# Water Meters

Codes and Standards Enhancement (CASE) Initiative
For PY 2012: Title 20 Standards Development

Analysis *of* Standards Proposal for
**Water Meters**



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# 1 Executive Summary

The Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), Southern California Gas (SCG), San Diego Gas & Electric (SDG&E) Codes and Standards Enhancement (CASE) Initiative Project seeks to address energy efficiency opportunities through development of new and updated Title 20 standards. Individual reports document information and data helpful to the California Energy Commission (CEC) and other stakeholders in the development of these new and updated standards. The objective of this project is to develop CASE Reports that provide comprehensive technical, economic, market, and infrastructure information on each of the potential appliance standards. This CASE Report covers a standards proposal for water meters intended for use at detached, single family homes. Multifamily residences are outside the scope of this standards proposal.

## 1.1 Regulatory Gap in Water Meter Accuracy

Water meters owned by private water companies are required by state law to meet minimum accuracy standards. These meters are regulated by the California Public Utilities Commission (CPUC), which has established standards equivalent to the recommendations of the American Water Works Association (AWWA). Water meters serving detached, single-family homes that are owned by public water utilities are not subject to any state or federal accuracy standards. About 11 million water meters are installed at single family homes in California. Of these, only two million are owned by private water companies; nine million are owned by public water utilities and not currently regulated by any state or federal law.

The standards proposal here would apply standards that are very similar in style and structure to those recommended by the AWWA to meters purchased by both public and private utilities for use at detached, single family homes. For private water companies, the standards proposal represents an increase in the stringency of accuracy requirements at low flow levels. By adopting the proposed standard, the CEC would be serving the interests of Californians by establishing for the first time a mechanism for regulating the accuracy of water meters owned by public utilities.

## 1.2 CEC has Mandate to Reduce Statewide Water Consumption

The CEC has a mandate to take a more aggressive approach to establishing and enforcing standards that will reduce statewide water consumption. Assembly Bill 662 (Ruskin 2007) and Assembly Bill 1560 (Huffman 2007) modified the language of the Warren-Alquist Act to give the CEC authority to set water efficiency appliance standards, and required the CEC to incorporate water efficiency standards into the existing building efficiency standards (Title 24, Part 6).

## 1.3 Proposed Water Meter Accuracy Standard

The proposed standard would require that service water meters two inches and smaller, purchased for installation in California, demonstrate an ability to accurately measure flows at extended low flow rates. To maintain consistency with industry practices and existing voluntary (AWWA) standards, the specific accuracy levels and flow rates required by the proposed standard vary by meter type.

## 1.4 More Accurate Water Meters Save Water and Energy

Meter accuracy can have a significant effect on water and energy consumption by end-users. Extended low flows, such as those created by leaking faucets or faulty toilet flappers, are not detected by lower-accuracy meters. Since water providers cannot directly charge for usage that is not detected by meters, lower-accuracy meters provide end-users with little incentive for making even simple repairs or behavioral changes that would eliminate wasteful leakage. Meters that accurately register low flows provide a better price signal to the end-users responsible for leaks and other low flows. In response to the price signal, end-users act to eliminate leaks and reduce total water consumption. Because energy is required for many processes involved in providing water to consumers, reducing water consumption simultaneously reduces energy consumption. The widespread use of more accurate water meters would reduce statewide water and energy consumption by approximately 1.3 billion gallons of water and eleven gigawatt-hours (GWh) of embedded energy after stock turnover.

## 1.5 Costs and Benefits

Water utilities – not individual people or households – are the primary consumers of water meters. In this respect, the proposed water meter standards are similar to the energy efficiency standards the Department of Energy (DOE) established for distribution transformers in 2007. The consumers of distribution transformers are electrical utilities, and the DOE assessed the costs and benefits of standards from the perspective of the utilities rather than individuals or households. Ultimately, the costs associated with transporting, treating, and disposing of wasted water, and the savings accruing as a result of reducing waste, are transferred to the utility's ratepayers.

The proposed water meter accuracy standards would produce net economic benefits of about $97 million in present-day value by the time the entire statewide stock turns over.

**Table 1.1 Lifecycle Costs and Benefits for Qualifying Products**

| Product Class | **Lifecycle Benefit / Cost Ratio**[a] | **Net Present Value ($)**[b] | | |
|---|---|---|---|---|
| | | Per Unit | First Year Sales | Stock Turnover [c] |
| Average of All Water Meter Types | 2.4 | $30 | $6,600,000 | $97,000,000 |

[a] Total present value benefits divided by total present value costs.
[b] Positive value indicates a reduced total cost of ownership over the life of the appliance.
[c] Stock Turnover NPV is calculated by taking the sum of the NPVs for the products purchased each year following the standard's effective date through the stock turnover year, i.e., the NPV of "turning over" the whole stock of less efficient products that were in use at the effective date to more efficient products, plus any additional non-replacement units due to market growth, if applicable. For example, for a standard effective in 2015 applying to a product with a 5 year design life, the NPV of the products purchased in the 5th year (2019) includes lifecycle cost and benefits through 2024, and therefore, so does the Stock Turnover NPV.

# 2 Product Description

Water meters are devices used to measure and record the cumulative volume of water flowing through them. Meters vary in their ability to perform accurate measurements when water is flowing at low rates for an extended period of time. Manufacturers produce a wide variety of meters suitable for agricultural, industrial, commercial, and residential applications. The proposed standards only address those meter types suitable for measuring cold water at detached, single-family homes (see Figure 2.1 for an example of a typical meter used for residential service connections). In some cases, similar types of meters used at detached, single-family homes may also be found in commercial applications, or for submetering at multi-family complexes. To simplify the analysis of the benefits and costs of efficiency standards for water meters, only meters at detached, single family homes are considered in this report. Benefits of the proposed standards would be magnified by consideration of other applications, so the results presented here should be understood as a conservative estimate. Hereafter, "meters" or "water meters" will be used to refer to those meters to which the proposed standards apply, unless otherwise noted.

As with electricity distribution transformers, for which DOE approved energy efficiency standards in 2007 (DOE, 2007), end-users are not the primary consumers of water meters. In California, the primary consumers of residential service water meters are typically water utilities. Water utilities usually purchase water meters in quantity from manufacturers (or their distributors) for installation at individual service connections by employees or subcontractors, although in some cases water utilities allow end-users to install their own meters provided they comply with rules regarding meter and contractor selection and proper installation procedures.

The Warren-Alquist Act specifically gives the CEC authority to promulgate regulations “to promote the use of energy and water efficient appliances whose use, as determined by the commission, requires a significant amount of energy or water on a statewide basis” (CEC 2013). A water meter in which no water is present cannot be said to be in use, while a water meter through which water is passing is clearly in use. Therefore, the use of a water meter can be fairly claimed to “require water” and is therefore a legitimate object of regulation by the CEC.

Meter accuracy can have a significant effect on water and energy consumption by end-users. Extended low flows, such as those created by leaking faucets or faulty toilet flappers, are not detected by low-accuracy meters. Since water providers cannot directly charge for usage that is not detected by meters, low-accuracy meters provide end-users with little incentive for making even simple repairs or behavioral changes that would eliminate wasteful leakage. Meters that accurately register low flows provide a better price signal to the end-users responsible for leaks and other low flows. In response to the price signal, end-users act to eliminate leaks and reduce total water consumption. Because energy is required for many processes involved in providing water to consumers, reducing water consumption simultaneously reduces energy consumption.

The proposed standards address the minimum requirements for water meter accuracy at low flow rates. An efficient water meter is defined in this analysis as a product that registers the volume of water passing through it at the flow rate and within the accuracy limits specified by the proposed standard for that meter type (see Section 9.2 for the specific standards proposed).

## Overview of Water Meter Characteristics

Meters vary primarily in size, measurement technology, outer casing material, and registration/encoding element. Water meters used for residential service connections are typically between 5/8 and 2 inches in size (sizes discussed in more detail below) and usually employ one of the following core measurement technologies: positive displacement (either nutating disc or oscillating piston), single jet, multi-jet, or fluidic-oscillator. Residential water meters are manufactured with either bronze or plastic outer casings, but since the outer casing does not affect the meter's low-flow accuracy, this characteristic is not considered further.

The registration/encoding elements serve to convert the signal generated by the measurement technology into quantitative information that reflects the volume of water that has passed through the meter in a specific standard unit of measure. Virtually all measurement error in modern water meters is associated with the core measurement technology and not with the method of registration. Therefore, while advanced encoders that enable remote reading and other sophisticated functionality may offer significant benefits for water and energy conservation, they do not affect the accuracy of the measurement technology itself, and are not further discussed in this report.

**Figure 2.1 Typical appearance of a water meter suitable for use in detached, single-family homes**

Source: Neptune

## Size

Water meter size designations refer to the internal diameter of the inlet and outlet apertures on either side of the measurement chamber. In many cases, the size designation is the same as the nominal pipe size of the service pipe. For historical reasons, this correspondence is imperfect, as 5/8" meters are designed for use with 1/2" pipes (AWWA M6). Some meters are manufactured with threads (called "spud threads") that permit connection to a service pipe with an internal diameter different from that meter's nominal inlet and outlet internal diameter. The sizes of such meters are designated with two values, the first corresponding to the inlet and outlet internal diameter and the second to the nominal pipe size to which the spud threads are designed to provide a connection. For example, a 5/8" x 3/4" meter is one with inlet and outlet internal diameters of 5/8" and spud threads allowing a connection to a 3/4" service pipe. In most cases, two fittings must be used to connect the meter to the service pipe: a tailpiece and a pipe coupling. The tailpiece includes a female, internal thread coupling nut on one end that connects to the meter spud thread and a male, external thread on the other end that connects to the pipe coupling. The pipe coupling includes female, internal threads on both ends to unite the tailpiece with the service pipe.

### Measurement Technology

Water meters for residential service are typically based on either nutating disc or oscillating piston measurement technologies. Both nutating disc and oscillating piston meters belong to the "positive displacement" category of water meter technologies because they function by coupling the displacement of a known volume of water to the transmission of a signal to the registration element. In a nutating disc meter, water striking the surface of a disc mounted on a spindle causes the disc to wobble, or nutate, as water flows into and out of the measurement chamber (see Figure 2.2). One complete revolution of the end of the spindle corresponds to the passage of a unit of water equal to the void volume of the measuring chamber. In an oscillating piston meter, water flowing into the measuring chamber pushes a piston element in a circular motion, with the revolution of the piston hub indicating the passage of a unit volume of water (see Figure 2.3).

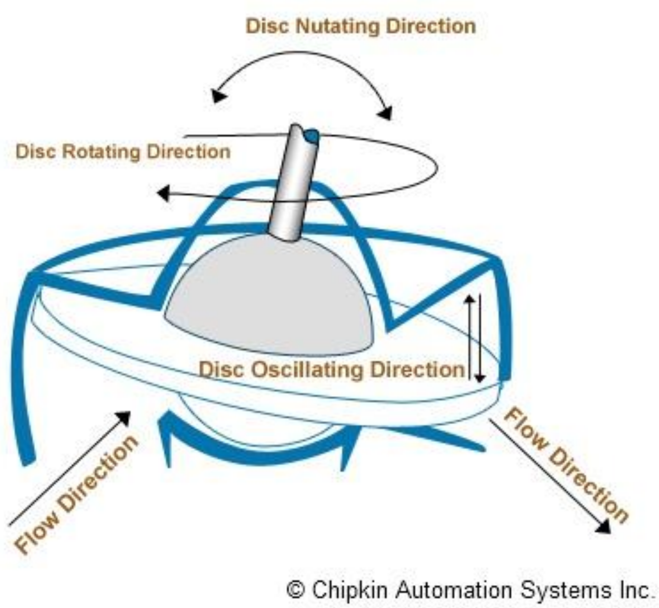


**Figure 2.2 Schematic diagram of nutating disc meter measuring chamber**
Source: Chipkin Automation Systems

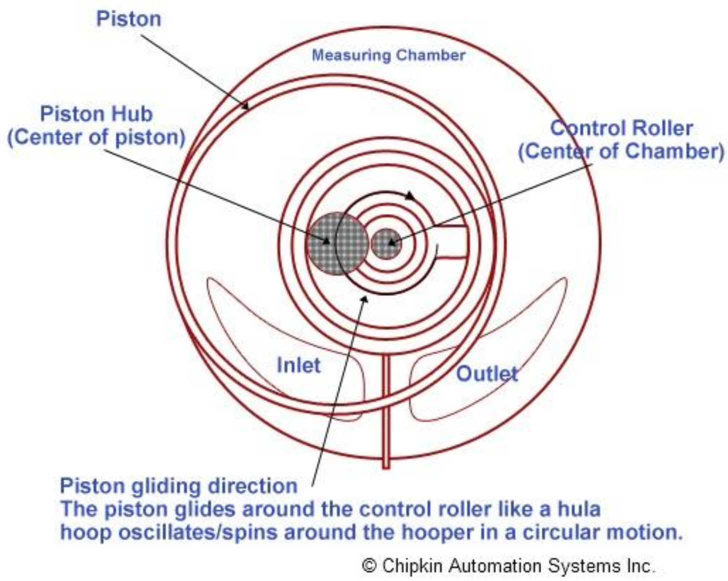


**Figure 2.3 Schematic diagram of oscillating piston meter measuring chamber**
Source: Chipkin Automation Systems Inc.

While positive displacement meters are by far the most common in residential and other applications involving meter sizes between 5/8" and 2", single jet and multi-jet meters are occasionally used. Single jet and multi-jet meters belong to the "velocity" category of meter technologies because they measure the water's velocity, from which volumetric flow can then be inferred. Single jet and multi-jet meters function by directing the flow of water against an impeller. The rotation speed of a spindle attached to the center of the impeller provides the signal to the registration element. In single jet meters, a single stream of water strikes the impeller at one location (see Figure 2.4); in multi-jet meters, water is dispersed and strikes the impeller at multiple locations (see Figure 2.5).

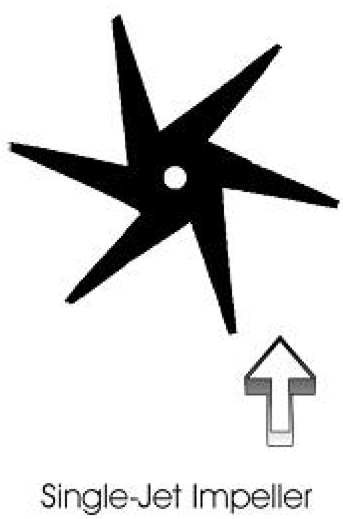


**Figure 2.4 Schematic of single jet meter measuring chamber**
Source: Metron-Farnier

**Figure 2.5 Photograph of multi-jet meter measuring chamber**
Source: Master Meter

Fluidic oscillator meters are infrequently used in residential and small service applications. Fluidic oscillator meters create a physical oscillation in the direction of the stream of water entering the measuring chamber. The oscillation frequency, which can be detected by electronic sensors within the measuring chamber, is proportional to the velocity of the water, and thus can be used to register flow. Fluidic oscillators are one example of a new class of advanced, "solid-state" or "static" meters that do not include moving parts, but often require a power supply.

# 3 Manufacturing and Market Channel Overview

The major water meter manufacturers include Badger, Elster-AMCO (including the former ABB), Hersey, Itron, Master Meter, Metron-Farnier, Neptune, Sensus, and Siemens. Manufacturers who produce positive displacement meters tend to specialize in either nutating disc (Badger, Hersey, Neptune) or oscillating piston (Elster, Master Meter, Sensus) technologies.

