Uses of GPCD: Challenges in Calculation and Interpretation

1. Introduction

Per capita water use is a *de facto* industry standard for tracking water use. The most widely recognized metric is gallons per capita per day (GPCD). GPCD is increasingly prominent in California as a measure of water use and water use efficiency. GPCD has become the unit of measurement used in conservation standards. As a concept, GPCD can be expressed in a simple formula with relatable terms. However, it is not as straightforward as it appears to be.

GPCD is sensitive to factors such as demographic pressure, weather conditions, the economy, and consumer response to drought-related restrictions. These factors vary from place to place and change over time, even for the same place. Even if all such variables are recognized and accounted for, the method by which GPCD is calculated should also be consistent for any comparisons to be valid.

In certain cases, meaningful comparisons over longer time scales are difficult to achieve even within the same water agency. Particular caution is advised when making normative interpretations of GPCD trends when transitioning between drought and non-drought time periods. Even more questions should be raised when comparisons between different water agencies are made.

This paper identifies some of the inherent difficulties and common pitfalls with using GPCD as a measure of water use. The inclination to rely on GPCD in this respect should be balanced with a general understanding of its limitations and nuances. The rest of this paper will describe these caveats for broader consideration.

2. What are we measuring with GPCD?

It is crucial to begin with a clear understanding of what GPCD is and what it is not. GPCD is a rate of water use. As a rate, it is calculated from different data components that are described below. Calculating GPCD consistently for a certain place over a period of time sheds light on trends. They indicate whether demands are accelerating or decelerating. In the absence of other information, these trends provide meaningful insights into how much water is used by a particular community. GPCD values can be affected by reasons unrelated to conservation and water-use efficiency. These factors will be further discussed in this paper.

The formula for calculating GPCD is to divide water use over a period of time by the total population served and then convert that into a daily rate. The equation for calculating GPCD is presented below:

$$GPCD = \frac{W_t}{P_t} x \frac{1}{D_t}$$

Where:

t is the period over which GPCD is calculated (e.g. monthly, annually, seasonally, etc.)
W_t is the total water use in gallons over a period t
P_t is population served within the study area for period t

D_t is the number of days in period t

The seeming simplicity of the GPCD formula belies a much larger and more nuanced question: what are we trying to measure? The answer to this question will determine the types of water usage and population scales used in the formula.

GPCD can be calculated for any or all water use sectors including residential and nonresidential, and for potable and/or non-potable uses. Additionally, it can also be calculated on various time scales. Hence, there is a need for clear and consistent definitions of water sources, uses, and timeframes. All this will help answer the fundamental question of what is being measured. For example, is it the trends in total water usage by an entire seaside resort town, or the potable residential water usage by the town's year-round inhabitants that we are interested in?

To answer this basic question, it must first be understood that GPCD is a rate. It is useful in determining trends but unsuitable as a measure of efficiency or for comparing communities with different characteristics.

Table 1 provides a summary of water use sectors, and the water sources included and excluded by different types of GPCD.

Table 1: GPCD components

		GPCD Types				
Water Use Sector	Water Type	Residential GPCD	Commercial, Industrial, and Institutional (CII) GPCD	Municipal &Industrial (M&I) GPCD	Total GPCD	Potable GPCD
Single Family Residential	Potable	X		X	X	X
	Indirect Potable Reuse	X		X	X	
Multi-family Residential	Potable	X		X	X	X
	Indirect Potable Reuse	X		X	X	
Commercial, Industrial, and Institutional	Potable		X	X	X	X
	Indirect Potable Reuse		X	X	X	
	Non-Potable Reuse		X	X	X	
Agricultural	All				X	
Groundwater Recharge	Potable				X	
	Reuse				X	
Other	All				X	
System Losses	All				X	

All the GPCD types shown in Table 1 are per-capita use rates that can describe any given service area. However, GPCD can also describe a wide range of water uses, thus resulting in significant variability.

