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# The Cost of Stability: Consumption-Based Fixed Rate Billing for Water Utilities

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**Abstract:** Municipal water utilities in the United States face the challenge of balancing the potentially conflicting goals of sending signals about water scarcity and maintaining revenue stability. Times of extreme shortage such as the current extended drought in California seriously challenge and can jeopardize this delicate balance. Mandatory or voluntary conservation strategies can be detrimental to revenue stability. This study explores the ability of the Consumption-Based Fixed Rates (CBFR) pricing method to solve this dual dilemma of scarcity pricing and revenue stability in both normal times and times of drought. CBFR proposes using a proportional consumer pricing system directly based on utility supply costs. We utilize utility-side cost data from Lomita, CA and Longmont, CO, to estimate how consumer prices change under the CBFR method. Using simulations comparing current pricing mechanisms with the CBFR, we find that the latter solves the revenue problem, but creates greater problems with equity and scarcity versus the former. A modified structure of CBFR, with prices based partially on household income, seems to alleviate some of these problems and could prove to be a useful tool during times of drought.

**Keywords:** *municipal water pricing, revenue stability, water scarcity, Southwestern United States*

The United States depends heavily upon public infrastructure for its water supply; 83% of Americans rely on publicly owned, large-scale water utilities to supply them with potable water and treat their wastewater (Rahill-Marrier and Lall 2013). While American customers pay some of the lowest water rates among developed nations (Mehan and Kline 2012), the country's water infrastructure faces an annual 11 billion dollar deficit to replace aging facilities and bring water supply quality up to code with environmental health regulations (Rahill-Marier and Lall 2013).

While water providers face huge fixed costs to maintain and upgrade infrastructure, revenues depend largely upon variable factors. Fixed costs stay the same or increase year-to-year, but revenues fluctuate with water consumption, which varies based on changes in demand due to population growth, economic activity, and weather patterns.

Steady, reliable decreases in consumption due to better water conservation measures or other factors also pose problems for water utilities. As costs remain largely the same, water utilities may choose to raise their water prices to bring in necessary revenue. However, consumers may view increased prices as a "punishment" for their reduced consumption. Higher prices could also usher in more conservation, leaving the utility facing the same revenue shortfall it sought to avoid. Times of extreme drought provide an example of this scenario; during California's 2007-2009 drought, the Los Angeles Department of Water and Power faced a $70 million revenue shortfall as water consumption plunged 30% (Sedlak 2015). From a resource allocation perspective, it is tempting to think that perhaps a different pricing system could have prevented such a dire financial outcome.

One solution to the revenue stability problem is proposed by Spang et al. (2015). They introduce the theory of "consumption-based fixed rates" (CBFR), a pricing system following the supply-side pricing reform concept. In the CBFR system, bills are calculated from the utility's costs, with customers paying a flat rate for fixed costs and a proportional rate for more variable costs. By calculating bills using overall system costs, the utility ensures stable, sufficient revenue regardless of the absolute level of water consumption.

This paper tests a water utility pricing model proposed by Spang et al. (2015) for consumption-based fixed rates as a means of pricing water to reflect scarcity and maintain equity for two cities (one in California and one in Colorado). We run simulations to evaluate the impacts of this technique with utility data in Longmont, Colorado and Lomita, California. We compare changes in billing rates for CBFR to the current pricing mechanism and examine the resulting impacts on consumer affordability, equity across different income groups, and the sensitivity of billing rates to changes in system costs or aggregate consumption. With the current severe drought in the state of California, managing water scarcity has become a top priority for water utilities across water scarce regions of the United States. Governor Jerry Brown's mandate for substantial reductions in water use by all California consumers (California State Water Board Emergency Regulations, Article 22.5, adopted Feb. 11, 2016) will likely have major, and as of yet unknown, impacts on water providers across the state.

## Natural Monopoly and the Revenue "Catch-22"

Natural monopoly arises when the cost of supplying the market for a good is lower when all production comes from one firm, versus two or more firms splitting market production. In the case of a water utility, this structure holds true due to the high upfront costs of water service infrastructure, and, once a system is established, the relatively low cost of supplying additional units of water.

Shaked and Sutton (1987) propose that demand-side characteristics, in addition to industry cost structures, can also influence the establishment of a natural monopoly. In the case of a water utility, this type of "demand pull," as they term it, motivates the firm to incur more costs in order to expand system capacity, particularly peak capacity. This type of expansion can be modeled as a marginal capacity cost, or a 'jump' along the marginal cost curve, as the utility extends system capacity to accommodate an additional unit of consumption (Mann et al. 1979). Figure 1 provides an example of such a scenario, where average per unit cost is falling for all sources, but average cost overall is slowly rising as the upfront costs of bringing on a new supply source are incurred.

Due to the relative inflexibility in setting prices, in conjunction with the high fixed-cost nature of the market, water utilities are vulnerable to high revenue instability. Of particular interest for this study is the case of fluctuating consumption without price adjustments, which can lead to revenue out of alignment with costs. In other words, if decreases in consumption without pricing adjustments yield insufficient revenue to cover operating costs, is CBFR a possible solution? We test this question in this paper.

From a long-term perspective, a utility operating under conditions of severe drought, even with demand-side conservation efforts, likely faces an upward shift of its costs; the available yield for each water source falls below the expected value, and getting enough total water to meet demand thus becomes more expensive (Figure 2).

While this model remains theoretical, Tampa, Florida (Tampa Bay Water. Water Supply. http://www.tampabaywater.org/tampa-bay-seawater-desalination-plant.aspx), and Santa Barbara, California (City of Santa Barbara. Desalinization. http://www.santabarbaraca.gov/gov/depts/pw/resources/system/sources/desalination.asp), offer examples of utilities facing huge cost increases during drought by building large desalinization plants. For both utilities, desalinization became an economically viable option as the cost of securing water from other means increased. Costs increased over periods of drought even with lower consumption, because existing projects provided water levels severely below their predicted average yield. Thus, costs rose from both a "spike" in procurement costs for existing sources and the need to expand into new sources. Under these circumstances, falling consumption -- without billing adjustments sufficient to reflect the new costs -- could lead to a revenue shortage for the water utility. Figure 2 models this type of situation. As typical supply levels fall for all water sources during a drought, the cost of extracting the necessary water volume from each source rises. If current sources cannot meet demand, new sources may be brought online which are then unnecessary in non-drought conditions.

If consumption decreases in response to drought-related conservation efforts/education, but only occurs during a drought-cycle, utilities would want to model long-term marginal costs along the same curve as before the reductions to get an accurate sense of what projects they will need to maintain or add, and when. In this case, a utility could develop one billing structure for normal periods ($D_0$) and one for drought periods (D').