The basic designs of many of the most widely used measurement technologies have changed very little over time. Patents for positive displacement meters of both the oscillating piston and nutating disc types date back to the late 19$^{th}$ century and some companies that are still manufacturing meters today were first established more than 100 years ago (AWWA M6). Recently, however, the market has witnessed the emergence of a variety of innovative, advanced, non-mechanical meter technologies with no internal moving parts, including fluidic oscillator, ultrasonic, magnetic, and remanent field meters (Berardinelli 2012). Of the non-mechanical meters, the fluidic oscillator meter has achieved the greatest market penetration, as evidenced by the fact that it is the only non-mechanical meter with its own industry standard (AWWA C713). AWWA standards for other non-mechanical meters are currently under development. Eventually, new meter technologies could challenge the market dominance of positive displacement meters in the residential market, but costs currently prohibit significant penetration.

# 4 Energy Usage

## 4.1 Test Methods

### 4.1.1 Current Test Methods

Water meter accuracy test methods fall into two broad groups corresponding to the standard being applied. In North America, the prevailing accuracy standards and test methods originate with the AWWA, an industry group. AWWA test methods are codified in slightly different forms by the CPUC and the National Institute of Standards and Technology (NIST), but both organizations rely on very similar approaches to meter accuracy testing. In virtually all markets outside of North America, governments and manufacturers use test methods and standards developed by the International Organization for Legal Metrology (OIML). Each of these test methods is described in more detail below.

**American Water Works Association**

The AWWA M6 manual includes a recommended procedure for testing water meter accuracy (AWWA 2012). The basic approach recommended by AWWA involves passing a known volume of water (test draft) through the meter at specific flow rates (minimum, normal, and maximum) and comparing the known volume with that registered by the meter. AWWA M6 also includes a recommendation for the minimum volume that should be used as a test draft, to reduce uncertainty associated with the value of the known volume and thus to minimize error in the determination of the meter's accuracy.

AWWA also publishes a series of water meter standards for different categories of meter types, including bronze-case positive displacement (C700), plastic-case positive displacement (C710), single jet (C712), multi-jet (C708), and fluidic oscillator (C713). Additional standards for emerging, non-mechanical meters are currently under development. AWWA standards include recommendations for a large number and variety of meter properties, including values for the minimum, normal, and maximum flow rates to be used to test each size and type of meter, as well as the recommended accuracy limits within which meter performance should fall.

AWWA does not itself perform testing, certify products as meeting its published standards, or certify that laboratories perform testing in accordance with its recommended procedures.

**California Public Utilities Commission**

In Order 103-A, CPUC prescribes minimum requirements for testing water meters to be used in the service connections of for-profit water utilities (CPUC 2009). Despite minor differences in approach, Order 103-A essentially requires the use of AWWA test methods.

**National Institute of Standards and Technology**

The NIST Handbook 44 includes specifications and test methods for a variety of measuring devices, including water meters (NIST 2012, Chapter 3.36). The test method for determining water meter accuracy prescribed in Handbook 44 are substantively equivalent to the recommendations of AWWA M6 and the individual AWWA meter standards, but presented in a format more consistent with test methods for other devices. The NIST method also includes quantitative requirements for the repeatability of the test results that are not included in AWWA test methods (NIST 2012, Table T.1.1).

The National Conference on Weights and Measures (NCWM) partners with NIST to develop Handbook 44. NCWM also conducts a National Type Evaluation Program (NTEP), which conducts testing of devices according to the standards and test methods prescribed in Handbook 44. There are currently seven laboratories in North America authorized to evaluate devices for compliance with Handbook 44, including the CA DMS. CA DMS' Field Reference Manual describes California's implementation of Handbook 44 pursuant to 4 CCR § 4000.

**International Organization for Legal Metrology**

OIML publishes the R49 standard, which includes both water meter performance standards and testing procedures (OIML 2006). OIML's R49 standard replaced EN 14154, which replaced International Organization for Standardization (ISO) 4064. R49 is considered authoritative for virtually all countries outside of North America, but employs a very different framework that is completely independent of that provided by AWWA and NIST.

#### 4.1.2 Proposed Test Methods

The proposed test method for the water meter standards recommended in this report is NIST Handbook 44, Section 3.36 with three modifications:

1. An additional, lower test flow rate (CEC Test Flow Rate) equal to one quarter of the current minimum test flow rate will be used to test any meter type and size combination where the proposed standard establishes an accuracy limit for a flow rate lower than the minimum flow rate specified in Handbook 44;
2. The range of accuracy measurements in repeated tests at the CEC Test Flow Rate of the same meter type will be required to fall within a specific limit; and
3. The test volume of water to be used for testing meters at the CEC Test Flow Rate will be required to be of sufficient size to ensure that the total equipment measurement error is within a specific limit.

Please see Section 9.2 for details on the specific modifications recommended above.

### 4.2 Water & Energy Use per Unit for Non-Qualifying Products

This section describes the water and energy use for non-qualifying products—products that do not meet the proposed standard described in Section 9.1of this report.

#### 4.2.1 Water Use

To determine the unit water use of non-qualifying meters, the CASE Team calculated the total annual statewide flow of water that would not be registered by meters incapable of meeting the proposed accuracy standards. Richards, Johnson and Barfuss (2010) described two methods for performing such a calculation: the "quantified leaks" method and the "flow profile" method. These methods served as a template for the calculations used in this report.

Both methods require that the unregistered flow be calculated for each meter type (combination of measurement technology and size), weighted according to the distribution of each meter type throughout the state. The distribution of meter types throughout the state is discussed later in this section, with the underlying data used for calculations in this report shown in Appendix B:.

In the quantified leaks approach, three vectors must be multiplied to calculate the unregistered flow for a given meter type: 1) the vector consisting of the low flow rates of interest; 2) the proportion of all household leaks that occur at the low flow rates of interest; and 3) the inaccuracy[1] of that meter type at the low flow rates of interest. The product of those vectors must be further reduced to account for two factors: 1) not all homes will have leaks; and 2) some low flows will be coincident with other flows, increasing the total flow and resulting in accurate registration by the meter. Finally, a conversion factor must be used to convert the flow rate to gallons per year. Table 4.1 presents a sample calculation for determining the unregistered flow passing through a non-qualifying 5/8" x 3/4" oscillating piston meter.

The flow profile approach is similar to the quantified leaks approach, but instead of accounting for the fraction of homes with leaks, the flow profile method relies on calculating the total flow through each meter type. In the flow profile method, the leak distribution vector is replaced with a flow distribution vector representing the proportion of all flows that occur at the flow rates of interest. Table 4.2 presents a sample calculation for determining the unregistered flow passing through a non-qualifying 5/8" x 3/4" oscillating piston meter.

The distribution of leakage flows, used in the quantified leaks method, and the total flow through all residential meters in California, used in the flow profile method, was derived from the California Single Family Water Use Efficiency study sponsored by the California Department of Water Resources (DeOreo et al. 2011). An example distribution of flows was derived from Richards, Johnson, and Barfuss (2010). The average accuracy of meters not meeting the proposed standards was determined using the results of a large battery of meter accuracy tests performed at various flow rates (Barfuss, Johnson & Neilson 2011). Following Richards, Johnson, and Barfuss (2010), 25 percent of all homes were assumed to have leaks and 10 percent of all leaks were assumed to be coincident with large flows.

To estimate the average unregistered flow per meter in California, the flows through each meter type must be weighted according to the distribution of each meter type throughout the state. The distribution of meter sizes and types in California was first estimated assuming that data provided by East Bay Municipal Utility District (EBMUD 2012) is representative of the statewide inventory (see Appendix B:).

To determine the potential impact of differences between the statewide distribution of meter sizes and types and EBMUD's meter population, a series of scenarios reflecting alternative distributions were developed and the water and energy use calculated for each scenario. The scenario definitions were developed to capture the likely possible range of variation in size and meter type composition, using EBMUD data as a baseline.

Two size scenarios were used: EBMUD, reflecting the distribution of meter sizes in EBMUD territory; and EVEN, a uniform distribution of meter sizes. Three meter type scenarios were used: EBMUD, reflecting the distribution of meter types in EBMUD territory; MORE DP, reflecting a distribution in which displacement piston meters represent a significantly higher proportion of all positive displacement meters than is the case among EBMUD's meters; and MORE MJ, reflecting a distribution in which multi-jet meters represent a significantly higher proportion of the total meter population. The meter distribution for each scenario is shown in Appendix B:.

The flow profile calculation method and the EVEN meter size and EBMUD type distributions are used as the basis for the analysis and conclusions presented throughout this report because that

[1] "Inaccuracy" is calculated as (1 – *accuracy*), where *accuracy* is the fraction of the true volume that is registered by the meter at a particular flow rate.

combination of assumptions produced the lowest estimate of the savings potential associated with the proposed meter accuracy standards. The implications of using the quantified leak method and alternative meter size and type distribution scenarios are presented in Section 7.

#### 4.2.2 Energy Use

Although non-mechanical service meters do not typically consume energy directly, the water passing through them can be understood as representing “embedded” energy consumption. The energy consumption embedded in water is defined as the energy required to supply, convey, make water potable, as well as deliver, collect, and treat wastewater. For this analysis, it was assumed that every million gallons of water passing through a residential service meter in California represents 9,032 kilowatt hours (kWH) of electricity use. This value reflects the weighted statewide average of the energy embedded in water used indoors (includes wastewater energy) and outdoors (excludes wastewater energy). Appendix A: describes the methodology for calculating the embedded energy value. Table 4.3 summarizes the average water and energy consumption associated with non-qualifying meters in California.

**Table 4.1 Sample "Quantified Leaks" Calculation of Water Use per Meter for Non-qualifying Products (Oscillating Piston, 5/8" x 3/4")**

| Meter Type | Meter Size | Fraction of Households with Water Leak[a] | X | Fraction of Leaks That Do Not Coincide with Larger Flows[a] | X | Flow Rate (gallons/min) | X | Proportional Distribution of Leakage Flows at Low Flow Rates[b] | X | (1 - Accuracy of Meter at Low Flow Rates)[c] | | X | Conversion Factor for Gallons/Year (min/hr X hr/day X day/year) | = | Unregistered Flow (gallons/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oscill. Piston | 5/8" x 3/4" | 0.25 | X | 0.9 | X | 1/64<br>1/32<br>1/16<br>1/8<br>1/4<br>1/2 | X | 0.151<br>0.144<br>0.214<br>0.210<br>0.066<br>0.138 | X | (1- | 0.000<br>0.003<br>0.921<br>0.976<br>0.997<br>1.003 | ) X | 60 X 24 X 365 | = | **2,449** |

Sources:
[a] Richards, Johnson, & Barfuss (2010)
[b] DeOreo et al. (2011)
[c] Barfuss, Johnson, & Neilson (2011)

**Table 4.2 Sample "Flow Profile" Calculation of Water Use per Meter for Non-qualifying Products (Oscillating Piston, 5/8" x 3/4")**

| Meter Type | Meter Size | Share of Flow Through Meter Type[a] | | Fraction of Leaks That Do Not Coincide with Larger Flows[b] | | Flow Rate (gallons/min) | | Proportional Distribution of Flows at Low Flow Rates[b] | | (1 - Accuracy of Meter at Low Flow Rates)[c] | | | | Total Water Flow To Meter Type (gallons/ year/meter)[d] | | Unregistered Flow (gallons/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Osc. Piston | 5/8" x 3/4" | 0.023 | X | 0.9 | X | 1/64 | X | 0.0025 | X | (1- | 0.000 | ) | X | 4.56E+06 | = | **1,162** |
| | | | | | | 1/32 | | 0.0025 | | | 0.002 | | | | | |
| | | | | | | 1/16 | | 0.0075 | | | 0.369 | | | | | |
| | | | | | | 1/8 | | 0.01 | | | 0.836 | | | | | |
| | | | | | | 1/4 | | 0.0125 | | | 0.948 | | | | | |
| | | | | | | 1/2 | | 0.015 | | | 0.996 | | | | | |

Sources:

[a] Calculated as meter type population/total meter population; meter type distributions estimated based on EBMUD 2012.

[b] Richards, Johnson, & Barfuss (2010)

[c] Barfuss, Johnson, & Neilson (2011)

[d] Calculated as total California single family home residential water flow from DeOreo et al. (2011) divided by meter type population (see note a)

**Table 4.3 Average Water & Energy Use for Non-Qualifying Products**

| Product Class | Unit Water Consumption (gal/yr) | Embedded Electricity Consumption (kWh/yr) |
|---|---|---|
| Average of All Water Meter Types | 1,391 | 13 |

Sources: Richards, Johnson, & Barfuss (2010); DeOreo et al. (2011); Barfuss, Johnson, & Neilson (2011); EBMUD (2012); CEC (2006); U.S. Census (2003); US Census (2011); see text on Page 11 for details.

## 4.3 Efficiency Measures

An efficient water meter is defined in this analysis as a product that registers the volume of water passing through it at the flow rate, and within the accuracy limits, specified by the proposed standard for that meter type. See Section 2 for an explanation of how water and energy savings are captured by more accurate water meters. The flow rates and accuracy requirements vary by meter technology and size and are listed in Section 9.2.

## 4.4 Water & Energy Use per Unit for Qualifying Products

This section describes the water and energy use for qualifying products—products that meet the proposed standard described in Section 9.1of this report. A method similar to that described in Section 4.2 for non-qualifying products was employed to determine the water and energy use per unit for qualifying products. Instead of multiplying the leakage flow vectors (quantified leaks method) or the flow distribution vectors (flow profile method) by the inaccuracy values of non-qualifying products, the inaccuracy values of the qualifying products were used (Barfuss, Johnson, & Neilson 2011). Table 4.4 and Table 4.5 present sample calculations for determining the annual unregistered flow passing through a qualifying 5/8" x 3/4" oscillating piston meter using the quantified leaks and flow profile calculation methods, respectively.

The flow profile method tended to produce lower estimates of the savings for the proposed standards. Therefore, to generate a conservative estimate of the benefits associated with the standards case, the flow profile method was used to develop the analysis and conclusions presented in this report (see also Figure 6.1in Section 6 for more information on the effect of different calculation methods and meter size and distribution scenarios on the estimate of the benefits of the proposed standard). Table 4.6 summarizes the average water and energy consumption associated with qualifying meters in California.

**Table 4.4 Sample "Quantified Leaks" Calculation of Water Use per Meter for Qualifying Products (Oscillating Piston, 5/8" x 3/4")**

| Meter Type | Meter Size | Fraction of Households with Water Leak[a] | | Fraction of Leaks That Do Not Coincide with Larger Flows[a] | | Flow Rate (gallons/min) | | Proportional Distribution of Leakage Flows at Low Flow Rates[b] | | (1 - Accuracy of Meter at Low Flow Rates)[c] | | | Conversion Factor for Gallons/Year (min/hr X hr/day X day/year) | | Unregistered Flow (gallons/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Osc. Piston | 5/8" x 3/4" | 0.25 | X | 0.9 | X | 1/64<br>1/32<br>1/16<br>1/8<br>1/4<br>1/2 | X | 0.151<br>0.144<br>0.214<br>0.21<br>0.066<br>0.138 | X | (1- | 0.000<br>0.003<br>0.921<br>0.976<br>0.997<br>1.003 | ) X | 60 X 24 X 365 | = | **989** |

Sources:
[a] Richards, Johnson, & Barfuss (2010)
[b] DeOreo et al. (2011)
[c] Barfuss, Johnson, & Neilson (2011)

**Table 4.5 Sample "Flow Profile" Calculation of Water Use per Meter for Qualifying Products (Oscillating Piston, 5/8" x 3/4")**

| Meter Type | Meter Size | Share of Flow Through Meter Type[a] | | Fraction of Leaks That Do Not Coincide with Larger Flows[b] | | Flow Rate (gallons/min) | | Proportional Distribution of Flows at Low Flow Rates[b] | | (1 - Accuracy of Meter at Low Flow Rates)[c] | | Total Water Flow To Meter Type (gallons/ year/meter)[d] | | Unregistered Flow (gallons/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Osc. Piston | 5/8" x 3/4" | 0.023 | X | 0.9 | X | 1/64 | X | 0.0025 | X | (1- 0.000 ) | X | 4.56E+06 | = | **559** |
| | | | | | | 1/32 | | 0.0025 | | 0.003 | | | | |
| | | | | | | 1/16 | | 0.0075 | | 0.921 | | | | |
| | | | | | | 1/8 | | 0.01 | | 0.976 | | | | |
| | | | | | | 1/4 | | 0.0125 | | 0.997 | | | | |
| | | | | | | 1/2 | | 0.015 | | 1.003 | | | | |

Sources:
[a] Richards, Johnson, & Barfuss (2010)
[b] DeOreo et al. (2011)
[c] Barfuss, Johnson, & Neilson (2011)

**Table 4.6 Average Water & Energy Use for Qualifying Products**

| Product Class | Unit Water Consumption (gal/yr) | Embedded Electricity Consumption (kWh/yr) |
|---|---|---|
| Average of All Water Meter Types | 1,013 | 9 |

Sources: Richards, Johnson, & Barfuss (2010); DeOreo et al. (2011); Barfuss, Johnson, & Neilson (2011); EBMUD (2012); CEC (2006); US Census (2003); US Census (2011); see text for details.

