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Economically Recoverable Water in Texas: An Underappreciated Water Management Strategy?

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Abstract: Conversations about the value or "true cost of water" and the nationwide infrastructure maintenance gap encourage a reconsideration of the value of utility water losses. Water loss audit data for 2014 for two planning regions that are home to almost a third of Texas' population and include three of the five largest cities are examined to explore the value of economically recoverable water losses from a perspective that better reflects the regional scenarios under which the state water plan is developed. The volume of real and apparent losses is valued per a new regional average composite price to arrive at an estimation for the water that should be feasible to recover. Normalized values of economically recoverable losses are generated to arrive at a statewide estimate of valuation. Industry standard financial and operational performance indicators are also developed and compared to a larger, multi-state data set. Results are presented in the context of state and regional water supply planning in two ways: 1) comparing the volume of economically recoverable water to the volume of supply expected from water loss control strategies, and 2) comparing the newly assessed value of recoverable water to the estimated costs associated with water loss control strategies.
Keywords: utility water loss, economic level of loss, water audits, value of water, water supply

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Terms used in paper

Acronyms	Descriptive name
AWWA	American Water Works Association
CARL	current annual real losses
ELL	economic level of loss
gpcd	gallons per capita per day
ILI	infrastructure leakage index
IWA	International Water Association
KWEC	Kunkel Water Efficiency Consulting
TWDB	Texas Water Development Board
UARL	unavoidable annual real losses
WSP	water service provider

INTRODUCTION

The United States faces a significant need for water delivery infrastructure maintenance and repair. Historical underpricing of drinking water is one reason for the state of infrastructure disrepair (Beecher 1997). The American Water Works Association (AWWA) estimates that $1 trillion is needed to maintain and expand water service to meet demands over the next 25 years (AWWA 2012). The American Society of Civil Engineers gives the nation's drinking water infrastructure a D grade in its 2017 Infrastructure Report Card (ASCE 2017). The state of the nation's water delivery infrastructure is one reason water supply is a rising cost industry (Beecher 1999). More recently, the AWWA (2016a) declared the North American water industry at a crossroads regarding nonrevenue water—the difference between system input volume and billed authorized consumption—of which real losses from leaking pipes are a major component.

Reducing utility system water loss has traditionally been viewed as a form of water conservation. A new emphasis on utility water loss is supported by studies that reveal the potential for recovery of lost revenue (or sunk costs) and new tools for its capture. The International Water Association (IWA) and the AWWA, for example, offer a water loss audit methodology that is being used by a growing number of utilities, also referred to as water service providers, across the country (AWWA 2016b). The AWWA Free Water Audit Software complements the IWA/AWWA method and enables utility staff to improve desktop accounting for water throughout the distribution and billing systems, including their nonrevenue water.

For Texas, the grade for drinking water infrastructure is D+, an improvement over the previous D- grade, but the grade is nonetheless an assessment of the $33.9 billion needed for drinking water infrastructure over the next 20 years (ASCE 2017). At the same time, Texas' population is growing rapidly and placing increasing strain on the state's water resources (TWDB 2016). Reducing utility-side water loss therefore holds great promise as a strategy for helping to make ends meet with respect to the growing imbalance between projected water demand and existing supplies during a prolonged drought.

The purpose of this pilot study is to evaluate water loss audit data from calendar year 2014 as reported by water service providers (WSP) from two of 16 regional water planning areas to the Texas Water Development Board (TWDB). Operational and financial performance indicators are presented along with a reframing of the cost impact of apparent and real losses identified in water loss audits in order to better reflect water scarcity in Texas and its assumption in state and regional water supply planning efforts. To that end, the study estimates the economic level of loss—the level of leakage below which it is not cost-effective to invest in reducing leakage further down (Farley and Trow 2003)—for several water service providers within the two planning regions. It then normalizes that figure to produce both regional and state-level estimates of the financial impact of lost water that could be economically feasible to recover.

The cost (of supplying drinking water), price (paid by ratepayers for delivery on demand), and value of water are different yet related terms (Raucher 2005). These terms all have some bearing on the thesis of this study, which is to reconsider the financial impacts of nonrevenue water for regional planning purposes in a state that will be severely challenged for water when the next drought of record occurs.

BACKGROUND

In 2003, the 78th Texas Legislature enacted House Bill 3338, which requires retail public utilities providing potable water to conduct a water audit based on the most recent annual system water loss. The results of such water loss audits must be submitted to the TWDB once every five years. The first year for this requirement was 2005, and reports were subsequently submitted in 2010 and 2015. Additionally, any retail water supplier that has an active financial obligation with the TWDB or has more than 3,300 service connections must now submit an audit annually (Texas Water Code, Section 16.0121). The annual water loss audits covering a calendar year are due on the first of May the following year.

The TWDB collects water audit data via an online form that is based on the AWWA audit software. Data inputs can be assigned a validity score that is a modified version of what is featured in the AWWA audit software. Validity scores from the AWWA audit software are totaled and placed into one of five levels, with a maximum score of 100 points. AWWA validity score levels are characterized to provide basic loss control guidance to water service providers. The Water Loss Audit Manual for Texas Utilities (Mathis et al. 2008) has a more streamlined guidance matrix with a total of 85 points possible.[2] The guidance matrix has possible points assigned by category: water supplied (20), authorized consumption (20), apparent losses (15), real losses (10), cost data (10), and system data (10). The Texas guidance matrix does not sum points and assign data validity levels as the AWWA does but offers three scoring categories (i.e., 0-40, 41-70, 71-85) that suggest in general terms the level of accuracy and thus the usefulness of the data collected.

In 2017, the 85th Texas Legislature enacted House Bill 1573, which amends Section 16.0121 of the Texas Water Code to require that water audits be completed by a person trained to conduct water loss auditing and that the TWDB make training on water loss auditing available without charge via the Board's website. This Act took effect September 1, 2017. Given that these new requirements aim to improve system understanding and thus accuracy and validity of data reported, it is reasonable to expect higher water loss audit data validity scores in the future.[3] To quantify the extent to which this might occur, it will be necessary to consider audit data in greater detail both prior to and after this new law took effect.

