps include two workshops with City staff and stakeholders to ultimately rank the alternatives for final assessment.

*Issue(s)*

Staff is presently addressing the following issues.

1. Coordination of project alternatives. The Water Supply Advisory Committee evaluated a number of recycled water concepts including direct potable (blending highly treated wastewater with surface water prior to treatment at the GHWTP), indirect potable (blending highly treated wastewater with Newell Creek Water in Loch Lomond Reservoir) and groundwater injection for a seawater barrier. The Recycled Water Study

approach was to develop a list of alternatives and corresponding groundwater modeling runs to capture the overall intent of the WSAS recommendation which was to fill a supply gap. Currently, it does not specifically evaluate a seawater barrier as a water supply alternative; however, groundwater modeling of IPR (injection of advanced treated wastewater) and ASR (injection of treated surface water) should reveal if seawater intrusion is an outstanding issue that needs addressing.

2. Competing interests. The study is attempting to address two, sometimes opposing objectives: the evaluation of RW as a supply alternative and the evaluation of RW for any beneficial use. These two concepts have different evaluation criteria; developing robust criteria for both objectives has been challenging.
3. Timing. The City's RW, ASR project and the SqCWD's project are on different timelines. There are a lot of areas of overlap; however, the timing is not always working in favor of sharing data. Staff strives to avoid inefficiencies but this is not always possible.

**Other (Source Water Monitoring, Newell Creek Pipeline Evaluation, Felton Diversion)**

Source Water Monitoring: $170,000 has been allocated in this fiscal year for this program to evaluate, through a robust and comprehensive monitoring plan, the water quality of the city's various sources, focusing on the San Lorenzo River and Newell Creek. This information will be used to inform decisions about future operation of the system including potentially modifying current operating procedures and performing upgrades to the GHWTP. At this time staff has drafted a source water sampling plan and is in the process of selecting a consultant for peer review and data interpretation. Several instruments have been purchased and should be installed by the end of October to measure various water quality parameters at the source and locations that are currently challenging to capture by staff.

Felton Diversion: $225,000 has been allocated in this fiscal year for this program to evaluate the condition of the rubber dam at Felton Diversion and develop a replacement strategy. Staff is meeting with inflatable dam vendors in September. Funds are available in future years for construction.

Embedded in the two projects mentioned above are the evaluation of operating procedures (e.g., the first flush and lake management protocols), condition assessment of the Newell Creek Pipeline, and evaluation of the pumps at Felton Diversion. These are funded in the current CIP.

**Outreach and Communication**

In addition to ongoing monthly reports to the community via email newsletters and media releases, the Department hosted two WSAS-related public events during this reporting period. On August 4, approximately 20 people attended a tour of the Beltz 12 Well and Water Treatment facility to learn about the role of Beltz 12 in our water supply portfolio, and how Beltz 12 can contribute to an ASR project. On August 10, the Department hosted a tour of the Bay Street tanks for approximately 30 people and educated participants on the WSAC recommendations, the lack of untreated water storage, and the role of/need for Bay Street tanks for treated water storage. The Department also participated in the August 31 City Hall To YOU event where we shared information with the public on the WSAC recommendations and the status thereof.

FISCAL IMPACT: None.

PROPOSED MOTION: Accept the report of the Status of the Water Supply Augmentation Strategy, Quarterly Work Plan Update.

ATTACHMENTS:

Attachment A 10 year CIP

Attachment B Rate Study Excerpt

Attachment C City/SqCWD Water Transfer Agreement

Attachment D ASR Tasks and Schedule

Attachment E RW Long List of Alternatives

Attachment F RW Short List of Alternatives

Attachment G RW Ranking Criteria

Attachment A

| City of Santa Cruz 10-Year CIP by Primary Driver | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FY2017 | FY2018 | FY2019 | FY2020 | FY2021 | FY2022 | FY2023 | FY2024 | FY2025 | FY2026 |
| **Rehabilitate or Replace** | | | | | | | | | | |
| Felton Diversion Replacement & Pump Station | | 1,500,000 | 1,500,000 | 1,500,000 | | | | | | |
| Laguna Dam | | | | | | | | | | 500,000 |
| Majors Creek Diversion | | | | | | | | | | 300,000 |
| San Lorenzo River Diversion & Tait Wells | | | | | | | | | | |
| Newell Creek Pipeline Rehabilitation | 1,000,000 | 1,000,000 | 8,000,000 | 8,000,000 | | | | | | |
| Newell Creek Dam I/O Pipeline & Aerators | 2,000,000 | 2,000,000 | 14,000,000 | 12,000,000 | 12,000,000 | | | | | |
| North Coast System Rehab | 4,150,000 | | | | | | | | | 4,000,000 |
| WTP Concrete Tank Evaluation & Replacement | 600,000 | 3,000,000 | 3,000,000 | 3,000,000 | | | | | | |
| WTP Solids Handling | 500,000 | | | | | | | | | |
| Water Main Replacements - City Engineering | 1,395,000 | 1,440,000 | 1,440,000 | 1,440,000 | 1,500,000 | 1,500,000 | 1,500,000 | 1,500,000 | 1,500,000 | 1,500,000 |
| Water Main Replacements - Outside Agency | 250,000 | 250,000 | 250,000 | 250,000 | 250,000 | 250,000 | 250,000 | 250,000 | 250,000 | 250,000 |
| Water Main Replacements - Customer Initiated | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 | 50,000 |
| Water Main Replacements - Distribution | 325,000 | 325,000 | 325,000 | 325,000 | 325,000 | 325,000 | 325,000 | 325,000 | 325,000 | 325,000 |
| Pressure Regulating Stations | 10,000 | 60,000 | 60,000 | 60,000 | | | | | | |
| Recoat University Reservoir No. 4 | 75,000 | 1,300,000 | | | | | | | | |
| Recoat University Reservoir No. 5 | 75,000 | 1,675,000 | | | | | | | | |
| Beltz 11 | 70,000 | 300,000 | | | | | | | | |
| Water Treatment Upgrades | 100,000 | | | | | | | | | |
| **Subtotal** | **10,600,000** | **12,900,000** | **28,625,000** | **26,625,000** | **14,125,000** | **2,125,000** | **2,125,000** | **2,125,000** | **2,125,000** | **6,925,000** |
| **With inflation** | **10,918,000** | **13,685,610** | **31,886,676** | **31,141,725** | **17,347,257** | **2,740,252** | **2,877,265** | **3,021,128** | **3,172,185** | **10,854,470** |
| **Upgrade or Improve** | | | | | | | | | | |
| Advance Metering Infrastructure (AMI) | | | | | 50,000 | 4,000,000 | 4,000,000 | | | |
| Loch Lomond Rec Improvements | | | 165,000 | 1,000,000 | | | | | | |
| Photovoltaic/SolarProjects | | 500,000 | | | | | | | | |
| Water Resources Building | 1,000,000 | | | | | | | | | |
| Security Camera & Building Access Upgrades | 95,000 | | | | | | | | | |
| **Subtotal** | **1,095,000** | **500,000** | **165,000** | **1,000,000** | **50,000** | **4,000,000** | **4,000,000** | **-** | **-** | **-** |
| **With inflation** | **1,127,850** | **530,450** | **183,801** | **1,169,642** | **61,406** | **5,158,122** | **5,416,028** | **-** | **-** | **-** |
| **Water Supply Reliability** | | | | | | | | | | |
| Aquifer Storage & Recovery | | 1,075,000 | 325,000 | 300,000 | | | | | | |
| Recycled Water | | | | | | | | | | |
| Water Supply- WSAS Implementation | | | | 1,200,000 | 7,200,000 | 6,000,000 | 30,000,000 | 30,000,000 | 30,000,000 | |
| Source Water Evaluation & Implementation | 400,000 | 500,000 | 3,000,000 | 3,000,000 | | | | | | |
| **Subtotal** | **400,000** | **1,575,000** | **3,325,000** | **4,500,000** | **7,200,000** | **6,000,000** | **30,000,000** | **30,000,000** | **30,000,000** | **-** |
| **With inflation** | **412,000** | **1,670,918** | **3,703,867** | **5,263,390** | **8,842,495** | **7,737,183** | **40,620,213** | **42,651,224** | **44,783,785** | **-** |