# 5 Market Saturation & Sales

## 5.1 Current Market Situation

California law enacted by AB 2572 requires that all water service connections be metered by 2025. The annual sales of water meters over time can be estimated by adding up the meters that must be replaced each year based on a typical meter lifetime of 15 years, the meters that will be installed each year for the purpose of complying with AB 2572, and the meters that will be installed for newly built homes each year.

This analysis assumes that water utilities will achieve 90 percent compliance with AB 2572 at single family homes by 2030, from a starting point of 75 percent compliance in 2012. To estimate the number of homes that will be built each year, this analysis relies on data provided by the California Department of Finance on population growth and the average number of people living in single family homes in California (a value which does not vary greatly over time).

Table 8.1 shows the annual sales and stock of water meters in California.

**Table 5.1 California Water Meter Stock and Sales - 2013**

| Product Class | Annual Sales[a] | Stock[b] |
|---|---|---|
| Water Meters in Single Family Homes | 829,432 | 10,640,588 |

[a] Water meter annual sales were calculated as the sum of new home installations, replacements of existing meters, and retrofits of homes not previously having meters. New homes construction was estimated using projected population growth between 2011 (US Census 2011) and 2030 (DOF 2012) and the ratio of people to single family homes in California (US Census 2003). The meter replacement rate assumes meter lifetime of 15 years. The retrofit rate was calculated assuming 90% compliance with AB 2572 by 2030.

[b] Water meter stock was estimated based on the state population (US Census 2011) and the ratio of people to single family homes (US Census 2003), assuming 75% of all homes are metered as of 2012.

### 5.1.1 Qualifying and Non-Qualifying Products

Meter accuracy varies by measurement technology, size, and manufacturer. A study funded by the nonprofit Water Research Foundation in conjunction with the United States (U.S.) Environmental Protection Agency (EPA) provides information about meter performance by measurement technology and size (Barfuss, Johnson & Neilson 2011). The figures in Appendix C depict the average performance of meters of different sizes and technologies from a variety of unidentified manufacturers based on the Water Research Foundation study (Barfuss, Johnson, & Neilson 2011). The fraction of qualifying products for each meter type and size are shown in Table 8.1. The experimental data demonstrate that many products currently on the market are capable of meeting the proposed standards. The minimum flow rate used in the study varied by meter technology and size, so independent empirical data on the fraction of qualifying products is not available for all product categories. It should be noted, however, that meter product information publicly available from a variety of manufacturers contain meter accuracy curves that corroborate feasibility of the proposed standards.

**Table 5.2 Qualifying Products by Meter Technology and Size**

| Meter Technology | Meter Size | Number Tested | Number Qualifying | % Qualifying |
|---|---|---|---|---|
| Positive Displacement | 5/8" x 3/4" | 78 | 43 | 55% |
| | 3/4" | 48 | 35 | 73% |
| | 1" | 48 | 47 | 98% |
| | 1 1/2" | 6 | 5 | 83% |
| | 2" | 6 | 3 | 50% |
| Multi-Jet | 5/8" x 3/4" | 43 | 6 | 14% |
| | 3/4" | 33 | 16 | 48% |
| | 1" | 33 | 25 | 76% |
| | 1 1/2" | 4 | 4 | 100% |
| | 2" | 4 | 4 | 100% |
| Single Jet | 5/8" x 3/4" | 24 | 5 | 21% |
| | 3/4" | 12 | 10 | 83% |
| | 1" | 6 | 6 | 100% |
| | 1 1/2" | 1 | 1 | 100% |
| | 2" | 2 | 0 | 0% |

Source: Determination of qualification based on comparison of meter accuracy test results from Barfuss, Johnson, & Neilson (2011) with proposed standards.

The data from Barfuss, Johnson and Neilson (2011) in the above table is a national sample of products, but may not be representative of the percentage of qualifying products sold each year in California. In this analysis, market penetration of qualifying products in California was assumed to be 75 percent in order to develop a conservative estimate of the benefits associated with the proposed standards. Table 5.3 shows the water and electricity consumption associated with water meters in California, assuming 75 percent of the current stock are qualifying products.

**Table 5.3 California Statewide Non-Standards Water & Energy Use - 2013**

| Annual Sales | | Stock | |
|---|---|---|---|
| Water Consumption (Mgal/yr) | Embedded Electricity Consumption (GWh/yr) | Water Consumption (Mgal/yr) | Embedded Electricity Consumption (GWh/yr) |
| 980 | 8.8 | 15,000 | 130 |

Sources: Richards, Johnson, & Barfuss (2010); DeOreo et al. (2011); Barfuss, Johnson, & Neilson (2011); EBMUD (2012); CEC (2006); U.S. Census (2003); US Census (2011); DOF (2012)

## 5.2 Future Market Adoption of High Efficiency Options

While the exact distribution of qualifying and non-qualifying products currently installed in detached, single family homes is not precisely known, this analysis assumes a 3:1 split (75 percent qualifying, 25 percent non-qualifying). This analysis further assumes that the distribution will remain relatively constant in the future.

Water utilities may increasingly purchase non-mechanical water meters, which are not covered under the proposed standards. The costs of non-mechanical meters are currently several times higher than the costs of mechanical meters, limiting their market share. If non-mechanical meters are able to approach price parity with mechanical meters, penetration of non-mechanical meters is likely to increase significantly. Many non-mechanical meters demonstrate exceptional accuracy at low flow rates and would be expected to outperform even the best-performing mechanical meters. However, non-mechanical meters may have other drawbacks, such as a lag in the commencement of flow measurement. Lags may result in under-registration of transient flows, leading to a problem similar to that created by inaccurate meters. The potential risks and benefits of non-mechanical water meters for statewide water and energy consumption merits further study.

Apart from a potential increase in the market share of non-mechanical meters, little change is expected in the relative distribution of qualifying and non-qualifying meters in the California market. It is possible that increasing awareness of variations in meter accuracy, which studies such as that conducted by Barfuss, Johnson and Neilson (2011) have helped to foster, will increase the penetration of qualifying products even in the absence of standards. Many water utilities, however, value the stability of established relationships with meter vendors and manufacturers and would be unlikely to significantly change purchasing patterns in the absence of the proposed standards.

Although the relative distribution of qualifying and non-qualifying meters is not expected to change greatly in the medium term, the requirement in the California Building Standards Code requiring that new homes include fire sprinklers (Title 24, CCR, Part 2.5; effective January 1, 2011) is likely driving average meter sizes up.

Jurisdiction over the required approach for metering water supplied for residential fire sprinklers lies with local fire authorities, cities, counties, and water purveyors. In many cases, jurisdictions allow water meters to be sized according to the combined flow needed for both domestic and fire sprinkler use.[2] As a result, the average residential service meter size in California is probably

[2] The National Fire Protection Association, as well as a group of Subject Matter Experts convened by the California State Fire Marshal, recommends that water be supplied for use by residential fire sprinklers via a single meter with a

increasing. Since larger meters are associated with lower accuracy at low flow rates, the total amount of unregistered flow is anticipated to increase.

Three of the six statewide meter composition scenarios described in Section 4.2 (the three EVEN scenarios) assume that larger meter sizes (1", 1 ½", and 2") represent a much larger fraction of California's meter population than what is reflected in the EBMUD data on which this analysis is based. Each of these three scenarios results in greater water and energy savings than the corresponding EBMUD meter size distribution scenarios. Therefore, if the residential fire sprinkler requirement is causing average meter size to increase, the standards proposal could be expected to yield even greater water and energy savings than what is presented in this report.

## 5.3 Statewide California Energy Savings

The analysis above calculates the annual water savings captured by replacing a non-qualifying meter with a qualifying meter as the difference between the unregistered flows. The energy associated with water savings is calculated using the embedded energy value (9,032 kWh/million gallons of water) introduced in Section 4.2.2 of this document, and detailed in Appendix A:.

The statewide potential water savings is computed as the difference in the annual unregistered flow through two modeled meter populations: the non-standards case and the standards case. The non-standards case is a population of meters whose mix of non-qualifying and qualifying meters does not change over time (assumed to be 50 percent, as stated above). The standards case is a population of meters whose mix of non-qualifying and qualifying meters is shaped by a rule that allows only qualifying products to be added to the population as of January 1, 2015 (the "effective date"). The meter stock growth model is described in Section 5.1 of this report.

Table 5.4 presents the estimated water and energy use for the non-standards case at two points in time: the first year after the effective date; and after the entire meter stock has been replaced. Similarly, Table 5.5 presents the estimated water and energy use for the standards case. Table 5.6 presents the difference between the non-standards case and the standards case, which is the estimated statewide savings potential for the proposed standard.

**Table 5.4 California Statewide Non-Standards Case Water & Energy Use by Water Meters**

| | **Annual Sales** | | **Stock** | |
|---|---|---|---|---|
| Year | Water Consumption (Mgal/yr) | Embedded Electricity Consumption (GWh/yr) | Water Consumption (Mgal/yr) | Embedded Electricity Consumption (GWh/yr) |
| 2015 (Effective Year) | 980 | 8.8 | 15,000 | 130 |
| 2029 (Stock Turnover) | 1,000 | 9.0 | 15,000 | 130 |

Sources: Richards, Johnson, & Barfuss (2010); DeOreo et al. (2011); Barfuss, Johnson, & Neilson (2011); EBMUD (2012); CEC (2006); US Census (2003); US Census (2011); DOF (2012)

domestic shut-off valve. The domestic shutoff valve diverts all flow to fire sprinklers when they are triggered, allowing meters to be sized according to the anticipated domestic flow, without adding the sprinkler flow.

**Table 5.5 California Statewide Standards Case Water & Energy Use by Water Meters**

| Year | Annual Sales | | Stock | |
|---|---|---|---|---|
| | Water Consumption (Mgal/yr) | Embedded Electricity Consumption (GWh/yr) | Water Consumption (Mgal/yr) | Embedded Electricity Consumption (GWh/yr) |
| 2015 (Effective Year) | 900 | 8.1 | 15,000 | 130 |
| 2029 (Stock Turnover) | 910 | 8.2 | 14,000 | 120 |

Sources: Richards, Johnson, & Barfuss (2010); DeOreo et al. (2011); Barfuss, Johnson, & Neilson (2011); EBMUD (2012); CEC (2006); US Census (2003); US Census (2011); DOF (2012)

**Table 5.6 California Statewide Standards Case Water & Energy Savings by Water Meters**

| Year | Annual Sales | | Stock | |
|---|---|---|---|---|
| | Water Savings (Mgal/yr) | Embedded Electricity Savings (GWh/yr) | Water Savings (Mgal/yr) | Embedded Electricity Savings (GWh/yr) |
| 2015 (Effective Year) | 84 | 0.76 | 84 | 0.76 |
| 2029 (Stock Turnover) | 85 | 0.77 | 1,300 | 11 |

Sources: Richards, Johnson, & Barfuss (2010); DeOreo et al. (2011); Barfuss, Johnson, & Neilson (2011); EBMUD (2012); CEC (2006); US Census (2003); US Census (2011); DOF (2012)

### 5.3.1 The Effect of Price Elasticity on Estimated Water Savings

Some customers may not choose to repair leaks or otherwise modify their water consumption behavior even after experiencing an increase in water bills caused by more accurate measurement of low flows. The effect of such behavior can be estimated using an elasticity value from economic studies on consumer responses to water prices. For the sake of illustration, assume an elasticity value of -0.51 (Espey 1997). An elasticity value of -0.51 means that the expected change in the percentage of water an end-user consumes is about half the percentage change in the price the end-user experiences.

Most water utilities in California have usage-based rates that increase with increased usage. Assuming a rate structure similar to that used by EBMUD, a typical end-user would notice a 1 to13 percent water bill increase upon the replacement of a non-qualifying meter with a qualifying meter, depending on the end-user's proximity to the next highest rate bin. The end-user would be expected to reduce consumption by a proportion about half as large (for an elasticity value of -0.51) as the proportion by which billing increased. End-users whose usage is not close to cutoff between rate bins would see a price increase of around 1 percent, and their response to that price increase would translate to annual water savings of about 340 gallons per meter per year, which is only a little less than the difference between the average unregistered flows of non-qualifying and qualifying meters.

For end-users whose water usage is close to the threshold of a higher usage bin, the increased registration of the qualifying meter could increase billing costs by 13 percent. An increase that high would occur if the incremental usage caused by accurately registering extended low flows pushed usage over the threshold into the higher rate bin. The result of such a large proportional increase in costs would result in an annual savings of over 4,000 gallons per year. In that case, the water savings would far exceed the difference between the unregistered flow of a non-qualifying and qualifying meter.

It should also be noted that demand responses to costs associated with leakage are not likely to follow the same pattern as responses to costs associated with water usage in general; water wasted is essentially a different product than water used for a purpose. For a marginal increase in a utility bill, consumers would be expected to reduce the total amount of leakage flows by a greater proportion than the total amount of all flows. Stopping dripping faucets and leaky toilets are assumed the least costly options for reducing water use, and would thus be the first actions taken when a consumer experiences a bill increase. Therefore, the marginal impact of billing increases on small leakage flows would be much higher than the marginal impact on usage as a whole.

In summary, price elasticity is not likely to exert a large, systematic, downward influence on an estimate of the water savings calculated as the difference between the unregistered flows of qualifying and non-qualifying meters.

Nevertheless, in order to develop a conservative estimate of the water and energy savings potential of this measure, the estimate of the average unregistered flow of qualifying meters is increased by 15 percent to account for low flows that end-users do not reduce in response to more accurate metering and billing.

### 5.4 State or Local Government Costs and Savings

There are no known additional costs to state or local governments from the implementation of the standards proposal, given the CEC's existing authority for establishing appliance standards and staffing to administer the process.

## 6 Economic Analysis

### 6.1 Incremental Cost

As discussed in Section 1, water utilities - not individual people or households - are the primary consumers of water meters. In this respect, the proposed water meter standards are similar to the energy efficiency standards DOE established for distribution transformers in 2007. The consumers of distribution transformers are electrical utilities, and DOE assessed the costs and benefits of standards from the perspective of the utilities rather than individuals or households.

Existing state policies encourage utilities to promote and support water conservation activities. The overall outcome of conservation activities will be to reduce the amount of water flowing through utilities' networks. In California, water utilities increasingly operate in a "decoupled" regulatory environment in which profits are not linked directly to sales in order to reduce disincentives to promote conservation.

Utilities that purchase water meters with greater low flow accuracy are likely to experience short term increases in revenue as previously unregistered flows are recorded and billed to individual customers. As customers respond to the price signal created by more accurate meters, total water demand will decrease. The decrease in demand will reduce both operating expenses and revenue, resulting in minimal net impact on utility revenue. Publicly owned water utilities are able to revise rates as necessary and could include anticipated demand reductions in the projections used to design future rate structures. Additionally, any incremental costs associated with purchasing meters with greater low flow accuracy would similarly be passed on to ratepayers, with no net impact on utility revenue. Therefore, the net impact of the proposed standard on water meter consumers (utilities) is likely to be neutral.