WATER-PLANNING REGIONS C AND K

Two of 16 water planning regions were chosen for this pilot study. Region C includes all or part of 16 counties in north-central Texas and includes the Dallas-Fort Worth metropolitan area. The city of Dallas is the third largest city in Texas. The population of Region C was 6,477,835 or about 25% of the state's population in 2010 (U.S. Census Bureau 2017). The Dallas Water Utility, the largest in the region, serves a population of 1,232,360, while the second largest water service provider in Region C, the city of Fort Worth, serves 781,100 people.[4] Region C's population is projected to be 7,504,200 in 2020, about a 16% increase during the current decade (Freese and Nichols, Inc. et al. 2015a).

Water demand in Region C's municipal sector, 1,481,530 acre-feet per year, is projected to account for 86% of total forecasted demand of 1,723,325 acre-feet per year among the six water-use sectors during the next decade (TWDB 2016). Under a worst case drought scenario using only existing water supplies, Region C's potential water shortage is projected to grow from 125,037 acre-feet per year in 2020 to 604,016 acre-feet per year in 2040 across all water-use sectors.[5] In response, the 2016 Region C Water Plan presents a range of potential supply enhancement strategies, including 259 water loss control management strategies that could produce water savings of 26,646 acre-feet[6] per year in the decade beginning 2020 at an expected annual cost of $36,546,937 or an annual unit cost of $1,372 per acre-foot or $4.21 per kilogallon[7] (personal com-

[2] The data validity scoring scheme was modified to total 100 points beginning with the 2015 audit reports.

[3] Without third-party validation (i.e., Level 1 validation), however, self-reported data validity will remain suspect regardless of complementary efforts to improve the quality of audit reports.

[4] Population served figures come from 2014 Water Audit Reports submitted to TWDB and shared with author.

[5] Water need or potential shortage is based on projected population growth/water demand and existing supplies. Any imbalance between demand and supply is predicated on a scenario of recurrence of drought of record conditions and not implementing any water management strategies presented in regional water supply plans.

[6] Tally by author of individual water loss control strategies listed in Appendix Q, Table Q-10 of the 2016 Region C Water Plan after corrections applied as referenced in the following footnote (Freese and Nichols, Inc. et al. 2015c).

[7] The published cost of $3.74/1,000 gallons of water saved in Appendix K, Summary Table K.3, 2020 column, of Region C's approved plan is in error, per email communication with Brain McDonald, Allan Plummer Associates, July 24,2018. Appendix Q, Table Q-10 of Region C's plan also features a couple of errors, most notably with the 2020 unit cost listed for Fort Worth,

Table 1. Recommended water management strategies for Region C, Texas for decade beginning 2020 unless otherwise noted.

Strategy type	Percentage of total[a]	Volume of water[b] (acre-feet/year)	Unit cost[c] ($/acre-feet) in 2070
Municipal conservation	29.0	55,628	154
Indirect reuse	21.6	41,442	111
Other surface water	20.0	38,371	571
Other direct reuse	20.0	38,331	285
New major reservoir	6.7	12,870	563
Groundwater wells & Other	2.7	5,135	350
Totals	100	191,777	n/a

[a] and [b] Source: Texas Water Development Board, Interactive 2017 State Water Plan, Region C. https://2017.texasstatewaterplan.org/region/C

Thirty-four acre-feet are not included in this table and are expected from irrigation conservation.

[c] Source: Texas Water Development Board. 2016. Water for Texas, 2017 State Water Plan. Table 8.5

munication with Brian McDonald, Senior Project Engineer, Water Infrastructure Planning, Alan Plummer Associates, Inc., July 24, 2018, via email). This unit cost will be placed in a value-of-water context later. Here, the unit cost will be considered relative to other strategies using data points made available by the Texas Water Development Board.

First, it is instructive to note that any comparison invokes a couple of caveats. For example, investment made in water loss control results in finished water that is captured and remains available in the distribution network. Other supply-augmentation strategies result in raw water at the source. Thus, one must add the cost of withdrawal, treatment, and pumping into the distribution network to more closely compare with the unit cost of supply gained from water loss control. Furthermore, other supply strategy unit costs will vary over time: a higher unit cost calculated over the initial 20 years during which a typical loan is amortized and a lower unit cost beyond that period.

The 2017 State Water Plan (TWDB 2016) projects that the recommended water management strategies in Region C will yield an annual volume of 192,000 acre-feet during the decade beginning 2020. The capital costs of producing this water total $3,730 million for the decade or $1,943 per acre-foot per year. Accordingly, supplies gained through investment in water loss control at an annual unit cost of $1,372 per acre-foot offer significant economic appeal.[8]

Table 1 illustrates the relative and absolute contributions of major categories of water management strategies that are expected to come online during the decade beginning in 2020. Table 1 also includes a column that features the unit cost of implementing these strategy categories in 2070, presumably after they have all been brought online and either fully or partially paid for.

The municipal conservation category includes water loss control, water waste prohibition, and other conservation practices (e.g., enhanced public and school education, price elasticity/rate structure impacts, and time-of-day irrigation restrictions) bundled together. Since the unit cost of water loss control has already been determined for the next decade, it is not necessary to unpack this category to arrive at unit costs for water waste prohibition or a collection of other practices simply dubbed "conservation."

The unit cost for municipal conservation in 2070 (Table 1, last column) is consistent with evidence found elsewhere (Richter 2014). Thus, conservation is the "low-hanging fruit" in economic terms and should be maximized first. Here it should be noted that indirect reuse options, unlike conservation, are not available to all utilities. Lastly, the unit costs in Table 1 reflect supplies gained and cost amortization over 50 years. The utility of this column of information is limited to comparison to other categories featured in the table at the end of the state planning horizon.

Region K includes all or part of 14 counties and generally follows the Colorado River from central Texas in the northwest part of the region to the Gulf of Mexico in the southeast. Region K had a population of 1,410,328 in 2010 (U.S. Census Bureau 2017) and is home to the city of Austin, the fourth largest city in the state. Austin Water, the region's largest water service provider, serves a population of 896,363.[9] Region

which should be $1,061 rather than the $357 currently published, per the same email communication. There are 259 water loss control strategies that are estimated to produce one or more acre-feet per year during the 2020s for a total of 26,646 acre-feet of water saved at a combined cost of $36,546,937. A tally of water loss control strategies downloaded from the Interactive 2017 State Water Plan sums to 26,638 acre-feet. Costs are not included in this file. The discrepancies in water volumes listed here and in Appendix K, Table K.2 of the Region C plan are minor: less than one-tenth of 1%.