By contrast, persistent changes in demand seem likely after extended periods of conservation, as consumers make long-term water-saving investments such as low-flow fixtures and xeriscaping. Additionally, new social norms and conservation habits (such as shorter showers) formed over the drought period could remain beyond the drought (Gregory and Di Leo 2003). If consumption cuts back sharply (D') and remains at that level, the utility faces a new cost structure where fewer procurement sources are needed. Permanent, severe declines could leave the utility with unnecessary infrastructure (reservoirs, water pipes, etc.) that can be phased out over time, leading to lower costs. Figure 3 shows that when drought-induced practices persist, fewer water sources may be necessary to meet average demand at all times. Thus, taking the sources necessary before drought-induced conservation offline could reduce utility costs.

## Previous Literature

While an extensive amount of literature exists on the topic of water pricing mechanisms, the literature on water utility revenue instability--resulting from the industry's natural monopoly structure--gained traction in the late 1980s and early 1990s. Early papers, such as Chesnutt et al. (1996), explore the implications of revenue instability through reduced consumption and offer potential solutions. These proposals remain exogenous to actual water pricing systems; they do not consider the overall disconnect between the water utility's sources of cost and sources of

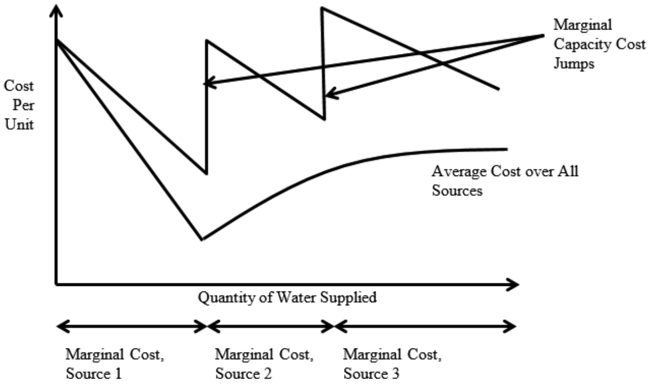

**Figure 1.** Theoretical model of a water utility cost structure (adapted from Hanemann 1998).

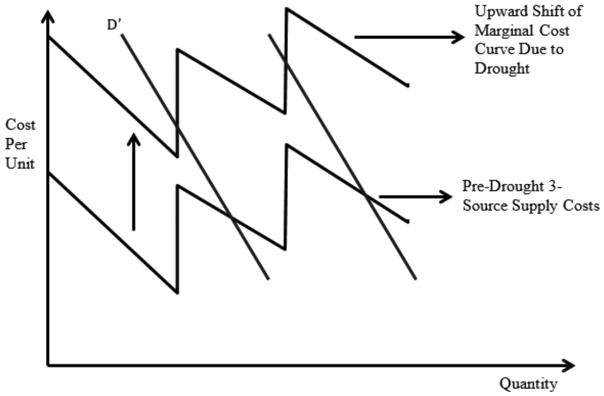

**Figure 2.** Utility supply costs under drought conditions. $D_0$ = demand under normal conditions. D' = demand during conservation period.

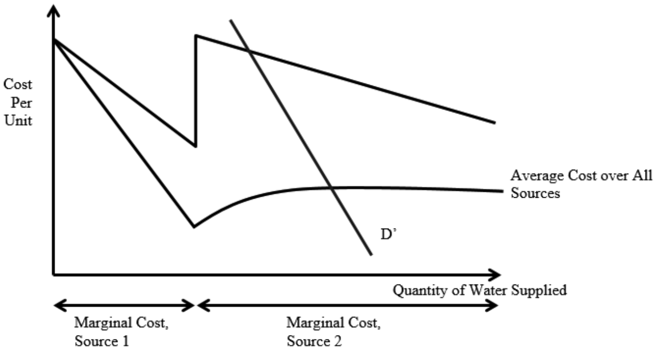

**Figure 3.** Post-drought cost planning, permanent consumption reduction. D' = new, lower demand (permanent reduction).

revenue. More recently, there has been an increase in both case studies and theoretical models of water pricing explicitly concerned with revenue stability via billing reform (Hoag and McKinley 2012; Rahill-Marier and Lall 2013; Schoengold and Zilberman 2014, for example).

Hoag and McKinley (2012), citing fears of inequality as a result of raising rates or fixed costs across the board, argue that the best option lies with a steeply increasing block price (IBR), as it conveys scarcity and encourages conservation. While this system provides more stability than a flat rate and more equality than indiscriminate rate hikes, IBR systems often do not fully incorporate system costs into a form of guaranteed revenue. Schoengold and Zilberman (2014) use a theoretical simulation to evaluate IBR pricing under different cost and scarcity conditions, in terms of both economic efficiency and social equity/affordability. The authors find that, in general, lower equity results in cases where the optimal minimum household price level lies above the maximum price that guarantees stable revenue without profits. Schoengold and Zilberman (2014) also find that pricing water with an IBR to ensure proper revenue requires adjusting rates frequently to account for changes in population, consumption level, supply sources, and technology. The CBFR system, by contrast, only requires that the utility have knowledge of its own cost structure to set prices.

Rahill-Marier and Lall (2013) and Olmstead et al. (2007) summarize some of the extensive literature on water pricing. Rahill-Marier and Lall (2013) analyze historical data from 190 water utilities within the United States. They find that, overall, water utilities where the primary water sources are from groundwater have the lowest average cost of supply, followed by surface water, a mix of the two, and utilities which rely on water purchases. This variation in costs provides context to understand what types of utilities might benefit most from a new form of consumer pricing such as CBFR.

Olmstead et al. (2007) analyze North American water consumption data for single-family households to measure price-elasticity of water demand under different pricing structures. Using a regression model for utility-maximizing households subject to a budget constraint, they find that price elasticity varies among different pricing mechanisms. However, they caution that these findings may result from either supply-side pricing decisions or demand-side responses to such prices. Olmstead and Stavins (2008) compare different price versus non-price mechanisms for water conservation in terms of equity and efficiency. While price-based mechanisms lead in efficiency, equity impacts remain highly dependent on design features for the program. Of particular concern, they mention that price elasticity is higher for low-income households; increases in price seem to result in greater consumption reductions among low-income users versus other groups. As a result, decreases in usage could come from low-use households who typically only consume to meet basic needs, versus those who consume water for luxury uses.

Renzetti et al. (2015) support these findings and show that price increases disproportionately affect low-income households (i.e., they pay a higher percentage of their income than other households). They hypothesize, for example, that the price increases will negatively affect equity of consumption; their results seem to support this hypothesis. These problems also arise with the Consumption-Based Fixed Rate model (Spang et. al. 2015), where the final impact on costs and equity depends upon the respective magnitudes of these two effects.