Ultimately, the costs associated with transporting, treating, and disposing of water, and the accrued savings as a result of reducing the volume of water passing through a utility's network, will be transferred to the utility's ratepayers. California water utilities are allowed to set rates that allow them to cover their operating expenses in addition to earning a reasonable return on their capital investments. Incremental changes in the amount of water flowing through a utility's infrastructure will tend to affect the utility's operating expenses. When flows are appropriately registered by customer meters, increases or decreases in flows will be compensated by changes in the revenue received by the utility. When flows are not registered by customer meters due to meter inaccuracy, the operating costs associated with providing that water is not compensated by revenue. As a result, the utility must increase rates for all customers in order to cover its expenses. It follows that if a utility begins to receive greater revenue from existing flow levels, the utility must postpone rate increases until they can be justified by increases in operating costs or capital investments.

Additionally, conservation and efficiency creates additional capacity in water and wastewater systems and therefore can postpone the need for significant investments in new infrastructure. Those costs would ultimately be passed on to the utility's ratepayers through rate increases. Rate increases that result from decreases in demand would be lower than rate increases required for capital improvements such as investments in new infrastructure. Therefore, in aggregate, ratepayers are likely to benefit more from the rate reduction associated with postponed capital investments than with rate increases resulting from lower sales.

## 6.2 Costs

Water meters have been manufactured for over a century. As a result, the market is quite mature and product costs are fairly uniform across manufacturers of similar meter types. Unit prices are not widely advertised, since meters are typically purchased in quantity by water utilities. Communications with manufacturers as well as industry guidance documents indicate that the cost of water meters for residential connections is around $40 per meter (Satterfield 2004).

Despite the uniformity in prices, water meter performance at low flow rates varies dramatically among technology types and manufacturers. The data in Table 5.2 and C-1 in Appendix C: show that many meters currently on the market are capable of meeting the proposed standards. Since there is no evidence of significant variation in market prices between qualifying and non-qualifying products, the incremental cost of implementing the proposed standards is limited to the cost of testing. Testing at low flow rates is more expensive than testing at high flow rates because of the time required to pass a sufficient volume to credibly demonstrate meter performance. Outreach to meter manufacturers suggests that if CEC requires test results only for a single or small number of representatives for each model to be sold, testing costs would not significantly impact product prices.

In summary, there is no evidence that superior low flow accuracy significantly raises the cost of water meters. This analysis assumes an incremental cost of $20, or 50 percent of the assumed cost of an average meter, to develop a conservative estimate of the benefits of the proposed standard.

## 6.3 Design Life

The useful service life of a service water meter is about fifteen years (Satterfield & Bhardwaj 2004). Manufacturers typically warranty initial accuracy levels only for one year. Maintenance and water quality can both impact the performance of the meter over time, so the average life varies by water utility service territory. Water utilities often operate testing programs that, combined with information about typical customer flows, allow them to replace meters only when accuracy has deteriorated enough to produce losses that financially justify purchasing new equipment.

## 6.4 Lifecycle Cost / Net Benefit

Although no substantial difference in the cost of qualifying and non-qualifying products is anticipated, this analysis assumes an incremental cost of $20, or 50 percent of the assumed cost of an average water meter, to develop a conservative estimate of the costs and benefits of the proposed standard. Over the lifecycle of a water meter, the present value of the water and embedded electricity saved by qualifying meters exceeds the present value of the incremental cost required to purchase qualifying meters by about $30 (see Table 6.1). Statewide, the proposed standard would save over $6 million in the first year in water and electricity costs and would save about $97 million by the time the entire stock of water meters turned over (see Table 8.1).

**Table 6.1 Costs and Benefits per Unit for Qualifying Products**

| | | **Lifecycle Costs per Unit (Present Value $)** | | **Lifecycle Benefits per Unit (Present Value $)** | | |
|---|---|---|---|---|---|---|
| Product Class | Design Life (years) | Incremental Cost | **Total PV Costs** | Water Cost Savings[a] | Electricity Cost Savings | **Total PV Benefits** |
| Average of All Water Meter Types | 15 | $20 | **$20** | $46 | $2.40 | **$48** |

[a] See Appendix D: for more details regarding water and electricity rates.

**Table 6.2 Lifecycle Costs and Benefits for Qualifying Products**

| Product Class | Lifecycle Benefit / Cost Ratio[a] | Net Present Value ($)[bd] Per Unit | For First Year Sales | After Entire Stock Turnover[c] |
|---|---|---|---|---|
| Average of All Water Meter Types | 2.4 | $30 | $6,600,000 | $97,000,000 |

[a] Total present value benefits divided by total present value costs.
[b] Positive value indicates a reduced total cost of ownership over the life of the appliance.
[c] Stock Turnover NPV is calculated by taking the sum of the NPVs for the products purchased each year following the standard's effective date through the stock turnover year, i.e., the NPV of "turning over" the whole stock of less efficient products that were in use at the effective date to more efficient products, plus any additional non-replacement units due to market growth, if applicable. For example, for a standard effective in 2015 applying to a product with a 5 year design life, the NPV of the products purchased in the 5th year (2019) includes lifecycle cost and benefits through 2024, and therefore, so does the Stock Turnover NPV.
[d] It should be noted that while the proposed standard is cost-effective, it may be more cost-effective if using alternative rate structures. For example, marginal utility rates may more accurately reflect what customers save on utility bills as result of the standard.

To account for the possibility that the distribution of meter sizes and technologies throughout the state differs from the distribution in EBMUD service territory, scenarios involving alternative statewide meter distributions were developed (described in Section 4.2.1). As shown in Figure 6.1 below, the EBMUD data on which this analysis is based are very likely to generate a conservative estimate of the economic benefits of the proposed standard to the state. Figure 6.1 also shows the effect of using alternative leak and flow-based methods for calculating the water savings from the proposed standards (also described in Section 4.2.1).

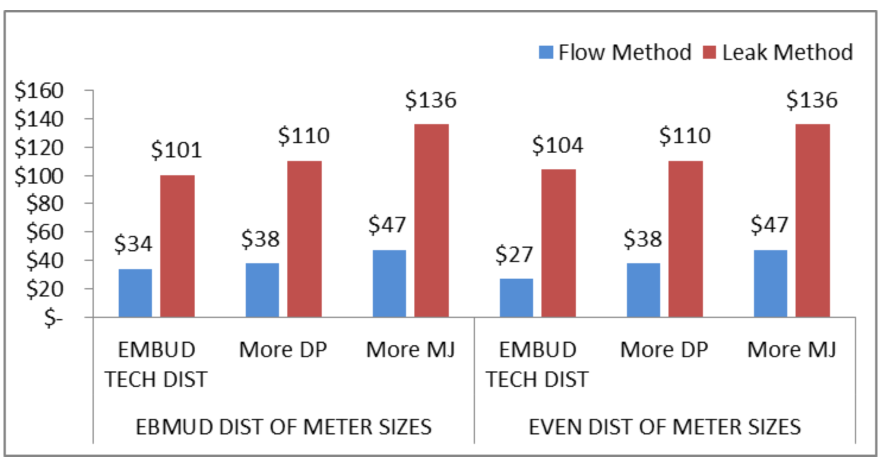


**Figure 6.1 Scenario Analysis of Net Present Value of Proposed Meter Accuracy Standards.** Values represent the net present value of the water and electricity savings in the first effective year of the standard under different combinations of assumptions about current statewide meter and technology distribution and different calculation methodologies. See Section 4.2.1 for an explanation of each scenario. The scenario with the most conservative (lowest) estimate of the benefits of the proposed standard was used as the basis for the calculations in this report.

# 7 Acceptance Issues

## 7.1 Infrastructure issues

The CA Division of Measurement Standards (DMS) currently maintains a laboratory in Sacramento that is accredited by NCWM to perform water meter testing according to the test method specified in NIST Handbook 44, Section 3.36. Since the test method recommended for evaluating compliance with the proposed standard is largely identical to the NIST method, the CA DMS laboratory would be well positioned to provide testing for the proposed standard as well. In fact, CA DMS already approves many of the same types of water meters that would be required to meet the proposed standard.

The major difference between the testing that CA DMS already performs on water meters and that required by the proposed standard is the addition of new, low CEC Test Flow Rates. Based on communications with CA DMS staff and staff at other water meter testing laboratories in California and elsewhere, the modifications to testing equipment and procedures required by the recommended test method would be minimal.

In order to ensure that the total equipment measurement error is sufficiently small while also minimizing the time required to complete the test at the new, lower CEC Test Flow Rates, the laboratory could use a scale to measure the mass of the test draft instead of measuring its volume. Gravimetric methods that use scales are typically able to provide much lower measurement error than volumetric methods that rely on calibrated tanks called "provers." Electronic sensor systems can also be used to automatically stop the flow of water once a given volume has been reached. Such systems could further reduce the incremental amount of labor required to perform testing at the CEC Test Flow Rates.

## 7.2 Existing Standards

In California, water meters at residences served by publicly-owned water utilities are the only residential water meters not subject to minimum legal accuracy standards. Through Order 103-A, CPUC requires that all water meters installed within the territories of for-profit water utilities meet AWWA accuracy standards (CPUC 2009). The CA DMS requires that all meters used for submetering in multifamily dwellings meet NIST accuracy standards described in Handbook 44, Section 3.36 (NIST 2012). It should be noted that meters installed in multifamily dwellings are subject to two tiers of regulation. Type approval, or approval of the basic model of each meter, is performed by CA DMS' own laboratory. Every individual meter that is actually installed must also pass inspection by a county lab that is certified by CA DMS.

The NIST standards for residential water meters are almost identical to AWWA standards. Two exceptions of note are: 1) AWWA standards require that 1.5 and 2 inch single jet meters meet their minimum accuracy standards at lower flow rates than those required by the NIST standards; and 2) for positive displacement (both nutating disc and oscillating piston) and fluidic oscillator meters, AWWA standards require a maximum over-registration of 101 percent at the minimum test flow, whereas NIST standards allow a maximum over-registration of 101.5 percent.

There is no federal standard for residential service water meter accuracy. The European Union’s Measuring Instruments Directive (MID) harmonizes the standards for a variety of measurement devices in its 27 member nations, including water meters. The requirements of MID for water meters are equivalent to OIML R49 (Himsley, personal communication).

The CEC has a mandate for taking a more aggressive approach to establishing and enforcing standards that will reduce statewide water consumption. Assembly Bill 662 (Ruskin 2007) and Assembly Bill 1560 (Huffman 2007) modified the language of the Warren-Alquist Act to give the CEC authority to set water efficiency appliance standards and required the CEC to incorporate water efficiency standards into the existing building efficiency standards (Title 24, Part 6).

The Warren-Alquist Act specifically states that the CEC may promulgate regulations "to promote the use of energy and water efficient appliances whose use, as determined by the Commission, requires a significant amount of energy or water on a statewide basis" (CEC 2013). A water meter through which no water is passing cannot be said to be in use, while a water meter through which water is passing is clearly in use. Therefore, the use of a water meter can be fairly claimed to "require water" and is therefore a legitimate subject of regulation by the CEC.

### 7.3 Stakeholder Positions

The CASE Team anticipates some negative feedback from meter manufacturers whose current products would not meet the proposed standard. Additionally, we anticipate that several meter manufacturers will voice concern over potential cost burdens from increased testing requirements. It should be noted that some manufacturers offer warranties on their products at extended low flows well below the current AWWA minimum test flow and claim to test 100 percent of the meters at the extended low flow rate specified in the warranty.

The CASE Team anticipates that the utilities will be concerned with the impact of the proposed standard on purchase price of qualifying meters. However, since utilities also consider long-term savings when evaluating cost-effectiveness, utilities will likely be less concerned than manufacturers.

## 8 Environmental Impacts

### 8.1 Hazardous Materials

There are no known incremental hazardous materials impacts from the efficiency improvements as a result of the proposed standards.

### 8.2 Air Quality

This proposed measure is estimated to reduce total criteria pollutant emissions in California by 1,800 lbs/year in 2029, after stock turnover, as shown in Table 8.1 due to 11 GWh in reduced end user electricity consumption with an estimated value of $19,000. Criteria pollutant emission factors for California electricity generation were calculated per MWh based on California Air Resources Board data of emission rates by power plant type and expected generation mix (CARB 2010). The monetization of these criteria pollutant emission reductions is based on CARB power plant air pollution emission rate data times the dollar per ton value of these reductions based on Carl Moyer values where available, and San Joaquin Valley UAPCD "BACT" thresholds for sulfur oxides (SOx). These dollar per ton values vary significantly for fine particulates, as discussed in Appendix E: (CARB 2011a; CARB 2013a; San Joaquin Valley UAPCD 2008).

**Table 8.1 Estimated California Criteria Pollutant Reduction Benefits (lbs/year) After Stock Turnover**

| | lbs/year | Carl Moyer $/ton (2013) | Monetization |
|---|---|---|---|
| ROG | 303 | $17,000 | $2,600 |
| NOx | 1,000 | $17,000 | $9,000 |
| Ox | 110 | $18,000 | $990 |
| PM2.5 | 450 | $350,000 | $78,000 |
| **Total** | | | **$19,000** |

## 8.3 Greenhouse Gases

Table 8.1 shows the annual and stock GHG savings by year and the range of the societal benefits as a result of the standard. By stock turnover in 2029, this standard would save about 4,900 metric tons of CO2e annually, equal to between $310,000 and $940,000 of societal benefits. The total avoided CO2e is based on CARB's estimate of 437 MT CO2e/GWh (and 53 MT CO2e/millon therms) of energy savings from energy efficiency improvements, and includes additional electrical transmission and distribution loses estimated at 7.8% (CARB 2008). The range of societal benefits per year is based on a range of annual dollars per metric ton of CO2 (in 2013 dollars) sourced from the U.S. Government's Interagency Working Group on Social Cost of Carbon (SCC) (Interagency Working Group 2013). The low end uses the average SCC, while the high end incorporates SCC values which use climate sensitivity values in the 95th percentile, both with 3 percent discount rate. It is important to note that this range can be lower and higher, depending on the approach used, so policy judgments should consider this uncertainty. See Appendix F: for more details regarding this and other approaches.

**Table 8.2 Estimated California Statewide Greenhouse Gas Savings and Cost Savings for Standards Case**

| Year | Annual GHG Savings (MT of CO2e/yr) | Stock GHG Savings (MT of CO2e/yr) | Value of Stock GHG Savings - low ($) | Value of Stock GHG Savings - high ($) |
|---|---|---|---|---|
| 2013 | 0 | 0 | $0 | $0 |
| 2014 | 0 | 0 | $ 0 | $0 |
| 2015 | 320 | 320 | $15,000 | $43,000 |
| 2016 | 320 | 650 | $31,000 | $90,000 |
| 2017 | 320 | 970 | $48,000 | $140,000 |
| 2018 | 330 | 1,300 | $65,000 | $190,000 |
| 2019 | 330 | 1,600 | $83,000 | $250,000 |
| 2020 | 330 | 1,900 | $100,000 | $320,000 |
| 2021 | 330 | 2,300 | $120,000 | $370,000 |
| 2022 | 330 | 2,600 | $140,000 | $430,000 |
| 2023 | 330 | 2,900 | $160,000 | $490,000 |
| 2024 | 330 | 3,300 | $190,000 | $560,000 |
| 2025 | 330 | 3,600 | $210,000 | $630,000 |
| 2026 | 330 | 3,900 | $230,000 | $700,000 |
| 2027 | 330 | 4,200 | $260,000 | $780,000 |
| 2028 | 330 | 4,600 | $280,000 | $860,000 |
| 2029 | 330 | 4,900 | $310,000 | $940,000 |

# 9 Recommendations

## 9.1 Recommended Standards Proposal

The proposed standards require that all positive displacement, single jet, and multi-jet cold water meters of sizes 5/8" x 3/4", 3/4", and 1" meet minimum accuracy standards. Additionally, positive displacement meters of sizes 1/2", 1/2" x 3/4", and 5/8"as well as both positive displacement and single jet meters of sizes 1 1/2" and 2" would also be required to meet minimum accuracy standards. The accuracy standards will be similar to those outlined in NIST Handbook 44, Section 3.36, but with lower test flow rates ("CEC Test Flow") equal to 25 percent of the current minimum flow rate, and different accuracy requirements (80 percent). The proposed standards would also require that all meters between 1/2" and 2" not covered by the proposed minimum accuracy standards (e.g., non-mechanical, static meters) be tested, with results reported to the CEC.