1. ***Residential GPCD*** – Residential GPCD measures the water use per day by an individual in a residential setting either living in a single- or multi-family housing unit. Residential water use, measured by a customer's meter, includes water for drinking, cooking, bathing, washing clothes and dishes, and flushing toilets. It also includes landscape irrigation and other outdoor uses. Water for residential use consists of potable water and treated wastewater that has been recharged into the groundwater basin and later produced for consumption (also known as indirect potable reuse). Non-potable recycled water is usually not included in residential use. However, large multi-family complexes and new housing developments may be plumbed to receive non-potable recycled water for landscape irrigation.
2. ***CII GPCD*** – Commercial, industrial, and institutional (CII) GPCD measures the water usage rate for non-residential activities and group quarter activities within a service area. Commercial and industrial water use, as measured by a customer's meter, includes food preparation, restroom, landscape, facility cleaning, and industrial processes. Institutional water use includes group quarters such as correctional facilities, nursing homes, college dormitories, and other institutions. Water for CII use may include potable and non-potable reuse (NPR). NPR refers to treated wastewater for commercial landscape irrigation or industrial processes for non-consumptive goods. CII GPCD is rarely used as a stand-alone measure because it is calculated based on the population residing in the service area. For most purposes, M&I GPCD is more suitable than CII GPCD.
3. ***M&I GPCD*** – Municipal and industrial GPCD measures the per capita water use for both residential and CII. M&I GPCD is commonly used as a measure for total water consumption within a service area. M&I water use is typically constructed by summing user's metered deliveries.
4. ***Total GPCD*** – Total GPCD measures the per capita water use for all types of water in the service area. Unlike M&I GPCD, Total GPCD includes agricultural and non-consumptive uses, such as groundwater replenishment and seawater barrier. It also includes unmetered water uses such as fire hydrant and system losses. This method reflects the total water balance and is useful to water agencies as a measure of the overall water demand and supply for planning efforts. The water usage for Total GPCD is typically constructed from total system inflows.
5. ***Potable GPCD*** – Potable GPCD measures the potable water use per day for residential and non-residential purposes. It is used to demonstrate compliance with Senate Bill x7-7 (Water Conservation Act of 2009). This legislation, often referred to as "20x2020," requires urban retail water suppliers to reduce GPCD by 20 percent by the year 2020 relative to an established baseline. Unlike M&I GPCD, Potable GPCD does not include non-potable recycled water use. Water usage for Potable GPCD is typically constructed from total GPCD minus system inflows (or customer deliveries, depending on the system) of recycled water.

2.1 Timeframe

After establishing the type of water use, the second part of the GPCD formula involves measuring over a certain period of time. Monthly and annual periods are usually used for ease of calculation and communication, and the ready availability of monthly water use and billing data. Monthly GPCD may be

useful in tracking seasonal or other intra-year trends, whereas annual GPCD may be better utilized to characterize water use in more general terms over a longer time frame.

Taken further, multiple years can be used to generate a long-term average GPCD. For the 20x2020 legislation, a long-term average GPCD of 10 to 15 years is used to create the baseline from which to establish the 20 percent reduction target. Temporary factors such as weather and economic growth cycles may influence per capita use. Using a long-term average can help address effects of year-to-year fluctuations.

2.2 Population

Population refers to the number of persons residing in single- and multi-family housing units, and group quarters within a service area.

2.3 Service Area

Water use data mostly come from water agencies and are based on billing and/or delivery information. For example, residential water use data are provided by retail water agencies. Wholesale water agencies' data are metered at service connections. Water agencies have distinct service area boundaries and the data provided by the agencies are for their defined service areas. Water agencies also track the population within their service area. For this reason, GPCD is usually calculated at the scale of a particular agency's service area.

3. Benefits of using GPCD

When used appropriately, GPCD can be a convenient measure of water use trends. Authorities often use GPCD to quantify conservation efforts and respond to drought-related emergencies. Baselines, targets, and tracking mechanisms are established using existing GPCD data.

Previously, Residential GPCD was used statewide for drought management (State Water Resources Control Board Resolution No. 2015-0032). At present, Potable GPCD is used for water use efficiency regulations in California (20x2020).

3.1 Ease of calculation and comprehension

The GPCD formula is simple and uses readily available actual-use data as opposed to assumptions of estimated conservation savings. It does not require sophisticated mathematical models or the gathering of new information. GPCD is also relatively easy to understand by the general public. It is easier for most people to understand gallons than more esoteric units of measurement such as cubic-feet and acre-feet.

