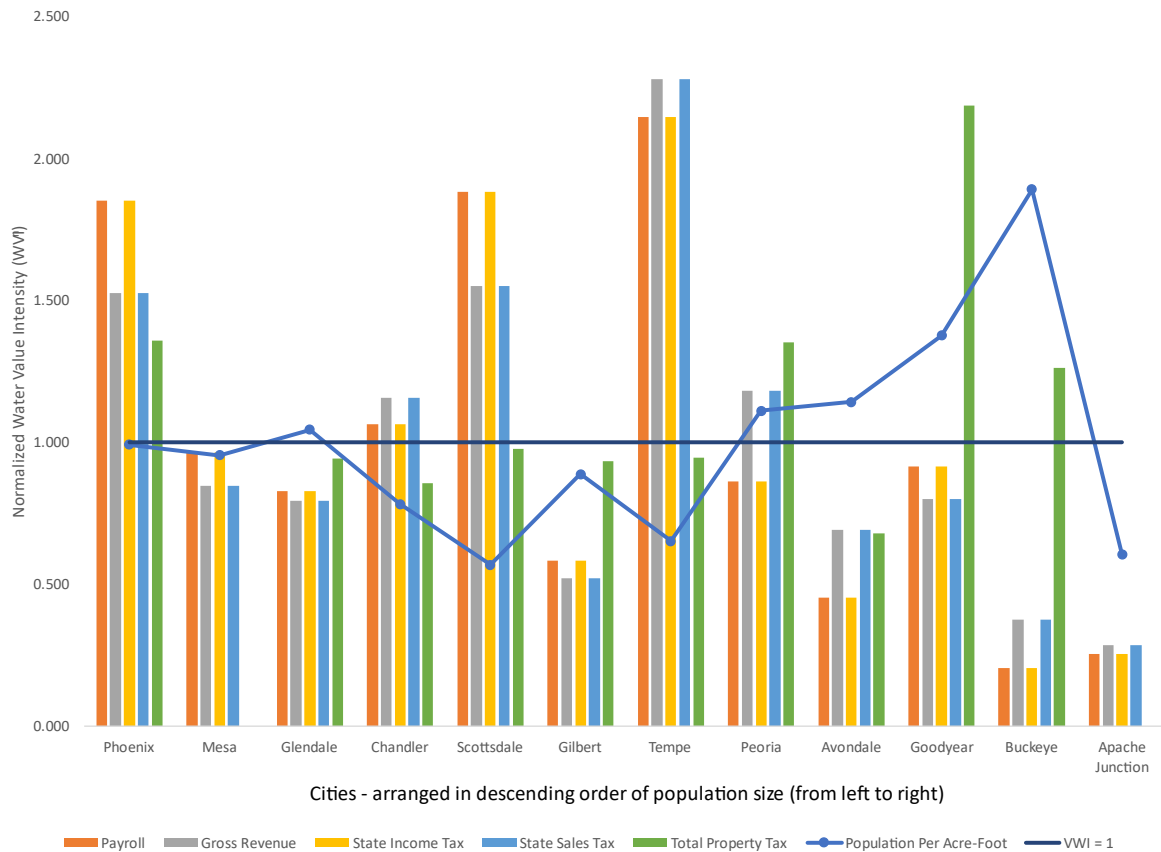
Water productivity is in the eye of the beholder: benchmarking the multiple values produced by water use in the Phoenix metropolitan area

Benjamin L. Ruddell[1] and Richard Rushforth[1]

[1] School of Informatics, Computing and Cyber Systems, Northern Arizona University, Flagstaff, Arizona, USA.

Correspondence to: Benjamin L. Ruddell (Benjamin.Ruddell@nau.edu)

Abstract. Water productivity (or efficiency) data informs water policy, zoning and planning along with water allocation decisions under water scarcity pressure. This paper demonstrates that different water productivity metrics lead to different conclusions about who is using water more effectively. In addition to supporting the population's drinking and sanitation needs, water generates many other public and private social, environmental, and economic values. For the group of municipalities comprising the Phoenix Metropolitan Area we compare several water productivity metrics by calculating the Water Value Intensity (WVI) of potable water delivered by the municipality to its residential and non-residential customers. Core cities with more industrial water uses are less productive by the conventional efficiency measure of water used per capita, but core cities generate more tax revenues, business revenues, and payroll per unit of water delivered, achieving a higher water productivity by these measures. We argue that policymakers should consider a more diverse set of socio-economic water productivity measures to ensure that a broader set of values are represented in water allocation policies.

Graphical Abstract

1 Introduction

The coming decades will see major challenges in meeting demands for water in the United States and across the globe (Postel, 1996; Devineni et al., 2015). Apportioning water effectively between agriculture, the world's largest water user and the water use of industry, energy and urban development will become increasingly important (Hoekstra, 2014; Vörösmarty, 2000; Gleick and Palaniappan, 2010). Reliable metrics are needed for informed decision-making about allocating water sustainably, equitably, and optimally. This is especially true in water-scarce regions like the American Southwest (Tidwell et al., 2012; Wildman and Forde, 2012; Schewe et al., 2014). However, in such regions, there is often a limit to how much water cities can reduce through conservation measures or other demand management policies - a phenomenon known as 'demand hardening'. Even if conservation is still producing water efficiency gains decoupled from growth to date (Richter et al., 2020), demand will eventually harden, so it is in the public's interest to allocate water based on the merit and benefit of use (Howe and Goemans, 2007), however merit and benefit might be defined.

Careful management of freshwater is especially important for the municipalities comprising the Phoenix Metropolitan Statistical Area (Phoenix MSA or PMA), Arizona (Gober et al., 2010; Gober et al 2013; Rushforth and Ruddell, 2015). With a population of 4.9 million, in 2019 Phoenix-Mesa-Chandler is the 10th most populous metropolitan area in the country (US Census Bureau, 2020). Economic growth has been tightly coupled with population growth in the PMA. In 2017 the GDP for the Phoenix MSA was close to $217 billion, having grown by 30% between 2010 and 2018 (US Bureau of Economic Analysis, 2019). Underlying the Phoenix MSA's population growth and economic growth are increasingly scarce water resources.

Studies of water use often employ variations of water footprint analysis to measure water use or water use efficiency (Hoekstra et al., 2011; Hoekstra et al.; 2015; Marston et al. 2018; Paterson et al., 2015; Rushforth and Ruddell, 2018). Water footprints have been calculated for cities in the US (Paterson et al. 2015), and even specifically for cities in Arizona (Bae and Dall'Erba, 2018; Rushforth and Ruddell 2015, 2016; Scott and Pasqualetti, 2010). Water productivity studies have been conducted on industries and products (Marston et al., 2020; Evenson et al. 2018; Maupin et al. 2014; Mayer et al., 2016; Blackhurst et al. 2010; Solley et al. 1983), on the electric power grid (Ruddell et al. 2014), and on Arizona semiconductors (Hubler et al 2012), in addition to the more common study of irrigation agricultural water productivity (Xu et al., 2019; Kinje et al., 2003; Hamdy et al., 2003). Water efficiency benchmark data can help policy makers to develop and implement sound water policy (Berg, 2010). Such benchmarks can help stakeholders to quantify progress towards policy objectives and can help regulators fine-tune efficiency goals (Haider et al., 2016).

Per the logic of Embedded Resource Accounting (Rushforth et al. 2013; Ruddell et al. 2014), produced values are accounted for differently by different parties because these parties have different worldviews and decision boundaries by which they account for internal and external costs and benefits. For instance, revenue is mostly valued by business owners, payroll (total salaries) is mostly valued by workers (and is a cost to business owners), taxes are mostly valued by the branch of government collecting the specific tax and by the public beneficiaries of this tax revenue (e.g. state income tax to the state, property tax to the municipality), and population is valued by (presumably) all people – but most especially by democratically elected government officials who set water policy because people vote. There are also many other social, environmental, and economic values produced where water

59   inputs are an input factor (Vardon et al., 2012), including for instance aquatic habitat created by outdoor water
60   use in a desert city, urban heat island mitigation, and federal tax revenue. The return of revenue directly to a water
61   department responsible for its provision is another important type of value needed for fiscal planning and support
62   of water operations (Borrego-Marin et al., 2016), but that kind of revenue is of very narrow interest to a single
63   department of a single municipal government and is discounted by other parties. Because there are many social,
64   environmental, and economic stakeholders with many different sets of interests and values, multiple water use
65   efficiency or productivity benchmarks are appropriate to measure the efficacy of water allocation. Although it
66   should be noted that current study did not include the social, environmental and full economic value of water due
67   to a lack of available data.

68   The standard residential water efficiency or water sustainability measure for water utilities in the United States is
69   Gallons per Capita per Day (GPCD). Water use efficiency is the reciprocal of the water productivity. Water
70   productivity – also called water value intensity (WVI, Ruddell et al. 2014) is a metric expressing the benefits of
71   water use (in units of the benefit) relative to the costs (in units of water use). The goal of water policy should be
72   to do more social, environmental, and economic good with limited water resources, but not necessarily to use less
73   water but to maximize the value of scarce resource, which may include conservation measures that allow for the
74   future use of water. Shifting to a water productivity (or WVI) perspective puts the emphasis on the values and
75   benefits that are produced, rather than the water that is saved. For example, if we invert the standard GPCD metric,
76   we obtain People per Gallon per Day (PPGD), and this makes it clear that such a metric values supporting
77   additional population using the water resources. It is not incorrect to use an efficiency metric, but we prefer the
78   positive productivity framing to the negative efficiency framing for these reasons.