## 9.2 Proposed Changes to the Title 20 Code Language

**1602. Definitions**

**General**

"NIST" means the National Institute of Standards and Technology.

"Water meter" means a device used to measure the cumulative quantity of water passing through it, generally applicable to meters installed in residences or business establishments for cold, potable water and excluding batching and industrial process meters.

**Water Meters**

"Accuracy" means the percentage of a known quantity of water passing through a water meter (test draft) at a particular flow rate that is indicated by the water meter.

"Fluidic oscillator meter" means a water meter in which registration of the quantity of water passing through it is affected by way of recording the frequency of an oscillation in the stream water entering the measuring chamber that is created by the meter itself.

"Multi-jet water meter" means a water meter in which the measuring element takes the form of a multi-blade rotor mounted on a vertical spindle in which water enters a cylindrical measuring chamber through several tangential orifices and which registers the quantity of water passing through it by recording the revolutions of a rotor set in motion by the force of flowing water striking the blades.

"Over-registration" means the percentage more than a known quantity of water passing through a water meter (test draft) that is indicated by the water meter.

"Positive displacement meter" means a water meter in which registration of the quantity of water passing through it is affected by way recording the revolutions of a spindle or piston whose motion is caused by the unidirectional displacement of a volume of water equal to the void volume of the measuring chamber.

"Single jet water meter" means a water meter in which the measuring element takes the form of a multiblade rotor mounted on a vertical spindle in which water enters a cylindrical measuring chamber through a single orifice and which registers the quantity of water passing through it by recording the revolutions of a rotor set in motion by the force of flowing water striking the blades.

"Test draft" means a known quantity of water used to test the accuracy of water meters.

"Tolerance" means a value fixing the limit of allowable error or departure from true performance or value.

"Total equipment measurement error" means the absolute value of the difference between the true quantity of water in a test draft and the value indicated through direct measurements, such as measurements of volume or mass.

"Under-registration means the percentage less than a known quantity of water passing through a water meter (test draft) that is indicated by the water meter.

The following standards are incorporated by reference in Section 1602:

National Institute of Standards and Technology (NIST)

| | |
|---|---|
| Handbook 44, Section 3.36 (2012) | Specifications, Tolerances, and Other Technical Requirements for Measuring Devices |
| Copies available from: | National Institute of Standards and Technology<br>100 Bureau Drive, Stop 2300<br>Gaithersburg, MD 20899-2300 |

**Test Standards**

**1604. Test Methods for Specific Appliances.**

**Water Meters**

The test methods for water meters are shown in Table X.

Table X.

| Appliance | Test Method |
|---|---|
| water meters intended for use at service connections | NIST Handbook 44, Section 3.36 (2012) with the following modifications:<br>Meter accuracy will be tested only at the applicable flow rates indicated below: |

| Type | Size | CEC Test Flow Rate (gallons/minute) |
|---|---|---|
| Positive Displacement | 1/2" | 0.0625 |
| | 1/2" x 3/4" | 0.0625 |
| | 5/8" | 0.0625 |
| | 5/8" x 3/4" | 0.0625 |
| | 3/4" | 0.125 |
| | 1" | 0.1875 |
| | 1 1/2" | 0.375 |
| | 2" | 0.5 |
| Single Jet | 5/8" x 3/4" | 0.0625 |
| | 3/4" | 0.125 |

| | | |
|---|---|---|
| | 1" | 0.1875 |
| | 1 1/2" | 0.125 |
| | 2" | 0.1250 |
| Multi-jet | 5/8" x 3/4" | 0.0625 |
| | | 0.125 |
| | | 0.1875 |
| Other (Fluidic Oscillator, other non-mechanic or static meters) | 1/2" | 0.0625 |
| | 1/2" x 3/4" | 0.0625 |
| | 5/8" | 0.0625 |
| | 5/8" x 3/4" | 0.0625 |
| | 3/4" | 0.125 |
| | 1" | 0.1875 |
| | 1 1/2" | 0.375 |
| | 2" | 0.5 |

The test draft used for testing meter accuracy at CEC Test Flow Rates must be of sufficient size to ensure that the total equipment measurement error is no greater than 0.25%.

When multiple tests of the same basic model are conducted at a single CEC Test Flow Rate, the range of test results shall not exceed 6%.

The percent registration of the test draft must be reported within 0.01% of the mean of at least three tests.

## 1605.3. State Standards for Non-Federally-Regulated Appliances.

### Water Meters

i. The accuracy of water meters shall be within the applicable tolerances shown in Table X for the applicable CEC Test Flow Rate listed in Section 1604.

**Table X. Standards for Water Meters**

| Type | Size | Maximum Over-registration at Applicable CEC Test Flow Rate | Maximum Under-registration at Applicable CEC Test Flow Rate |
|---|---|---|---|
| Positive Displacement | 1/2" | 1% | 20% |
| | 1/2" x 3/4" | 1% | 20% |
| | 5/8" | 1% | 20% |
| | 5/8" x 3/4" | 1% | 20% |
| | 3/4" | 1% | 20% |
| | 1" | 1% | 20% |
| | 1 1/2" | 1% | 20% |
| | 2" | 1% | 20% |
| Single Jet | 5/8" x 3/4" | 1.5% | 20% |
| | 3/4" | 1.5% | 20% |
| | 1" | 1.5% | 20% |
| | 1 1/2" | 1.5% | 20% |
| | 2" | 1.5% | 20% |
| Multi-jet | 5/8" x 3/4" | 3% | 20% |
| | 3/4" | 3% | 20% |
| | 1" | 3% | 20% |

**§ 1606. Filing by Manufacturers; Listing of Appliances in Database.**

**Table X. Data Submittal Requirements for Inclusion in Table V of Title 20.**

| Appliance | | Required Information | Permissible Answers |
|---|---|---|---|
| V | Service Water Meters | *Type | Positive Displacement, Single Jet, Multi-jet, Fluidic Oscillator [others possible] |
| | | *Size | 1/2", 1/2 " x 5/8", 5/8" x 3/4", 3/4", 1", 1 1/2", 2" |
| | | Percent registration at CEC Test Flow Rate | |
| | | Registration Range at CEC Test Flow Rate | |
| | | Total Equipment Measurement Error for CEC Test Flow Rate | |

***"Identifier" information as described in Section 1602(a).**

## 9.3 Implementation Plan

The expected implementation for this standards proposal is for the CEC to proceed with its appliance standards rulemaking authority, from pre-rulemaking and rulemaking through adoption, and for manufacturer compliance upon effective date.

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# Appendix A: Embedded Energy in Water

The embedded energy value used in the analysis is 9,032 kWh/million gallons of water (MG). This value was derived from a CEC PIER study (CEC 2006), which states the embedded energy values shown in the table below "are sufficient for informing policy and prioritization of research and development investments."

**Table A.1 Recommended Embedded Energy Estimates**

| | Indoor Uses | | Outdoor Uses | |
|---|---|---|---|---|
| | Northern California kWh/MG | Southern California kWh/MG | Northern California kWh/MG | Southern California kWh/MG |
| **Water Supply and Conveyance** | 2,117 | 9,727 | 2,117 | 9,727 |
| **Water Treatment** | 111 | 111 | 111 | 111 |
| **Water Distribution** | 1,272 | 1,272 | 1,272 | 1,272 |
| **Wastewater Treatment** | 1,911 | 1,911 | 0 | 0 |
| **Regional Total** | 5,411 | 13,022 | 3,500 | 11,111 |

Source: CEC 2006. Table 7.

The total regional values shown in Table A.1 were weighted based on the population in Northern and Southern California in 2011 (U.S. Census Bureau).[3] Approximately 53 percent of water use in California single family homes is for outdoor use, so the embedded energy in water passing through water meters was weighted accordingly (DeOreo et al. 2011).

The CPUC has conducted additional research on embedded energy since the CEC's 2006 report was released. However, the values presented in the CEC's 2006 report are still the most up-to-date values recommended for use to inform policies. Therefore, the authors have used the CEC's 2006 embedded energy values for this analysis.

The CPUC has made notable progress in improving understanding of the relationship between water and energy in California. The CPUC's Decision 07-12-050[4], issued December 20, 2007, authorized the largest electricity utilities to partner with water utilities and administer pilot programs that aimed to save water and energy. The Decision also authorized three studies to validate claims that saving water can save energy and explore whether embedded energy savings associated with water use efficiency are measurable and verifiable. The pilot programs succeed at demonstrating that water conservation measures also result in energy savings.

The CPUC studies were effective at obtaining a more granular understanding of how energy use varies based on a number of factors, including supply, (i.e. surface, ground, brackish, or ocean desalination), geography, and treatment technology. The authors found "that the value of energy embedded in water is higher than initially estimated in the CEC's 2005 and 2006 studies." Although the data collected for the studies is the most comprehensive set of data on energy used to meet water demand, the data is still just a small sampling of all the potential data points in California. Since the authors did not find strong patterns within the sample data, and there was no strong

[3] Northern and Southern California populations are 39.1% and 60.9% of total California population, respectively.

[4] Decision 07-12-050: http://docs.cpuc.ca.gov/PUBLISHED/FINAL_DECISION/76926.htm.

evidence that the sample data was representative for a particular region, process, or technology type, the authors did not have a strong basis to estimate the embedded energy values for specific geographic regions. Further, the CPUC studies did not recommend changes to the embedded energy values presented in the CEC's 2006 report.

# Appendix B: Meter Distribution Scenario Data

The scenarios used to assess the impact of potential differences between the statewide meter population composition and EMBUD's meter composition were based on data provided by EBMUD. It should be noted, however, that in order to include non-positive displacement meter types, the actual distribution of EBMUD meter types was altered slightly in all scenarios as follows: a total of 1 percent of the meter population from the most frequently occurring positive displacement meter type in each size category was redistributed evenly to each of the other meter technology types in the same size category.

**Table B.1 Distribution of Meters in the EBMUD Size Distribution Scenario**

| | | # of Meters | | |
|---|---|---|---|---|
| | | TECH DISTRIBUTION SCENARIO | | |
| | | EBMUD | +DP | +MJ |
| MeterTech | SizeDesc | A | B | C |
| DP | 5/8 inch | 314,153 | 6,025,517 | 251,745 |
| ND | 5/8 inch | 11,736,881 | 6,025,517 | 9,405,312 |
| SJ | 5/8 inch | 40,576 | 40,576 | 40,576 |
| MJ | 5/8 inch | 40,576 | 40,576 | 2,434,552 |
| FO | 5/8 inch | 40,576 | 40,576 | 40,576 |
| DP | 3/4 inch | 28,425 | 45,227 | 22,778 |
| ND | 3/4 inch | 62,030 | 45,227 | 49,707 |
| SJ | 3/4 inch | 305 | 305 | 305 |
| MJ | 3/4 inch | 305 | 305 | 18,274 |
| FO | 3/4 inch | 305 | 305 | 305 |
| DP | 1 inch | 86,061 | 245,646 | 69,110 |
| ND | 1 inch | 405,230 | 245,646 | 325,412 |
| SJ | 1 inch | 2,481 | 2,481 | 2,481 |
| MJ | 1 inch | 2,481 | 2,481 | 99,251 |
| DP | 1-1/2 inch | 39,727 | 219,484 | 31,902 |
| ND | 1-1/2 inch | 399,241 | 219,484 | 320,603 |
| SJ | 1-1/2 inch | 2,217 | 2,217 | 2,217 |
| MJ | 1-1/2 inch | 2,217 | 2,217 | 88,680 |
| DP | 2 inch | 34,718 | 99,707 | 27,879 |
| ND | 2 inch | 164,697 | 99,707 | 132,256 |
| SJ | 2 inch | 1,007 | 1,007 | 1,007 |
| MJ | 2 inch | 1,007 | 1,007 | 40,286 |
| **Total:** | | **13,405,214** | **13,405,214** | **13,405,214** |

**Table B.2 Distribution of Meters in the EVEN Size Distribution Scenario**

| MeterTech | SizeDesc | # of Meters | | |
|---|---|---|---|---|
| | | TECH DISTRIBUTION SCENARIO | | |
| | | EBMUD | +DP | +MJ |
| | | A | B | C |
| DP | 5/8 inch | 69,192 | 1,327,116 | 55,447 |
| ND | 5/8 inch | 2,585,040 | 1,327,116 | 2,071,514 |
| SJ | 5/8 inch | 8,937 | 8,937 | 8,937 |
| MJ | 5/8 inch | 8,937 | 8,937 | 536,209 |
| FO | 5/8 inch | 8,937 | 8,937 | 8,937 |
| DP | 3/4 inch | 834,073 | 1,327,116 | 668,382 |
| ND | 3/4 inch | 1,820,159 | 1,327,116 | 1,458,579 |
| SJ | 3/4 inch | 8,937 | 8,937 | 8,937 |
| MJ | 3/4 inch | 8,937 | 8,937 | 536,209 |
| FO | 3/4 inch | 8,937 | 8,937 | 8,937 |
| DP | 1 inch | 464,951 | 1,327,116 | 373,370 |
| ND | 1 inch | 2,189,281 | 1,327,116 | 1,758,059 |
| SJ | 1 inch | 13,405 | 13,405 | 13,405 |
| MJ | 1 inch | 13,405 | 13,405 | 536,209 |
| DP | 1-1/2 inch | 240,210 | 1,327,116 | 192,896 |
| ND | 1-1/2 inch | 2,414,023 | 1,327,116 | 1,938,533 |
| SJ | 1-1/2 inch | 13,405 | 13,405 | 13,405 |
| MJ | 1-1/2 inch | 13,405 | 13,405 | 536,209 |
| DP | 2 inch | 462,098 | 1,327,116 | 371,078 |
| ND | 2 inch | 2,192,135 | 1,327,116 | 1,760,351 |
| SJ | 2 inch | 13,405 | 13,405 | 13,405 |
| MJ | 2 inch | 13,405 | 13,405 | 536,209 |
| **Total:** | | **13,405,214** | **13,405,214** | **13,405,214** |