In the wake of the ongoing California drought, recent studies are evaluating California communities employing non-traditional water pricing structures. Barr and Ash (2015) focus on the Western Municipal Water District (WMWD) in the semi-desert inlands of Southern California. To solve problems with falling revenue despite the need for even greater conservation, the district adopted a "water budget" style of billing, where an efficient water amount for various activities (showering, cooking, cleaning, watering, etc.) is calculated for each customer based on household characteristics (number of occupants, ages, yard size, etc.), and steep charges are imposed for levels above one's "budget." The system has been successful in maintaining revenue, and receives high levels of customer satisfaction. However, potential problems with this system exist that are likely avoidable under the CBFR system. When prices are based on a unique customer profile, high levels of tenant turnover would make it difficult to keep up with the changes in data required to calculate new water budgets. In the CBFR system, the only information required about the customer is the consumption level; such data are often already recorded. The CBFR system also does not directly limit how much water each customer may consume and may not have large impacts on household consumption patterns, considering that water tends to be a price inelastic resource (Klaiber et al. 2012).

While many articles raise concerns over water revenue stability, few propose any substantive customer price changes to help ensure the proportions of fixed versus variable charges more closely reflect the high fixed-cost nature of the water utility industry. The Consumption-Based Fixed Rates model by Spang et al. (2015) provides an explicit formula to align cost and revenue composition; this formulation will be tested on two utilities' operating costs, demand levels, and customer characteristics. In this paper, we test the Spang et al. (2015) pricing method with utility data from Longmont, Colorado and Lomita, California.

### Consumption-Based Fixed Rates: Theoretical Background from Spang et al. (2015)

Spang et al. (2015) proposes a CBFR method designed to ensure appropriate utility revenue regardless of system use. The CBFR system distributes fixed costs faced by the utility across all users, such that the sum of all consumer bills yields revenue sufficient to cover operating costs (Equation 1).

$$\sum_{s_1}^{s_n} s_n C = C \qquad \text{(Equation 1)}$$

where $s_n$ = consumer $i$'s billing proportion and $C$ = utility operating costs.

This relationship created by the structure of the billing calculations for each customer for each cost category (Table 1) is shown in Equations 2-4:

Fixed-Fixed Costs:

$$i\text{th customer's bill} = \frac{FF\ Costs}{X};$$

$$\left(\frac{FF\ Costs}{X}\right) * X = FF\ Costs \qquad \text{(Equation 2)}$$

Fixed-Fixed Costs:

$$i\text{th customer's bill} = FV\ Costs * \frac{A_n}{W};$$

$$\sum_{A_1}^{A_n} FV\ Costs * \frac{A_n}{W} = FV\ Costs \qquad \text{(Equation 3)}$$

Variable Costs:

$$i\text{th customer's bill} = V\ Costs * \frac{A_n}{W};$$

$$\sum_{A_1}^{A_n} V\ Costs * \frac{A_n}{W} = V\ Costs \qquad \text{(Equation 4)}$$

where $X$ = Total Number of Utility Customers, $A_n$ = Customer $i$'s Consumption, and $W$ = Total System Consumption.

Regardless of system demand, bills calculated for period *a* will always recoup the costs for period *a*. Thus, the bill sent at the start of time *a+1* will represent period *a* costs, with bills sent out at *a+2* representing *a+1* costs, etc. Periodically determining billing prices provides stable revenue to the utility and an up-to-date pricing signal for consumers. Further, it provides a community-level incentive to conserve, as any reductions in usage are realized in lower prices almost immediately.

## Two Case Studies: Lomita, California and Longmont, Colorado

We present four simulations for two case studies in the West/Southwest United States. Simulation one utilizes the cost data for each utility to model

**Table 1.** Cost definitions and categorization.

| | |
|---|---|
| Fixed-Fixed Costs: Constant regardless of system use | Compliance costs, safety checks, office personnel, treatment plant energy use, etc. |
| Fixed-Variable Costs: Exist regardless of system use, but change in magnitude based on system demand | Piping infrastructure, chemicals, repairs and maintenance, etc. |
| Variable Costs: Depend directly upon consumption levels | Water purchases, energy for water pumping, etc. |

consumer prices in both Lomita, CA and Longmont, CO under the CBFR system. Simulation two experiments with different adjustments to the CBFR formula to address issues of fair consumer pricing and equity. Simulation three models prices under a completely proportional system. Simulation four explores the response of consumer prices to changes in the operating costs faced by the utility.

Lomita, California, located 22 miles from the City of Los Angeles, has a population of 20,596, with a median household income of $58,907, slightly below the state average of $60,190 (City-Data Lomita, California). Average yearly rainfall measures around 14 inches (Graphiq 2016).

The town's water is provided by a publicly owned utility operated by the city manager's office. The current billing structure consists of a bi-monthly meter fee and an IBR fee charged per hundred cubic feet (hcf, or 750 gallons). The data on utility costs and revenue used in this study come from a commissioned report by the consulting firm Black and Veatch (2013). The study includes observed data for fiscal year 2012-2013 costs and revenues, and projected levels for fiscal years 2013-2014 through 2016-2017. Projected data assume that growth in costs will be 3% per year, growth in fixed revenue (non-billing revenue) will be about 0.2%, and growth in consumption will be 0.25% per year.

The Lomita water utility collected insufficient revenue to fully cover its operation costs in FY 2012-2013; Black and Veatch (2013) also project shortfalls in the fiscal years 2013-2014 through 2016-2017. These results suggest that revenue needs might be better met under the CBFR system.

Longmont, Colorado, located 33 miles from Denver, has a population of approximately 89,919 with a median household income around $65,096, higher than the state average of $58,823 (City-Data Longmont, Colorado). Yearly rainfall averages 14.3 inches (US Climate Data 2016), similar to that of Lomita. Water service is provided by a publicly owned utility managed by the public works and natural resources department of the city government.

The Longmont Public Works and Natural Resources Department provided data for utility operation costs, as well as data on the number of customers serviced at each meter size, from 2011 to 2014. The city website (https://www.longmontcolorado.gov/departments/departments-n-z/water/rates-and-fees) provides information on billing rates. Table 2 shows the cost categories used in this study.

Tables 3 and 4 show how the different cost categories are classified (fixed-fixed, fixed-variable, or variable) for the purposes of the following simulations.

## Simulations

### Simulation 1: Consumer Cost Impacts of CBFR

The first simulation compares consumer bills under the IBR system currently in place in each city with consumer bills under the CBFR method. IBR bills are calculated with the assumption that residential users (single family homes) pay for meters within the 5/8” to 3/4” range for Lomita (the size of over 50% of all meters) and 5/8” for Longmont (the size of 90% of all meters).