79   Comparing multiple water productivity metrics and benchmarks is particularly helpful when there are multiple
80   values and benefits associated with the water use. In this paper we develop a case study comparing multiple water
81   productivity benchmarks for the group of municipalities comprising the Phoenix Metropolitan Area. For these
82   municipalities we compare the water productivity in units of value produced per acre-foot of water delivered.
83   Water productivity metrics in this paper's case study include (1) residential population supported, (2) payroll, (3)
84   gross revenue, (4) state income tax, (5) state sales tax, and (6) total property tax. Other productivity metrics could
85   be used such as the water intensity of land use, or we could add more social and environmental value
86   considerations, but these are beyond the scope of this paper's case study due primarily to a lack of data availability.
87   Our research question is, "What is the comparative water productivity of the municipalities of the Phoenix area,
88   using multiple water productivity measures?"

89   **2 Methods**

90   Water that is available to PMA cities is allocated using a complex system of legal water rights and conveyed to
91   the municipalities via large-scale physical infrastructure systems (Jacobs & Megdal, 2004; Holway, 2007). Most
92   PMA municipalities draw water from three main physical water sources: the Colorado River, the Salt-Verde River
93   system, and the large, interconnected groundwater aquifer underlying the metro area. However, while many
94   municipalities have access to all three sources, some municipalities, typically newer ones on the outer edge of the
95   metropolitan area, may not have access to SRP or CAP water (Rushforth et al., 2020).

96

Within each municipality water is delivered to residential and non-residential uses, which yield residential values (income tax, property tax, population) and non-residential values (payroll, net/gross revenue, sales tax). Of the many municipalities comprising metropolitan Phoenix area, we include twelve in this study (Figure 1): Apache Junction, Avondale, Buckeye, Chandler, Gilbert, Glendale, Goodyear, Mesa, Peoria, Phoenix, Scottsdale, and Tempe. Smaller and outlying cities (e.g. Litchfield Park, El Mirage, Paradise Valley, Queen Creek, Guadalupe, Surprise, Cave Creek, Fountain Hills) were omitted due to a lack data at the time of analysis.

Water use studies may be based on consumption or withdrawal accounting. However, in this study area water withdrawal is equal to water consumption, so we have simplified the language to water use, which is defined as the total volume of water delivered in a municipality less loss and unaccounted (L&U) for water. This is the right choice for most water use studies per the arguments in Ruddell (2018), because city water resources, infrastructures, operating costs, and water rights are measured and priced in units of water volumes delivered, not in terms of net hydrological water balances. We use acre-feet units for this study, not SI units, because acre-feet is the unit of measurement used and understood throughout the water management community in the USA and converting to SI units renders the results more difficult for use in policy applications. Reclaimed water use was not included in this study since it is not delivered to municipalities by an external agency and because it is not withdrawn from the three major hydrological water sources of the region. Also, we do not consider the indirect value of reclaimed water because the reclaimed water uses, such as recreational turf irrigation, make it difficult to measure associated economic value. Additionally, reclaimed water (unlike potable water) is subject to varied city and county policies and standards for reporting and accounting, making it is difficult to compare reclaimed water data robustly between municipalities.

This paper's "value intensity" water productivity metrics relate gross value-output to gross water-input, including the residential population supported by potable water deliveries, gross revenues, payroll, state sales tax, state income tax, and property taxes. Water productivity could be calculated using a range of metrics – to include for example, different social and environmental benefits of a city's water use, or the marginal product (instead of gross), or the complete Scope 1+2+3 indirect supply chain water use (instead of Scope 1). Also, these multiple value metrics could be weighted to assign differential importance if appropriate. Because this is the first study of its kind, we calculate a simple set of metrics that are readily computable and straightforward to explain (Table 1), and we weight the metrics equally in the figures for simplicity of visual comparison. Note that payroll and taxes are two components of gross revenue, and as such are not independent from gross revenue.

2.1 Data Sources

This study uses older data from calendar year 2007 due to data availability constraints. The specific variety of data for residential and non-residential water use was no longer collected by the State of Arizona after 2009. We chose 2007 because this is the most recent pre-2009-year coinciding with the publication of the U.S. Census Economic Census.

Residential and non-residential water use data for the PMA's municipalities in this study were obtained from the Arizona Department of Water Resources Imaged Records. Reported water use data for 2007 were used to match

135 US Economic Census data for the same year. Specifically, water use data contained in this report is found in
136 ADWR Notifications on Gallons Per Capita per Day (GPCD) and Lost and Unaccounted (L&U) for Water sent
137 to the individual cities studied in this report (ADWR, 2011a-i). L&U water was incorporated into this study by
138 attributing L&U water proportionately to total water use by residential and non-residential sectors (for an example
139 see Appendix A and the equation in Appendix B).

140 Income data were obtained from the U.S. Census Bureau (2009a-f). Property tax data were obtained from the
141 annual budgets from each of the cities in the study (City of Chandler, 2008, 2009; City of Glendale, 2008; City of
142 Goodyear, 2007; City of Mesa, 2008; City of Peoria, 2007; City of Phoenix, 2007; City of Scottsdale, 2008; City
143 of Tempe, 2007; Town of Avondale, 2010; Town of Buckeye, 2007; Town of Gilbert, 2007). Manufacturing,
144 retail, information services, real estate, and professional and technical services data were obtained from the 2007
145 Economic Census (U.S. Census Bureau, 2009a-f). See Appendix C for the full economic data used in this study.

146 Water Value Intensities (WVIs) were calculated using the water-volume weighted averages of residential and
147 non-residential sectors (Table D1). Economic values on a water use basis were analysed for several economic
148 categories in the U.S. Economic Census: city-level or town-level income data (Tables D2, D3), city- or town-level
149 manufacturing (Tables D4, D5), city- or town-level retail data (Table D6), city- or town-level information services
150 (Table D7), city- or town-level real estate data (Table D8) and city- or town-level professional and technical
151 services (Table D9).

2.2 Simplified Embedded Resource Accounting: Point of View Matters in Water Use Accounting

153 This analysis employs a simplified version of Embedded Resource Accounting (ERA, Ruddell et al. 2014) to
154 associate indirect and direct values with direct (Scope 1) and indirect (Scope 2+3) impacts in an input-output
155 network. In this case there are direct and local values produced (e.g., Tables D1-D9), direct impact on the local
156 freshwater stock, and indirect values and impacts are neglected. The water use metrics in this paper are therefore
157 calculated from the point of view of a hypothetical manager of the water resources of the Phoenix metropolitan
158 area (PMA) who is interested in maximizing a diverse basket of values that are directly associated with water use
159 processes in the PMA. The same hypothetical manager is therefore also disinterested in indirect value creation
160 and impact such as federal tax revenues or the water impacts of the PMA's supply chains lying outside the area.
161 Everything inside the PMA is "internal" and everything outside the PMA is "external" from this hypothetical
162 manager's point of view. We assert that this point-of-view is historically responsible for water allocation decisions
163 and regulations for the PMA and resembles the point of view of the Governor's office, the regional government,
164 or the Arizona Department of Water Resources, so this is an appropriate choice for this study. Because the
165 worldview of this hypothetical manager encompasses the metro area, ERA defines the resource stock of interest
166 as the total combined annual water deliveries from the Central Arizona Project (2012), Salt River Project (SRP),
167 and groundwater resources to the PMA's major municipalities individually and collectively. If a different point
168 of view is chosen for the accounting, the results will change. For example, the business owners of the City of

169   Tempe internalize revenue-generating value, but not necessarily other values like payroll or taxes benefitting the
170   City of Tempe and its labor force.

171   The direct water value intensity $WVI_{x,l}$ used here is simply the ratio of the value (V) of type (l) produced as an
172   output of the municipality's (x) collective processes to the input of water (W) to the municipality's processes. In
173   other words, $WVI_{x,l}$ is the ratio of value out to water in. $\overline{WVI_l}$ is the mean WVI for value l for all municipalities
174   in the area. $WVI^n_{x,l}$ has been normalized (n) by dividing $WVI_{x,l}$ by the mean $\overline{WVI_l}$, such that municipalities with
175   results above 1 have above-average WVI for that value type. $BWVI_x$ is the basket-weighted water value intensity
176   for municipality x; it is the weighted average across all value types for that municipality. In this study, we assume
177   weights of 1 for all value types. From this point of view, all six types of value assessed here are weighted equally.
178   $BWVI_x^n$ is the normalized value, like $WVI^n_{x,l}$ above.

179

180   WVI's may include economic data and measures of economic value, but a WVI – or any VI – is not a price or a
181   measure of marginal value, product, or cost according to the classical economic Theory of Value, because it does
182   not consider the marginal contribution of the impact on the resource stock to the production of values, or the cost
183   of the resource, or value-added by the process. Since VI's are not prices or costs, they may not be added together
184   to directly measure the value produced by a process. Rather, VI's should be interpreted as multiple independent
185   benchmarks of the gross productivity of the water use. Per Kumar (2021), we present here as WVI is similar to
186   the water productivity definition based on single factor of production using water use. In other words, WVI is
187   similar to the Partial factor productivity (PFP), which is a ratio of a measure of total output to a measure of a
188   single input category. The two differences are technicalities, and are that (a) WVI could include indirect value
189   production, and (b) WVI makes no attempt to use total productivity and instead is calculated several times using
190   several different and non-commensurable productivities (i.e. values). Gross WVI is a disambiguated metric that
191   is a precise subtype of gross water productivity metric, per the ERA mathematics.

2.2 Residential Sector Water Value Intensities

193   Property taxes were used as a measure for the values produced by residential water use. Primary, secondary, and
194   total levied property taxes by municipalities were considered in this analysis. Calculation of the value intensity of
195   residential water on a per volume use basis is shown in Appendix A.