[8] Water loss cost/acre-foot calculations made by author for this study.

[9] *Ibid.* 4

Table 2. Water demand/supply/needs for Regions C and K, Texas in the next decade.

2020 (decade)	Texas Planning Region (acre-feet/year)	
	C	K
Projected annual water demand – all water-use sectors	1,723,325	1,183,325
Projected annual water demand – municipal water-use sector	1,481,530	306,560
Existing supplies – all sectors	1,650,227	998,867
Existing supplies – municipal sector	1,390,169	457,961
Needs (potential shortage) – all sectors	125,037	373,563
Needs (potential shortage) – municipal sector	106,718	7,881
Strategy supplies – all sectors	191,811	436,423
Strategy supplies – municipal sector	164,144	174,777

K's population is projected to be 1,737,227 in 2020, a 23% increase during the current decade (Lower Colorado Regional Water Planning Group 2015a).

Water demand in Region K's municipal sector, 306,560 acre-feet per year, accounts for 26% of total forecasted water demand of 1,183,325 acre-feet per year across all water-use sectors during the next decade. Region K's potential water shortage is projected to grow from 373,563 acre-feet per year in 2020 to 387,321 acre-feet per year in 2040 across all water-use sectors. The potential shortage in the municipal sector is small, 2% in 2020, but grows to 12% by 2040 (TWDB 2016). The Lower Colorado (K) Regional Water Plan does not present any explicit water loss control management strategies for the next decade or beyond as is done in the Region C plan. Rather, "leak reduction" is included only in the city of Austin's "conservation" water management strategy. Thus, it is not possible to determine expected savings/supply or costs associated solely with water loss control apart from the other conservation measures listed: landscaping, efficiency, etc. (Lower Colorado Regional Water Planning Group 2015b). What can be determined is the annual unit cost of securing all planned water management strategies during the next decade—$704 per acre-foot—the bulk of which, 96%, is for the irrigation and steam electric power (i.e., nonmunicipal) sectors (TWDB 2016).

Collectively, these two water planning regions capture both urban and rural areas that are located predominately in the eastern, more populated half of the state and are home to almost a third of the state population.[10] As such, conservation programs in these planning regions can offer useful examples for other water planning regions in the heavily populated Texas Triangle and Lower Rio Grande Valley, as well as larger cities in West Texas and the Panhandle. Findings from this sample of two regions are instructive about the state as a whole. Table 2 provides water supply/demand and other data for the upcoming decade taken from the 2017 Interactive State Water Plan.[11]

WATER LOSS AUDIT DATA

In June of 2016, the author requested that the Texas Water Development Board provide water loss audit data for Regions C and K from 2014, the most recent and complete set of audits available at that time. The TWDB responded with data from the 106 (87 from Region C and 19 from Region K) WSPs that submitted a report during an off-year (i.e., audit data for 2015 by all systems per the five-year cycle were not yet available). Thus, the audits received by the author represent the WSPs that either have at least 3,300 service connections or have borrowed money from the TWDB, as these are by law required to provide annual water loss audit data to the TWDB.

From the data file for 106 WSPs, the top 27 water service providers (Table 3) were selected for many of the analyses because this subset produces 85%—333,259.83 million gallons per 1,022,735 acre-feet—of the total system input volume of 392,764.71 million gallons per 1,205,349 acre-feet distributed by the 106 WSPs. As it turns out, all but one are situated within Region C.

Other analyses use a variable "n" based on data plausibility. Thus, the sample size of each analysis is noted accordingly. The current state of data is unvalidated, but it does undergo some filtering by the TWDB staff (personal communication with John Sutton, Municipal Water Conservation Manager, Water Science and Conservation, Texas Water Development Board, July 27, 2017, via email.) Data from the two regions have been combined into one data set. Table 4 features several characteristics of WSPs that have been partitioned based on their size (i.e., population served).

[10] 31.4% in 2010

[11] Interactive 2017 State Water Plan: https://2017.texasstatewaterplan.org/statewide

Table 3. Top 27 water service providers based on system input volume from 2014 in Regions C and K, Texas.

Public water service provider	Region	Public water service provider	Region	Public water service provider	Region
Dallas Water Utility	C	City of Frisco	C	City of Southlake	C
City of Fort Worth	C	City of Richardson	C	City of Coppell	C
City of Austin Water & Wastewater	K	City of Carrollton	C	City of Sherman	C
City of Arlington	C	City of Mesquite	C	City of Keller	C
City of Plano	C	Town of Flower Mound	C	City of Farmers Branch	C
City of Irving	C	City of Grapevine	C	City of Euless	C
City of Garland	C	City of Lewisville	C	City of Bedford	C
City of McKinney	C	City of Allen	C	City of DeSoto	C
City of Grand Prairie	C	City of North Richland Hills	C	City of Colleyville	C

Table 4. Public water service provider characteristics for Regions C and K, Texas in 2014.

WSP size class	No. of WSPs	Range of population served	Average population served	Average system input volume in acre-feet/year	Total system input volume in acre-feet/year	Average no. of service connections	Average production MGD/acre-feet per day	Average deliveries MGD/acre-feet per day	Average miles of main	Total miles of main
X-Large	3	781,100–1,232,360	969,941	185,715	557,145	260,047	165.80/509	142.54/437	4,089	12,268
Large	12	91,429–369,308	178,305	28,906	346,877	67,124	25.81/79	23.01/71	829	9,951
Medium	58	10,005–68,667	28,463	4,836	280,523	10,788	4.32/13	3.87/12	228	13,208
Small	33	190–8,819	2,936	336	20,805	1,168	0.30/0.92	0.25/0.76	28	1,566
Totals	106	N/A	N/A	N/A	1,205,350	N/A	N/A	N/A	N/A	36,993

Note: Average production and deliveries do not include wholesale. Averages for small water service providers are median values. All other size classes feature mean averages. MGD = million gallons per day. X-Large WSPs include Dallas, Austin, and Fort Worth. Large WSPs include Arlington, Plano, Garland, Irving, Grand Prairie, McKinney, Frisco, Mesquite, Carrollton, Richardson, Lewisville, and Allen.