**Table 4-4: Example MFR Tier Range**

| MFR Tiers | Proposed Tier Breakpoint per DU [A] | # of Dwelling Units [B] | MFR Tier Breakpoint [C] (A x B) | MFR Tier Range w/ 3 DU [D] |
|---|---|---|---|---|
| Tier 1 | 5 ccf | 3 | 15 ccf | 0-15 ccf |
| Tier 2 | 7 ccf | 3 | 21 ccf | 16-21 ccf |
| Tier 3 | 9 ccf | 3 | 27 ccf | 22-27 ccf |
| Tier 4 | 10 & above | | 28 & above | 28 & above |

### 4.2.3 Commercial – Uniform Rate Structure

Commercial customers are currently charged a uniform volumetric rate. Based on direction from the Water Department, RFC evaluated implementing an inclining tiered rate structure where tiers varied by meter size. Commercial customers vary considerably in size, use profile and needs, which makes it challenging to place them in a "one size fits all" tiered rate structure. For example, consider the drastically different usage characteristics of a bookstore compared to a coffee shop. RFC presented the results of the analysis over the course of several meetings and it was determined that the inclining tiered rate structure would not be implemented at this time. Therefore, no changes are proposed to the commercial rate structure.

### 4.2.4 Landscape – Budget Based Rate Structure

Landscape customers are currently charged a uniform volumetric rate. However, to more closely align with the pricing objectives of promoting efficiency and conservation, the Water Department would like to move to a water budget rate structure. Table 4-5 shows the current and proposed landscape rate structure.

**Table 4-5: Landscape Rate Structure Adjustments**

| Landscape Tiers | Current Tier Range | Proposed Tier Range |
|---|---|---|
| Tier 1 - Efficient Use | Uniform | 100% of TWB[13] |
| Tier 2 - Inefficient Use | N/A | 101-150% of TWB |
| Tier 3 - Excessive Use | N/A | 151% & above |

RFC recommends implementing a three-tiered water budget rate structure as shown in Table 4-5 and discussed in more detail below.

[13] TWB = Total Water Budget

#### *4.2.4.1 Tier 1 – Efficient Outdoor Use (100% of TWB)*

**Landscape Water Budgets**

The approach the Water Department Staff will use to calculate the landscape water budget is first to set an annual budget that is based on four variables, which are described below:

1. Size of the customer's landscape area,
2. A reference evapotranspiration or ETo value,
3. A crop coefficient, (Kc) and
4. An irrigation efficiency coefficient

Once the annual budget is determined and entered into the EDEN billing system, the monthly budget is calculated in the billing system according to the historical percentage of annual ET occurring each month.

The formula for the Annual Landscape Budget (ccf):

$$\frac{\text{Landscape Area (sqft)} \times \text{ETo (feet)} \times \text{Kc (\%)} \times \frac{1}{\text{Irrigation Efficiency (\%)}}}{100}$$

The basis for quantifying the four variables in this equation is as follows:

**Landscape Area:** The Water Department contracts with Waterfluence, LLC of Menlo Park, CA, to estimate landscape area using satellite imagery. While the maps are as accurate as possible, sometimes changes occur or corrections are needed. Each landscape has a unique size, shape, and composition of plant materials. Accounts with little to no water use (10 ccf per year or less) were not measured and are given a temporary placeholder or dummy value in place of a measured landscape area. These accounts would be monitored annually and measured if consumption rises.

**Reference Evapotranspiration:** Reference evapotranspiration is the depth of water evaporated and transpired from a reference crop (4 to 7-inch tall fescue grass) with an abundant water supply. ETo is the "standard" measure of water needs from which other plant types are compared via the crop coefficient Kc. It is typically based on several factors, including temperature and humidity. ETo varies geographically and seasonally and is lowest in winter and highest in summer. In Santa Cruz, ETo is measured at the CIMIS[14] Station 104 at the De Laveaga golf course, which is maintained by the California Department of Water Resources. The ETo is listed in Table 4-6. Annual ETo in Santa Cruz is 3.05 feet.

[14] California Irrigation Management Information System

**Table 4-6: Reference ETo[15]**

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ETo (ft)** | 0.125 | 0.150 | 0.217 | 0.292 | 0.358 | 0.367 | 0.400 | 0.367 | 0.316 | 0.233 | 0.142 | 0.100 | 3.05 |
| **% of annual** | 4% | 5% | 7% | 10% | 12% | 12% | 13% | 12% | 10% | 8% | 5% | 3% | 100% |

**Crop Coefficient:** Different types of plants require different amounts of water and significantly affect the actual rate of evapotranspiration. Crop coefficients are used to modify the reference ETo rate into specific landscape's water requirements. Cool season turf grass uses about 80% of the local ETo, while shrubs, trees, and groundcover use about 40%. Water features such as pools, ponds, and fountains use 100%. Because it is impractical to track the actual vegetation for each customer, an average crop coefficient for urban landscape is used. For the purposes of this study, the crop coefficient used is 60% which assumes 50% season turf grass and 50% shrubs, trees, and groundcover.