2.3 Non-Residential Sector Water Value Intensities

197   City-level net and gross revenues and payrolls were used as a measure for the values produced by non-residential
198   water uses such as commercial, industrial, and governmental uses of the city's potable water supplies. City-level
199   state sales tax contributions and income taxes paid to the state were estimated for the non-residential sector using
200   the gross revenue and payroll data, respectively. The state sales tax rate was set at 6.6% and the income tax rate
201   3.3%, per statutes in effect in Arizona during the study period. From these data, the value intensity of non-
202   residential water uses was calculated for city-level net/gross revenues, payroll, state sales tax contribution, and
203   income taxes paid to the state. Note that income tax is considered a value product of the non-residential sector in
204   this analysis, and taxed payroll is a value product of the business sector, not the residential sector. Net and gross
205   revenue and payroll data were obtained from the US Economic Census. Population data were obtained from the

206 U.S. Census Bureau (2007b). Equations for Revenue, Payroll, and Tax VI's follow. Calculation methods are show
207 in Appendix A.

3 Results

209 In terms of residential population supported per acre-foot of water used (Figure 2), outlying cities such as Buckeye,
210 Goodyear and Avondale are more productive (or efficient) than core cities like Phoenix, Tempe and Scottsdale.
211 However, when economic productivity measures are considered (Figure 3), core cities like Phoenix, Tempe and
212 Scottsdale, dominate the rankings because they produce far more payroll, tax, and business revenue per gallon of
213 water used.

4 Discussion

215 Each city has its own unique water value profile (Table 1) which contribute to its water productivity profile. For
216 example, Chandler is the fourth largest city in the PMA by population, and had the fourth lowest normalized WVI
217 per capita, but its normalized WVI for gross revenue is well above the PMA average (Figure 3). Chandler has a
218 disproportionately large industrial sector dominated by High Value Semiconductor Manufacturing products and
219 services. Previous studies have found this sector produces an unusually large amount of economic value relative
220 to use of water (Hubler et al., 2012). Figure 3 reveals tradeoffs between multiple normalized water productivity
221 objectives. For example, there is a tradeoff between WVI for gross revenue versus WVI for population. The
222 relatively higher business revenue a community generates with its water, the relatively lower population it
223 supports with its water. A detailed study of the Pareto frontiers and tradeoffs between these multiple objectives is
224 beyond the scope of this paper, but such a tradeoff appears to have emerged within the PMA. Despite this, the
225 standard U.S. measure of water efficiency, Gallons per Capita per Day, (GPCD, Evenson et al., 2018), implies
226 that water's value lies entirely in supporting residents and their swimming pools and lawns. When applied in
227 isolation from other metrics for other objectives, this standard measure favors allocating water to bedroom
228 communities. But this comes at a cost of the jobs and tax revenues that the residents of those bedroom communities
229 need for their livelihoods and to pay for their water rights and water infrastructure.

230 Because cities, state government, and economic development organizations want to promote high-quality
231 economic development, and the City of Chandler uses much of its water for this kind of economic activity,
232 allocating more water toward Chandler as compared with a bedroom community would seem to merit
233 consideration based on economic water productivity benchmarks. After all, a bedroom community's residents
234 need the payroll and tax revenues produced by companies in the City of Chandler. But, in turn, those companies
235 employ the workforce that lives in the bedroom communities and depend on that labor for their operations. A
236 residential population cannot be supported without jobs and revenues; both values matter and each supports the
237 other. Therefore, a more diverse set of water productivity benchmarks can help decision makers understand the
238 trade-offs involved in their allocation of water to different kinds of cities and can help policymakers avoid
239 undervaluing the economic allocations of water that are needed to support employment for the residential
240 population. Additionally, the tax base is the major constraint on the ability of a city to finance water rights and
241 water infrastructure to provide adequate water for its residential population. Linking economic and population

242   growth is important. There have been several advocates for the concept of 'wet growth' (Arnold, 2005) and water-

243   conscious land-use planning (Bates, 2012). Water-conscious economic planning and growth can help to promote,

244   protect, and restore water sources, and can prevent growth beyond the limits of water resources (Gober et al. 2010;

245   Larson et al, 2013; Li et al., 2016).

246   Accurate estimation of the water resources required to "build out" the municipality's zoning and master plan is

247   crucial part of this land use planning process (Gober et al., 2010; Gober et al., 2013; Larson et al, 2013; Li et al.,

248   2016). Once land is allocated to a use (i.e., zoned), the water and land associated with that use cannot be reallocated

249   easily or inexpensively, if at all (Marston and Cai, 2016). In addition, as a municipality continues to grow, it

250   typically approaches the "build-out" stage where further changes become prohibitive due to the scarcity and

251   depletion of land and water resources. Balancing various water productivity values is therefore important in the

252   land use planning process before development occurs.

253   We present results that focus narrowly on economic water productivity in the PMA as an alternative to GPCD as

254   an efficiency metric, but it is preferable to also include broader economic, environmental, and social dimensions

255   of water productivity. For example, urban tree and shade programs, which are water consumers, may not have

256   high economic water productivity or generate tax revenue, but they do produce demonstrable ecological service

257   benefits such as shade, mitigation of air pollution, flood amelioration, and reduced urban heat island effects. Water

258   planners and decision-makers do not apply equal weighting to their multiple values, so any stakeholder would

259   have their own weights to apply to the multiple-objective decision process that is implied by the use of multiple

260   water productivity metrics. Additionally, combining indirect water use analysis (Rushforth and Ruddell, 2015)

261   with the present paper's multiple value analysis to provide a complete evaluation of the value crated by water use,

262   but it is outside the scope of this work. We think it is important to develop a clear presentation of the multiple-

263   values argument first, and on its own merits, before adding the complexity of indirect value creation from water

264   use.

265   When broader values like revenue, payroll, and tax benefits are factored into water allocation decisions, different

266   water allocation decisions could emerge. These are political and value-based decisions, not engineering decisions,

267   but such decisions should be more broadly informed with a broader set of water productivity benchmarks.

268   **5 Conclusions**

269   This study finds that bedroom communities show higher water productivity based on the standard efficiency

270   benchmark of gallons per capita, but core cities which host large businesses show higher water productivity using

271   a basket of economic values like taxes, payroll, and business revenues. There may be tradeoffs between these

272   competing values produced by water use, and different decision makers bring different points of view and value

273   weighting to that policy discussion. A broader basket of water productivity benchmarks could inform more

274   balanced and equitable water allocation decisions by policymakers.

275 **Appendices**

276 *Appendix A: Detailed VI Equations*

277 The VI of residential water ($VI_{Property\ Tax}$) was measured on a per volume use basis using property taxes by dividing

278 the amount of levied property taxes by the municipality's volume of water delivered to residential uses. Property

279 tax data in Appendix C were obtained from the Maricopa County Department of Finance (2007). For some cities,

280 property taxes were reported as zero due to city-specific policies that restrict the ability of the city to collect

281 property tax.

282

283
$$VI_{Property\ Tax} = \frac{\$\ Levied\ Property\ Tax}{Volume_{H_2O}Residential_i\ (ac-ft)}$$

284

285 Per capita water use by the residential water use sector of a municipality $VI_{Population}$ is calculated as shown in

286 Equation 13. This metric is included because per-capita equity in water use is currently the primary type of value

287 intensity utilized for water allocation decisions.

288

289
$$VI_{Population} = \frac{Population}{Volume_{H_2O,}Residential_i\ (ac-ft)}$$

290

291

292 Data in Appendix C were used to calculate the VIs for net and gross revenue, payroll, sales tax and income taxes

293 using the following equations:

294

295
$$VI_{Revenues} = \frac{\$Revenues}{Volume_{H_2O}Non-Residential_i\ (ac-ft)}$$

296

297
$$VI_{Payroll} = \frac{\$\ Payroll}{Volume_{H_2O}Non-Residential_i\ (ac-ft)}$$

298

299
$$VI_{Sales\ Tax} = \frac{\$\ Gross\ Revenues_i \times State\ Sales\ Tax\ Rate}{Volume_{H_2O}Non-Residential_i\ (ac-ft)}$$

300

301
$$VI_{Income\ Tax} = \frac{\$\ Payroll_i \times State\ Income\ Tax\ Rate}{Volume_{H_2O}Non-Residential_i\ (ac-ft)}$$

302

303

304

305 *Appendices B, C, and D: Source Data Tables*

306

307   Appendix B: Water Data Tables B1-B3

308   Appendix C: Tax Data Tables C1

309   Appendix D: Financial Data Tables D1-D9

310

Table B.1. Reported Total Water Demand for PMA Municipalities Included in this Study.

City	Demand Category	Year									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Apache Junction	Total	10,627	10,523	11,416	10,983	10,639	11,396	11,251	11,825	11,112	11,144
Avondale	Total	5,653	7,758	9,295	10,040	11,123	9,893	13,378	14,185	13,033	13,277
Buckeye	Total	1,094	1,049	2,434	2,601	738	751	3,028	4,135	4,363	4,277
Chandler	Total	48,969	53,263	55,475	55,657	55,697	58,439	61,070	64,404	63,076	60,773
Gilbert	Total	30,438	32,800	33,984	38,047	36,596	40,190	50,515	47,915	49,085	46,239
Glendale	Total	49,472	49,773	51,193	48,707	48,828	49,242	49,740	46,849	49,586	48,133
Goodyear	Total	2,570	3,309	3,555	4,243	5,307	6,328	6,409	8,088	8,163	8,289
Mesa	Total	101,461	102,935	97,180	100,458	95,933	100,363	100,203	100,027	93,317	89,794
Peoria	Total	24,602	21,503	22,593	21,715	22,656	25,421	27,659	28,527	28,717	27,388
Phoenix	Total	332,038	340,870	346,226	329,939	337,412	314,314	331,174	321,476	304,153	305,124
Scottsdale	Total	79,479	78,165	84,508	77,901	74,426	80,772	84,427	85,249	84,051	83,444
Tempe	Total	63,236	61,729	60,223	58,526	57,644	53,515	52,201	54,915	50,239	49,682

Table B.2. Reported Residential Water Demand for PMA Municipalities Included in this Study.