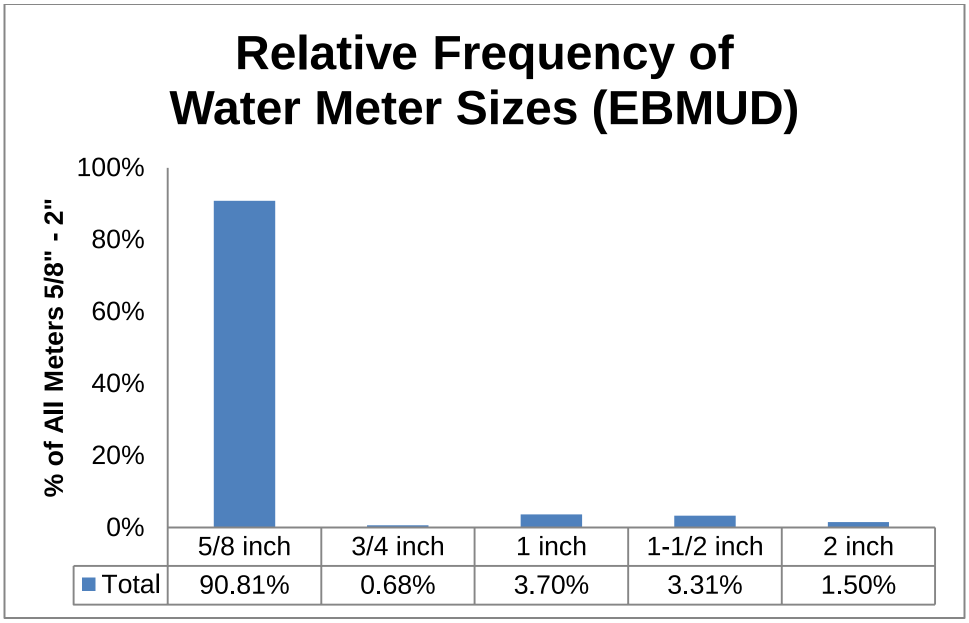


**Figure B.1 Distribution of Water Meter Sizes in EBMUD territory**

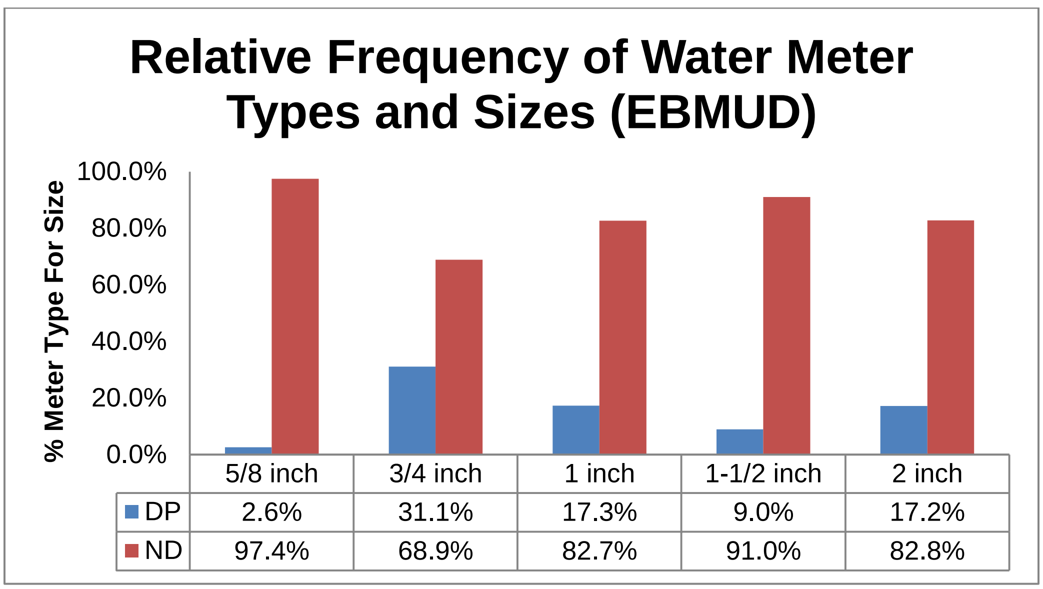


**Figure B.2 Distribution of Water Meter Types**

# Appendix C: Qualifying and Non-qualifying Meter Performance

The figures below depict the average performance of meters of different sizes and technologies from a variety of unidentified manufacturers based the Water Research Foundation's study (Barfuss, Johnson, & Neilson, 2011). Only the lowest test flow rates and standards are shown, as meter performance does not vary significantly at higher flow rates.

The existing NIST low-flow accuracy standard is shown with gray dashes, indicating both the minimum test flow rate and the required accuracy. The proposed standard would adopt the existing NIST standard and extend accuracy requirements to even lower flow rates. The proposed standard is shown schematically with a blue dashed line.

Note that low-flow meter accuracy in mechanical meters is inherently inversely proportional to diameters, so the minimum flow rate for which it was feasible to set a standard varies by meter size. Similarly, certain meter technologies have inherently poorer performance at low flow rates, so it was not feasible to set a standard at the same minimum flow rate for all meter technologies. In general, the standards were set at levels such that at least a small proportion of meters of that size and technology could qualify. This avoids biasing the standards proposal against any particular type of meter that may serve a purpose in the market.

For each size and meter type, results are grouped by whether or not meter performance satisfies the requirements of the proposed standards. The average performance of meters that do satisfy the requirements of the proposed standards (qualifying) are shown in green and meters not satisfying the requirements of the proposed standards (non-qualifying) are shown in red.