The amount of water consumed per month (based on the Black and Veatch estimates of high, average, and low use) is multiplied by the cost/unit within the consumer's block; yearly consumption costs are presented as this value multiplied by 12. Total yearly costs equal the monthly consumption cost multiplied by 12 plus the bi-monthly meter cost multiplied by 6. The same consumption levels designated as high, average, and low are used in both the Lomita and Longmont calculations. While this study lacks the necessary data to firmly conclude that customer usage is similar for these two utilities, analysis of some additional data (Yolles 2016) suggests that this is a reasonable approach. Household level water consumption data for Sharon, MA, Los Angeles, CA, and West Palm Beach, FL, suggest that average rainfall impacts total water consumption. West Palm Beach receives an average 61 inches of precipitation per year (U.S. Climate Data-Palm Beach 2016), and average monthly water consumption stands at 8 hcf. Sharon receives around 49 inches of precipitation per year (U.S. Climate Data-Sharon 2016); average water use for those households is 10 hcf per month. Los Angeles, however, receives the same amount of average yearly precipitation as Lomita, around 14 inches (Los Angeles Almanac

**Table 2.** Water utility cost categories per fiscal year.

| Lomita, California | Longmont, Colorado |
|---|---|
| All Personnel | Regulatory Compliance |
| Debt Service | Water Administration: Offices and Personnel |
| WRD Assessment Expense | Water Plant Personnel |
| Safety Compliance | Water Distribution Personnel |
| Power and Utilities | Water Quality Laboratory: Personnel |
| Chemicals, Fuels, Supplies | Instrumentation: Personnel |
| Repair and Maintenance | Survey Engineers: Personnel |
| Contract Services | Distribution System Rehab |
| Capital Outlay | Water Distribution Supplies |
| Water CIP Projects | Water Quality Laboratory: Supplies |
| Miscellaneous | Instrumentation: Supplies |
| Water Purchases | Survey Supplies |
|  | St. Vrain Pipe Project |
|  | Operation and Maintenance Costs |
|  | Water Plant Chemicals, Energy, Misc. Supplies |

2016), and average household water consumption measures around 34 hcf a month. These two cities, with identical rainfall, have similar monthly household consumption levels. Therefore, it seems reasonable to assume that Longmont, with average rainfall also around 14 inches, could also have an average usage of about 35 hcf per customer.

Water bills for high, average, and low consumption users under the CBFR system were calculated using data on costs and revenues for each city. Table 1 shows how costs were divided for this study. While there is no definitive way to partition costs, this study attempts to follow the recommendation in Spang et al. (2015). For the fixed-fixed category, each consumer's bill equals the total cost of this category divided by the total number of users. Both the fixed-variable and the variable category cost sums are multiplied by a consumer's proportion of overall water consumption (consumer/Lomita total) to determine his/her bill. While the example bills provided in the study apply at the residential level, non-residential customers and their consumption are included in the CBFR definitions of total system use (W) and total number of customers (X). Dividing these yearly billing amounts by 12, and adding the quotients, provides an estimate for a monthly bill.

Yearly costs for each level of consumption were also divided by median household income for each city, in order to estimate the affordability of water costs under the CBFR; the EPA recommends that yearly water expenses account for 2% or less of median household income or MHI (Meiburg et al. 2006). The results of this calculation show that the CBFR fits within the boundaries recommended by the EPA; no estimated costs, for any level of use, exceed 1% of MHI.

Overall, consumers face lower average billing charges under the CBFR system versus the current IBR plus meter charge system. At an "average use" level of 35 hcf per month, a consumer would pay $37.11 per billing period with the CBFR system; he/she would pay around $100 under the current system. For the average user, the new system decreases billing costs by 64%.

While both high- and low-use customers over

**Table 3.** Lomita utility costs per fiscal year categorized for CBFR system.

| Fixed-Fixed Category | Fixed-Variable Category | Variable Cost |
|---|---|---|
| All Personnel | Power and Utilities | Water Purchases |
| Debt Service | Chemicals, Fuels, Supplies | |
| WRD Assessment Expense | Repair and Maintenance | |
| Safety Compliance | Contract Services | |
| (Predictable Revenue)* | Capital Outlay | |
| | Water CIP Projects | |
| | Miscellaneous | |

*Predictable revenue includes all utility revenues accrued regardless of total water consumption. This value was subtracted from the sum of the fixed-fixed costs category in order to decrease the value of the portion of the consumer's bill unrelated to personal consumption.

**Table 4.** Longmont utility cost categories per fiscal year.

| Fixed-Fixed Category | Fixed-Variable Category | Variable Cost |
|---|---|---|
| Regulatory Compliance | Distribution System Rehab | Water Plant Chemicals<br>Energy |
| Water Administration: Offices and Personnel | Water Distribution Supplies | Misc. Supplies |
| Water Plant Personnel | Water Quality Laboratory: Supplies | |
| Water Distribution Personnel | Instrumentation: Supplies | |
| Water Quality Laboratory: Personnel | Survey Supplies | |
| Instrumentation: Personnel | St. Vrain Pipe Project | |
| Survey Engineers: Personnel | Operation and Maintenance Costs | |

this same time period would also see decreases in their monthly water bill, the CBFR formula actually provides a greater magnitude of savings for high-use versus low-use consumers. This is the result of splitting fully fixed costs evenly across all consumers. A smaller portion of the bill changes with consumption level in the CBFR system versus the current system.

In the case of Longmont, high users see their bills decrease by about 60% under the CBFR versus the *status quo*. However, average and low users face substantial bill increases; bills under the CBFR are almost twice their current value for average consumption and three times their current value for low consumption. This disparity between different user groups, and the magnitude of the increase, stands in marked contrast to the Lomita example. These results suggest that the CBFR method, in its current form, would not be suitable for use in Longmont. The next simulation explores possible alterations to the cost categorization that might better maintain price levels like those under the IBR system, affordability, and conservation incentives for high users. Table 5 shows the results of Simulation 1; Figures 4 and 5 present the results for Lomita and Longmont, respectively.

***Alternative Distribution of Fixed Costs in CBFR Formula.*** The distribution of costs to different categories defined by CBFR remains largely subjective; different utility managers will likely have different opinions of what constitutes a fully fixed cost versus a partially fixed cost. To understand the level of sensitivity of consumer bills to changes in cost categorization, consumer bills for three different categorizations are compared to the CBFR bills from Simulation 1 (see supplemental tables for results).

Moving two costs from fixed-variable to fixed-fixed increased the former cost by 5%; the latter decreased by 45%. This re-categorization shows how increasing the absolute value of the fixed-fixed cost category has a strong impact on consumer bills. Not only do bills for all levels of use increase, the increase also affects low-use bills the most. The increased fixed-fixed cost more than offsets the decrease in the fixed-variable category cost.