City	Demand Category	Year									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Apache Junction	Residential	4,701	4,917	5,387	5,605	5,678	5,804	6,059	6,059	6,059	5,761
Avondale	Residential	4,835	5,481	6,119	6,483	7,175	7,093	8,362	8,362	8,832	8,715
Buckeye	Residential	581	604	679	622	599	643	1,617	1,617	1,617	2,629
Chandler	Residential	27,488	29,152	31,316	31,599	32,465	33,906	35,539	36,563	34,424	34,766
Gilbert	Residential	19,816	21,702	23,905	24,647	25,633	27,110	28,684	28,684	28,684	30,910
Glendale	Residential	35,135	34,667	36,044	34,348	34,427	33,567	34,660	34,660	34,660	31,457
Goodyear	Residential	1,335	1,640	2,006	2,430	3,086	3,481	3,883	3,883	3,883	4,397
Mesa	Residential	64,242	65,180	67,026	65,655	65,890	63,972	65,319	65,139	65,139	60,494
Peoria	Residential	14,400	15,208	17,077	16,925	16,962	16,224	18,981	18,981	18,981	18,819
Phoenix	Residential	208,431	205,247	209,018	201,004	200,214	195,013	202,387	202,387	202,387	188,503
Scottsdale	Residential	49,659	49,370	52,737	51,083	46,873	54,719	57,401	57,401	57,401	56,568
Tempe	Residential	29,814	30,826	31,884	27,593	27,368	25,989	26,208	26,208	26,209	25,024

Table B.3. Reported Non-Residential Water Demand for PMA Municipalities Included in this Study.

City	Demand Category	Year									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Apache Junction	Non-Residential	5,419	5,137	5,585	5,183	4,741	5,145	5,048	5,048	5,048	4,748
Avondale	Non-Residential	2,305	2,150	2,866	2,821	3,118	1,983	4,097	4,097	3,846	4,060
Buckeye	Non-Residential	301	188	848	1,788	106	110	1,270	1,270	1,270	1,482
Chandler	Non-Residential	18,149	19,936	20,795	20,126	19,164	20,259	22,043	23,635	23,316	21,739
Gilbert	Non-Residential	6,503	8,354	8,030	9,244	9,679	9,995	11,585	11,585	11,585	11,929
Glendale	Non-Residential	10,595	11,521	12,351	11,311	11,013	10,797	12,965	12,965	12,965	12,135
Goodyear	Non-Residential	1,156	1,668	1,486	1,730	2,199	2,959	2,756	2,756	2,756	3,442
Mesa	Non-Residential	27,053	36,579	29,500	29,028	29,252	26,898	29,373	29,373	29,373	27,340
Peoria	Non-Residential	4,923	4,334	3,890	3,539	4,183	5,573	7,248	7,248	7,248	7,449
Phoenix	Non-Residential	102,683	102,182	105,805	100,008	101,098	106,018	109,194	109,194	109,194	102,979
Scottsdale	Non-Residential	18,730	20,071	18,740	16,140	25,392	21,305	23,725	23,725	23,725	21,274
Tempe	Non-Residential	27,656	26,117	24,887	25,396	25,343	23,811	24,393	24,392	24,392	22,761

Table C.1. 2007 Payroll and Gross Revenue for PMA Municipalities Included in this Study

Economic Characteristics	Tempe	Scottsdale	Phoenix	Peoria	Chandler	Mesa	Goodyear	Glendale	Avondale	Gilbert	Buckeye	Apache Junction
Population	172,589	233,105	1,536,632	152,795	242,522	459,742	53,654	249,455	78,043	204,904	37,678	32,901
Payroll ($1000's)	138,748	188,927	700,624	28,946	80,686	113,398	8,702	48,377	7,534	32,876	990	3,364
Gross Revenue ($1000's)	1,658,541	1,750,750	6,504,679	445,974	987,115	1,121,299	85,776	521,636	129,608	330,023	20,513	42,344

Table C.2. 2007 Tax Data for PMA Municipalities Included in this Study

Taxes Collected	Tempe	Scottsdale	Phoenix	Peoria	Chandler	Mesa	Goodyear	Glendale	Avondale	Gilbert	Buckeye	Apache Junction
State Income Tax Paid ($1000's)	4,440	6,046	22,420	926	2,582	3,629	278	1,548	241	1,052	32	108
Primary Property Tax Paid ($1000's)	10,371	21,166	103,664	3,002	8,506	-	4,172	3,888	1,796	-	2,839	-
Secondary Property Tax Paid ($1000's)	21,365	29,673	163,227	20,527	25,109	-	6,633	24,669	4,087	27,258	347	-
State Sales Tax Paid ($1000's)	109,463,701	115,549,495	429,308,843	29,434,280	65,149,612	74,005,744	5,661,210	34,427,999	8,554,147	21,781,503	1,353,845	2,794,705

Table D.2. Income Data for Municipalities in the Phoenix Active Management Area (Sources: US Census Bureau and AZ Department of Revenue)

City	Population	HOUSEHOLD INCOME $	Average FAGI $	Per Capita FAGI $	Average Tax Liability $	Tax Liability Per Return $	State Transaction & Priviledge Tax Distributed to Cities $ (2004)	State Sales Tax Per Capita $	State Transaction and Priviledge Tax Distributed to Cities $ (2011)
Apache Junction	32,901	46649	45569	23115	1039	804	2661210	81	2618154
Avondale	78,043	69069	45162	18332	952	769	3001578	38	5351475
Buckeye	37,678	71177	48216	18785	1010	816	710766	19	2112351
Chandler	242,522	86333	63336	29647	1670	1393	14770829	61	17695102
Gilbert	204,904	94151	67378	28504	1703	1418	9176047	45	13787266
Glendale	249,455	65769	48584	21643	1159	919	18303410	73	1843879
Goodyear	53,654	87264	62050	26471	1388	1157	1581887	29	3661678
Mesa	459,742	63739	47815	21871	1141	908	33254566	72	34220312
Peoria	152,795	78677	58290	26943	1372	1126	9064543	59	10673717
Phoenix	1,536,632	66661	50734	22341	1382	1077	110504126	72	112704366
Scottsdale	233,105	106485	103539	55155	3960	3100	16956076	73	17843974
Surprise	87,488	68704	49775	25436	1014	790	2580405	29	6946254
Tempe	172,589	66359	52168	28510	1401	1148	13268827	77	12656738
Tolleson	6,989	41342	39084	14834	807	643	416070	60	497422

Table D.3. Income Data for Municipalities in the Phoenix Active Management Area (Sources: US Census Bureau and AZ Department of Revenue)

City	State Sales Tax Per Capita $	Sales Tax per City Area $	Sales Tax per GPCD $	Sales Tax per Ac-Ft of Water $	Distribution of Income Tax as Urban Revenue Sharing $	Per Capita Urban Revenue Sharing $	Urban Revenue Sharing per GPCD $	Urban Revenue Sharing per City Area $	Urban Revenue Sharing per Ac-Ft of Water $
Apache Junction	79.58	74826	10287	255.58	3316127	100.79	13030	94774	323.72
Avondale	68.57	117357	38703	441.58	6750611	86.50	48822	148040	557.03
Buckeye	56.06	5629	15440	364.87	2427836	64.44	17745	6470	419.36
Chandler	72.96	274726	108412	398.03	22468783	92.65	137659	348840	505.41
Gilbert	67.29	214055	71564	310.98	17280849	84.34	89697	268295	389.78
Glendale	7.39	30742	7448	26.58	23590446	94.57	95287	393305	340.12
Goodyear	68.25	19123	19754	327.83	4498039	83.83	24266	23491	402.71
Mesa	74.43	250790	167542	324.49	43614424	94.87	213536	319637	413.57
Peoria	69.86	61203	35609	207.51	13445840	88.00	44857	77098	261.40
Phoenix	73.35	218123	515447	298.68	143647008	93.48	656962	278009	380.68
Scottsdale	76.55	97020	42832	163.61	22849062	98.02	54846	124234	209.50
Surprise	79.40	65686	92569	942.12	8591077	98.20	114488	81239	1165.21
Tempe	73.33	316973	34153	176.20	16137384	93.50	43545	404142	224.66
Tolleson	71.17	86508	5107	650.69	632468	90.49	6494	109994	827.35

Table D.4. Manufacturing Data for Municipalities in the Phoenix Active Management Area (Source: US Census Bureau)

City	Population	Manufacturers shipments, 2007 ($1000)	Merchant wholesaler sales, 2007 ($1000)	Retail sales, 2007 ($1000)	Retail Sales Per Capita (2007) $	Accommodation and food services sales, 2007 ($1000)	Number of establish-ments	Sales ($1,000)
Apache Junction	32,901	NA	24707	447477	13756	36282	17	24707
Avondale	78,043	0	73438	1601272	20243	94636	NA	NA
Buckeye	37,678	NA	NA	215169	5676	17210	9	NA
Chandler	242,522	3956031	4585919	3608290	14787	500934	220	4585919
Gilbert	204,904	415891	649322	2079066	10063	191244	147	649322
Glendale	249,455	912989	1013545	3627782	14457	340736	135	1013545
Goodyear	53,654	185496	NA	631710	11669	105052	17	NA
Mesa	459,742	3072462	2037336	6294523	13669	753178	301	2037336
Peoria	152,795	267830	251210	2340433	15135	258496	56	251210
Phoenix	1,536,632	16926892	23670515	21859505	14209	3644383	1946	23670515
Scottsdale	233,105	4806562	3445500	6645363	28447	1314297	538	3445500
Surprise	87,488	NA	20359	888224	9878	115082	23	20359
Tempe	172,589	5877588	7286114	6172475	35768	606835	511	7286114
Tolleson	6,989	2128242	NA	138737	19777	17065	22	NA

Table D.5. Manufacturing Data for Municipalities in the Phoenix Active Management Area (Source: US Census Bureau)