3.2 Shedding light on water use trends

When the data used to calculate GPCD are internally consistent (i.e. data source, timeframe, service area, and method), it can shed light on water use trends in ways water use alone cannot. By normalizing demand on a per capita basis, changes in water use efficiency are reflected. This enables water agencies to track water use independent of population growth, hence demonstrating the efficacy of water conservation efforts. Everything else equal, effective conservation should result in decreased GPCD.

4. Important considerations: Assumptions, limitations, and caveats

When comparing GPCD between time periods and/or agencies, it is important to consider its associated assumptions, limitations, and caveats. Water use data come in many forms. No two water agencies are alike. This section highlights some common differences in data used to calculate GPCD. These differences make it difficult to compare GPCD across agencies.

4.1 Consistency with water use classification

There can be many inconsistencies in the way water agencies define water use sectors (single-family vs. multi-family vs. commercial) and use types. It is inaccurate to compare Residential GPCD, CII GPCD and M&I GPCD between agencies that account for water use differently. Some agencies classify water use according to meter size. For example, water supplied by large dedicated meters for outdoor irrigation at large condominiums may be considered as commercial use rather than residential use.

4.2 Consistency with point of use data

Water use data are collected and reported differently across agencies. One retail agency may utilize customer billing data while other agencies may rely on system meter data that measure how much water enters their distribution systems. Customer billing data reflect customer end uses, but it does not include system losses which are inherent in the water distribution system. On the other hand, system meter data include non-consumptive water uses (e.g. groundwater recharge and long-term storage) to meet all operational needs including customer use and system losses.

Depending on the intended purpose, it may be more appropriate to use either customer billing data or system meter data. However, they should not be used interchangeably. In assessing the effectiveness of conservation efforts, billing data is the preferred source of data to observe reductions in customer usage. However, due to the staggered nature of customer meter reads, customer billing data sometimes need to be prorated into monthly or annual timeframes. On the other hand, system meter data are more appropriate when planning to meet overall service area demands.

4.3 Consistency with population data

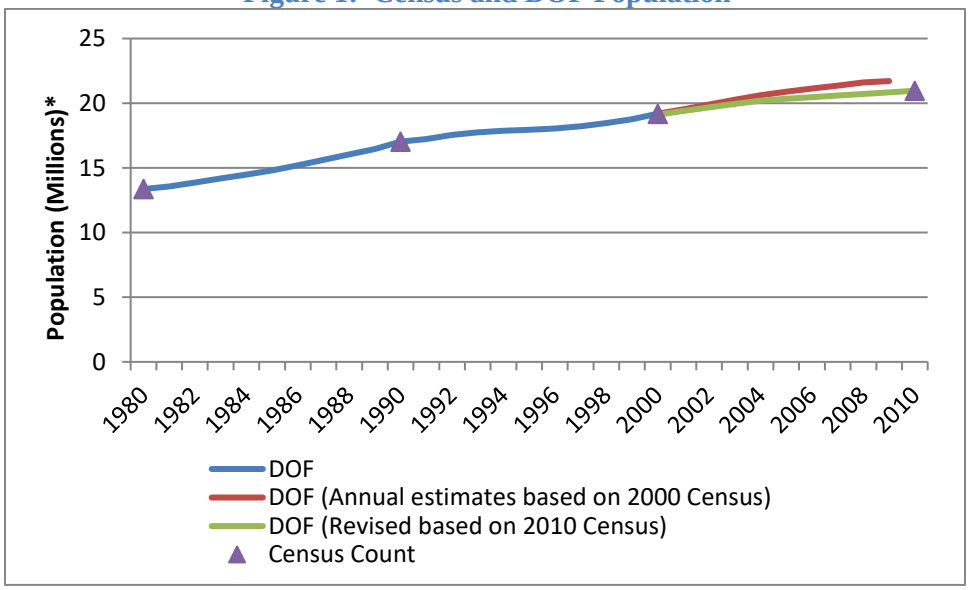
Unlike water use data which is based on actual metered data for the respective water agency service area, population data are often independently estimated by governmental agencies. Population data are produced on different spatial scales that can differ from water agency service area boundaries. The U.S. Census data provides an official population count by Census block every 10 years. The California Department of Finance (DOF) produces annual population estimates for counties and cities.