**Table 5.** Consumer prices under CBFR system, FY 2013-2014.

Monthly Bills Simulation 1

| **High (50 hcf)** | **Lomita** | **Longmont** |
|---|---|---|
| Fixed-Fixed Charge | $25.62 | $19.88 |
| Fixed-Variable Charge | $6.35 | $1.81 |
| Variable Charge | $9.71 | $0.67 |
| Monthly Bill | $41.68 | $22.36 |
| Total Paid Over 12 Billing Cycles | $500.16 | $268.36 |
| % IBR System | 30% | 35% |
| **Average (35 hcf)** | **Lomita** | **Longmont** |
| Fixed-Fixed Charge | $25.62 | $19.88 |
| Fixed-Variable Charge | $4.44 | $1.27 |
| Variable Charge | $6.80 | $0.47 |
| Monthly Bill | $36.86 | $21.62 |
| Total Paid Over 12 Billing Cycles | $442.36 | $259.43 |
| % IBR System | 40% | 171% |
| **Low (15 hcf)** | **Lomita** | **Longmont** |
| Fixed-Fixed Charge | $25.62 | $19.88 |
| Fixed-Variable Charge | $1.90 | $6.52 |
| Variable Charge | $2.91 | $2.41 |
| Monthly Bill | $30.44 | $20.63 |
| Total Paid Over 12 Billing Cycles | $365.29 | $247.53 |
| % IBR System | 63% | 268% |

For Lomita, increasing the value of the fixed-variable costs category not only lowers consumer bills, but leads to greater savings for low-use versus high-use. This is the opposite of what occurs when fixed-fixed costs are increased. The greater the value of fixed-variable costs versus fixed-fixed costs, the more pricing corresponds to usage and therefore the greater the difference among consumer types.

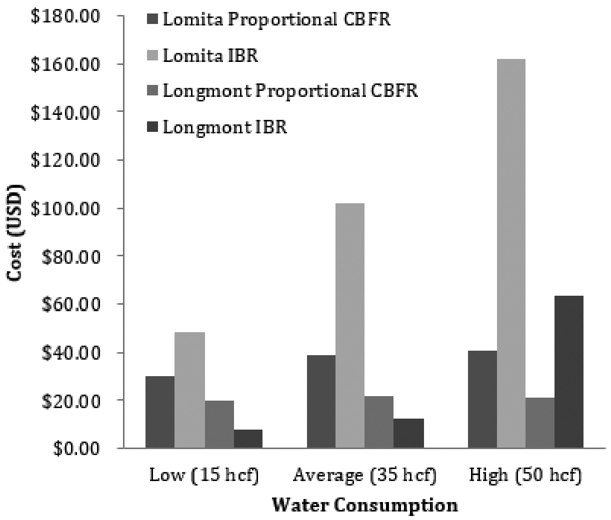

**Figure 4.** Monthly billing rate: IBR versus Standard CBFR in Longmont and Lomita, FY 2013-2014.

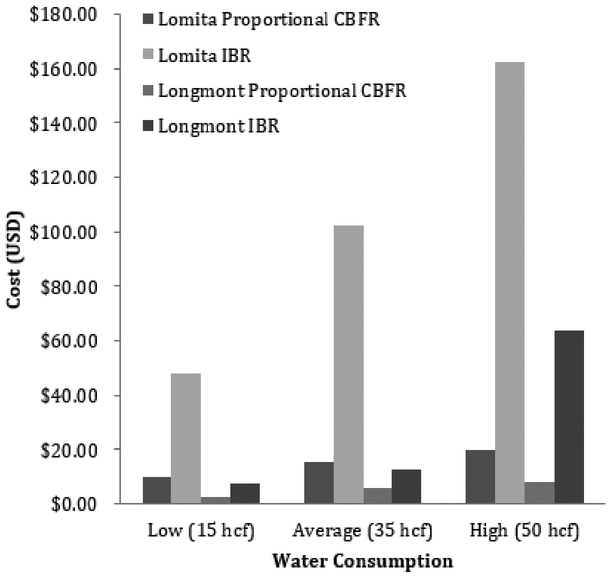

**Figure 5.** Monthly billing rate: IBR versus Entirely Proportional CBFR in Longmont and Lomita, FY 2013-2014.

In Longmont, personnel accounts for a large portion of costs. This simulation measures the impact of moving personnel costs from the fixed-fixed section to the fixed-variable section. The result is a more equitable system with prices similar to those under the current IBR plan.

These results suggest that a substantial change in costs categorization is necessary to make the CBFR system benefit customers of the Longmont utility. Even under this system the benefits are greatest for the highest use customers; the pricing mechanism fails to encourage conservation.

### Simulation 2: Altering the Formula of CBFR

Simulation 2 explores modifications to the CBFR formula that provide water services at a more affordable rate for low-income users. Studies suggest that, beyond drinking and cleaning based on household size, greater water consumption is driven by the use of luxury goods like pools or irrigated landscaping (Mini et al. 2014). The unequal burden for low-income or low-use households stems from the CBFR system's relationship to the utility costs as a whole: the more water a household consumes, the lower the per unit cost they pay as they distribute the fixed-fixed cost section over more and more units of water. Only the fixed-fixed portion of the costs (as it is not already scaled by use to help lower-income users) will be altered: The original value for the category is multiplied by 2/3 for low income and 4/3 for high income. Average income costs remain unchanged. Low-income constitutes earnings at or below 75% of MHI; median includes those making between 75 and 150% or more of MHI; high-income is defined as any income at or above 150% of the MHI.

The public data set excludes consumer-level data, so this simulation uses 'fabricated' consumers with low, middle, and high income. The low-income household makes 50% of the MHI, the average income household makes exactly the MHI, and the high-income household makes 200% of the MHI. Providing different pay scales for different income levels improves affordability for low-income groups by keeping prices below 2% of income, but still allows high-income users to pay a smaller share of their income for water.

Using this proportional pricing method in Longmont lowers bills by about 30% for low-income groups and also ensures that, for up to 50 hcf of use, bills remain below 2% of an income of $32,548.

The proportional method raises high-income user bills by about 30%; these bills still account for well below 2% of household income. These results suggest that a modified CBFR billing system based on income can keep bills fairly close to their pre-CBFR levels, as a proportion of the household's income. Table 6 shows the results of pricing in a low income model, and Table 7 shows the results of a high income model.

### Simulation 3: An Entirely Proportional System

Given that the original CBFR system eliminates any conservation incentive (the more water consumed, the lower the per-unit price of water), a fully proportional system seems worth exploring. In this case (Simulation 3), the lump-sum costs for the utility in time *t* are distributed using the formula:

$$\text{Customer } i\text{'s Bill} = C * \frac{A_i}{W} \qquad \text{(Equation 5)}$$

where $C$ equals total utility system costs, $A_i$ equals customer $i$'s consumption, and $W$ equals total system consumption. The results of this system are shown in Table 8 and Figure 5.