Nonrevenue water, as a percentage of system input volume, can be calculated but has shortcomings as a measure of WSP operational performance (AWWA 2016b). The percentage of nonrevenue water derived is biased against WSPs with relatively lower consumption and sensitive to average operating pressures, which are often set to overcome the amount of relief present in a service area (Farley and Trow 2003). A more efficient community (i.e., lower gallons per capita per day or gpcd) with both an identical population served and an annual volume of water loss as a community with a higher gpcd will indicate a higher nonrevenue water percentage. With these caveats shared, nonrevenue-water percentages for the full data set of 106 WSPs analyzed here range from 4–47% with a median value of 16%.

The AWWA and IWA prefer use of a scaling factor where losses are expressed relative to number of service connections or miles of water main. Additionally, the infrastructure leakage index (ILI) in loss-control parlance is the ratio of current annual real losses to unavoidable annual real losses and is the best operational performance indicator for comparisons between peer systems (AWWA 2016b). Figure 1 graphs ILI values for the three extra-large WSPs—Dallas, Fort Worth, and Austin—along with eight large-sized WSPs.

As an indicator, ILI values range from 1.3 to 5.6 with an average of 3.6 that indicates current annual real losses among the largest WSPs are about three and one-half times greater on average than the reference minimum or theoretical lower limit of water loss. There is no apparent pattern based on either size WSP.

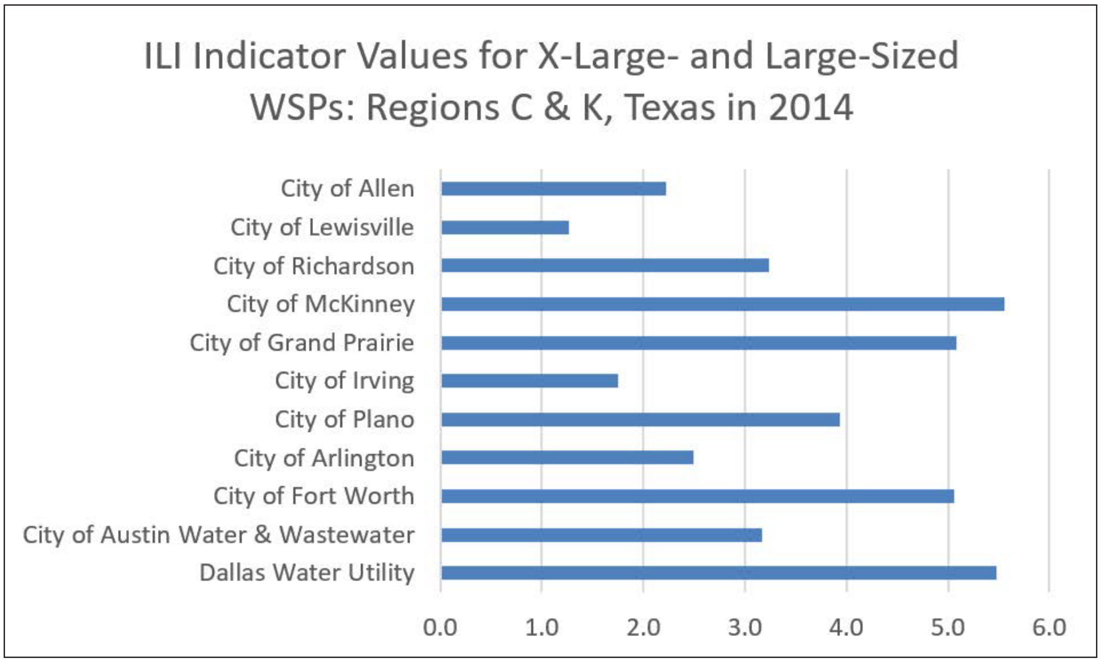

Figure 1. Comparison of infrastructure leakage index (ILI) indicator values among extra-large- and large-sized WSPs: Regions C and K, Texas in 2014.

For medium-sized water-service providers (Figure 2), ILI indicator values range from 1.0 (the lowest possible value) to 6.0 with an average of 2.7. The range among these 47 WSPs is more dynamic than that of the larger systems, and on average at least, the medium-sized systems appear to be performing a little better during the one year studied.

For the five smallest WSPs whose data led to plausible ILI indicator values (Figure 3), the range is from 1.2 to 6.2 with an average ILI of 2.9. Taken together, the 63 of 106 WSPs who reported both current and unavoidable real losses and/or plausible data (i.e., an ILI greater than or equal to one), do not yield obvious conclusions based on size alone.

Water loss is segmented into two types: real losses and apparent losses. Real losses result from actual leaks in transmission and distribution pipes, storage tanks, and on service connections up to the point of customer metering. Traditionally (i.e., IWA/AWWA water loss audit methodology), this water is valued at variable production cost, and the TWDB-approved water loss audit methodology in Texas follows this tradition. It is important to note, however, that the AWWA supports using a retail water rate to value real losses if scarcity is part of the local/regional context within which water service providers operate (AWWA 2016b). The rationale is simple: Every drop of leaked water saved can be projected as a water sale to someone using that same source.

The other type of water loss, apparent losses, results from data handling or billing errors, including faulty customer meters and unauthorized consumption (e.g., theft). This type of lost water is valued using the retail water rate because water was delivered, but revenue was not captured in return. Real and apparent losses constitute the majority of nonrevenue water, which also includes two types of unbilled authorized consumption: metered and unmetered. This study does not concern itself with unbilled authorized consumption, which was reported to be 2.5% and 4.5% of total system input (n = 106) for metered and unmetered consumption respectively.[12] This is not to say that the amount of nonrevenue water attributed to unbilled authorized consumption is inconsequential. Rather, this study is focused on real and apparent water losses and the value of such.

