Water Usage in Data Centers

Technology Innovation Spotlight

KEY TAKEAWAYS

As the number of data centers grows and AI-driven electricity consumption increases across the U.S. and globally, water usage is also rising due to greater cooling demands. Data centers consume an estimated 4% of U.S. electricity generation today and are expected to grow to consume 4.6% to 9.1% annually by 2030 [1]. This is leading to a rise in water consumption due to increasing cooling demands. For example, from fiscal year 2022 to 2023, Google's total water consumption grew by 14% and Microsoft's rose by 23% [2,3].

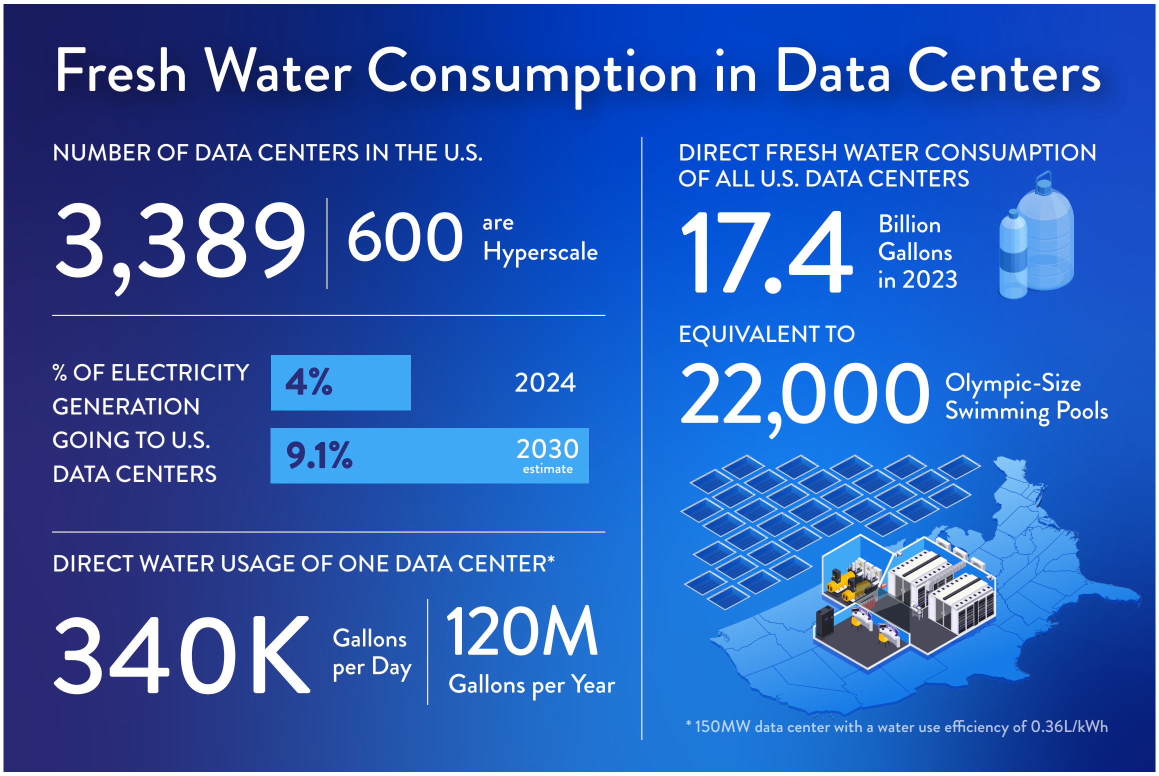
In 2023, data centers in the U.S. directly consumed 17.4 billion gallons of water [4]. This is equivalent to the annual household water use of over 580,000 Americans, or the equivalent of over 22,000 Olympic-sized swimming pools [5]. One 150-MW hyperscale data center could consume approximately 340,000 gallons/day or 120 million gallons/year. With over 3,000 data centers in the U.S. and counting, water usage of data centers could overstress freshwater resources [6]. The direct water consumption rates do not account for indirect water consumption from increased power generation.

Innovative cooling technologies, like IT liquid cooling with dry coolers, can cut data center water use by over 90%. For a 150-MW facility, this means using 69 million gallons of water annually instead of 970 million gallons with traditional water-cooled chillers, promoting sustainability despite climate and site variations

Data centers in water stressed regions may prioritize water-efficient cooling strategies and utilize alternatives to freshwater resources. The increased freshwater demand from the rapid growth of data centers strain water resources. For example, 15% of Google's freshwater withdrawals came from watersheds with high water scarcity in 2023 [2]. Using water-efficient cooling strategies would be the most efficient way to reduce water consumption.