### Simulation 4: Sensitivity of Consumer Bills to Changes in Utility Operation Costs

The CBFR method makes consumer costs much more sensitive to changes in utility operation costs than a traditional increasing block rate. In fact, the relationship between changes in utility costs and increases in consumer bills is 1-to-1. Given this quality of the CBFR, Simulation 4 seeks to provide a limit at which increases in utility costs yield consumer bills in excess of 2% of MHI. These values are calculated for the FY 2012-2013 data.

***Lomita.*** This simulation raises all costs simultaneously until the average use customer's bill exceeds 2% of MHI. Performing calculations with the Lomita, CA data suggests that costs could increase by up to 250% to ensure that average or conserving consumers bills remain below 2% of Lomita HMI. This suggests that CBFR bills remain at reasonable rates even if certain utility costs were to spike due to an increase in energy prices, a large unforeseen repair project, etc.

***Longmont.*** For Longmont, utility costs could more than triple and still keep bills within 2% of MHI range. This suggests that CBFR bills remain at reasonable rates even if certain utility costs were to spike.

### Extension: Lomita Consumer Costs over Time with 25% Decreased Consumption over Five Years

The benefit of the CBFR method of pricing centers around its ability to ensure income to cover operating costs regardless of fluctuations in consumption. In this simulation, using the costs for fiscal years 2012-2013 to 2016-2017, the effects of a 25% reduction in consumption over five years (via a 5% yearly reduction) are compared in the traditional versus the CBFR system. For all costs classified as fixed-fixed and fixed-variable, total yearly costs for FY 2012-2013 will be used over the five-year period. Water purchases are assumed to have a constant marginal cost/hcf, which will be used to estimate total water purchase costs per year. With this assumption that average cost equals the marginal cost of water purchases, the cost of water purchases for a given year equals $2.32 per hcf.

Given the lack of consumer-level data, the estimates of revenue shortfalls from a 25% consumption decrease under the current system are rough estimates. The values shown below assume that, on average, each unit of water consumed is charged at the middle block rate of 21/35 hcf/month. Assuming that no meters are added or removed over the 5-year period, yearly meter revenue can be calculated with near-certainty.

Table 9 reports the revenue shortfalls per year with the current billing structure and constant costs; table 10 shows shortfalls with an estimated 2% decrease in costs for the fixed-variable category.

For the CBFR scenario, the same formulas from Simulation 1 were used. Assuming costs remain stable, the only changes to a consumer's bill will come from the fixed-variable and variable categories. Since these costs are multiplied by the consumer's proportion of total consumption, a decrease in overall consumption increases the proportion represented by each "generic" customer profiled here. Table 11 models cost impacts with no change in utility costs.

**Table 6.** CBFR consumer prices, low income model.

| **High (50 hcf)** | **Lomita** | **Longmont** |
|---|---|---|
| Yearly Fixed-Fixed | $204.99 | $159.07 |
| Yearly Cost | $397.67 | $188.88 |
| Monthly Cost (assume 1 bill/month) | $33.14 | $15.74 |
| % MHI | 1.35% | 0.15% |
| **Average (35 hcf)** | **Lomita** | **Longmont** |
| Yearly Fixed-Fixed | $204.99 | $159.07 |
| Yearly Cost | $339.86 | $179.88 |
| Monthly Cost (assume 1 bill/month) | $28.32 | $14.99 |
| % MHI | 1.15% | 0.14% |
| **Low (15 hcf)** | **Lomita** | **Longmont** |
| Yearly Fixed-Fixed | $204.99 | $159.07 |
| Yearly Cost | $262.79 | $168.00 |
| Monthly Cost (assume 1 bill/month) | $21.90 | $14.00 |
| % MHI | 0.89% | 0.13% |

**Table 7.** CBFR consumer prices, high income model.

| **High (50 hcf)** | **Lomita** | **Longmont** |
|---|---|---|
| Yearly Fixed-Fixed | $409.98 | $318.14 |
| Yearly Cost | $602.66 | $347.88 |
| Monthly Cost (assume 1 bill/month) | $50.22 | $28.99 |
| % MHI | 0.51% | 0.27% |
| **Average (35 hcf)** | **Lomita** | **Longmont** |
| Yearly Fixed-Fixed | $409.98 | $318.14 |
| Yearly Cost | $544.85 | $339.00 |
| Monthly Cost (assume 1 bill/month) | $45.40 | $28.25 |
| % MHI | 0.46% | 0.26% |
| **Low (15 hcf)** | **Lomita** | **Longmont** |
| Yearly Fixed-Fixed | $409.98 | $318.14 |
| Yearly Cost | $467.78 | $327.12 |
| Monthly Cost (assume 1 bill/month) | $38.98 | $27.26 |
| % MHI | 0.40% | 0.25% |

**Table 8.** Completely proportional pricing system.

| **High (50 hcf)** | **Lomita** | **Longmont** |
|---|---|---|
| Fixed-Fixed Charge | $5.48 | $5.83 |
| Fixed-Variable Charge | $4.74 | $1.81 |
| Variable Charge | $9.54 | $0.70 |
| Total Paid over 12 Billing Cycles | $237.24 | $100.41 |
| Monthly Bill | $19.77 | $8.34 |
| % of IBR Bill | 14% | 13% |
| **Average (35 hcf)** | **Lomita** | **Longmont** |
| Fixed-Fixed Charge | $5.48 | $4.12 |
| Fixed-Variable Charge | $3.32 | $1.27 |
| Variable Charge | $6.68 | $0.47 |
| Total Paid over 12 Billing Cycles | $185.76 | $70.29 |
| Monthly Bill | $15.48 | $5.86 |
| % of IBR Bill | 15% | 46% |
| **Low (15 hcf)** | **Lomita** | **Longmont** |
| Fixed-Fixed Charge | $5.48 | $1.77 |
| Fixed-Variable Charge | $1.42 | $0.55 |
| Variable Charge | $2.86 | $0.20 |
| Total Paid over 12 Billing Cycles | $117.24 | $30.12 |
| Monthly Bill | $9.77 | $2.51 |
| % of IBR Bill | 20% | 33% |

**Table 9.** Consumption and revenue with 25% decrease over five years, 0 inflation.

| **Fiscal Year** | **12-13** | **13-14** | **14-15** | **15-16** | **16-17** |
|---|---|---|---|---|---|
| Total Consumption (hcf) | $903,813.85 | $813,432.47 | $768,241.77 | $723,051.08 | $677,860.39 |
| Estimated Total Consumption Revenue | $3,678,250.85 | $3,310,425.77 | $3,126,513.22 | $2,942,600.68 | $2,758,688.14 |
| Estimated Revenue Shortage | $455,043.15 | $1,214,553.24 | $1,842,159.83 | $2,121,829.13 | $2,657,870.83 |

**Table 10.** Consumption and revenue with 25% decrease over five years and 2% yearly decrease in fixed-variable costs, 0 inflation.

| Fiscal Year | 12-13 | 13-14 | 14-15 | 15-16 | 16-17 |
|---|---|---|---|---|---|
| Total Consumption (hcf) | $903,814 | $813,432.47 | $768,241.77 | $723,051.08 | $677,860 |
| Estimated Total Consumption Revenue | $3,678,250.85 | $3,310,425.77 | $3,126,513.22 | $2,942,600.68 | $2,758,688.14 |
| Estimated Revenue Shortage | $399,731.97 | $571,390.10 | $664,989.63 | $759,455 | $859,057 |

These results support the assumption that, as consumption decreases, consumers face larger CBFR bills to cover system costs. However, individual bills do not increase proportionally to consumption decreases: a 25% system-wide decrease in consumption over five years raises a high user's bill by 8%, an average user's bill by 6%, and a low user's bill by 3%.