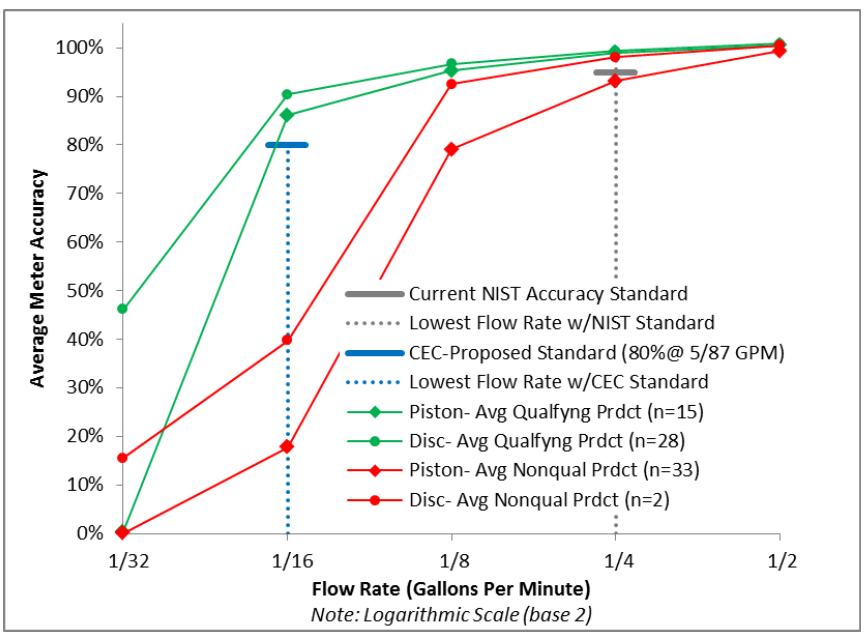


**Figure C.1 Average Performance of 5/8 x 3/4" Positive Displacement (Piston and Disc) Meters**

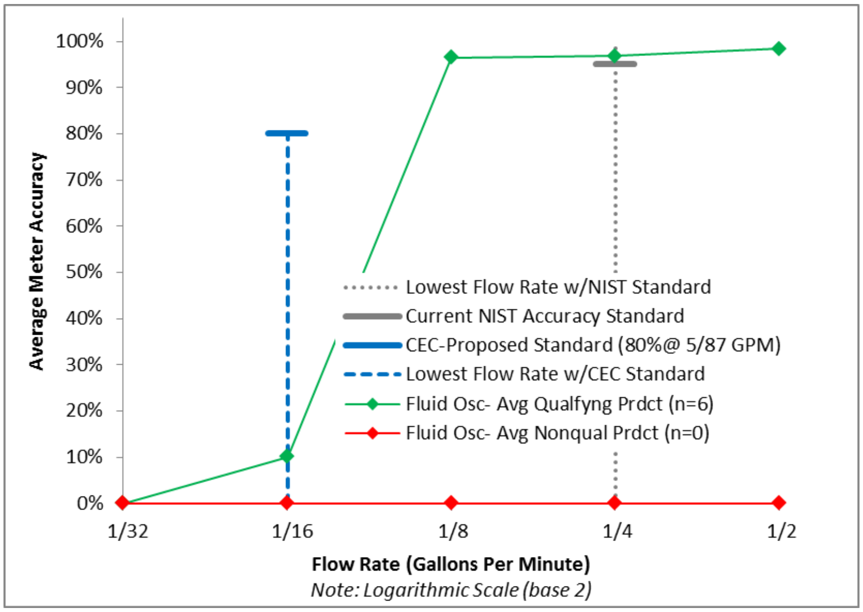


**Figure C.2 Average Performance of 5/8 x 3/4" Multi-jet Meters**

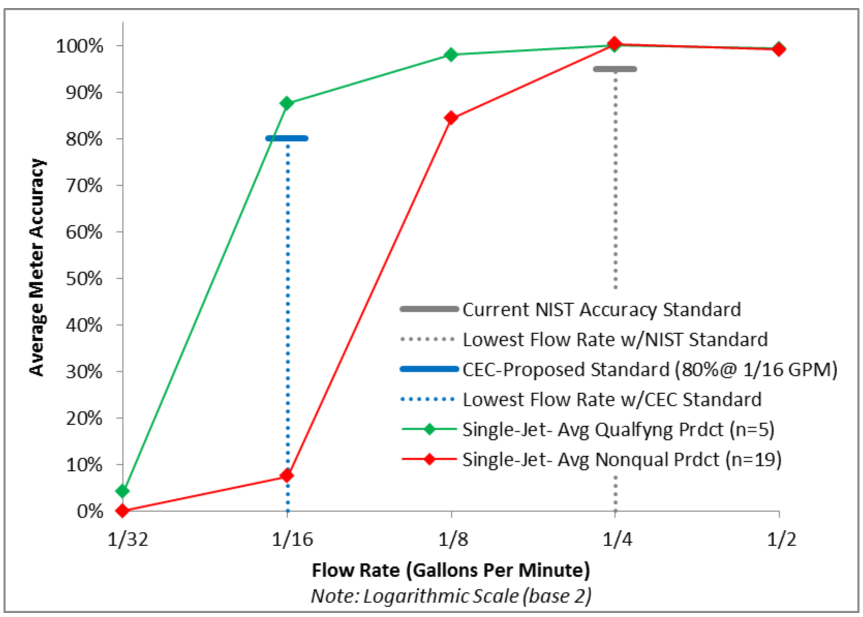


**Figure C.3 Average Performance of 5/8 x 3/4" Single Jet Meters**

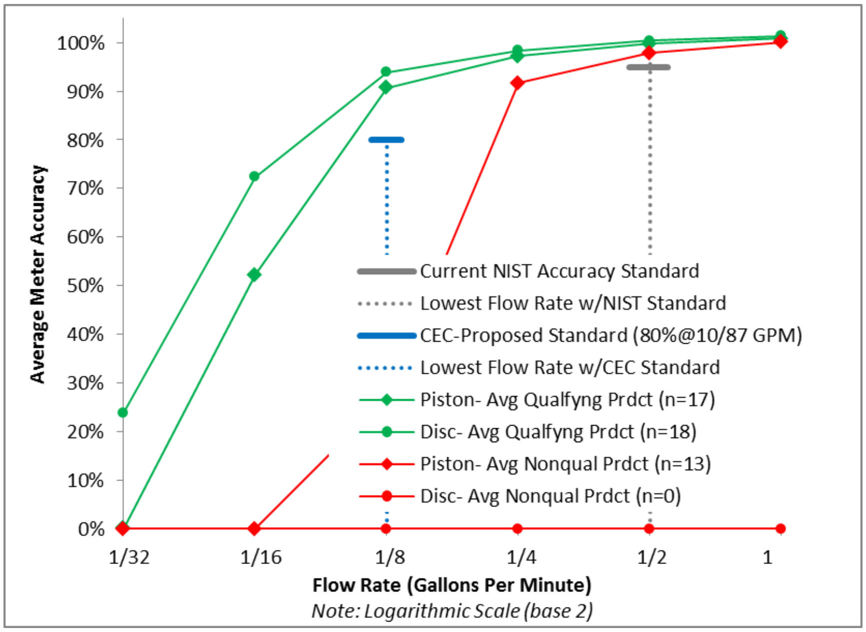


**Figure C.4 Average Performance of 3/4" Positive Displacement (Piston and Disc) Meters**

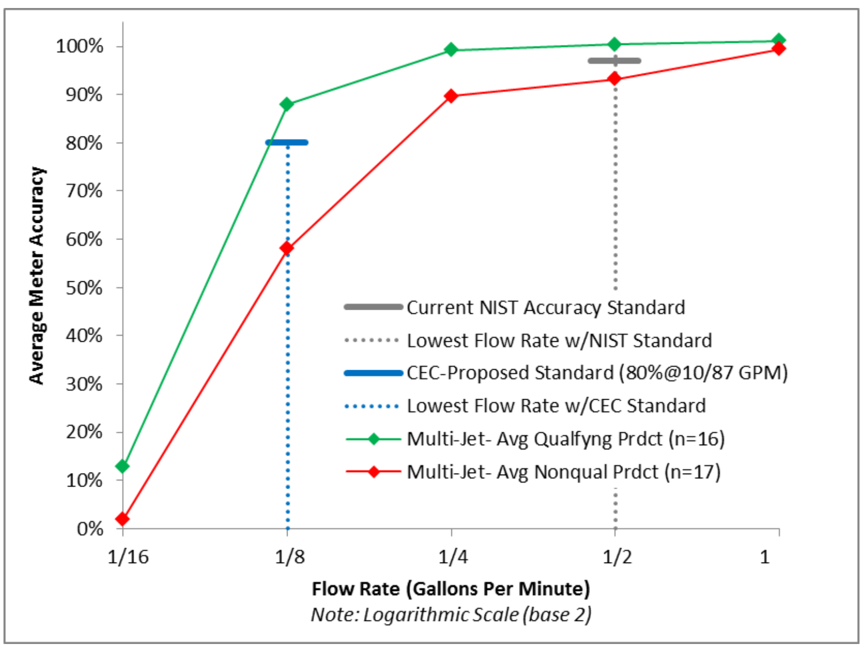


**Figure C.5 Average Performance of Qualifying and Non-qualifying 3/4" Multi-Jet Meters**

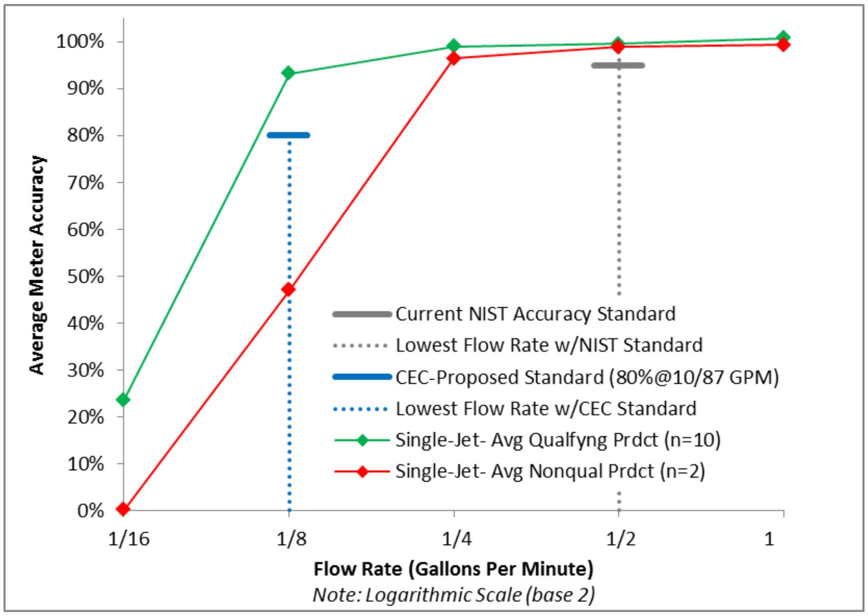


**Figure C.6 Average Performance of Qualifying and Non-qualifying 3/4" Single Jet Meters**

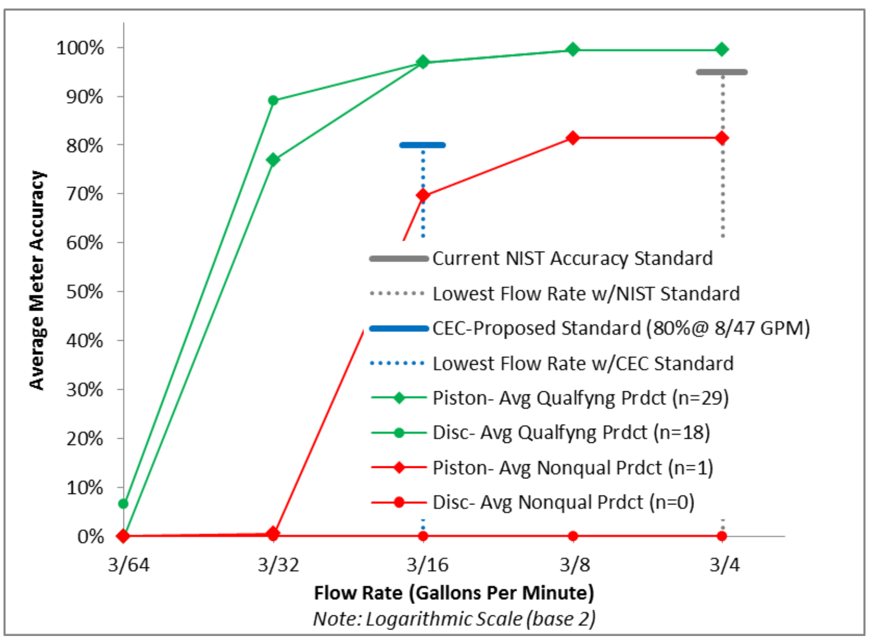


**Figure C.7 Average Performance of 1" Positive Displacement (Piston and Disc) Meters**

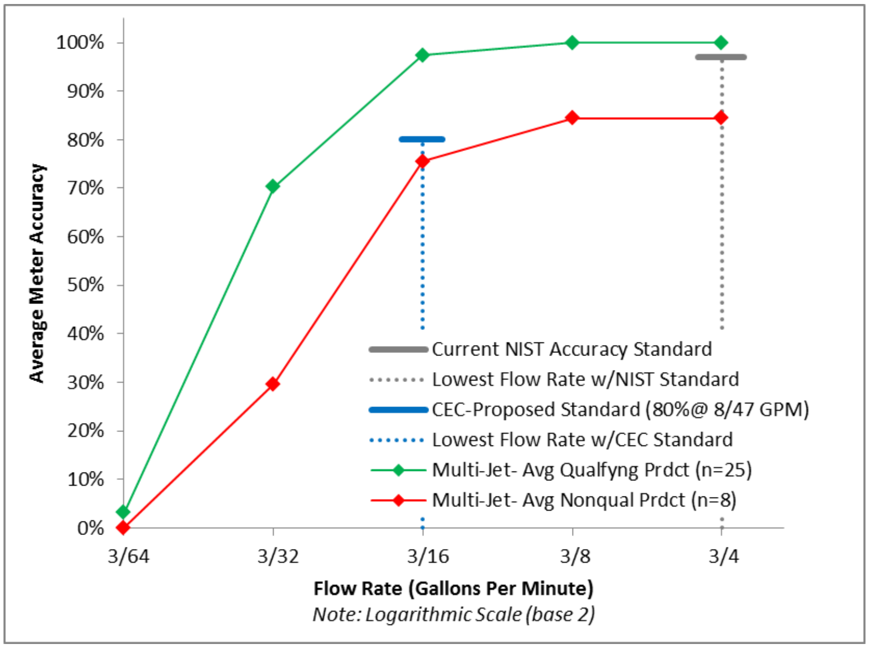


**Figure C.8 Average Performance of Qualifying and Non-qualifying 1" Multi-Jet Meters**

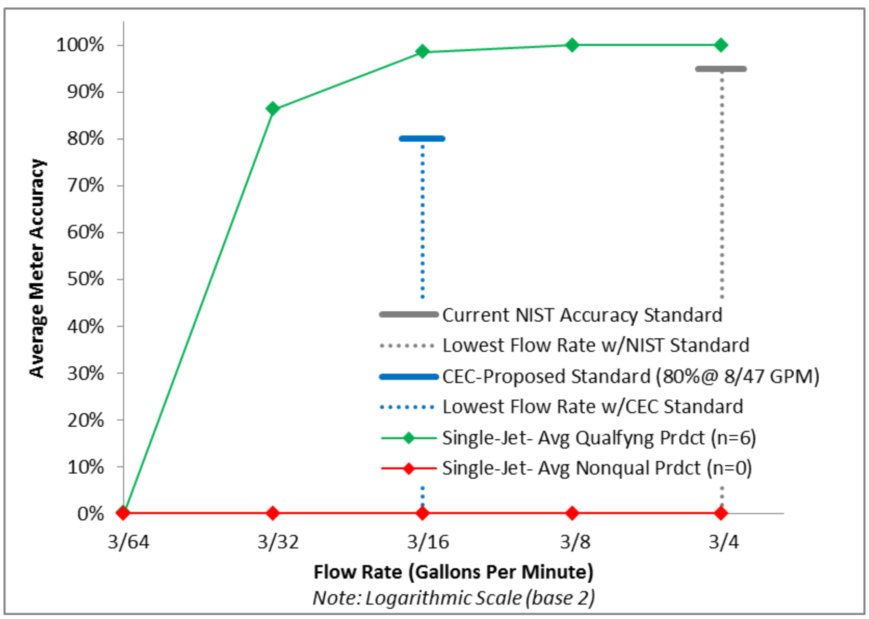


**Figure C.9 Average Performance of Qualifying and Non-qualifying 1" Single Jet Meters**

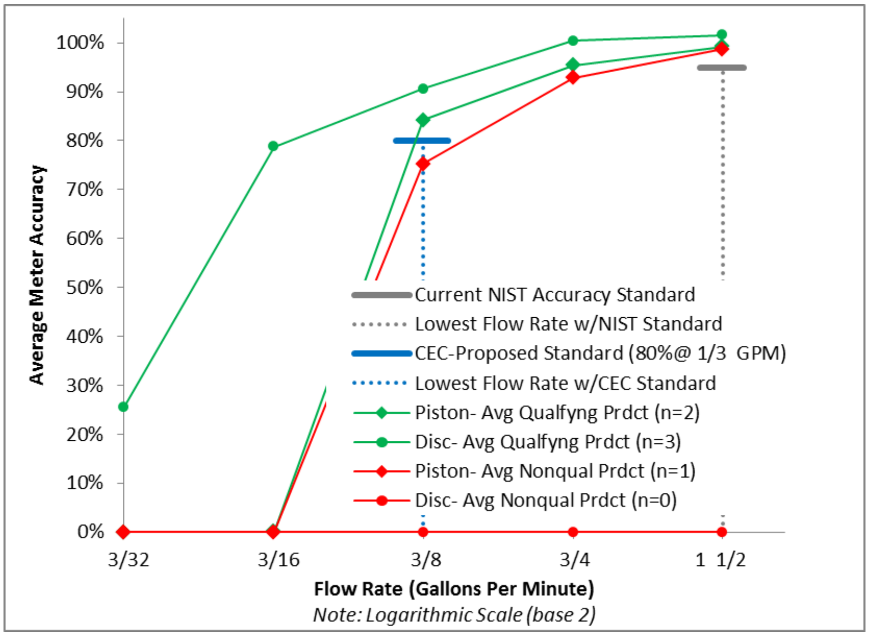


**Figure C.10 Average Performance of 1 1/2" Positive Displacement (Piston and Disc) Meters**

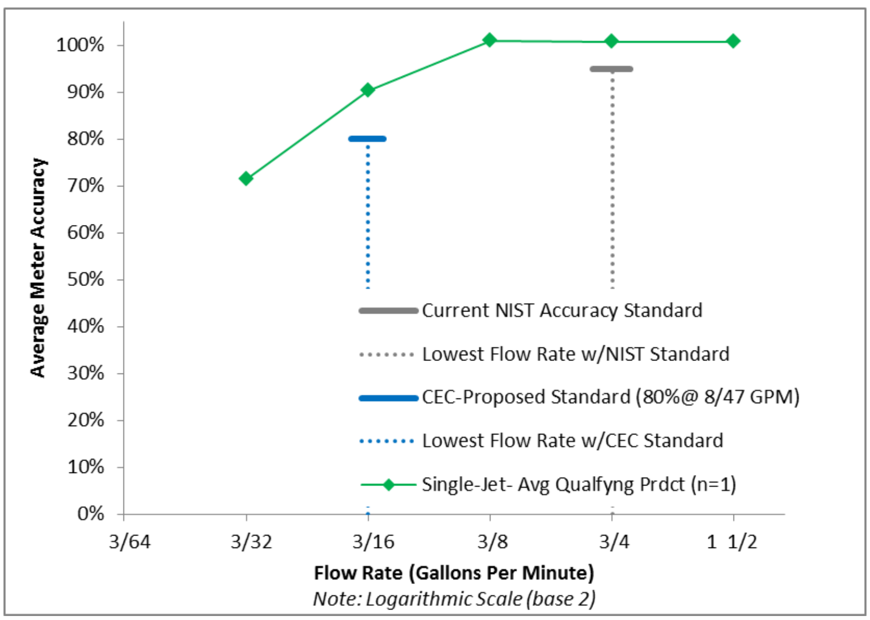


**Figure C.11 Average Performance of 1 1/2" Single Jet Meters**

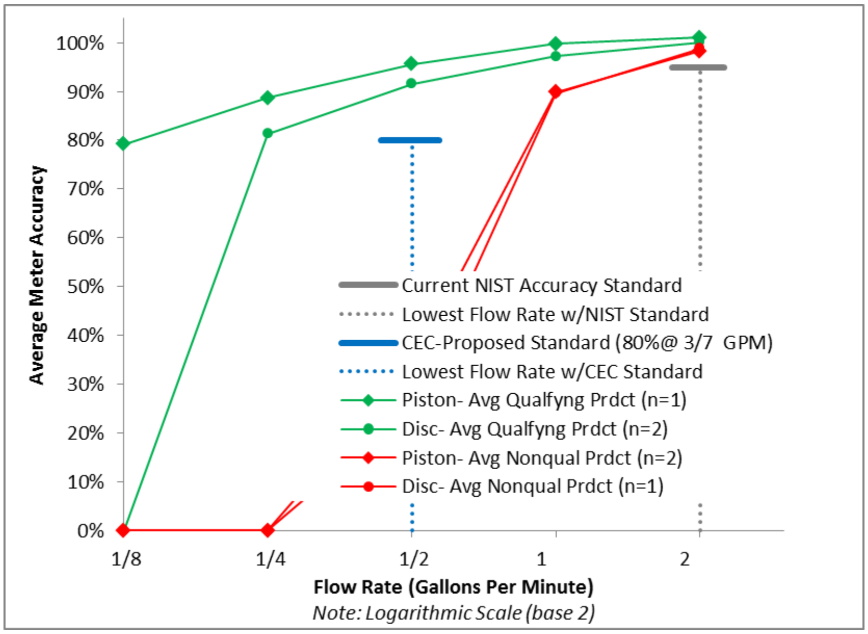


**Figure C.12 Average Performance of 2" Positive Displacement (Piston and Disc) Meters**

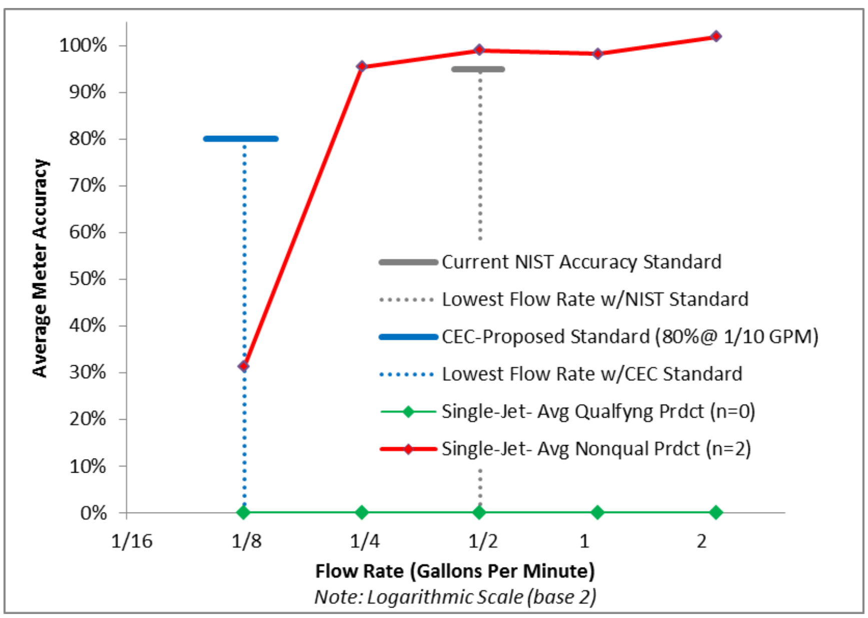


**Figure C.13 Average Performance of 2" Single Jet Meters**

# Appendix D: Cost Analysis Assumptions

The cost analysis presented in this CASE Report assumes that water purveyors including utilities (consumers of water meters) will realize cost savings from lower consumption of water through lower operating expenses associated with potable water acquisition, conveyance, treatment, distribution; through wastewater treatment and conveyance; and through avoided capital investments. Since water rates are indexed to water purveyors' operating expenses and capital investments, this analysis uses residential water rates as a proxy for water costs.

The potable water rates used in the analysis presented in this CASE Report are based on water rate data from Raftelis Financial Consultants Inc. (Raftelis 2008, Raftelis 2011). The residential potable water rate was derived using data from a 2011 study of rates from 216 water utilities in California. The commercial rates are derived from the 2008 American Water Works Association Water and Wastewater Survey using values from the western region.

Wastewater rates are based on data from Black & Veatch on rates in the eight largest cities[5] in California (Black & Veatch 2010). About 30 percent of Californians live in one of these eight cities, and it is assumed that these city's rates are representative of rates throughout the state. The CASE analysis uses the population-weighted wastewater rate from the eight cities. The 2009 residential rate is based on cost data that assumes customers use 15,000 gallons per month. The 2009 commercial wastewater rates were derived from cost data that assumes customers use 100,000 gallons per month.

Future potable water and wastewater rates were projected based on the Consumer Price Index (CPI) for Water and Sewer Maintenance and assuming a 3 percent annual discount rate. In recent years water rates have been increasing faster than CPI projections (Black & Veatch 2010, Raftelis 2011). It is likely that water rates will increase faster than the CAES analysis predicts, and it follows that the cost savings presented in this report could understate the true potential savings. See the rates by year below in Table D.1.

The analysis also includes cost savings associated with embedded energy savings (see section below). The electricity rates used in the analysis of this CASE Report were derived from projected future prices for residential, commercial and industrial sectors in the CEC's "Mid-case" projection of the 2012 Demand Forecast (2012), which used a 3% discount rate and provide prices in 2010 dollars. The sales weighted average of the 5 largest utilities in California was converted to 2013 dollars using an inflation adjustment of 1.07 (DOL 2013). A sector weighted average electricity rate was then calculated using 0 percent commercial, 100 percent residential and 0 percent industrial. See the rates by year below in Table D.2

[5] The eight largest cities in California are: Fresno, Long Beach, Los Angeles, Oakland, Sacramento, San Diego, San Francisco, and San Jose.