**Irrigation Efficiency:** Irrigation efficiency measures the percent of applied water that is beneficially used by plants. All irrigation systems have some inefficiency as water is lost as runoff, overspray, percolates past the root zone, or is otherwise unevenly distributed. Irrigation efficiency by the type of equipment used and is generally lower for overhead spray sprinklers (65% at best) to low volume drip systems (80% efficient at best). Irrigation efficiency is based on a typical landscape that has a mix of both overhead spray and low volume irrigation systems. For the purposes of this study, the irrigation efficiency was set at 75%.

Since each account has a different billing cycle with different beginning and ending meter read dates, the plan is to always apply the percentage of annual ETo in the month in which the end meter reading is taken. This practice may have the effect of allotting slightly more water than needed in the spring and slightly less water than needed in the fall. In addition, real weather will vary from historic ETo conditions each month. For these reasons, the distribution of ET entered on the billing system may be slightly different to accommodate such variations, and equal more than 100%.

Example: A homeowner's association landscape is 15,000 square feet in size. The annual landscape water budget allotment would be:

$$\frac{15{,}000\ sqft\ \times 3.05\ ft\ \times 0.6\ \times \frac{1}{0.75}}{100} = 366\ ccf$$

Table 4-7 summarizes the monthly landscape water budget for this example account.

[15] Source: Reference ETo Table, California Code of Regulations, Title 23, Div. 2. Chapter 2.7, Appendix A, Santa Cruz

**Table 4-7: Sample Monthly Landscape Water Budget**

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **% of annual** | 4% | 5% | 7% | 10% | 12% | 12% | 13% | 12% | 10% | 8% | 5% | 3% | 100% |
| **Landscape Budget (ccf)** | 15 | 18 | 26 | 37 | 44 | 44 | 48 | 44 | 37 | 29 | 18 | 11 | 371[16] |

#### *4.2.4.2 Tier 2 – Inefficient Use (101-150%)*

Tier 2 is designed to capture inefficient usage. Based on policy direction, Tier 2 is set to capture usage between 101% and 150% of the TWB.

#### *4.2.4.3 Tier 3 – Excessive Use (all usage above 150% of TWB)*

Tier 3 is designed to capture excessive usage. Based on policy direction, Tier 3 is set to all usage over 150% of the TWB.

### *4.2.5 UCSC & North Coast – Uniform Rate Structure*

University of California, Santa Cruz (UCSC) and North Coast customers are currently charged a uniform volumetric rate. No changes in the rate structure are proposed for either customer class. Although both are affected by the switch to more volume based rates.

## 4.3 INSIDE VS. OUTSIDE CUSTOMERS

The Utility services customers both inside city limits and outside city limits. Outside customers cause the Water Department to incur additional costs and therefore should pay a surcharge. For example, department staff must travel farther to reach outside customers for service calls, meter reading, and meter maintenance. In addition, as the analysis below shows, outside customers require more assets per equivalent meter unit than inside customers.

In order to determine the appropriate surcharge to apply to outside customers, the Water Department performed a detailed analysis of the Utilities treated water system and shared assets[17]. The Water Department identified which assets served inside customers and which assets served outside customers.

[16] Does not exactly equal annual water budget due to rounding.
[17] A detailed Asset Listing is on file with the Water Department.

# COOPERATIVE WATER TRANSFER PILOT PROJECT FOR GROUNDWATER RECHARGE AND WATER RESOURCE MANAGEMENT BETWEEN CITY OF SANTA CRUZ AND SOQUEL CREEK WATER DISTRICT

The parties to this Agreement are the CITY OF SANTA CRUZ, hereafter referred to as "CITY", and the SOQUEL CREEK WATER DISTRICT", hereafter referred to as "DISTRICT".

## RECITALS

A. The CITY of Santa Cruz is a charter city which owns and operates a municipal water system in the City of Santa Cruz and in portions of the County of Santa Cruz adjoining the District water system.

B. The DISTRICT is a special district which operates a water system, adjacent to the eastern service boundary of the CITY, and provides water service to a significant portion of mid-Santa Cruz County.

C. A shared groundwater basin that the DISTRICT relies upon for a significant portion of its water supply, and from which the CITY obtains a small portion of its water supply, has been in a state of overdraft since the 1980s and is at risk of additional seawater intrusion.

D. The DISTRICT and the CITY cooperatively manage groundwater in the over-drafted basin and would benefit from this agreement.

E. The CITY and the DISTRICT have established three metered interties located at the DISTRICT's O'Neill Ranch well site, at Jade Street and at Bain Street.

F. During the winter and spring, the CITY may have available surface water from its pre-1914 North Coast water rights that could be treated and delivered to the DISTRICT for purchase.

G. Purchasing and using this treated surface water to meet some part of the DISTRICT's demand would enable the DISTRICT to reduce its groundwater pumping, reduce the potential for accelerating seawater intrusion, and contribute to the beginnings of a longer term process to ameliorate the overdraft condition of the groundwater basin that impacts both entities and other pumpers of groundwater from the Soquel-Aptos basin.

H. The period during which this agreement operates can be viewed as an opportunity to begin to assess the effects of reduced pumping of the basin by the DISTRICT on the shared groundwater basin. During this pilot project, the CITY and the DISTRICT intend to use this opportunity to collect information related to:

   1) the physical operating system issues;
   2) system water quality;
   3) response of groundwater levels from in-lieu recharge; and
   4) the potential opportunity of developing a longer term agreement in which the groundwater basin would be used for a combined in lieu and aquifer storage and recovery program that would help resolve the basin overdraft that would protect CITY and DISTRICT wells from addition seawater intrusion and provide needed drought storage for the CITY.

l. The CITY and DISTRICT recognize that a fair and appropriate agreement can benefit both parties, the community, and provide better management of locally available water resources.

**NOW, THEREFORE, IT IS HEREBY AGREED:**

**1. AGREEMENT TERM:**

Except as provided in Paragraph 11 hereafter, the term of this Agreement shall be for the period commencing at the completion of the CEQA process or November 1, 2015, whichever date is later and ending approximately five years later on December 31, 2020. This Agreement shall not extend beyond said date unless the governing bodies of both the CITY and the DISTRICT so agree in writing.