City	Annual payroll ($1,000)	First-quarter payroll ($1,000)	Number of paid employees	Operating expenses ($1,000)	Total inventories, beginning of year ($1,000)	Total inventories, end of year ($1,000)	Sales, receipts, or revenue from administrative records (%)	Sales, receipts, or revenue estimated (%)	Sales Per Establishment ($1000)	Payroll Per Establishment ($1000)
Apache Junction	1790	361	66	3834	3200	3582	14%	0%	1453	105
Avondale	NA	NA	NA	NA	NA	NA	0%	0%	NA	NA
Buckeye	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chandler	291766	71408	4198	543461	204970	206196	1%	3%	20845	1326
Gilbert	59745	14564	1450	117011	49213	50744	7%	13%	4417	406
Glendale	70030	16869	2079	141645	127262	133548	17%	5%	7508	519
Goodyear	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mesa	174055	35616	3372	290320	479762	476581	3%	9%	6769	578
Peoria	14834	4002	368	31285	16012	16168	6%	4%	4486	265
Phoenix	1650697	404324	34585	2989800	1655286	1669772	4%	7%	12164	848
Scottsdale	314307	75139	5811	664083	334508	361302	12%	14%	6404	584
Surprise	3461	862	97	5980	769	918	5%	37%	885	150
Tempe	722174	156112	11117	1201352	468771	499405	4%	4%	14259	1413
Tolleson	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table D.6. Retail Data for Municipalities in the Phoenix Active Management Area (source: US Census Bureau)

City	Population	Number of establishments	Sales ($1,000)	Annual payroll ($1,000)	First-quarter payroll ($1,000)	Number of paid employees for pay period including March 12	Sales, receipts, or revenue from administrative records (%)	Sales, receipts, or revenue estimated (%)
Apache Junction	32,901	96	447477	45386	12047	2181	6%	8%
Avondale	78,043	NA	NA	NA	NA	NA	0%	0%
Buckeye	37,678	48	215169	14158	2830	449	10%	26%
Chandler	242,522	694	3608290	353274	87134	15714	2%	2%
Gilbert	204,904	441	2079066	207222	48614	8466	2%	4%
Glendale	249,455	714	3627782	332276	83526	15566	3%	2%
Goodyear	53,654	109	631710	61449	16588	2955	2%	4%
Mesa	459,742	1,507	6294523	653862	164729	28855	6%	6%
Peoria	152,795	353	2340433	216892	53154	8143	5%	2%
Phoenix	1,536,632	4,266	21859505	1913730	470361	77534	7%	5%
Scottsdale	233,105	1,378	6645363	664928	163704	22923	4%	5%
Surprise	87,488	147	888224	85661	21606	4064	2%	1%
Tempe	172,589	847	6172475	447488	110713	16389	4%	7%

Table D.7. Real Estate Data for Municipalities in the Phoenix Active Management Area (source: US Census Bureau)

City	Population	Number of establish-ments	Revenue ($1,000)	Annual payroll ($1,000)	First-quarter payroll ($1,000)	Number of paid employees	Sales, receipts, or revenue from administrative records (%)	Sales, receipts, or revenue estimated (%)
Apache Junction	32,901	42	23469	3822	1024	123	12%	11%
Avondale	78,043	NA	NA	NA	NA	NA	NA	NA
Buckeye	37,678	15	46949	2305	637	58	2%	0%
Chandler	242,522	301	227950	37680	10260	1171	13%	11%
Gilbert	204,904	307	185181	34687	8767	1003	11%	8%
Glendale	249,455	250	202866	30910	7560	1208	11%	16%
Goodyear	53,654	61	33695	5577	1201	166	23%	20%
Mesa	459,742	594	524907	80140	20491	2834	15%	13%
Peoria	152,795	152	114499	25124	6266	710	11%	12%
Phoenix	1,536,632	2227	3261013	746350	185769	17353	11%	12%
Scottsdale	233,105	1102	1992041	335830	85047	5637	9%	8%
Surprise	87,488	55	48095	6761	1653	445	6%	6%
Tempe	172,589	451	768874	138486	32144	3423	9%	9%
Tolleson	6,989	3	1068	370	77	12	39%	0%

Table D.8. Information Services Data for Municipalities in the Phoenix Active Management Area (source: US Census Bureau)

City	Population	Number of establishments	Receipts ($1,000)	Annual payroll ($1,000)	First-quarter payroll ($1,000)	Number of paid employees for pay period including March 12	Sales, receipts, or revenue from administrative records (%)??	Sales, receipts, or revenue estimated (%)??
Apache Junction	32,901	6	N	1996	492	50	N	N
Avondale	78,043	NA	N	NA	NA	NA	N	N
Buckeye	37,678	5	N	933	214	18	N	N
Chandler	242,522	77	N	104599	31878	2125	N	N
Gilbert	204,904	41	N	26622	6502	454	N	N
Glendale	249,455	40	N	22578	5956	520	N	N
Goodyear	53,654	8	N	D	D	b	N	N
Mesa	459,742	120	N	149666	39598	3006	N	N
Peoria	152,795	26	N	9088	2390	252	N	N
Phoenix	1,536,632	694	N	1347304	347914	21256	N	N
Scottsdale	233,105	249	N	541288	134269	6725	N	N
Surprise	87,488	7	N	1593	482	30	N	N
Tempe	172,589	162	N	209756	54879	4157	N	N
Tolleson	6,989	5	N	D	D	a	N	N

Table D.9. Professional and Technical Services Data for Municipalities in the Phoenix Active Management Area (source: US Census Bureau)

City	Population	Number of establish-ments	Receipts/Revenue ($1,000)	Expenses ($1,000)	Annual payroll ($1,000)	First-quarter payroll ($1,000)	Number of paid employees for pay period including March 12	Sales, receipts, or revenue from administrative records	Sales, receipts, or revenue estimated (%)	Annual Payroll Per Establishment $
Apache Junction	32901	30	9679	N	2722	687	122	30%	21%	91
Avondale	78043	NA	NA	NA	NA	NA	NA	NA	NA	NA
Buckeye	37678	22	22110	N	7136	1884	149	2%	12%	324
Chandler	242522	610	373941	N	490947	126119	7138	37%	18%	805
Gilbert	204904	463	412515	N	152162	34923	3538	16%	6%	329
Glendale	249455	303	NA	N	NA	NA	NA	NA	NA	NA
Goodyear	53654	67	36598	N	15146	3501	355	16%	18%	226
Mesa	459742	1084	709255	N	302360	69800	7120	26%	14%	279
Peoria	152795	219	79141	N	27921	6860	702	33%	8%	127
Phoenix	1536632	5055	7158437	N	2947465	671593	46810	15%	7%	583
Scottsdale	233105	1972	3573147	N	1158253	272299	17313	15%	6%	587
Surprise	87488	83	27484	N	11120	3024	437	20%	22%	134
Tempe	172589	1005	1321432	N	606044	152654	10930	15%	8%	603
Tolleson	6989	2	NA	N	NA	NA	NA	NA	NA	NA

Data Availability

The data used in this study is publicly sourced and reproduced in the paper's appendices.

Author Contributions

15   BR designed the study and led the writing. RR carried out data collection and calculations and helped with the writing. DH edited and rewrote the manuscript, including preparation of the results.

Competing interests

The authors declare that they have no conflict of interest. BR and RR disclose that they were paid consultants to the City of Chandler, Arizona in 2012.

20   **Acknowledgements**

Diane Hope provided editorial services and input to an earlier version of the manuscript. The authors gratefully acknowledge the City of Chandler, Arizona; the City's water resource engineering staff provided advice and data to support the study- in particular Doug Toy and Bob Groff. The authors acknowledge funding from NSF/USDA ACI-1639529, INFEWS/T1: Mesoscale Data Fusion to Map and Model the U.S. Food, Energy, and Water (FEW)
25   System, and from internal funding by Northern Arizona University. This work was conducted as a part of the "Reanalyzing and Predicting U.S. Water Use using Economic History and Forecast Data; an experiment in short-range national hydro-economic data synthesis" Working Group supported by the John Wesley Powell Center for Analysis and Synthesis, funded by the U.S. Geological Survey. The opinions expressed are those of the researchers, and not necessarily the funding agencies.

30   **References**

Arizona Department of Water Resources. 2011a. "Notification of 2009 Gallons per Capita per Day (GPCD) and Lost and Unaccounted (L&U) for Water Percentages. Notification for Arizona Water Company - Apache Junction." Report Number: 56-002000.000. Arizona Department of Water Resources, Phoenix, AZ.

Arizona Department of Water Resources. 2011b. "Second Notification of 2009 Gallons per Capita per Day
35   (GPCD) and Lost and Unaccounted (L&U) for Water Percentages. Notification for City of Avondale." Report Number: 56-002003.000. Arizona Department of Water Resources, Phoenix, AZ.

Arizona Department of Water Resources. 2011c. "Notification of 2009 Gallons per Capita per Day (GPCD) and Lost and Unaccounted (L&U) for Water Percentages. Notification for Town of Buckeye". Report Number: 56-002006.000. Arizona Department of Water Resources, Phoenix, AZ.

40   Arizona Department of Water Resources. 2011d. "Notification of 2009 Gallons per Capita per Day (GPCD) and Lost and Unaccounted (L&U) for Water Percentages. Notification for City of Chandler." Report Number: 56-002009.000. Arizona Department of Water Resources, Phoenix, AZ.

Arizona Department of Water Resources. 2011e. "Notification of 2009 Gallons per Capita per Day (GPCD) and Lost and Unaccounted (L&U) for Water Percentages. Notification for Town of Gilbert." Report Number: 56-

45   002017.000. Arizona Department of Water Resources, Phoenix, AZ.

Arizona Department of Water Resources (ADWR), 2011f. "Notification of 2009 Gallons per Capita per Day (GPCD) and Lost and Unaccounted (L&U) for Water Percentages. Notification for City of Glendale." Report Number: 56-002018.000. Arizona Department of Water Resources, Phoenix, AZ.