**Table D.1 Statewide Average Potable Water and Wastewater Rates 2015 - 2040 in 2013$/1000gal**

| Potable Water and Wastewater Rates (2013$ / 1000 gal) | | | | | | |
|---|---|---|---|---|---|---|
| | Residential Rate | | | Commercial Rates | | |
| Year | Potable Water | Waste-water | Total | Potable Water | Waste-water | Total |
| 2015 | $2.82 | $4.66 | $7.49 | $2.58 | $4.84 | $7.42 |
| 2016 | $2.88 | $4.77 | $7.66 | $2.52 | $4.72 | $7.25 |
| 2017 | $2.95 | $4.88 | $7.83 | $2.58 | $4.83 | $7.41 |
| 2018 | $3.01 | $4.98 | $8.00 | $2.64 | $4.94 | $7.58 |
| 2019 | $3.08 | $5.09 | $8.17 | $2.70 | $5.05 | $7.75 |
| 2020 | $3.14 | $5.20 | $8.34 | $2.76 | $5.16 | $7.92 |
| 2021 | $3.21 | $5.30 | $8.51 | $2.81 | $5.27 | $8.09 |
| 2022 | $3.27 | $5.41 | $8.68 | $2.87 | $5.38 | $8.26 |
| 2023 | $3.33 | $5.51 | $8.85 | $2.93 | $5.49 | $8.43 |
| 2024 | $3.40 | $5.62 | $9.02 | $2.99 | $5.60 | $8.59 |
| 2025 | $3.46 | $5.73 | $9.19 | $3.05 | $5.71 | $8.76 |
| 2026 | $3.53 | $5.83 | $9.36 | $3.11 | $5.82 | $8.93 |
| 2027 | $3.59 | $5.94 | $9.53 | $3.17 | $5.93 | $9.10 |
| 2028 | $3.65 | $6.04 | $9.70 | $3.22 | $6.04 | $9.27 |
| 2029 | $3.72 | $6.15 | $9.87 | $3.28 | $6.15 | $9.44 |
| 2030 | $3.78 | $6.26 | $10.04 | $3.34 | $6.26 | $9.61 |
| 2031 | $3.85 | $6.36 | $10.21 | $3.40 | $6.37 | $9.77 |
| 2032 | $3.91 | $6.47 | $10.38 | $3.46 | $6.48 | $9.94 |
| 2033 | $3.98 | $6.57 | $10.55 | $3.52 | $6.59 | $10.11 |
| 2034 | $4.04 | $6.68 | $10.72 | $3.58 | $6.70 | $10.28 |
| 2035 | $4.10 | $6.79 | $10.89 | $3.64 | $6.81 | $10.45 |
| 2036 | $4.17 | $6.89 | $11.06 | $3.69 | $6.92 | $10.62 |
| 2037 | $4.23 | $7.00 | $11.23 | $3.75 | $7.03 | $10.79 |
| 2038 | $4.30 | $7.10 | $11.40 | $3.81 | $7.14 | $10.95 |
| 2039 | $4.36 | $7.21 | $11.57 | $3.87 | $7.25 | $11.12 |
| 2040 | $4.42 | $7.32 | $11.74 | $3.93 | $7.36 | $11.29 |

**Table D.2 Statewide Weighted Average Electricity Rates 2015 - 2040 (PG&E, SCE, SDG&E, LADWP and SMUD - 5 largest Utilities) in 2013 cents/kWh**

| Year | Residential | Commercial | Industrial | Sector Weighted Average |
|---|---|---|---|---|
| 2015 | 16.82 | 14.67 | 11.31 | 16.82 |
| 2016 | 17.02 | 14.84 | 11.43 | 17.02 |
| 2017 | 17.24 | 15.02 | 11.56 | 17.24 |
| 2018 | 17.47 | 15.22 | 11.70 | 17.47 |
| 2019 | 17.71 | 15.42 | 11.84 | 17.71 |
| 2020 | 18.00 | 15.67 | 12.01 | 18.00 |
| 2021 | 18.34 | 15.98 | 12.23 | 18.34 |
| 2022 | 18.70 | 16.29 | 12.45 | 18.70 |
| 2023 | 19.06 | 16.61 | 12.67 | 19.06 |
| 2024 | 19.43 | 16.93 | 12.90 | 19.43 |
| 2025 | 19.81 | 17.27 | 13.13 | 19.81 |
| 2026 | 20.19 | 17.60 | 13.37 | 20.19 |
| 2027 | 20.59 | 17.95 | 13.61 | 20.59 |
| 2028 | 20.98 | 18.30 | 13.86 | 20.98 |
| 2029 | 21.39 | 18.66 | 14.12 | 21.39 |
| 2030 | 21.81 | 19.03 | 14.38 | 21.81 |
| 2031 | 22.23 | 19.40 | 14.64 | 22.23 |
| 2032 | 22.66 | 19.78 | 14.92 | 22.66 |
| 2033 | 23.10 | 20.17 | 15.19 | 23.10 |
| 2034 | 23.55 | 20.57 | 15.48 | 23.55 |
| 2035 | 24.01 | 20.97 | 15.77 | 24.01 |
| 2036 | 24.48 | 21.38 | 16.06 | 24.48 |
| 2037 | 24.96 | 21.80 | 16.37 | 24.96 |
| 2038 | 25.44 | 22.23 | 16.68 | 25.44 |
| 2039 | 25.94 | 22.67 | 16.99 | 25.94 |
| 2040 | 26.44 | 23.12 | 17.32 | 26.44 |

# Appendix E: Criteria Pollutant Emissions and Monetization

## E.1 Criteria Pollutant Emissions Calculation

To calculate the statewide emissions rate for California, the incremental emissions between CARB's high load and low load power generation forecasts for 2020 were divided by the incremental generation between CARB's high load and low load power generation forecast for 2020. Incremental emissions were calculated based on the delta between California emissions in the high and low generation forecasts divided by the delta of total electricity generated in those two scenarios. This emission rate per MWh is intended to provide a benchmark of emission reductions attributable to energy efficiency measures that could help achieve the low load scenario instead of the high load scenario. While emission rates may change somewhat over time, 2020 was considered a representative year for this measure.

## E.2 Criteria Pollutant Emissions Monetization

Avoided ambient ozone precursor and fine particulate air pollution benefits were monetized based on avoided control costs rather than damage costs due to the availability of emission control cost-effectiveness thresholds, as well as challenges in quantifying a specific value for damages per ton of pollutants.

Two sources of data for cost-effectiveness thresholds were evaluated. The first is Carl Moyer cost-effectiveness thresholds for ozone precursors and fine particulates (CARB 2011a, CARB 2013a and 2013b). The Carl Moyer program has provided incentives for voluntary reductions in criteria pollutant reductions from a variety of mobile combustion sources as well as stationary agricultural pumps that meet specified cost-effectiveness cut-offs.

The second is the San Joaquin Valley UAPCD Best-Available Control Technology ("BACT") cost-effectiveness thresholds study. Pollution reduction technologies that are not yet demonstrated in practice (in which case they are required without a cost-effectiveness evaluation) can be required at new power plants and other sources if technologically feasible and within cost-effectiveness thresholds. San Joaquin Valley UAPCD conducted a state-wide study as the basis for updating their BACT thresholds in 2008.

This CASE report relies primarily on the Carl Moyer thresholds due to their state-wide nature and applicability to combustion sources[6]. In addition, the Carl Moyer fine particulate values for fine particulate apply to combustion sources with specific health impacts, while BACT thresholds include both combustion sources and dust. The Carl Moyer values are somewhat more conservative for ozone precursors than San Joaquin Valley UAPCD BACT thresholds, and significantly higher for fine particulate[7].The Carl Moyer program does not address sulfur oxides, however, thus the San Joaquin BACT thresholds were used for this pollutant.

Price reports for California Emission Reduction Credit (ERCs, i.e. air pollution credits purchased to offset regulated emission increases) for 2011 and 2012 were also compared to the values selected

[6] Further evaluation of the qualitative impacts of combustion fine particulate emissions from power generation and transportation sources may be beneficial.

[7] We note that both the Carl Moyer and San Joaquin Valley UAPCD BACT cost-effectiveness thresholds for fine particulates fall within the wide range of fine particulate ERC trading prices in California in 2011 and 2012.

in this CASE report. For each pollutant there is a wide range of ERC values per ton that are both higher and lower than the values per ton used in this CASE report (CARB 2011b and 2012). Due to wide variability and low trading volumes, ERC values were evaluated for comparative purposes only.

# Appendix F: Greenhouse Gas Valuation Discussion

The climate impacts of pollution from fossil fuel combustion and other human activities, including the greenhouse gas effect, present a major risk to global economies, public health and the environment. While there are uncertainties of the exact magnitude given the interconnectedness of ecological systems, at least three methods exist for estimating the societal costs of greenhouse gases: 1) the Damage Cost Approach 2) the Abatement Cost Approach and 3) the Regulated Carbon Market Approach. See below for more details regarding each approach.

## F.1 Damage Cost Approach

In 2007, the U.S. Court of Appeals for the Ninth Circuit ruled that the National Highway Transportation Traffic Safety Administration (NHTSA) was required to assign a dollar value to benefits from abated carbon dioxide emissions. The court stated that while there are a wide range of estimates of monetary values, the price of carbon dioxide abatement is indisputably non-zero. In 2009, to meet the necessity of a consistent value for use by government agencies, the Obama Administration established the Interagency Working Group on the Social Cost of Carbon to establish official estimates (Johnson and Hope).

The Interagency Working Group primarily uses estimates of avoided damages from climate change which are valued at a price per ton of carbon dioxide, a method known as the damage cost approach.

### F.1.1 Interagency Working Group Estimates

The Interagency Working Group SCC estimates, based on the damage cost approach, were calculated using three climate economic models called integrated assessment models which include the Dynamic Integrated Climate Economy (DICE), Policy Analysis of the Greenhouse Effect (PAGE), and Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) models. These models incorporate projections of future emissions translated into atmospheric concentration levels which are then translated into temperature changes and human welfare and ecosystem impacts with inherent economic values. As part of the Federal rulemaking process, DOE publishes estimated monetary benefits using Interagency Working Group SCC values for each Trial Standard Level considered in their analyses, calculated as a net present value of benefits received by society from emission reductions and avoided damages over the lifetime of the product. The recent U.S. DOE Final Rulemaking for microwave ovens contains a Social Cost of Carbon section that presents the Interagency Working Group's most recent SCC values over a range of discount rates (DOE 2013) as shown in Table F.1. The two dollar per metric ton values used in this CASE report were taken from the two highlighted columns, and converted to 2013 dollars.

**Table F.1 Social Cost of $CO_2$ 2010 – 2050 (in 2007 dollars per metric ton of $CO_2$)**

| Discount Rate | 5.0% | 3.0% | 2.5% | 3.0% |
|---|---|---|---|---|
| Year | Avg | Avg | Avg | 95th |
| 2010 | 11 | 33 | 52 | 90 |
| 2015 | 12 | 38 | 58 | 109 |
| 2020 | 12 | 43 | 65 | 129 |
| 2025 | 14 | 48 | 70 | 144 |
| 2030 | 16 | 52 | 76 | 159 |
| 2035 | 19 | 57 | 81 | 176 |
| 2040 | 21 | 62 | 87 | 192 |
| 2045 | 24 | 66 | 92 | 206 |
| 2050 | 27 | 71 | 98 | 221 |

Source: Interagency Working Group on Social Cost of Carbon, United States Government, 2013

The Interagency Working Group decision to implement a global estimate of the SCC rather than a domestic value reflects the reality of environmental damages which are expected to occur worldwide. Excluding global damages is inconsistent with U.S. regulatory policy aimed at incorporating international issues related to resource use, humanitarian interests, and national security. As such, a regional SCC value specific to the Western United States or California specifically should be at similarly inclusive of global damages. Various studies state that certain values may be understated due to the asymmetrical risk of catastrophic damage if climate change impacts are above median predictions, and some estimates indicate that the upper end of possible damage costs could be substantially higher than indicated by the IWG (Ackerman and Stanton 2012, Horii and Williams 2013).

## F.2 Abatement Cost Approach

Abating carbon dioxide emissions can impose costs associated with more efficient technologies and processes, and policy-makers could also compare strategies using a different by estimating the annualized costs of reducing one ton of carbon dioxide net of savings and co-benefits. The cost of abatement approach could reflect established greenhouse gas reduction policies and establish values for carbon dioxide reductions relative to electricity de-carbonization and other measures. (While recognizing the potential usefulness of this method, this report utilizes the IWG SCC approach and we note that the value lies within the range of abatement costs discussed further below.)

The cost abatement approach utilizes market information regarding emission abatement technologies and processes and presents a wide-range of values for the price per ton of carbon dioxide. The California Air Resources Board data of the cost-effectiveness of energy efficiency measures and emission regulations would provide one source of potential data for an analysis under this method. To meet the AB 32 target, ARB has established the "Cost of a Bundle of Strategies Approach" which includes a range of cost-effective strategies and regulations (CARB 2008b). The results of this approach within the framework of the Climate Action Team Macroeconomic Analysis are provided for California, Arizona, New Mexico, the United States, and a global total identified in that same report, as shown in Table F.2 below.

**Table F.2 Cost-effectiveness Range for the CAT Macroeconomic Analysis**

Exhibit 3: Cost-effectiveness Range for the CAT Macroeconomic Analysis, Selected States, United States, Global -

| State | Cost-effectiveness Range $/ ton $CO_2$eq | Tons Reduced MMt$CO_2$e/yr | Percent of BAU |
|---|---|---|---|
| California 2020 (CAT[1], CEC[2]) | - 528 to 615 | 132 | 22 |
| Arizona[3] 2020 | - 90 to 65 | 69 | 47 |
| New Mexico[4] 2020 | - 120 to105 | 35 | 34 |
| United States (2030)[5] | -93 to 91 | 3,000 | 31 |
| Global Total (2030) | -225 to 91 | 26,000 | 45 |

Source:
1. Climate Action Team Updated Macroeconomic Analysis of Climate Strategies, Presented in the March 2006 Climate Action Team Report, September 2007.
2. California Energy Commission, *Emission Reduction Opportunities for Non-CO2 Greenhouse Gases in California*, July 2005, ICF ($/MTC$0_2$eq).
3. Arizona Climate Change Advisory Group, *Climate Change Action Plan*, August 2006, ($/MTC$0_2$eq).
4. New Mexico Climate Change Advisory Group, Final Report, December 2006.
5. McKinsey & Company, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?* December 2007.
6. The McKinsey Quarterly, McKinsey & Company, *A Cost Curve for Greenhouse Gas Reduction*, Fall 2007.

Source: CARB 2008b

Energy and Environmental Economics (E3) study defines the cost abatement approach more specifically as electricity de-carbonization and is based on annual emissions targets consistent with existing California climate policy. Long-term costs are determined by large-scale factors such as electricity grid stability, technological advancements, and alternative fuel prices. Near-term costs per ton of avoided carbon could be$200/ton in the near-term (Horii and Williams 2013), thus as noted earlier the value used in this report may be conservative.

## F.3 Regulated Carbon Market Approach

Emissions allowance markets provide a third potential method for valuing carbon dioxide. Examples include the European Union Emissions Trading System and the California AB32 cap and trade system as described below. Allowances serve as permits authorizing emissions and are traded through the cap-and-trade market between actors whose economic demands dictate the sale or purchase of permits. In theory, allowance prices could serve as a proxy for the cost of abatement. However, this report does not rely on the prices of cap-and-trade allowances due to the vulnerability of the allowance market to external fluctuations, and the influence of regulatory decisions affecting scarcity or over-allocation unrelated to damages or abatement costs.

### F.3.1 European Union Emissions Trading System

The European Union Emissions Trading System (EU ETS) covers more than 11,000 power stations, industrial plants, and airlines in 31 countries. However, the market is constantly affected by over-supply following the 2008 global recession and has seen prices drop to dramatic lows in early 2013, resulting in the practice of "back-loading" (delaying issuances of permits) by the European parliament. At the end of June 2013, prices of permits dropped to $5.41/ton, a price which is well below damage cost estimates and sub-optimal for encouraging innovative carbon dioxide emission abatement strategies.

### F.3.2 California Cap & Trade

In comparison, California cap-and-trade allowance prices were reported to be at least $14/ton in May of 2013, with over 14.5 million total allowances sold for 2013 (CARB 2013b). However, cap-and-trade markets are likely to cover only subsets of emitting sectors of the industry covered by AB 32. In addition, the market prices of allowances are determined only partly by costs incurred by society or industry actors and largely by the stringency of the cap determined by regulatory agencies and uncontrollable market forces, as seen by the failure of the EU ETS to set a consistent and effective signal to curb carbon dioxide emissions.