**2. TERMS AND CONDITIONS FOR PROVIDING WATER:**

Contingent upon the CITY securing all necessary permits and completion of the environmental review process in accordance with Paragraphs 4 and 5 below, water supplied by the CITY will be made available to the DISTRICT for purchase within the scope of the CITY's valid pre-1914 appropriative water rights and changes thereto in compliance with the law. The quantity and availability of water supplied by the CITY under the terms of this agreement shall be based on the following conditions and at the sole discretion of the Director of the Water Department of the CITY. In determining whether supply can be provided, the CITY may take into account any or all of the following factors:

a. The CITY has not declared, and is not operating under, any mandatory water curtailment stage of its 2009 Water Shortage Contingency Plan, as it may be amended, updated, or replaced by the CITY from time to time.[1]
b. Loch Lomond Reservoir is full and is spilling, or if not spilling is projected to be full by April 1 of the water year during which water will be provided to the DISTRICT. The calculation of the potential for the Loch Lomond Reservoir to fill shall be based on the City's short term streamflow modeling tools used to conduct the City's annual water supply forecast, as those tools or other measures to forecast water supply may be amended, updated, or replaced from time to time by CITY.
c. The CITY is providing flow for aquatic resources that meet regulatory requirements, or other requirements agreed to in writing with the fisheries agencies.
d. The City Beltz Wells are off, and not needed to meet daily demand.
e. The planned operation is in compliance with the project as described in the CEQA documents, including the general provision that the water transfer may occur when water is available as described in these terms and conditions between the months of November to April
f. On a monthly basis, the volume of water delivered to the DISTRICT shall be less than or equal to the amount diverted from the CITY's Liddell Springs and/or Majors Creek supplies as reported to the state of California.

[1] Mandatory curtailments begin with Stage 2 of the 2009 plan.

g. The daily volume of water supplied shall not exceed the hydraulic capacity of the interties between the CITY's system and the DISTRICT's system located at the District's O'Neill Ranch well site and at Jade Street and Bain Street. The hydraulic capacity of these interties is estimated to be 1.5 million gallons per day (mgd) during normal operations and up to 2 mgd on an emergency basis, and is a function of the pressure difference between the CITY and DISTRICT water systems at that point.
h. The CITY has not determined, in its discretion, that the supply of water to DISTRICT must be suspended or discontinued due to unusual or unanticipated circumstances, which suspension or discontinuation shall not be implemented without providing at least 3 days' advance written notice, except in the case of an emergency, in which event the City shall endeavor to provide DISTRICT notice as soon as reasonably possible after the emergency determination has been made.

**3. PRICE**

The CITY agrees to sell to the DISTRICT treated water delivered to the CITY-DISTRICT interties located on the DISTRICT's O'Neill Ranch well site and at Jade Street and Bain Street under the terms and conditions described hereof at a price that is equal to $1,000 per million gallons, or a pro rata amount thereof based on actual volume provided.

The CITY shall bill the DISTRICT on a monthly basis for water delivered to the DISTRICT based on the meter installed at the above specified intertie connections between the CITY and the DISTRICT. The pricing specified above is for this pilot project only. Future water deliveries made outside of this agreement will be subject to a pricing structure developed under any future water transfer or exchange agreement.

**4. REGULATORY COMPLIANCE – CEQA**

The CITY shall be the designated lead agency for the purposes of California Environmental Quality Act (CEQA) compliance. Cost of CEQA compliance, including preparation of an initial study and any negative declaration, mitigated negative declaration or environmental impact report, and implementation of mitigation measures identified therein and agreed to by the CITY will be equally split between the parties, with the DISTRICT's share shall be billed on a quarterly basis for the duration of this agreement.

CEQA compliance shall address the agreement herein to implement pilot testing of the transfer of water under certain conditions from the CITY to the DISTRICT commencing approximately November 1, 2015 and ending approximately five years later on December 31, 2020. Given that the agreement may potentially be extended beyond said date if both the CITY and the DISTRICT so agree in writing, CEQA shall also address the long-term transfer of water that may occur under such an extended agreement.

**5. REGULATORY COMPLIANCE -- PERMITTING**

The CITY shall be responsible for obtaining any other permits or approvals required to support providing water to the DISTRICT under this agreement, and shall be responsible for compliance with all laws, as necessary to make water available for purchase or to transfer pursuant to this Agreement.

## 6. REGULATORY COMPLIANCE – TREATED WATER DELIVERIES

Delivered water shall be in compliance with all drinking water regulatory requirements at the intertie point of delivery. Once the water has been delivered the DISTRICT shall be responsible in all respects for that water, and its delivery and use, including without limitation compliance with any distribution system requirements, and any relevant water quality regulations.

## 7. OPERATIONS PLAN

Prior to initiating the proposed water transfer, the CITY and the DISTRICT agree to jointly prepare and then implement an Operations Plan as the basis for joint operation. The CITY and the DISTRICT may amend the Operations Plan by written joint consent without needing to otherwise amend this agreement.

## 8. NOTICATION OF STARTING AND STOPPING WATER DELIVERIES

The water to be delivered hereunder shall be delivered to the DISTRICT on an interruptible basis, depending upon the availability of water and the terms and conditions described in paragraph 2 of this agreement. A determination that the delivery of water to the DISTRICT must be interrupted shall be at the sole discretion of the CITY Water Director, which determination shall be conclusive upon the DISTRICT. The CITY shall give the DISTRICT notice of interruption or cessation of the transfer of water in accordance with Paragraph 2(g), above.

## 9. DATA COLLECTION, MONITORING, AND ANALYSIS

The CITY and the DISTRICT shall jointly share the cost to develop, and implement, a data collection, monitoring, and analysis program to further characterize the benefits of the proposed water transfer and identify any potential issues. This program shall include, but not be limited to, monitoring and analyzing groundwater levels from existing wells in the vicinity of wells that the DISTRICT takes offline due to the available of water from an alternate water source, and distribution system water quality to assess any impacts from surface water being distributed through pipes that have only been used solely for groundwater distribution in the past. The plan shall be developed and implemented by the CITY and DISTRICT prior to commencing any sale of water.

## 10. NOTIFICATIONS AND RECORD KEEPING

For the purposes of this agreement, the parties shall abide by the record keeping and notification provisions in the Operations Plan.

## 11. NATURE OF AGREEMENT

It is understood and acknowledged by the DISTRICT and the CITY that this Agreement is only for the term specified herein, that no obligations are imposed on the parties beyond the term hereof, that the water rights of the CITY are not impacted, and that the water during the term hereof is solely dependent on the availability of surplus water as stated in this agreement.

This agreement makes no assumption about the availability or quantity of water to be delivered back to the CITY for use as a drought supply.

**12. EFFECTIVE DATE:**

This Agreement shall become effective only upon its approval by the governing bodies of each party hereto.

**13. TERMINATION ON THIRTY-DAY NOTICE**

This Agreement may be terminated by either party hereto upon the furnishing to the other party by United States Mail, first class, a thirty (30) day notice of intent to terminate or with an email notification that is acknowledged by the receiving party provided, however that DISTRICT'S obligations to pay for water delivered and indemnify, defend and hold CITY harmless pursuant to paragraph 14, below, shall survive termination.