Arizona Department of Water Resources. 2011g. "Notification of 2009 Gallons per Capita per Day (GPCD) and

50   Lost and Unaccounted (L&U) for Water Percentages. Notification for City of Goodyear." Report Number: 56-002019.000. Arizona Department of Water Resources, Phoenix, AZ.

Arizona Department Of Water Resources. 2011h. "Notification of 2009 Gallons per Capita per Day (GPCD) and Lost and Unaccounted (L&U) for Water Percentages. Notification for City of Mesa." Report Number: 56-002023.00. Arizona Department of Water Resources, Phoenix, AZ.

55   Arizona Department of Water Resources. 2011i. "Second Notification of 2009 Gallons per Capita per Day (GPCD) and Lost and Unaccounted (L&U) for Water Percentages. Notification for City of Peoria." Report Number: 56-002029.000). Arizona Department of Water Resources, Phoenix, AZ.

Arnold, C. A. 2005. "Is Wet Growth Smarter than Smart Growth?: The Fragmentation and Integration of Land Use and Water." Environmental Law Reporter 35 (3): 10152–10178.

60   https://www.academia.edu/10850352/The_Most_Important_Current_Research_Questions_in_Urban_Ecosystem_Services

Bae, J. and Dall'Erba, S. 2018. "Crop production, export of virtual water and water-saving strategies in Arizona." Ecological Economics 146: 148-156. https://doi.org/10.1016/j.ecolecon.2017.10.018

Bates, S. 2012. "Bridging the Governance Gap: Emerging Strategies to Integrate Water and Land Use Planning."

65   Journal of Natural Resources 52: 61. https://digitalrepository.unm.edu/nrj/vol52/iss1/3

Berg, S. 2010. Water Utility Benchmarking: Measurement, Methodologies and Performance Incentives. London: IWA Publishing.

Blackhurst, B. Y. M., Hendrickson, C., and Vidal, J. S. I. 2010. "Direct and indirect water withdrawals for U.S. industrial sectors." Environmental Science and Technology 44 (6): 2126–2130.

70   https://doi.org/10.1021/es903147k

Borrego-Marín, M. M., Gutiérrez-Martín, C., & Berbel, J. 2016. Estimation of cost recovery ratio for water services based on the system of environmental-economic accounting for water. Water Resources Management, 30 (2): 767-783. DOI:10.1007/s11269-015-1189-2

Central Arizona Project. 2012. "CAP's Subcontracting Status Report for CAP allocations". http://www.cap-

75   az.com/Water/Allocations.aspx, accessed 10 Sep 2012.

City of Chandler. 2009. City of Chandler Annual Budget 2008-09. (http://www.chandlz.gov/content/2008_09AnnualReport.pdf; access date 08/12/2012.

City of Chandler. 2008. Arizona General Plan. (http://www.chandlz.gov/gov/ChandlerGenlPlan.pdf; access date 09/10/2012).

80   City of Glendale. 2008. Schedule 5: Expenditure Limitation & Property Tax Rate. (http://www.glendaleaz.com/budget/AnnualBudgetBooks.cfm; access date 8/12/2012).

City of Goodyear. 2007. City of Goodyear 2007-2008 Annual Budget. (http://www.goodyearaz.gov/DocumentCenter/Home/View/4267; access date 8/12/2012).

City of Mesa. 2008. City of Mesa Final Budget for Fiscal Year Ending 2008.
85   (http://www.mesaaz.gov/budget/Documents/FY_03_09/Reso_9002_Budget_07_08.pdf; access date 8/12/2012).

City of Peoria, 2007. City of Peoria Annual Program Budget - Fiscal Year 2007. (http://www.peoriaaz.gov/uploadedFiles/Peoriaaz/Departments/Budget/Historical_Budget_Books/FY2007 AnnualProgramBook.pdf; access date 8/12/2012).

90   City of Phoenix. 2007. Arizona Comprehensive Annual Financial Report, Financial Year 2007. (http://phoenix.gov/webcms/groups/internet/@inter/@gov/@fin/@plan/documents/web_content/080342.pd f: access date 8/12/2012).

City of Scottsdale. 2008. City of Scottsdale Arizona Adopted Financial Year 2007/08 Budget. (http://www.scottsdaleaz.gov/Assets/Public+Website/finance/Archive/FY+2007-08/FY+2007-
95   08+Volume+1+Budget+Summary.pdf; access date 8/12/2012.

City of Tempe. 2007. City of Tempe Annual Budget - July 1, 2007 through June 30, 2008. (http://www.tempe.gov/modules/showdocument.aspx?documentid=631); access date 8/12/2012

Devineni, N., Lall, U., Etienne, E., Shi, D. and Xi, C. 2015. "America's water risk: Current demand and climate variability." Geophysical Research Letters 42: 2285–2293. https://doi.org/10.1002/2015GL063487

100   Evenson, E.J., Jones, S.A., Barber, N.L., Barlow, P.M., Blodgett, D.L., Bruce, B.W., Douglas-Mankin, K., Farmer, W.H., Fischer, J.M., Hughes, W.B., Kennen, J.G., Kiang, J.E., Maupin, M.A., Reeves, H.W., Senay, G.B., Stanton, J.S., Wagner, C.R., and Wilson, J.T. 2018. "Continuing progress toward a national assessment of water availability and use." U.S. Geological Survey Circular 1440, 64 p., https://doi.org/10.3133/cir1440.

Gleick, P. H. and Palaniappan, M. 2010. "Peak water limits to freshwater withdrawal and use." Proceedings of
105   the National Academy of Sciences of the United States of America 107 (25): 11155–11162. https://doi.org/10.1073/pnas.1004812107

Gober, P., Kirkwood, C. W., Balling, R. C. Jr., Ellis, A. W. and Deitrick, S. 2010. "Water planning under climatic uncertainty in Phoenix: Why we need a new paradigm." Annals of the. Association of American. Geographers. 100 (2): 356– 372. https://doi.org/10.1080/00045601003595420

110   Gober, P., Larson, K. L., Quay, R., Polsky, C., Chang, H. and Shandas, V. 2013. "Why Land Planners and Water Managers Don't Talk to One Another and Why They Should!" Society and Natural Resources 26 (3): 356– 364. https://doi:10.1080/08941920.2012.713448

Haider, H., Sadiq, R., and Tesfamariam, S. 2016. Inter-Utility Performance Benchmarking Model for Small-to-Medium-Sized Water Utilities: Aggregated Performance Indices. Journal of Water Resources Planning and
115   Management 142(1). https://ascelibrary.org/doi/full/10.1061/%28ASCE%29WR.1943-5452.0000552

Hamdy, A., Ragab, R. and Scarascia-Mugnozza, E., 2003. Coping with water scarcity: water saving and increasing water productivity. Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage, 52(1), pp.3-20.

120 Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M. and Mekonnen, M. M. 2011. "The water footprint assessment manual: Setting the global standard." London: Earthscan.

Hoekstra, A. Y. 2014. "Sustainable, efficient, and equitable water use: The three pillars under wise freshwater allocation." Wiley Interdisciplinary Reviews Water 1 (1): 31–40. https://doi.org/10.1002/wat2.1000

Hoekstra, A. Y., Chapagain, A. K. and Zhang, G. 2015. "Water footprints and sustainable water allocation." Sustainability 8 (1): 20. https://doi.org/10.3390/su8010020

125 Holway, J. M. 2007. Urban growth and water supply. Arizona Water Policy: Management Innovations in an Urbanizing, Arid Region, 157-172.

Howe, C. W., and Goemans, C. 2007. "The simple analytics of demand hardening." Journal-American Water Works Association 99 (10): 24-25. https://doi.org/10.1002/j.1551-8833.2007.tb08052.x

Hubler, D. K., Baygents, J. C., Mackay, C., Megdal, S. B. 2012. "Evaluating economic effects of semiconductor 130 manufacturing in water-limited regions." Journal of the American Water Works Association 104:2. https://doi:10.5942/jawwa.2012.104.0024

Jacobs, K., & Megdal, S. 2004. Water management in the active management areas. Arizona's Water Future: Challenges and Opportunities Background Report, 71-94.

Kijne, J.W., Barker, R. and Molden, D., 2003. Improving water productivity in agriculture: editors' overview. 135 Water productivity in agriculture: Limits and opportunities for improvement, pp.xi-xix.

Kumar, M.D. (2021). Conceptual issues in water use efficiency and water productivity. In Kumar, M. D. (Ed.), Water Productivity and Food Security: Global Trends and Regional Patterns (pp. 49-61). Netherlands: Elsevier Science.

Larson, K. L., Polsky, C., Gober, P., Chang, H. and Shandas, V. 2013. "Vulnerability of Water Systems to the 140 Effects of Climate Change and Urbanization: A Comparison of Phoenix, Arizona and Portland, Oregon (USA)." Environmental Management 52: 179–195. https://doi.org/10.1007/s00267-013-0072-2.

Li, E., Li, S. and Endter-Wada, J. 2016. "Water-smart growth planning: linking water and land in the arid urbanizing American West." Journal of Environmental Planning and Management 60 (6): 1056-1072, https://doi.org/10.1080/09640568.2016.1197106

145 Maricopa County Department of Finance. 2007. Maricopa County 2007 Tax Levy. http://www.maricopa.gov/Finance/PDF/Tax/TaxLevy2007.pdf; access date 08/11 2012).

Marston, L. and Cai, X. 2016. "An overview of water reallocation and the barriers to its implementation." Wiley Interdisciplinary Reviews Water 3 (5): 658–677. https://doi.org/10.1002/wat2.1159

Marston, L., Ao, Y., Konar, M., Mekonnen, M. M. and Hoekstra, A. Y. 2018. "High-resolution water footprints 150 of production of the United States." Water Resources Research 54: 2288–2316. https://doi.org/10.1002/2017WR021923.