Audit inputs in both methodologies include a retail rate for water. The TWDB's audit guidance document acknowledges that typical utility water rate structures feature multiple tiers of pricing and guides utilities (i.e., WSPs) to use a single composite price rate to represent the retail cost of water, adding "where appropriate, use the tier with the majority of the consumption." (TWDB 2018). Yet the reported retail rates are neither calculated to reflect actual bills paid by ratepayers nor do they appear to be determined in a consistent fashion across reporting water service providers.[13] Thus, audit data likely undervalue water losses.

[12] These percentages of unbilled authorized consumption are calculated such that they are included in the nonrevenue water total for the entire data set (n = 106) calculated at 19.3% (i.e., sum of nonrevenue water volumes / sum of total system input volumes or 75,725,919,325 / 392,764,711,972).

[13] In fairness to water service providers, they are neither guided to assign a retail rate that reflects an actual water bill nor are they expected to charge the same price as neighboring communities.

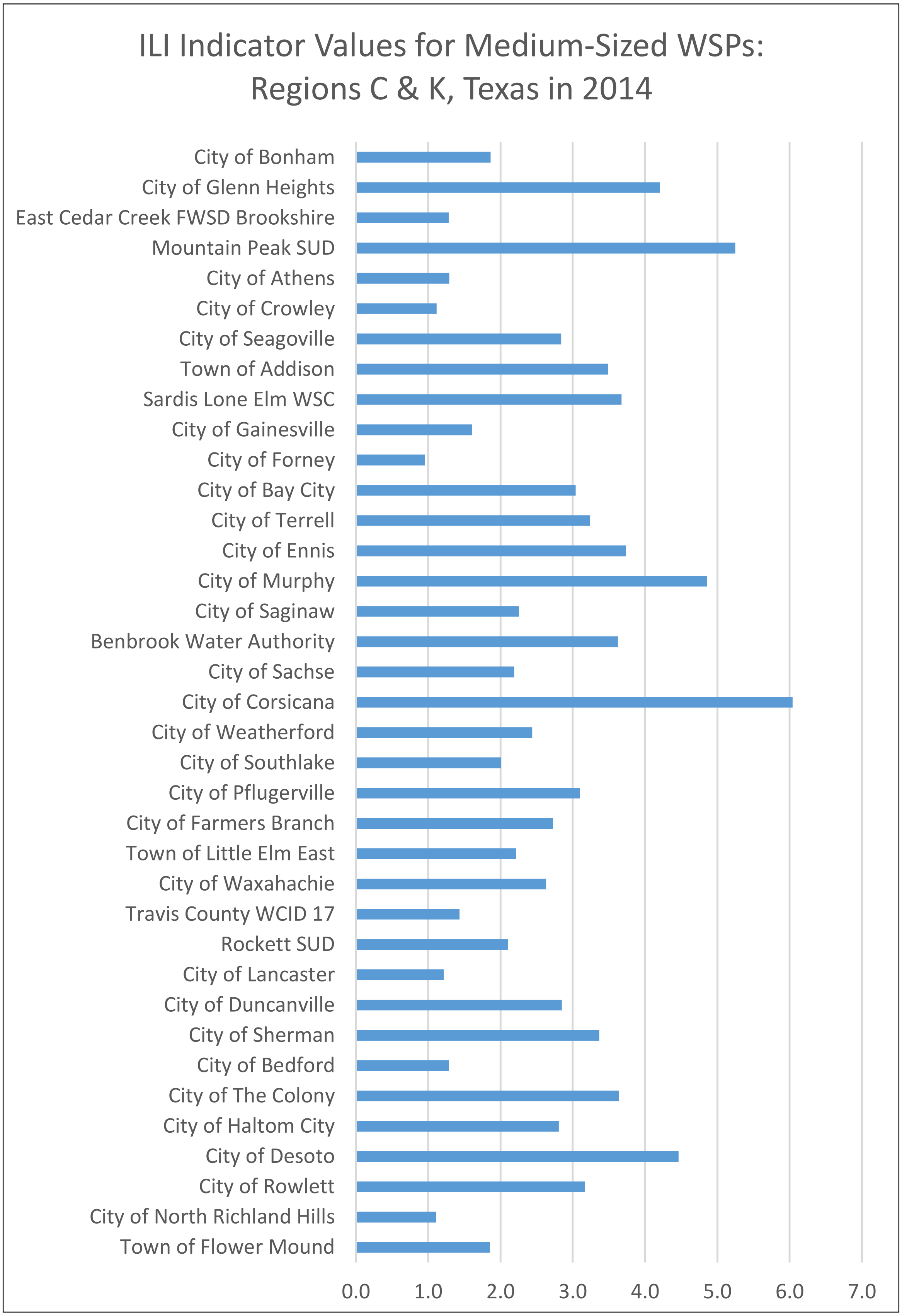

Figure 2. Comparison of infrastructure leakage index (ILI) indicator values among medium-sized WSPs: Regions C and K, Texas in 2014.