**14. RELEASE AND INDEMNITY**

DISTRICT agrees to indemnify, defend and hold harmless CITY, and any agency or instrumentality thereof, and its elected and appointed officials, officers, employees and agents from and against all liabilities, claims, actions, causes of action, proceedings, suits, damages, judgments, liens, levies, costs and expenses of whatever nature, including reasonable attorneys' fees and disbursements (collectively "Claims") arising out of any actions taken by the City in the implementation of this agreement, or any environmental review conducted under the California Environmental Quality Act (CEQA) in connection with this agreement.

Dated: 8-1-16

CITY OF SANTA CRUZ

By: [signature]

City Manager of City of Santa Cruz

Dated: July 25, 2016

SOQUEL CREEK WATER DISTRICT

By: Bruce Daniels

President of the Board of Directors

APPROVED AS TO FORM:

[signature]

CITY Attorney

[signature]

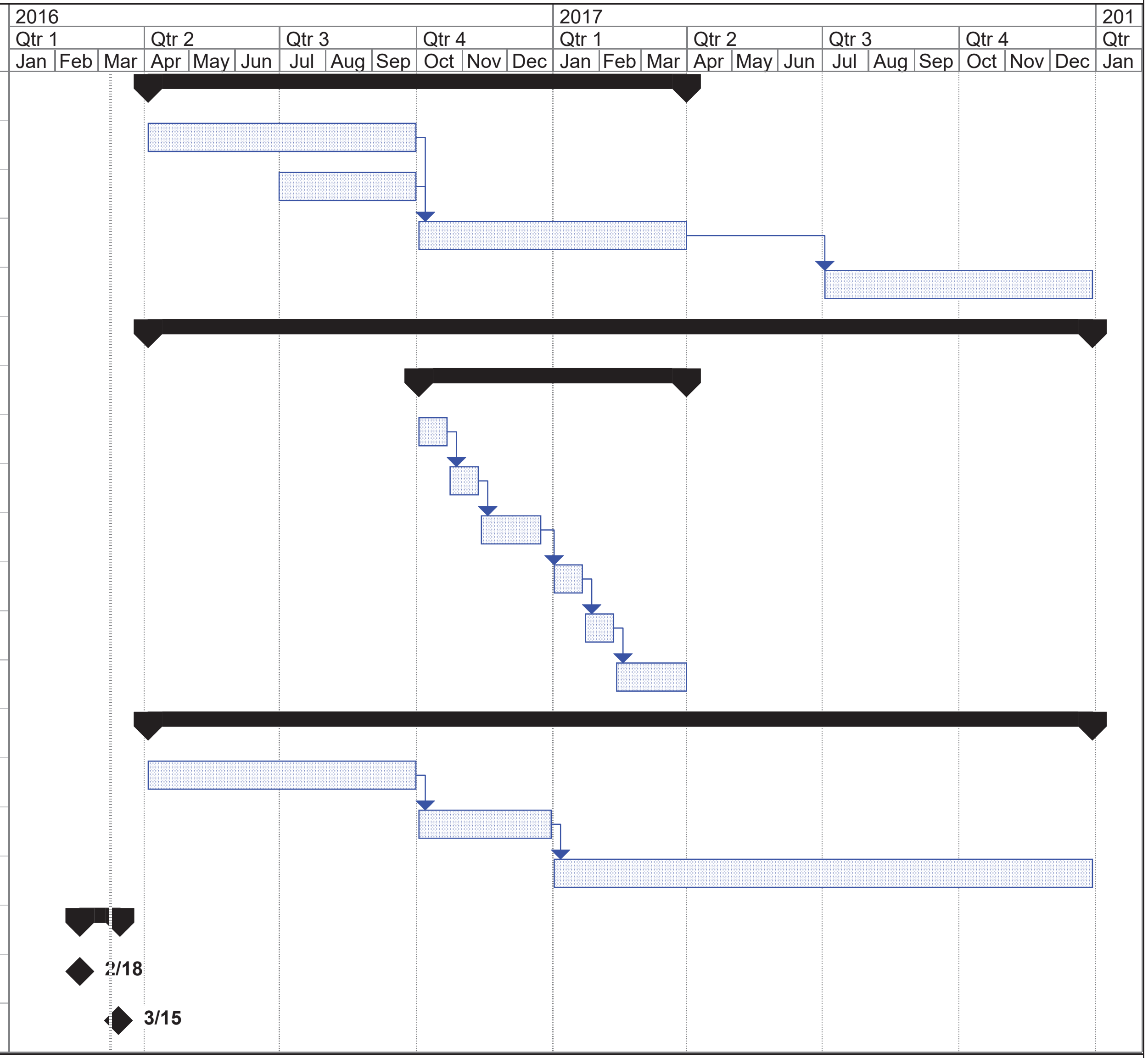
DISTRICT Counsel

# Attachment D

City of Santa Cruz Water Department
ASR Project - Phase 1 Feasibility Investigation
PWR Project No. 15-0111

**PROJECT SCHEDULE**

| ID | Task Name |
|---|---|
| 1 | **Higher-Level Feasibility Analyses** |
| 2 | T1.1 - Existing Wells Screening |
| 3 | T1.2 - Site-Specific Injection Capacity Analyses |
| 4 | T1.3 - Geochemical Interaction Analysis |
| 5 | T1.4 - Pilot ASR Testing Program Development |
| 6 | **Groundwater Modeling** |
| 7 | **T.5.1 - Well Siting Study** |
| 8 | T1.5.1.1 - Review Hydrogeologic Literature |
| 9 | T1.5.1.2 - Prepare Existing Well Database |
| 10 | T1.5.1.3 - Compile and Review GIS Databases |
| 11 | T1.5.1.4 - PCA Assessment |
| 12 | T1.5.1.5 - Field Surveys |
| 13 | T1.5.1.6 - Potential Well Site Ranking |
| 14 | **T1.5.2 - Groundwater Modeling Coordination** |
| 15 | T1.5.2.1 - Confluence Model Coordination |
| 16 | T1.5.2.2 - ASR Model Scenario Development |
| 17 | T1.5.2.3 - Modeling Coordination |
| 18 | **PM and Meetings** |
| 19 | NTP |
| 20 | Project KO Meeting |




Project: 15-0111_SC_ASR_Ph_1_sch
Date: Wed 3/9/16

| | | | | | |
|---|---|---|---|---|---|
| Task | | Milestone | | External Tasks | |
| Split | | Summary | | External Milestone | |
| Progress | | Project Summary | | Deadline | |