Marston, L.T., Lamsal, G., Ancona, Z.H., Caldwell, P., Richter, B.D., Ruddell, B.L., Rushforth, R.R. and Davis, K.F., 2020. Reducing water scarcity by improving water productivity in the United States. Environmental Research Letters, 15(9), p.094033.

155 Maupin, M. A., Kenny, J. F., Hutson, S. S., Lovelace, J. K., Barber, N. L. and Linsey, K. S. 2014. "Estimated Use of Water in the United States in 2010." Circular 1405. Reston, VA: U.S. Geological Survey. http://pubs.usgs.gov/circ/1405/.

Mayer, A., Mubako, S. and Ruddell, B.L., 2016. Developing the greatest Blue Economy: Water productivity, fresh water depletion, and virtual water trade in the Great Lakes basin. Earth's Future, 4(6), pp.282-297.

160 Paterson, W. Rushforth, R., Ruddell, B.L., Ikechukwu, C., Gironás, J., Konar, M., Mijic, A., Mejia, A. 2015. "Water Footprint of Cities: A Review and Suggestions for Future Research." Sustainability 7: 8461-8490. https://doi.org/10.3390/su7078461

Postel, S. L., Daily, G. C. and Ehrlich, P. R. 1996. "Human appropriation of renewable fresh water." Science 271 (5250): 785–787. https://doi.org/10.1126/science.271.5250.785

165 Richter, Brian D., et al. "Decoupling Urban Water Use and Growth in Response to Water Scarcity." Water 12.10 (2020): 2868.

Ruddell, B. L. (2018) HESS Opinions: How should a future water census address consumptive use? (And where can we substitute withdrawal data while we wait?), Hydrol. Earth Syst. Sci., 22, 5551–5558, https://doi.org/10.5194/hess-22-5551-2018.

170 Rushforth, R. R., Adams, E. A. and Ruddell, B. L. 2013. "Generalizing ecological, water and carbon footprint methods and their worldview assumptions using Embedded Resource Accounting". Water Resources and Industry, 1: 77-90. https://doi.org/10.1016/j.wri.2013.05.001

Ruddell, B. L., Adams, E. A., Rushforth, R. and Tidwell, V. C. 2014. "Embedded resource accounting for coupled natural-human systems: An application to water resource impacts of the western US electrical energy trade."

175 Water Resources Research 50: 7957– 7972. https://doi.org/10.1002/2013WR014531

Rushforth, R. R. and Ruddell, B. L. 2015. "The hydro-economic interdependency of cities: Virtual water connections of the Phoenix, Arizona metropolitan area." Sustainability 7 (7): 8522–8547. https://doi.org/10.3390/su7078522

Rushforth, R. R. and Ruddell, B. L. 2016. "The vulnerability and resilience of a city's water footprint: The case

180 of Flagstaff, Arizona, USA." Water Resources Research 52: 2698–2714. https://doi.org/10.1002/2015WR018006S

Rushforth, R. R. and Ruddell, B. L. 2018. "A spatially detailed blue water footprint of the United States economy." Hydrology and Earth System Sciences 22: 3007–3032, https://doi.org/10.5194/hess-22-3007-2018.

Rushforth, Richard R., Maggie Messerschmidt, and Benjamin L. Ruddell. "A Systems Approach to Municipal

185 Water Portfolio Security: A Case Study of the Phoenix Metropolitan Area." Water 12.6 (2020): 1663.

Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N. W., Clark, D. B., Dankers, R., Eisner, S., Fekete, B.M., Colón-González, F.J., Gosling, S.N., Kim, H., Liu, X, Masaki, Y, Portmann, F.T., Satoh, Y., Stacke, T., Tang, Q., Wada, Y., Wisser, D., Albrecht, T., Frieler, K., Piontek, F., Warszawski, L., Kabat, P. 2014. "Multimodel assessment of water scarcity under climate change." Proceedings of the National Academy of

190 Sciences 111 (9): 3245–3250. https://doi.org/10.1073/pnas.1222460110S

Scott, C.A. and Pasqualetti, M.J. 2010. "Energy and water resources scarcity: Critical infrastructure for growth and economic development in Arizona and Sonora." Natural Resources Journal 50 (3): 645-682. JSTOR, www.jstor.org/stable/24889651

Solley, W. B., Chase, E. B. and Mann IV, W.B. 1983. Estimated use of water in the United States in 1980. USGS

195 Circular 1001, U.S. Geological Survey, Washington D.C. https://doi.org/10.3133/cir1001

Tidwell, V. C., Kobos, P. H., Malczynski, L. A., Klise, G. and Castillo, C. R. 2012. "Exploring the water-thermoelectric power nexus.", Journal of Water Resources Research, Planning and Management 138 (5): 491– 501. https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29WR.1943-5452.0000222

Town of Avondale. 2010. Annual Budget & Financial Plan - Fiscal Year 2010-2011. (http://www.avondale.org/documents/22/54/56/Avondale%20Budget%20Document%20INet.pdf; access date 8/12/2012).

Town of Buckeye. 2007. Arizona Adopted Budget Fiscal Year 2007/08. (http://www.buckeyeaz.gov/DocumentCenter/Home/View/490; access date 8/12/2012).

Town of Gilbert, 2008. Summary Schedule of Estimated Revenues and Expenditures/Expenses. Fiscal Year 2007-08.

(http://www.gilbertaz.gov/budget/pdf/schedule/FY08%20Gilbert%20Official%20C&T%20Budget%20Schedule%20A.pdf; access date 8/12/2012).

U.S. Bureau of Economic Analysis. 2019. https://www.bea.gov/data/gdp/gdp-county-metro-and-other-areas

U.S. Census Bureau. 2007a. "American Community Survey, Information: Geographic Area Series: Summary Statistics for the United States, States, Metro and Micro Areas, Metro Divisions, Consolidated Cities, Counties, and Places: 2007." (http://factfinder2.census.gov; access date 08/11/ 2012). Now: "City and Town Intercensal Data sets: 2000 – 2010" (https://www.census.gov/data/datasets/time-series/demo/popest/intercensal-2000-2010-cities-and-towns.html).

U.S. Census Bureau. 2007b. "American Community Survey, All sectors: Geographic Area Series: Economy-Wide Key Statistics". (2007http://factfinder2.census.gov; access date 08/11/ 2012). Now 'Economic Census (2017, 2012, 2007, 2002)." (https://www.census.gov/data/developers/data-sets/economic-census.2007.html).

U.S. Census Bureau. 2009a. "American Community Survey, Selected Economic Characteristics: 2005-2009." (http://factfinder2.census.gov; access date 08/11/ 2012).

U.S. Census Bureau. 2009b. "American Community Survey, Selected Housing Characteristics: 2005-2009." (http://factfinder2.census.gov; access date 08/11/ 2012).

U.S. Census Bureau. 2009c. "American Community Survey, ACS Demographic and Housing Estimates: 2005-2009." (http://factfinder2.census.gov; 08/11/2012).

U.S. Census Bureau. 2009d. "American Community Survey, Mean Income in the Past 12 Months (In 2009 Inflation-Adjusted Dollars)." (http://factfinder2.census.gov; access date 08/11/2012).

U.S. Census Bureau. 2009e. "American Community Survey, Median Income in the Past 12 Months (In 2009 Inflation-Adjusted Dollars)." (http://factfinder2.census.gov; access date 08/11/2012).

U.S. Census Bureau. 2009f. "American Community Survey, Financial Characteristics." (http://factfinder2.census.gov; access date 08/11/ 2012).

U.S. Census Bureau. 2020. https://www.census.gov/newsroom/press-releases/2020/pop-estimates-county-metro.html

U.S. Census (2021). QuickFacts. URL: https://www.census.gov/quickfacts/fact/table/US/PST045219

Vardon, M., Martinez-Lagunes, R., Gan, H., & Nagy, M. 2012. The system of environmental-economic accounting for water: development, implementation and use. Water Accounting, International Approaches to Policy and Decision Making. Edward Elgar, United Kingdom, 32-57. https://DOI: 10.4337/9781849807494.00010

Vörösmarty, C. J. 2000. "Global water resources: Vulnerability from climate change and population growth." Science 289 (5477): 284-288. https://doi.org/10.1126/science.289.5477.284

Wildman, R. A., Jr., and N. A. Forde. 2012. "Management of water shortage in the Colorado river basin: Evaluating current policy and the viability of interstate water trading." Journal of the American Water Resources Association 48 (3): 411– 422. https://doi.org/10.1111/j.1752-1688.2012.00665.x

Xu, Z., Chen, X., Wu, S.R., Gong, M., Du, Y., Wang, J., Li, Y. and Liu, J., 2019. Spatial-temporal assessment of water footprint, water scarcity and crop water productivity in a major crop production region. Journal of Cleaner Production, 224, pp.375-383.