The result that greater users face greater price increases over time also suggests that some amount of progressive pricing is built into the system, for as overall community consumption decreases, those who persist in using high volumes of water will account for a larger fraction of the total and face higher bills as a result. This explains why high-use bills increase more than low-use bills. No bill value exceeds the 2% of MHI limit recommended by the EPA.

If fixed-variable costs decrease in absolute value by at least 2% per year, CBFR bills should be lower for all users versus the status quo with no conservation. Table 12 shows the results of such a simulation.

At any level of consumption, decreasing the fixed-variable costs over time decreases the consumer's bill. Compared to the *status quo* from Simulation 1, lowering costs and consumption lowers bills by 6% for high users, 5% for average users, and 2.6% for low users.

In contrast to the scenario with no change in utility costs, this scenario provides a greater savings the greater the amount of water used. This suggests that the yearly cost decreases overpower increases in the proportion of the total accounted for by the high-use consumer. While all consumers see a decrease in bills, the disproportionate benefit provided to high-income users may conflict with other goals like equity and conservation-focused billing.

Based on the significant difference in billing prices for CBFR between Lomita and Longmont, it is clear that the results of switching to the CBFR system are largely dependent upon the current utility pricing situation and community characteristics. For Lomita, the CBFR system lowered billing costs to customers, whereas in Longmont, the system decreased bills for high users but increased bills for low and average use customers. Comparing the IBR systems employed by each utility reveals some key differences in current pricing that ultimately make the CBFR either helpful or harmful to customers. In the case of Lomita, the current system imposes a large meter cost ($218/year) but then charges similar costs for its three blocks; the difference between the first block and the top (third) block is 44%. With a high fixed cost and relatively low penalties for increased consumption, this billing system more closely mirrors the cost structure for the water utility itself, with its costs predominately fixed regardless of consumption. As a result, the CBFR's slight positive increase on the fixed portion of the bill is more than offset by the much lower per-unit costs.

**Table 11.** Billing impacts of a 25% total decrease in consumption FY 2014-2015.

| **High (50 hcf)** | |
|---|---|
| Fixed-Fixed Charge | $25.62 |
| Fixed-Variable Charge | $7.90 |
| Variable Charge | $9.68 |
| Monthly Bill | $43.20 |
| Total Paid Over 12 Billing Cycles | $518.42 |
| % of MHI | 0.88% |
| **Average (35 hcf)** | |
| Fixed-Fixed Charge | $25.62 |
| Fixed-Variable Charge | $5.53 |
| Variable Charge | $6.78 |
| Monthly Bill | $37.93 |
| Total Paid Over 12 Billing Cycles | $455.14 |
| % of MHI | 0.77% |
| **Low (15 hcf)** | |
| Fixed-Fixed Charge | $25.62 |
| Fixed-Variable Charge | $2.37 |
| Variable Charge | $2.90 |
| Monthly Bill | $30.90 |
| Total Paid Over 12 Billing Cycles | $370.76 |
| % of MHI | 0.63% |

**Table 12.** Billing impacts of a 25% decrease in consumption with an absolute decrease in fixed-variable costs of 2% per year, FY 2014-2015.

| **High (50 hcf)** | |
|---|---|
| Fixed-Fixed Charge | $25.62 |
| Fixed-Variable Charge | $3.92 |
| Variable Charge | $9.68 |
| Monthly Bill | $39.22 |
| Total Paid Over 12 Billing Cycles | $470.68 |
| % of MHI | 0.80% |
| **Average (35 hcf)** | |
| Fixed-Fixed Charge | $25.62 |
| Fixed-Variable Charge | $2.74 |
| Variable Charge | $6.78 |
| Monthly Bill | $35.14 |
| Total Paid Over 12 Billing Cycles | $421.72 |
| % of MHI | 0.72% |
| **Low (15 hcf)** | |
| Fixed-Fixed Charge | $25.62 |
| Fixed-Variable Charge | $1.18 |
| Variable Charge | $2.90 |
| Monthly Bill | $29.70 |
| Total Paid Over 12 Billing Cycles | $356.44 |
| % of MHI | 0.61% |

The current IBR system in Longmont is almost the opposite of the Lomita system. The meter cost is only $58.80/year, while the consumption cost increases by 145% between the first block and the final (fourth) block (the amount of water included in each block is reasonably consistent for the two utilities to allow for this type of comparison). The CBFR method greatly upsets the IBR and its greater variation in the consumption-based portion of a customer's bill; low-use customers in Longmont who no longer benefit from conserving suffer the most under the CBFR system. The severity of the change from switching to CBFR highlights the difference between Longmont's pricing system and the typical water utility's cost structure.

## Conclusion

Were a utility to consider the CBFR method, system planners would need to be highly confident in their cost categorizations: failing to allocate the system properly could have unnecessarily negative impacts on consumer bills, especially for low users. Given the negative effects on low-use customers, utilities should be very cautious about if and when to pursue the CBFR system. The similarity between the CBFR bill and the water utility's cost structure disadvantages low-use customers; just like the utility, the fixed-fixed portion of their bill is spread over fewer units of water, so they pay a higher per-unit cost than high-use customers. Equity remains an issue in a system where all types of users face the same, substantial, fixed cost bill component. In addition, the higher price elasticity for low-income users (Olmstead et al. 2007) suggests that lower-use households could end up reducing consumption more than higher-use (high-income) homes. More conservation might come from lower-cost households who already use smaller amounts of water. Thus, equity concerns in the CBFR system stem from the high proportion of a user's bill accounted for by the fixed-fixed charge, and how low-use, low-income households may decrease consumption by a larger amount than other households.