# Attachment E



**LEGEND**

- ○ Meets Guidelines
- ◖ Somewhat Meets Guideline
- ● Does Not Meet Guideline
- Not applicable (blank)
- (dark shading) Consistently meets guidelines
- (light shading) Meets most guidelines to some degree
- (no shading) Remove from further consideration

**PURPOSE: Identify the Project Components that are the building blocks for developing alternatives. Apply the Basic Guidelines from Table 1 to identify project components to be included in the alternatives development process (Table 3). Provide rational for removal of Project Components from further consideration.**

**Table 2: Preliminary Evaluation of Potential Project Components (Revised)**

| Potential Project Components | Recycled Water Use | Source Water | Treatment | Description | Reuse of Santa Cruz WWTF Effluent | Offset or Increase Potable Supplies | Right Treatment for Right Use | Consolidate Treatment Facilities | Sufficient Flows and Demands for MBR | Minimize Impacts to WW collection and treatment | GWRR at Identified ASR Sites | AWTF Capacity Limited by Siting | Preliminary Agreements Imminent | Approved/Practiced Reuse | Reason for Removal from Further Consideration. (To be included in the narrative of the RWFPS) | Inclusion in Preliminary List of Alternatives |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Basic Guidelines for Evaluation of Project Components** | | | | | | | | | | | |
| 1 | Non-Potable Reuse | Santa Cruz WWTF | Secondary | Limited use in Santa Cruz (in-plant, restricted areas, truck filling) | ○ | ● | ◖ | ○ | | ○ | | | ○ | ○ | - limited uses, minimal benefit to water supply<br>- public acceptance issues<br>- Pasatiempo denied use of secondary effluent due to proximity to residents<br>- Assume secondary effluent could only be used with additional on-site treatment | |
| 2 | | | Tertiary | Unrestricted use in Santa Cruz (irrigation, commercial, industrial, truck filling) including UC Santa Cruz | ○ | ○ | ○ | ○ | | ○ | | | ○ | ○ | | 1a/b, 3a/b |
| 3 | | | | North Coast Agricultural Irrigation | ○ | ● | ○ | ○ | | ○ | | | ◖ | ○ | - uncertainty about the quantity, water quality and seasonal reliability of groundwater available for exchange in a multi-year drought;<br>- permitting challenges for State Parks (the major landowner) approval for GW pumping for the water exchange<br>- potential opposition by local organic growers (challenge to confirm willingness to use)<br>- high cost and high risk for City with minimal incentive to support rates for revenue<br>- would be studied as a potential opportunity to achieve zero discharge in another study, however volume of reuse would be limited by demand with minimal demand occurring in the winter months. | |
| 4 | | | Advanced Treatment | Unrestricted use in Santa Cruz (irrigation, commercial, industrial, truck filling) including UC Santa Cruz | ○ | ○ | ● | ○ | | ○ | | | ○ | ○ | - significantly higher cost/energy to treat beyond regulatory requirement | |
| 5 | | | | North Coast Agricultural Irrigation | ○ | ● | ● | ○ | | ○ | | | ◖ | ○ | - same reasons above #3<br>- significantly higher cost/energy to treat beyond regulatory requirements | |
| 6 | | | | Customers along pipelines alignments to IPR/DPR or streamflow augmentation | ○ | ○ | ◖ | ○ | | ○ | | | ○ | ○ | | 3c, 4a/b, 5, 6a/b, 7 |
| 7 | | Local Raw Wastewater | MBR (Tertiary) | Anchor customers in Santa Cruz (Unrestricted use) | ○ | ○ | ○ | ◖ | ● | ◖ | | | ● | ○ | - lack of anchor customer (the largest demand (DeLaveaga Golf Course) is < 0.2 mgd and the next largest < 0.02 mgd<br>- constructing and operating an MBR for demand of this size would not be cost effective and would have O&M challenges<br>- limited potential participants, would need commitments from all parties<br>- sensitivity of neighbors (NIMBYism) | |
| 8 | | | | UC Santa Cruz | ○ | ○ | ○ | ◖ | ◖ | ◖ | | | ○ | ○ | | 2 |
| 9 | | | | North Coast Agricultural Irrigation | ○ | ● | ○ | ◖ | ● | ● | | | ● | ○ | - same reasons above #3<br>- lack of nearby source of raw wastewater | |
| 10 | | Scotts Valley WWTF | Secondary (outfall) | Pasatiempo Golf Course | ● | ○ | ● | ◖ | | ○ | | | ○ | ○ | - Project already in progress (planned cartridge filter treatment onsite)<br>- does not beneficially reuse SC WWTF effluent | |
| 11 | Seawater Intrusion Barrier | Santa Cruz WWTF | Advanced Treatment | Identified groundwater basin subject to seawater intrusion | ○ | ● | ○ | ○ | | ○ | ◖ | ○ | ○ | ○ | - provides limited water supply because threat to City wells is currently low<br>- very costly "insurance" against potential future loss of Beltz coastal wells<br>- would be studied as a potential opportunity to achieve zero discharge in another study<br>- Seawater intrusion avoidance could be considered a baseline assumption for any groundwater replenishment project | |
| 12 | | Local Raw Wastewater | MBR + Advanced Treatment | Identified groundwater basin subject to seawater intrusion | ○ | ● | ○ | ◖ | ● | ○ | ◖ | | ○ | ○ | - same as #11 above<br>- limited available supply from DA Porath and siting challenges for MBR/AWTF | |
| 13 | Groundwater Replenishment | Santa Cruz WWTF | Advanced Treatment | Suitable Santa Cruz GWRR site(s) to be defined in the ASR Study | ○ | ○ | ○ | ○ | | ○ | ○ | ○ | ○ | ○ | | 3c/d, 4a/b |
| 14 | | | | SqCWD GWRR Sites in Aptos/Purisima Basins (per GWRR Feasibility Study) | ○ | ● | ○ | ○ | | ◖ | | ○ | ○ | ○ | - does not augment potable supplies in City of Santa Cruz water service area<br>- would require complex institutional arrangements and significant new infrastructure to result in increased potable supplies for the City<br>- potential to "T" off of conveyance system for NPR or IPR in Santa Cruz is covered under other alternatives | |
| 15 | | | | Santa Margarita GW Basin | ○ | ● | ○ | ○ | | ○ | ● | ○ | ○ | ○ | - does not augment potable supplies in City of Santa Cruz water service area<br>- would require complex institutional arrangements and significant new infrastructure to result in increased potable supplies for the City<br>- high cost to treat and pump to this upper basin | |
| 16 | | Local Raw Wastewater | MBR + Advanced Treatment | Suitable Santa Cruz GWRR site(s) to be defined in the ASR Study | ○ | ○ | ○ | ◖ | ◖ | ◖ | ○ | ○ | ○ | ○ | | 4c |
| 17 | | | | SqCWD GWRR Sites in Aptos/Purisima Basins (per GWRR Feasibility Study) | ○ | ● | ○ | ◖ | ○ | ◖ | | ○ | ○ | ○ | - same as #14 above<br>- siting challenges for MBR/AWTF and higher cost (as described in the SqCWD GWRR Feasibility Study | |
| 18 | | Scotts Valley WWTF or Outfall | Advanced Treatment | Suitable site to be defined in the ASR Study | ● | ○ | ○ | ○ | | ○ | ○ | ○ | ○ | ○ | - Minimal flow is available in the outfall due to (1) existing SVWD recycled water program, (2) planned Pasatiempo use of RW from the outfall and (3) proposed GWRR currently being explored for SVWD | |
| 19 | | | | Santa Margarita GW Basin | ● | ● | ○ | ○ | | ○ | ● | ○ | ○ | ○ | - SVWD is already studying this project is a separate RWFPS<br>- SVWD's efforts will be referenced but Study Partners agreed not to study this component in the RWFPS<br>- Use of outfall for conveyance is not viable due to operational concerns if discharge is needed | |
| 20 | Reservoir Augmentation | Santa Cruz WWTF | Advanced Treatment | Loch Lomond Reservoir | ○ | ○ | ○ | ○ | | ○ | | ○ | ○ | ◖ | | 5 |
| 21 | Streamflow Augmentation | Santa Cruz WWTF | Tertiary | San Lorenzo River (Direct/Indirect Discharge) | ○ | ○ | ● | ○ | | ○ | | | ○ | ◖ | - environmental and habitat concerns related to water quality<br>- proximity to raw water diversion, regulatory and permitting challenges would likely require the higher level of treatment<br>- TMDL for nitrogen is a limiting factor - existing water quality barely achieves the existing TMDL thus, any additional nitrogen loading would be a concern. | |
| 22 | | | Advanced Treatment | San Lorenzo River (Direct/Indirect Discharge) | ○ | ○ | ○ | ○ | | ○ | | ○ | ○ | ◖ | | 6a/b |
| 23 | Direct Potable Reuse | Santa Cruz WWTF | Advanced Treatment | Raw Water Blending at Graham Hill WTP (via Coast PS) | ○ | ○ | ○ | ○ | | ○ | | ○ | ○ | ◖ | | 7 |
| 24 | | | | Pipe to Pipe (Downstream of Graham Hill WTP) | ○ | ○ | ○ | ○ | | ○ | | ○ | ○ | ● | - lacks additional treatment, barrier an response time provided by blending prior to a drinking water treatment plant<br>- no project of this type is currently or has been permitted in the US<br>- significant public acceptance issues | |