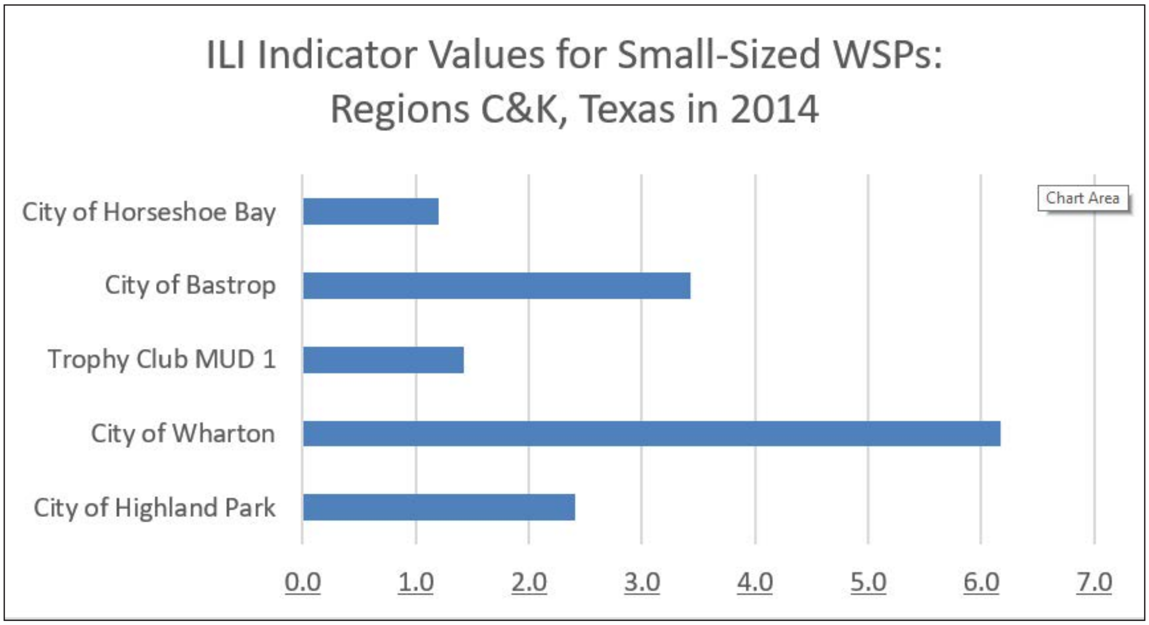

Figure 3. Comparison of infrastructure leakage index (ILI) indicator values among extra-large- and large-sized WSPs: Regions C and K, Texas in 2014.

Table 5. Retail price of water for top 26 water service providers in Texas: reported vs. calculated from current water rates.

	Water audit / average current rate ($)	X-Large WSP (3) audit / current ($)	Large WSP (11) audit / current ($)	Medium WSP (12) audit / current ($)
Retail price per 1,000 gallons	3.94/5.22	3.68/5.37	4.29/4.93	3.64/5.27
Retail price for 8,000 gallon bill	31.52/41.76	29.44/42.96	34.32/39.44	29.12/42.16

Note: Lewisville, one of the top 27 WSPs, is not included due to reported data implausibility. Thus, n = 26 rather than 27. Seventy-four percent of rate sheets were revised in 2016 or 2017, which will tend towards slightly higher current rates from those used in 2014 audits.

Valuing water losses using retail price can help planners and utility managers more realistically calculate the benefit/cost ratio of this supply option versus others, and valuation using retail price will better reflect scarcity in a drought-prone state where surface water is overallocated relative to its availability during a record drought (Sansom 2008; McGraw 2018).

Furthermore, valuation using retail price also speaks to the needs of both water service providers and the communities they serve (Beecher and Shanaghan 1999) and should come closer to capturing the opportunity cost associated with impacts of urban water use/loss on other competing uses and the environmental cost related to impacts, for example, on environmental flows (see Freebairn 2008).[14]

To examine the difference in retail price reported and a retail rate calculated from current rate sheets, an average monthly water bill was developed that is based on consumption of 8,000 gallons per residential (single-family) household.[15] Table 5 illustrates the disparity in retail price between rates reported in water loss audits and rates calculated for this study using current rate sheets in a manner consistent across water service providers.

[14] Protecting environmental flows and the aquatic species that such flows maintain in Texas is an evolving issue since passage of Senate Bill 3 in 2007 (Sansom 2008). Protecting the flow of natural springs, baseflow, and aquifers from overdraft (see, for example, Chaudhuri and Ale 2013; Sheng 2013) are other compelling reasons for pricing/valuing water to help minimize negative externalities. Elsewhere, an attempt to estimate the shadow price of system leakage as a proxy of the environmental and resource/opportunity costs of water losses is predicated on using the retail price of water, divined from utility bills, delivered to end-users (Molinos-Senante, Mocholi-Arce, and Sala-Garrido 2016). Thus, assigning a defensible retail value to real and apparent losses has value for multiple reasons.

[15] Monthly consumption is based on 2.84 persons per household (U.S. Census Bureau 2017) and 94 gallons per capita per day (statewide average) derived from Hermitte and Mace (2012). The monthly bill, from which a per 1,000 gallon rate is derived, includes any fixed or minimum charge, charge based on meter size, and applicable volumetric rates. Thus, the water bill for 8,000 gallons is what a ratepayer will receive either as an average of all 26 WSPs used in this particular analysis or an average from grouped WSPs that are similarly sized.

Table 6. Median water loss performance indicators for Regions C and K, Texas in 2014 compared to other data set.

Data	Performance indicator	TWDB 2014 median	Andrews & Strum (2016) median	Unit
Financial	Retail cost (n = 99)	4.00	4.67	$/1,000 gallons
	Variable production cost (n = 98)	1,680.00	950.00	$/MG
	Annual reported cost of real and apparent losses (n = 94)	238,921	---	$/year
	Nonrevenue water as percentage of operating cost	---	7.8	percentage
Operational	Apparent losses	5.81	5.73	gallons/service connection/ day
	Real losses (normalized to service connections)	32.03	39.88	gallons/service connection/ day
	Real losses (normalized to miles of main)	1,424	785.54	gallons/miles of main/day
	Real losses (normalized to pressure)	0.47	0.59	gallons/service connection/ day/psi
	Infrastructure leakage index (n = 50)	2.82	2.48	dimensionless
	Data validity score	38	73.1	points out of 85/points out of 100

Note: n refers to 2014 TWDB sample only and varies due to implausibly high or low reported data or retail or variable production cost data that were deemed inaccurate. For operational performance indicators, n = 106 unless otherwise noted. MG = million gallons; psi = pounds per square inch

The average actual retail prices of the audited WSPs ranged from 15% to 46% higher than the retail rates used in their water loss audits (average difference of 32%). The calculations assumed monthly household consumption of 8,000 gallons. This difference is unlikely to be explained solely or even mostly by current rates that for the majority of the WSPs have increased during the last three years, as noted in Table 5. Dallas Water Utility, for example, reports a retail rate of $1.80 per 1,000 gallons in 2014 versus their current reported rate of $1.90 per 1,000 gallons, an increase of under 6%.

Rates calculated here do not include wastewater treatment charges that the AWWA indicates can be included in an approach to valuing real losses using retail price if wastewater treatment charges are included in the water bill. And no additional attempt has been made to more carefully estimate the environmental and resource costs (i.e., cost of negative externalities and opportunity cost alluded to above) that have been innovatively estimated by Molinos-Senante, Mocholi-Arce, and Sala-Garrido (2016) for Chilean water companies to be 32% of the delivered water price. Thus, the rates that were calculated consistently across the sample based on average household water use in Texas and presented in Table 3 might be considered conservative at capturing scarcity/opportunity, environmental, and other costs despite being greater than reported rates in the study year.