240

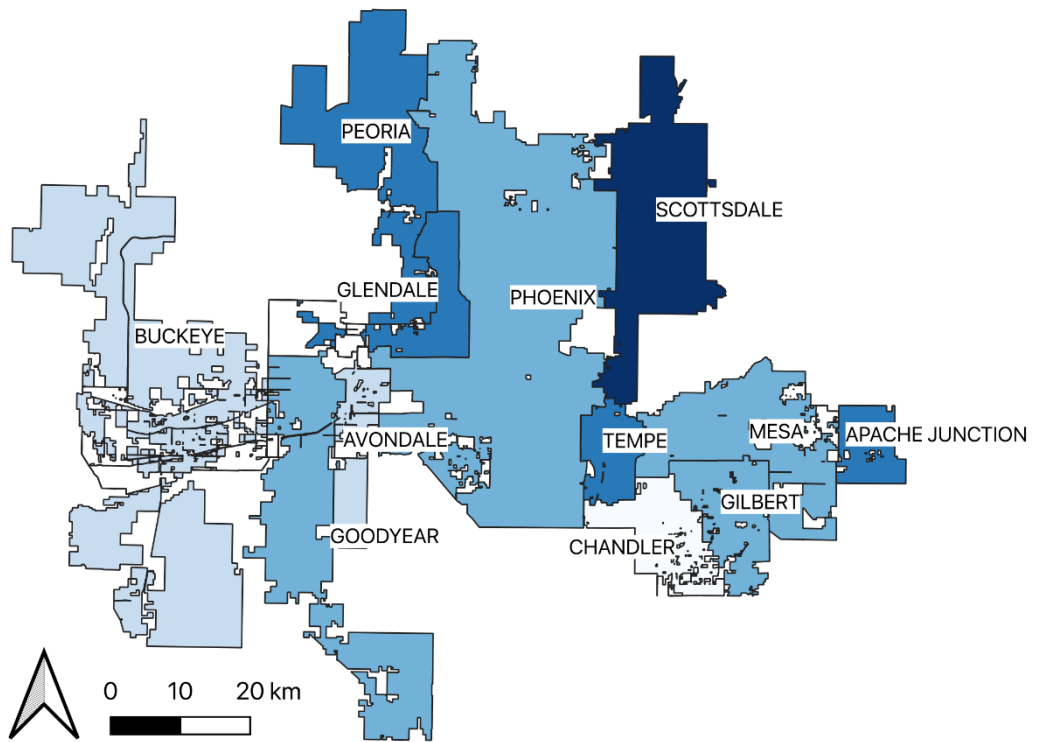



Figure 1. Map of the Phoenix metropolitan statistical area (PMA) showing the member municipalities.

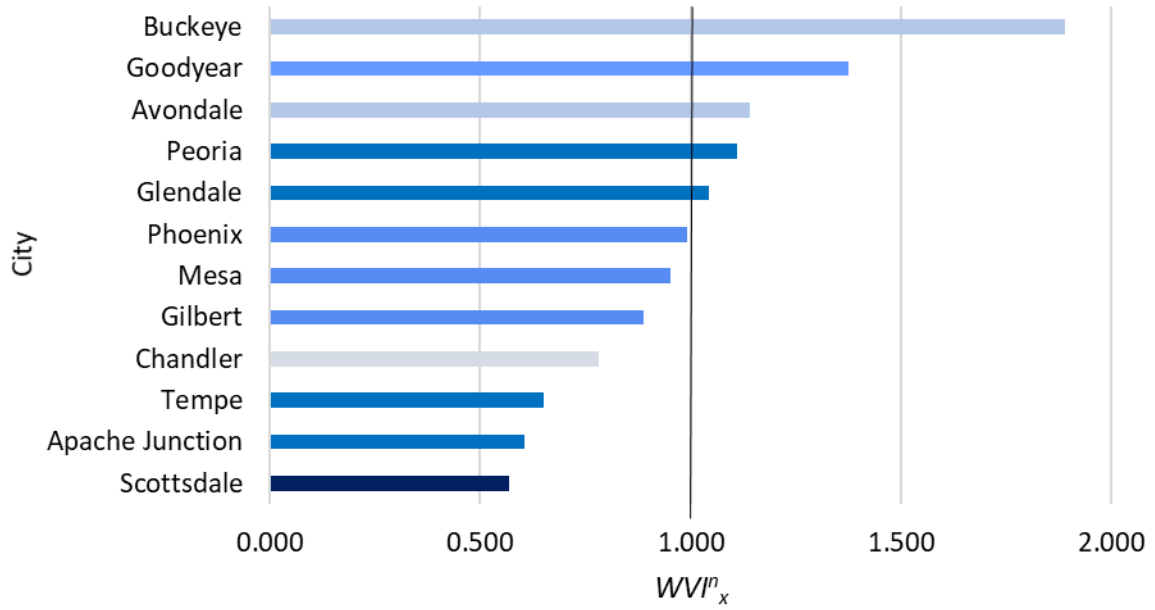



Figure 2. PMA municipalities x listed in order of their relative WVI^n_x for residential population supported. The PMA's mean value is 1. Outlying bedroom communities like Buckeye, Goodyear, and Avondale score above average on the traditional per-capita basis of water use benchmarking (cities are color-coded to correspond with Figure 1).

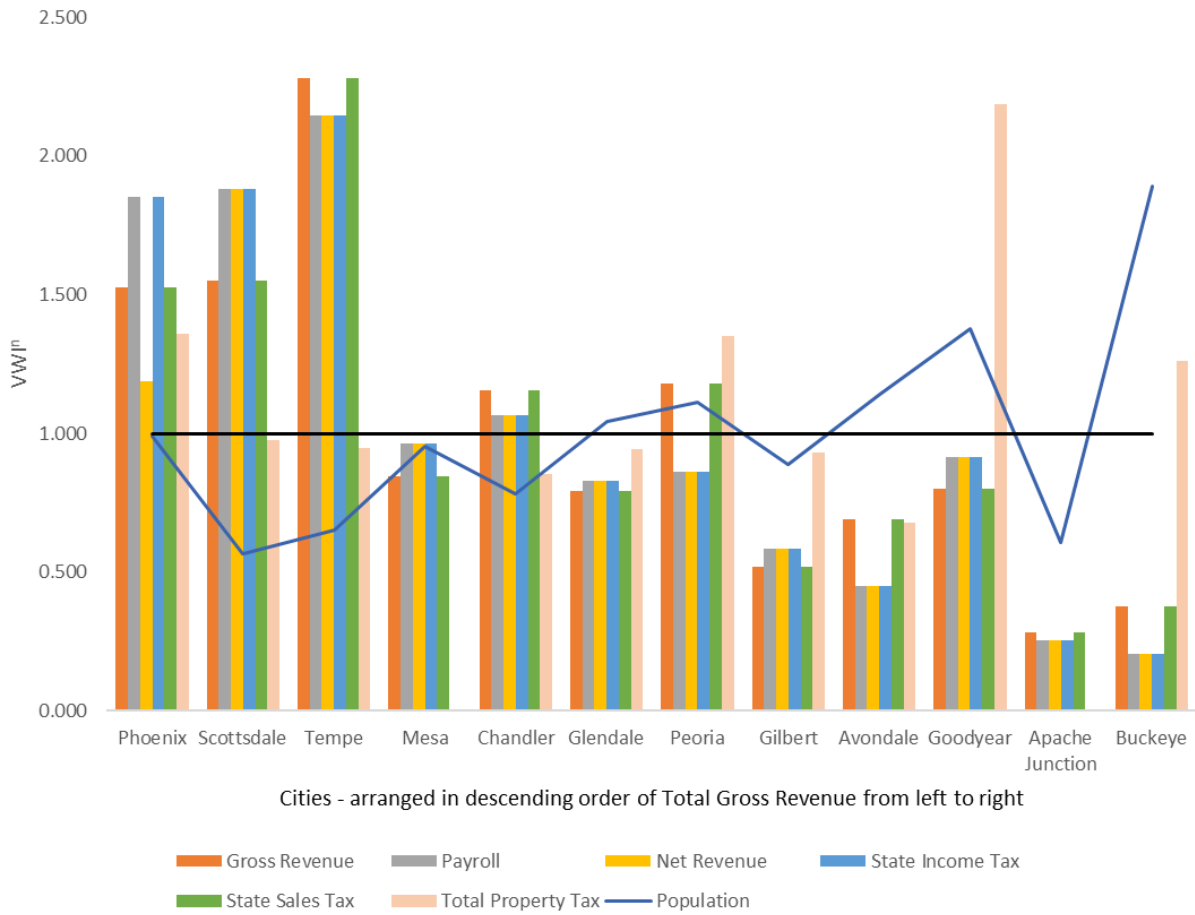



Figure 3. *WVI^n* for economic value types (colored bars) and population value type (blue line) for each PMA municipality. The PMA's mean value is 1 (black). Municipalities are arranged in order of decreasing tax revenues from left to right. This ranking also corresponds approximately with geographic distance from the overall urban center of Phoenix, and to size of population and economic GDP. Core municipalities like Tempe, Scottsdale, and Phoenix score above average on an economic basis of water use benchmarking, but below average on a population basis of population supported, demonstrating some degree of tradeoff between these productivity objectives.

Table 1. General Characteristics of Cities in the Phoenix Metropolitan Statistical Area (*no reclaimed water)

City	Population	Area (km²)	Density (pop km⁻²)	Payroll ($x1000)	Gross Revenue ($x1000)	Total Property Tax ($x1000)	Income Tax ($x1000)	Sales Tax ($x1000)	Total Water Use* (ac-ft)	Acre Feet Per Km² of City	Acre Feet Per Person Per Km²
Apache Junction	32,901	91	362	3,364	42,344	NA	108	2,795	10,244	759	28
Avondale	78,043	119	656	7,534	129,608	5,883	241	8,554	12,119	689	18
Buckeye	37,678	971	39	990	20,512	3,186	32	1,354	4,989	34	129
Chandler	242,522	166	1460	80,685	987,115	33,616	2,582	64,150	23,501	945	16
Gilbert	204,904	166	1234	32,876	330,022	22,258	1,052	21,782	44,335	1,782	36
Glendale	249,455	155	1609	48,376	521,636	28,557	1,548	34,428	69,359	2,994	44
Goodyear	53,654	495	108	8,702	85,775	10,805	278	5,661	11,169	150	104
Mesa	459,742	352	1306	133,398	1,121,299	NA	3,628	74,006	105,459	2002	80
Peoria	152,795	451	339	28,945	445,973	23,529	926	29,434	51,437	764	153
Phoenix	1,536,632	1339	1148	700,624	6,504,679	266,891	22,420	429,809	377,341	1,891	329
Scottsdale	233,105	477	489	188,927	1,750,749	50,838	6,046	115,549	109,065	1,536	223
Tempe	172,589	104	1660	138,748	1,658,540	31,736	4,439	109,463	70,907	4,600	41

270