# Attachment F

**PURPOSE: Combine the Project Components identified in Table 2 to create Alternatives for evaluation in the Santa Cruz RWFPS. Discuss, refine and come to alignment on this list during the Alternatives Workshop.**

**Table 3: Santa Cruz RWFPS - Preliminary List of Alternatives for Further Development**

| Alternative | Sub Alt | Description | Source Water | Treatment | | Use | Notes |
|---|---|---|---|---|---|---|---|
| Alternative 1 – Centralized Non-Potable Reuse | 1a | Santa Cruz PWD Phase 2 Project | Santa Cruz WWTF | Tertiary Treatment at SC WWTF | 3° | In-plant uses, truck filling and demonstration site (park near WWTF) | Current plan is for 175 gpm Capacity. Project going out for RFP soon. |
| | 1b | Maximize tertiary treatment at the SC WWTF | | | 3° | Unrestricted use in Santa Cruz including UC Santa Cruz. (Sites TBD) | RW delivered to be limited by available space at the SCWWTF for tertiary or the identified NPR demand in SC Service area |
| Alternative 2 – Decentralized Non-Potable Reuse | 2 | UC Santa Cruz | Local Raw Wastewater (UCSC) | MBR at UCSC | 3° | On campus uses (irrigation, agricultural, cooling towers, dual-plumbed facilities) | UCSC to look into a proposed location for the scalping plant. No clear spot for it yet and it wasn't identified by Carollo either. They have concerns about O&M requirements and getting operators licenses, permitting etc. Response from UCSC will guide whether this stays in or drops out. |
| Alternative 3 – Santa Cruz Participation in SqCWD led Groundwater Recharge Reuse (GWRR) Project | 3a | Send secondary effluent from SCWWTF to SqCWD for injection in SqCWD basin (serve NPR users along the way) | Santa Cruz WWTF | On-Site Treatment at NPR Customer sites | 2° + filter | NPR Customers along secondary pipelines alignment from SC WWTF to AWTF | These alternatives will focus on facilities needed to utilize RW utilized within the Santa Cruz Service Area only.<br>- upsizing conveyance to serve NPR customers<br>- additional treatment to serve NPR customers<br>- additional treatment to recharge in SC GW Basin<br>- available space at the AWTF site to produce enough purified water to recharge requirements at the SqCWD GWRR sites + a Santa Cruz GWRR site<br>- new City owned wells to extract recharged groundwater<br>-proportional cost sharing of facilities (TBD)<br>- other cost sharing items (TBD) |
| | 3b | Send tertiary effluent from SCWWTF to SqCWD (serve NPR users along the way) | | Tertiary Treatment at SC WWTF | 3° | NPR Customers along tertiary pipeline alignment from SC WWTF to AWTF | |
| | 3c | Send additional secondary effluent from SCWWTF to SqCWD AWTF and deliver purified water from SqCWD AWTF o recharge Santa Cruz GWRR | | Advanced Treatment at SqCWD Headquarters | AWT | Deliver purified water from SqCWD AWTF to Santa Cruz GWRR injection sites | |
| | 3d | Send advanced treated RW from SCWWTF to SqCWD, (serve NPR users along the way) | | Advanced Treatment at SC WWTF | AWT | NPR Customers along pipeline alignment from SC WWTF to SqCWD injection sites | |
| | 3e | Send advanced treated RW from SCWWTF to SqCWD, (GWRR and NPR along the way) | | | AWT | GWRR in Santa Cruz (Beltz Well Field) and NPR customers along pipeline alignments | |
| | removed | GWRR in Santa Cruz through an extension from MBR + AWTF at SqCWD | Local Raw Wastewater (SCCSD) | MBR + Advanced Treatment at SqCWD | AWT | GWRR in Santa Cruz (Beltz Well Field) | This alternative was not considered to be viable because SqCWD is not certain there would be enough flow from the Soquel PS and Capitola PS to meet SqCWD demands let alone excess supply to send to City recharge sites. |
| Alternative 4 – Santa Cruz GWRR Project | 4a | Santa Cruz GWRR with AWTF at SC WWTF (serve NPR users along the way) | Santa Cruz WWTF | Advanced Treatment at SC WWTF | AWT | Suitable Santa Cruz GWRR site(s) to be defined in the ASR Study. Once extracted, recharged water would be distributed through the existing potable water distribution system. | The parallel ASR study is assuming a full-scale ASR system to consist of a total of eight (8) 0.5 million gallon per day (mgd) ASR wells;<br>- 4 wells in the SCWD service area (i.e., the Beltz well field)<br>- 2 wells in the SqCWD service area<br>- 2 wells in the SVWD service area<br><br>* need to confirm it the RWFPS is only looking at 2 wells in the SCWD service area (1 mgd? or more)<br>* discuss if we want to keep DA Porath on the table given findings in the SqCWD RWFPS |
| | 4b | Santa Cruz GWRR with AWTF of secondary effluent at off-site location (serve NPR users along the way) | | Advanced Treatment off-site (location TBD) | AWT | | |
| | 4c | Santa Cruz GWRR with MBR + AWTF at DA Porath PS (serve NPR users along the way) | Local Raw Wastewater (SCCSD) | MBR + Advanced Treatment | AWT | | |
| Alternative 5 – Surface Water Augmentation (SWA) in Loch Lomond Reservoir | 5 | Advanced treatment of Santa Cruz effluent for bending in Loch Lomond Reservoir | Santa Cruz WWTF | Advanced Treatment at SC WWTF | AWT | Reservoir augmentation in Loch Lomond for blending and storage, to be conveyed to the GHWTP and enter the City's potable water distribution system. | RW delivered to be limited by<br>- available space at the SCWWTF for an AWTF<br>- available space at an offsite location<br>- reservoir dilution and retention time (it is unlikely that we will be able to meet 1% and 6 months unless the flow is very small)<br><br>*do we want more than one sub alternative to reflect this?<br>*previously this included conveyance to the District via a new intertie and cost sharing. |