Different methods of calculating service area population yield different results. Tools are required to assist water agencies with population estimates. For example, the California Department of Water Resources provides a tool to assist water agencies in determining service area population for use in Urban Water Management Plans. Other tools such as GIS can also be used to calculate population for service areas that are not aligned with the boundaries provided by Census data. Consistency in the tool, data source, and methodology are important in order to have valid GPCD calculations.

In addition, official annual population estimates by DOF are subject to periodic revision due to the timeliness and coverage of the data and records.

For example, DOF calibrates their estimates with the decennial Census counts. DOF significantly overestimated population growth in the years following the 2000 Census. After the release of the 2010 Census, DOF revised downwards its annual population estimates for the years between 2001 and 2009 (Figure 1). These revisions retroactively impacted GPCD calculations for service areas throughout California. When considering GPCD, be aware of the possibility of retroactive population revisions by governmental agencies. For this reason, all GPCD estimates based on DOF population are subject to change and past GPCD numbers should be made internally consistent.

Figure 1: Census and DOF Population



**Population for six counties in Southern California: Ventura, Los Angeles, Orange, Riverside, San Bernardino, and San Diego.*

A problem also arises in areas that undergo significant cyclical changes in population. Examples include regional employment centers, tourist destinations, and areas having high transient populations such as university or military towns. In these situations, simply using an average for the entire year could understate demand during active times and overstate it during inactive periods.

4.4 Temporal variation

Even for the same location, conditions change over time. When tracking changes in GPCD, consider that one year or even one season may not be the same as another. Be it weather patterns or economic cycles, these conditions vary from day to day (weather), month to month (season), and year to year (economic condition, drought to non-drought periods). They affect water use over time for businesses, households, even for individuals. For example, all else remaining constant, weather and economic activities have a significant influence on water use. Due to these variations, changes in water use may or may not be indicators of conservation.

Transition from drought to non-drought periods

Particular caution needs to be exercised when comparing extreme drought and non-drought periods, which often have substantially different water use profiles. GPCD is expected to be lower during periods of drought when GPCD is artificially suppressed in response to government actions such as conservation messaging and mandatory reductions. However, when emerging from a drought, GPCD usually rebounds

to a level that more closely resembles pre-drought usage. A drought level GPCD is unlikely to be sustained.

Table 2: Temporal variations

Type	Variation	Impacts
Weather	Month-to-month, season-to-season (year over year)	Weather is different from month to month and season to season. It often varies when comparing the same month or season in different years.
	Year-to-year	Demands are higher in dry years and lower in wet years.
	Dry-year demand vs. drought response demands	In a typical dry year, water demand increases, but in an emergency drought declaration, water demand decreases in response to restrictions.
	Drought vs. non-drought period	GPCD is artificially suppressed during drought emergencies. When emerging from a drought, GPCD usually rebounds to a level that more closely resembles pre-drought usage.
Economy	Economic cycles	Water use tends to increase in a growing economy whereas a recessionary economy has the opposite effect. However, performance of businesses with international clientele is less affected by local economic conditions.
	Changing industries	Businesses may change over time. For example, a water-intensive manufacturing company may move out of the area and be replaced by a service-based company with different water use profiles.
	Local economies	When comparing water use across agencies, in a state as large as California, different regions could experience different cycles of growth and decline due to differences in local economy.

4.5 Spatial variation

Inherent differences across space make it difficult to compare GPCD for different locations even across the same timeframe. For this reason, GPCD of each agency's service area should not be compared against one another even if the agencies are adjacent to each other. The following table illustrates some of the impacts due to spatial variations.

Table 3: Spatial variation

Type	Variations	Impacts
Land use	Residential/CII mix	Water use profile for residential is different from commercial. The relative mix of residential and commercial sectors affects GPCD. For example, a predominantly industrial city is expected to have a higher GPCD than a bedroom community with less industry.
	Population density	Urban areas with high population densities use less water per person than do more rural or suburban areas. High density dwellings tend to have shared outdoor spaces resulting in less landscaped area per person that needs to be irrigated.
	Lot size	Properties with larger lots tend to have more irrigable area and are likely to use more water.
	Age of housing stock/historic development	In newer communities, residential housing units are constructed with more water-efficient fixtures, resulting in less water used per person as compared to older communities.
	Development	Changes in land use affect water usage. For instance, increasing development leads to the conversion of non-irrigated lands to irrigated lands, raising water use.