Given the difference between high and low users, weighting the value of each user's fixed-fixed cost bill based on income could help mitigate potential equity problems. Especially for Longmont, the current system, with its steep blocks and its minimal meter fee, allows customers to save money by using less water. Multiplying the fixed-fixed bill by 2/3 for low income and 4/3 for high income ensures that all customers making at least 50% of the MHI will not pay more than 2% of their income to consume up to 50 hcf of water. However, even this type of scale lets high-income groups pay a smaller portion of their income overall versus other users. While income scalars certainly ease the burden for low-income groups, they need to be highly complex in order to ensure all customers pay an equal portion of their income for any given consumption amount. Furthermore, the burden on the utility to obtain income information for all customers could be severe; other methods like census tract data are certain to have errors. Any attempt to base price on income is also likely to be politically controversial.

Experimentation with the Lomita data shows that all users' bills inevitably increase under the CBFR with a system-wide consumption decrease. However, cost increases are of a lower magnitude than the consumption decrease: reducing system consumption by 25% does not raise bills by more than 10%, up to monthly consumption of 50 hcf. High-use customers also see their bill rise more than low-use customers; costs increase by 8% at 50 hcf/month, 6% at 35 hcf/month, and just 3% at 15 hcf/month. With the magnitude of the increase higher for high-use customers, the CBFR system seems like an effective means of incentivizing high users to decrease use in the face of community-wide conservation; customers who ignore the conservation trend will have to shoulder more of the costs for running the system. Higher volume users tend to have more price elastic demand (more luxury water uses) and as such might be most responsive to these incentives. Under extreme conservation measures, like the 25% reduction call currently faced in California, some utilities could employ a CBFR system to guarantee revenue to cover costs, and also send conservation signals to their high-use consumers.

Both Lomita and Longmont consumer bills prove remarkably resilient to utility cost fluctuations. Increases in operating costs of up to 250% for Lomita and 300% for Longmont still keep consumer bills within the "affordable" range defined by the EPA, or 2% of MHI. The magnitude of the increase in consumer bills is significantly lower than the increase in utility operating costs, but still provides sufficient revenue to cover these greater costs.

This study finds that the CBFR ensures stable revenue at the cost of equitable billing and conservation pricing. The CBFR pricing mechanism is not a good solution for water utilities over the long term. However, the system could be useful in times of severe drought, where utilities face a large threat of revenue shortfalls. For example, if consumption reductions are determined exogenously, such as the current situation in California, the CBFR appears to be the simplest way to ensure that utilities can cover their high fixed costs. In particular, the system would be best applied to drought-stricken communities where income is largely homogenous for all customers.

Further research is needed to explore the ideal scalar system, or to explore any other methods for making the CBFR system more equitable and conservation-focused. While a proportional system yields bills more responsive to a customer's consumption, it depresses prices too much below the IBR rates such that any conservation or scarcity pricing currently in place is eliminated. With water prices accounting for only 0.5 to 0.6% of the average U.S. family's household budget (Mehan III and Kline 2012), higher, not lower prices seem necessary to induce water conservation-- especially for high-income consumers-- in water-scarce environments. For now, a "SCBFR" (Scaled Consumption-Based Fixed Rates) system seems the best option for ensuring revenue stability for the water utility without jeopardizing affordability for low-income households.

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## Supplemental Tables (S1 - S3)

**Table S1.** Alternative distribution of fixed costs in CBFR formula. Impact of moving "capital outlay" and "misc. costs" from fixed-variable to fixed-fixed on consumer bills FY 2014-2015.

| **High (50 hcf)** | **New** | **Previous** | **% Change** |
|---|---|---|---|
| Fixed-Fixed Charge | $27.71 | $25.62 | 8.13 |
| Fixed-Variable Charge | $5.89 | $6.35 | -7.17 |
| Variable Charge | $9.71 | $9.71 | 0.00 |
| Total Amount Due | $43.31 | $41.68 | 3.90 |
| **Average (35 hcf)** | **New** | **Previous** | **% Change** |
| Fixed-Fixed Charge | $27.71 | $25.62 | 8.13 |
| Fixed-Variable Charge | $4.12 | $4.44 | -7.17 |
| Variable Charge | $6.80 | $6.80 | 0.00 |
| Total Amount Due | $38.63 | $36.86 | 4.79 |
| **Low (15 hcf)** | **New** | **Previous** | **% Change** |
| Fixed-Fixed Charge | $27.71 | $25.62 | 8.13 |
| Fixed-Variable Charge | $1.77 | $1.90 | -7.17 |
| Variable Charge | $2.91 | $2.91 | 0.00 |
| Total Amount Due | $32.39 | $30.44 | 6.39 |

**Table S2.** Alternative distribution of fixed costs in CBFR formula. Impact of movement of "safety compliance" and "WRD assessment expense" categorization on consumer bills FY 2014-2015.

| **High (50 hcf)** | **New** | **Previous** | **% Change** |
|---|---|---|---|
| Fixed-Fixed Charge | $24.60 | $25.62 | -3.98 |
| Fixed-Variable Charge | $6.57 | $6.35 | 3.51 |
| Variable Charge | $9.71 | $9.71 | 0.00 |
| Total Amount Due | $40.88 | $41.68 | -1.91 |
| **Average (35 hcf)** | **New** | **Previous** | **% Change** |
| Fixed-Fixed Charge | $24.60 | $25.62 | -3.98 |
| Fixed-Variable Charge | $4.60 | $4.44 | 3.51 |
| Variable Charge | $6.80 | $6.80 | 0.00 |
| Total Amount Due | $36.00 | $36.86 | -2.34 |
| **Low (15 hcf)** | **New** | **Previous** | **% Change** |
| Fixed-Fixed Charge | $24.60 | $25.62 | -3.98 |
| Fixed-Variable Charge | $1.97 | $1.90 | 3.51 |
| Variable Charge | $2.91 | $2.91 | 0.00 |
| Total Amount Due | $29.49 | $30.44 | -3.13 |

**Table S3.** Alternative distribution of fixed costs in CBFR formula. Movement of personnel from fixed-fixed to fixed-variable: impact on bills.

| **High (50 hcf) 2014** | |
|---|---|
| Fixed-Fixed Charge | $61.62 |
| Fixed-Variable Charge | $82.06 |
| Variable Charge | $8.03 |
| Total Paid over 12 Billing Cycles | $151.71 |
| Monthly Bill | $12.64 |
| % of MHI | 0.23% |
| % of Status quo | 20% |
| **Average (35 hcf) 2014** | |
| Fixed-Fixed Charge | $61.62 |
| Fixed-Variable Charge | $57.45 |
| Variable Charge | $5.62 |
| Total Paid over 12 Billing Cycles | $124.69 |
| Monthly Bill | $10.39 |
| % of MHI | 0.19% |
| % of Status quo | 82% |
| **Low (15 hcf) 2014** | |
| Fixed-Fixed Charge | $61.62 |
| Fixed-Variable Charge | $24.62 |
| Variable Charge | $2.41 |
| Total Paid over 12 Billing Cycles | $88.65 |
| Monthly Bill | $7.39 |
| % of MHI | 0.14% |
| % of Status quo | 96% |

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