| Alternative 6 – Streamflow Augmentation | 6a | AWTF of secondary effluent with direct discharge to the San Lorenzo River btw Felton and Tait (serve NPR users along the way) | Santa Cruz WWTF | Advanced Treatment at SC WWTF | AWT | Augment San Lorenzo River flows to maintain habitat, meet future fish release requirement, and allow for increased diversions to expand future drinking water supplies. | Key consideration: Nitrogen TMDL in the river.<br>A direct discharge facility would consist of a diffuser to blend and direct flows downstream. Potential concerns may arise related to the proximity of the discharge to the point of diversion. One discharge facility and site will be provided, no mixing/modeling will be performed. |
| | 6b | AWTF of secondary effluent with indirect discharge to the San Lorenzo River d/s of Tait Street Diversion at Tait Well Field (serve NPR users along the way) | | | AWT | | Key consideration: Nitrogen TMDL in the river.<br>An indirect discharge facility would consist of near-river injection wells, which would percolate purified water through the shallow aquifer before blending with streamflow. One injection well configuration at one location will be provided, no mixing/modeling will be performed. |
| Alternative 7 – Direct Potable Reuse | 7 | Raw Water Blending at Graham Hill WTP (via Coast PS) | Santa Cruz WWTF | Advanced Treatment at SC WWTF | AWT | The advanced treated water would be blended with raw water coming from North Coast sources, the San Lorenzo River, and Loch Lomond water at the Coast Pump Station, and further treated at the GHWTP prior to distribution as finished water, suitable for drinking. | * Confirm that the maximum capacity will be determined based on a 2-storey AWTF at the SC WWTF.<br>* If there is interest at treatment at an off-site location we should probably have another sub-alternative. (similar to comment for Alt 5, which would also apply to Alt 6)<br>* High turbidity and high TOC in GHWTP source water. Consider synergies between GHWTP and AWPF when evaluating siting and blending. |

# Attachment G

## PROJECT PARTNER INPUT

**HOMEWORK: Each Project Partner to fill out and submit their proposed weighting (%) for each of the screening criteria such that the sum of all screening criteria weightings is 100%. For a given criteria, the percentage should represent the importance of all considerations listed.**

| Categories | Alternatives Screening Criteria | Considerations for Assessing Project based on Criteria | TEAM: / Individual: |
|---|---|---|---|
| ENGINEERING & OPERATIONAL CONSIDERATIONS | Improve Water Supply | - Ability to fill City supply gap (1.2 BGY or 3,700 AFY), supplement peak season supply with a new source or offset and/or contribute to regional supply<br>- Ability to implement Project, with supplies available in a timely manner | |
| | Maximize Beneficial Reuse | - Maximizes reuse of wastewater effluent now and/or does not limit future options to fully utilize wastewater effluent | |
| | Ease of Implementation | - Regulatory viability and ability to obtain a recycled water permit<br>- Current (DDW and RWQCB) regulatory pathway/approved use<br>- Potential construction challenges (#/size of facilities, ROW, utilities, terrain, disturbed/undisturbed area, seismic/sea level rise vulnerability etc.<br>- Flexibility for phasing and opportunities to expand/transition to a higher yield and/or treatment level. | |
| | Operational Complexity | - Source of wastewater and/or type treatment required for beneficial reuse minimizes impacts to wastewater collection and/or WWTF operations<br>- Siting new treatment facilities minimize impacts on SC WWTF operations | |
| ECONOMIC | Cost Effectiveness | - Economically feasible or cost effective project (relative life cycle unit costs | |
| | Financial Implementability | - Financially implementable project (relative capital investment, need to issue debt, impact on rates and required tradeoffs) | |
| ENVIRONMENTAL | CEQA Considerations | - Potential environmental impacts and mitigation requirements | |
| | Financial Implementability | - Enhance local and regional ecosystems and environments including rivers, groundwater basins<br>- Social cost of carbon compared to other projects and supplies; Relative contribution to global warming (based on GHG emissions) | |
| SOCIAL | Agency Coordination, Partnerships and Agreements | - Level of cooperation and coordination required between multiple outside agencies/users<br>- Willingness and interest of anticipated users/partners for cost-sharing | |
| | Social Issues & Siting | - Perceived public acceptance and comfort with level of public health and safety associated with reuse<br>- Level of impact on local residents for new construction and ongoing maintenance<br>- land acquisition requirements (property not currently owned by the City) | |
| | | | 0% |

*** Percentages must add up to 100%**