Finally, the average (median) variable production cost reported by the top 27 water service providers is $1.87 per 1,000 gallons.[16] This production cost value is a little less than half of the reported in 2014 retail price (average of $3.94) and a little more than a third of the retail price calculated from current rate sheets (average of $5.22). Applying retail price to real losses, therefore, results in a significantly higher valuation of economically recoverable water than is currently the case when its value is equated with its variable production cost.

PERFORMANCE INDICATORS

Industry standard performance indicators, both financial and operational, were calculated from audits reported to the TWDB for comparison (Table 6) to a composite water loss audit data set from five states, including Texas data from 2010 and 2013 (Andrews and Sturm 2016).

Differences in four indicators warrant comment. First, retail prices found in the Andrews and Sturm (2016) composite data set are almost 17% higher than retail rates reported in 2014 Texas water loss audits despite the former coming from mostly older data (i.e., 2010-2014). Because most of the data in the composite data set come from states other than Texas, the comparison suggests that Texas retail water rates are either set low, reported low, or both. Secondly, there is a big difference

[16] The variable production cost of $1.87, taken from the top 27 water service providers, is somewhat higher than the average taken from the 98 water service providers that reported plausible data; see Table 4.

in real losses normalized by miles of main: 1,424 gallons per mile of main per day in this study versus 785.5 gallons per mile of main per day in the Andrews and Sturm (2016) data set. This could be the result of older infrastructure that is generally in poorer condition or a reflection of a different split between urban and rural service areas among the Texas utilities. Examining this operational performance indicator alone will not explain the difference in results.

The third noticeable difference between the Texas data and the composite data set concerns data validity scores. As suggested above, Texas measured on a different scale than the AWWA method in 2014. But even when viewed as an adjusted data validity score of 45 (i.e., 38/85), the average self-reported data validity score is very low in Texas compared to the composite data set and may reflect the lack of confidence in the reliability of the available data, the auditor's inexperience with conducting an audit, or both. The composite data set includes Georgia, which benefits from third-party audit validation and technical assistance, both thought to improve audit quality and data validity score accuracy (Andrews and Sturm 2016). Finally, real losses, normalized to service connections, are nearly 20% lower in the 2014 Texas data set than what was found in the multistate composite data set. One plausible explanation is that the current study data set likely reflects a more urban/suburban and thus higher density service area than the composite data set evaluated by Andrews and Sturm (2016).

ECONOMIC LEVEL OF LOSS

Not all water loss that is technically recoverable is economically feasible to recover (US EPA 2010). The economic level of loss (ELL) is the point where the value of the water saved is less than the cost of making any additional reduction in system water losses (Farley and Trow 2003). The economic level of loss only considers the direct costs incurred by the water service provider, not the environmental and scarcity costs of urban water use that is more fully captured by another metric, the Sustainable Economic Level of Leakage, which has been proposed by Ofwat (2007), estimated by Molinos-Senante, Mocholi-Arce, and Sala Garrido (2016), and discussed by others. That said, the ELL is also a function of how water is valued and entails both a short-term ELL and long-term ELL, as elucidated by Farley and Trow (2003). Furthermore, Farley and Trow (2003) describe supply-side and demand-side options for maintaining system capacity (i.e., headroom) when considering the calculation of ELL.

While it is up to each water service provider to determine their unique economic level of loss, it is unknown how common this understanding might be among water service providers. Furthermore, the ELL is not a calculation whose result remains static. A WSP's economic level of loss will vary over time and in response to the degree of active leakage control that is implemented (Farley and Trow 2003). In any event, it is a best management practice for water service providers to pursue water loss control to the point where they reach an economic level of loss, at a minimum. Such a level of loss exists somewhere between unavoidable annual real losses (UARL) and current annual real losses (CARL) per the IWA/AWWA water loss audit methodology (AWWA 2016b).

Here, two techniques are considered for estimating the ELL. First, a simple midpoint between CARL and UARL volumes is selected, given the regional scale nature of the analysis. A second estimation technique is detailed in a report that evaluated water audit data for Pennsylvania water utilities (Kunkel Water Efficiency Consulting (KWEC) 2017). In short, this technique considers median values of customer retail unit cost of water (for apparent losses), variable production cost (for real losses), and normalized apparent/real loss indicators. Utilities with values for these three variables that are found to be greater than the median values calculated from the full data set of utilities were thought to have the greatest economic incentive for recovering apparent and real losses.

Both approaches were applied to the top 27 WSPs. Eighteen of the 27 WSPs qualified for further calculations when applying the midpoint technique. Applying the KWEC technique (tested on real losses only) resulted in a smaller sample size (n = 7) and given the greater-than-median-value criteria involved, did not capture the three largest utilities. Thus, given the pilot nature of this study, small resultant sample size from applying the KWEC method, and the argument made in this study for using retail price rather than variable production cost for identifying the economic value of real losses, the author chose to apply the simple midpoint method: a volume of water that is halfway between UARL and CARL. The midpoint method is applied in Table 7.

EXTRAPOLATION OF REGIONAL RESULTS

Table 7 illustrates several normalized loss values, economically recoverable loss estimates, and more. Results from Regions C and K data analysis are shown in one column and extrapolated statewide as shown and explained in the notes below the table. The purpose of Table 7 is to arrive at an approximation of the combined annual financial impact of both apparent and real losses in utility operations statewide that are estimated to be economically feasible to recover.

Table 7. Population, water usage, loss, and value estimates for Regions C and K and State of Texas.