Agency variations	Size of agencies	Water agencies vary dramatically in size and scope. There are agencies that serve over 1 million customers with both water and wastewater services, and there are agencies that serve fewer than 50,000 customers with water service.
	Recycled water	Agencies have varying levels of accessibility to and implementation of recycled water. Depending on the type of GPCD, this recycled water may be included or excluded in the calculation.
	Water prices	Water prices provide a monetary incentive for customers to conserve water. Effective rate structures can deter excessive water use.
	Drought messaging	Drought awareness messages can temporarily reduce water use. Agencies typically issue messages for their respective service areas. The messages may not be issued at the same time or intensity.
Socio-economic	Lot size and income	Areas with higher incomes tend to use more water than areas with lower incomes. Larger landscaped residential lots that require more water are often associated with more affluent communities. Additionally, higher income households may be less sensitive to water prices.
Climate zones	Evapotranspiration zones	Outdoor irrigation needs are higher for arid inland areas than cooler coastal areas. Areas that are more inland and/or have less rainfall need to use more water to maintain a standard of outdoor landscaping.

5. Addressing variations

Despite the temporal and spatial differences in the calculation of GPCD, there are some common methods for normalizing, benchmarking, and averaging GPCD so that it can be useful for some comparisons. Although these methods resolve some of the aforementioned issues associated with comparisons, this paper does not discuss in full all of the variations.

5.1 Normalization

Regression analysis can be used to quantify the major drivers of water use. Major drivers of water use, beyond population, may include: employment and employment mix, weather, plumbing regulations, the mix of single and multi-family housing, and calls for short-term water use curtailments in response to drought or emergency. Understanding the interactions among these variables enables the establishment of benchmarks for further comparison. For example, if we understand the factors that impact water use in a dry year as compared to a normal year, then we can infer what the water use during a dry year would have been if the year were normal.

5.2 Benchmarking to common units

One method for addressing spatial variation among agencies is to benchmark water usage at a common spatial unit such as Census blocks or zip codes to create consistency in the number of households. For example, the energy sector commonly uses publicly accessible data at the zip code level. However, even with common spatial units, any valid comparison of GPCD would still need to account for differences in housing type, density and external factors including climate zone.

5.3 Averaging

Using a moving average is a simple method for correcting demand variations that may be caused by short-term volatility. For example, a 10-year moving average could control for economic growth and recession as well as annual weather. Likewise, a 12-month moving average could control for seasonal variations, although not always weather. The remaining changes driving water use would be from other temporal and spatial factors. Although a moving average can improve the reliability and validity of GPCD trend data, it still does not account for changes in land use, behavioral shifts, or population changes.

A comprehensive understanding of the residual effects of temporal or spatial variations would be needed to accurately compare water use within an agency or between agencies. However, even with the methods described above, it is not possible to account for all changes in GPCD. For this reason, GPCD may always be problematic as a benchmark for water use.

6. Conclusion

GPCD is a useful but imperfect measure of water use. At best, it can help shed light on water use trends during non-drought periods (and separately for drought periods) for a single agency. To use GPCD effectively, users must be clear on what it is that is being measured. This includes a firm understanding of GPCD type (e.g. Residential GPCD, M&I GPCD, Potable GPCD), timeframe, service area population, point of use data, and water use classifications. Care must also be taken to keep calculations internally consistent and up-to-date. This is because annual population estimates are subject to routine retroactive revisions and water use data are subject to routine reconciliation.

Even with impeccable data and calculations, temporal and spatial variations embedded within and across different water agencies may not be easily reconciled. How exactly one should attend to these variations is beyond the scope of this paper, but any examination of GPCD data should at least have an appreciation of the existence of such variations.

One major takeaway from this paper is the difficulty of harnessing GPCD as a means of comparison over long time periods or across different agencies. GPCD is particularly unsuitable for making normative evaluations of water use behavior when transitioning between drought restrictions and non-drought periods, since water use behavior is artificially suppressed during emergencies. It is difficult to ascertain the sustainability of lowered drought-related GPCD after normal conditions resume and institutional restrictions are lifted.

7. Further Reading

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