	Regions C and K in 2014	State of Texas in2010
Population served	6,816,020[a]	25,260,000
Total system inputs (MG/acre-feet)	392,764/1,205,348[a]	1,456,350/4,469,374[b]
Average economically recoverable real losses (gallons/person/year)[c]	2,519	(assumes 2,519 gallons/person for entire population)
Value of economically recoverable real losses/ person/year[d]	Calculated for water (1,000 gallons) valued at: a) variable production cost: $4.71 b) audit reported retail: $10.08 c) current rate retail price: $13.15	
Value of economically recoverable real losses/ year based on population served	a) $32,103,454 b) $68,705,482 c) $89,630,663	$118,974,600–$332,169,000
Average economically recoverable apparent losses (gallons/person/year)[a]	590	(assumes 589.85 per person for entire population)
Value of economically recoverable apparent losses/person/year	$2.36–$3.08 Calculated for water valued at audit reported retail ($4.00/1,000 gallons) and by the current rate retail price ($5.22/1,000 gallons)	
Value of economically recoverable apparent losses per year based on population served	$16,085,807–$20,993,342	$59,613,600–$77,800,800
Average economically recoverable real and apparent losses (gallons/person/ year)	3,109	(assumes total loss of 3,109 per person for entire population)
Value of economically recoverable real and apparent losses/person/year	$12.44–$16.23 Calculated for water valued at reported retail ($4.00/1,000 gallons) and by current-rate price ($5.22/1,000 gallons) for Regions C and K.	
Total volume (MG/acre-feet) economically recoverable real and apparent losses	21,191.01/65,033	78,533.34/241,010
Total value of economically recoverable real and apparent losses/ year	Applying retail rates only: reported: $84,791,289 -current: $110,624,005	$314,234,400–$409,969,800

[a] includes full data set from Regions C and K (2014; n = 106) unless noted otherwise. MG = million gallons

[b] Source: Maupin et al. 2010 (public water supply sector only)

[c] n = 52 because negative (CARL-UARL) values in data set led to exclusion of 54 WSPs. Real loss volume of 27,565.12 MG * 0.50 = economic level of loss volume of 13,782.56 MG/population served (n = 52) of 5,471,921.

[d] n = 52 as in c. above. Range of value was calculated by multiplying 2,518.78—the average economically recoverable real loss per person per year—by the median reported retail price ($4.00/1,000 gallons) and by the average retail price calculated from current rate sheets ($5.22/1,000 gallons).

DISCUSSION AND CONCLUSIONS

This is a regional-scale study of nonrevenue water and the portion of such water that is estimated to be economically recoverable. A regional average water bill has been calculated for assigning a consistent retail value to economically recoverable water losses, to more appropriately value the water in question.

The author's analysis of water loss audit data submitted by the WSPs to the TWDB suggests that the water loss audit methodology employed—assigning a variable production cost rather than a retail price—underestimates the value of economically recoverable water leaking out of their distribution systems by nearly a factor of three. The volume in question was assessed to be worth approximately $32.1 million using a variable production cost per gallon versus the $89.6 million that it would be worth using a regional average retail rate per thousand gallons (Table 7). Given this difference in assigned values, it seems fair to ask about the potential consequences of this undervaluation. Might the undervaluation suppress investment in reclaiming water lost to leakage and by comparison lead to overinvestment in other supply strategies? Perhaps the answer to that question depends in part on the volume of water loss that can be economically recovered.

The total volume of economically recoverable water from the two regions in 2014, both real and apparent losses, is 21.19 billion gallons per 65,032 acre-feet (Table 7). For perspective, the volume of economically recoverable water estimated here for Regions C and K is over 22% of projected annual water demand (all water-use sectors) in 2020 for both regions.[17] More strikingly, the recoverable water estimate represents over 36% of projected annual water demand within the municipal water-use sector of both regions in 2020 where the leaky infrastructure is situated.

More aggressive investments aimed at capturing nonrevenue water could form an important pillar of many WSPs' water supply strategies in coming years. Region C alone projects municipal water supply savings of 8.682 billion gallons per 26,646 acre-feet per year during the next decade from enhanced water loss control programs (i.e., as planned water management strategies; Freese and Nichols Inc., et al. 2015b). For perspective, this volume of water planned for recovery in Region C is sufficient to meet the residential needs of a city sized between Lubbock (population 247,323) and Laredo (population 255,305) for one year.[18] While positive, the amount of water supply planned for recovery in Region C is less than half—41%—of what is estimated to be economically recoverable from both regions. Furthermore, the unit cost of capturing this water is a relative bargain compared to the unit cost of securing other water supplies.

Water savings from Region K's water loss control strategies are unknown because they are included in the more comprehensive category of conservation. But there is little reason to believe that the city of Austin's investment in water loss control will yield a volume of water sufficient to make up the difference between the economically recoverable water volume estimated here, 21.191 billion gallons per 65,033 acre-feet (Table 7), and the amount planned for recovery in Region C.

The economically recoverable nonrevenue water from the two planning regions has been estimated to have a retail value of over $110 million in the one year examined. This estimated value is three times the amount of $36.5 million that is planned to be spent on water loss control strategies in Region C each year over the course of the next decade. The loss-control costs expected to be incurred by Region K, including the City of Austin, are not detailed in the Region K plan and are thus unknown to the author. That said, it is likely that even if the two regions were considered together and the City of Austin's cost for water loss control implementation was included to enable an "apples-to-apples" comparison, the yawning gap between the value of economically recoverable water and funds planned for water loss control in the larger of two regions studied would not materially narrow.

The statewide impact of ignoring the nonrevenue water that could be economically feasible to recover ranges from $314 million per year using the audit reported retail price of water to as much as $400 million annually using a retail price that is derived from a regional average of ratepayer bills calculated for this study (Table 7). While these numbers are based on 2014 data, they are very likely to be similar—and perhaps higher—for each of the years since then.

Given the magnitude of infrastructure repair needs, robust population growth in Texas, and the proposed cost of implementing myriad water management strategies to make drinking water ends meet, it does not serve the public interest to either ignore the economically recoverable portion of nonrevenue water or underestimate its value. This is especially true given that recovering nonrevenue water, particularly real losses, is now considered a source of new water in state and regional water supply planning efforts. There is an urgent economic and environmental case for realistically valuing nonrevenue water in order to incentivize water service providers to reduce losses to the point where they reach an economic level of loss.

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[17] The 2017 State Water Plan projects annual water demand in 2020 for both Regions C and K will be 2,906,000 acre-feet across all water-use sectors and 1,788,090 acre-feet for the municipal water-use sector alone.

[18] This assumes the same gpcd of 94 as used to derive average household use and the resultant monthly water bill. City population estimates are from U.S. Census Bureau via Texas Demographics by Cubit https://www.texas-demographics.com/cities_by_population

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