Traditional cooling methods pose a trade-off between energy and water efficiency. Water-cooled chillers, for example, are highly efficient yet require significant water usage; while air-cooled chillers minimize water usage but are less energy efficient. New and innovative cooling solutions are gaining traction as the industry aims to decrease power and water consumption across data center sites.

Collaboration between data centers, utilities, and local jurisdictions can advance cooling solutions tailored to regional conditions, incentivize reclaimed and recycled water use, and balance electricity and water demands holistically. Available data suggests the industry should invest in sustainable cooling technologies and policies to help manage the potential environmental impact of data centers.



INTRODUCTION

The rapid expansion of data centers worldwide is fueled by increasing digital demands, artificial intelligence (AI) advancements, and the growing reliance on cloud computing. However, this growth brings significant sustainability challenges, particularly in water consumption.

Servers in data centers generate substantial amounts of heat that must be effectively managed to maintain operational efficiency. Currently, the common cooling methods involve using water to regulate temperatures and maintain operational efficiency. As data centers continue to proliferate, optimizing water use and utilizing alternative cooling methods is essential to minimizing environmental impact while supporting ongoing technological progress.

WATER WITHDRAWAL, CONSUMPTION, AND DISCHARGE

Water for data centers is generally classified by usage. In this context, water withdrawal is the total amount of water sourced for data center cooling, while water discharge is used and then expelled to a local municipal wastewater treatment facility or returned to the environment. Water consumption is the portion lost, mainly through evaporation. Data center water consumption can be classified as a direct or an indirect water consumption source:

Direct Water Consumption Source

- Data Center Cooling: Water used on-site, explicitly for cooling systems and air humidification within the data center.

Indirect Water Consumption Source

- Electricity Generation: Water used off-site in power generation for electricity supply.
- IT Equipment Manufacturing: Water used off-site in manufacturing the servers.

This analysis focuses on the direct, on-site water consumption of data centers.

The Relationship Between Water- and Power-usage Effectiveness in Data Centers

Before looking at water consumption, it is helpful to understand the connection between Water Usage Effectiveness (WUE) and Power Usage Effectiveness (PUE).

WUE is a metric that estimates site water consumption. This is calculated in the following equation by comparing the total water required for operations, such as cooling and humidification, to the energy used by IT equipment:

A lower WUE indicates more efficient water usage whereas a high WUE would be a result of water-intensive cooling techniques.

$$WUE = \frac{Annual\ Water\ Usage\ (liters)}{IT\ Equipment\ Energy\ Usage\ (kWh)} \quad (1)$$

Site WUE varies greatly, depending on cooling technology, data center facility size and local climate conditions. Various sources report site WUE values ranging from 0.1 L/kWh to 9.0 L/kWh. One report estimates that the average site WUE across all U.S. data centers to be 0.36 L/kWh for 2023. This value is expected to increase to between 0.45 and 0.48 L/kWh by 2028, reflecting increasing WUEs in the hyperscale and colocation data centers [4].

The PUE is a metric that measures the energy efficiency of a data center by comparing the total facility power consumption to the power used specifically by IT equipment, as calculated using the formula:

Similar to the WUE, a lower PUE value indicates more efficient use of power whereas a high PUE would indicate a less-efficient use of power.

$$PUE = \frac{Total\ Facility\ Energy\ Consumption}{IT\ Equipment\ Energy\ Consumption} \quad (2)$$

Balancing both PUE and WUE is crucial, as cooling strategies affect both metrics. For instance, evaporative cooling can enhance PUE by lowering electricity demand but raise WUE due to increased water consumption. On the other hand, air-based or liquid cooling can reduce WUE but may increase PUE due to more energy-intensive systems. Achieving sustainable data center operations requires a holistic approach that optimizes both energy and water efficiency.

WATER CONSUMPTION

The majority of data centers today use potable water sources for cooling purposes, with Google reporting that, in 2023, 7.7 billion gallons of water were withdrawn globally—of which 6.1 billion gallons was consumed, and 1.6 billion gallons were discharged [2]. In the U.S., Google reported that only one of its 18 data center locations utilized reclaimed wastewater [2].

Generally, most of the water withdrawn from water sources for direct data center use is consumed in the form of evaporation. Evaporative cooling systems have high consumption, whereas closed-loop systems return most of the withdrawn water.

Climate and Geographical Considerations

Climate conditions and data center location also influence direct water consumption. For example, higher temperatures in hot and arid regions increase cooling demands, which leads to greater water consumption. Conversely, natural air cooling in colder climates can reduce reliance on water-intensive cooling systems.

Energy vs. Water Trade-off

Cooling is essential for maintaining optimal data center operational performance, but traditional and emerging cooling solutions present trade-offs between energy efficiency and water usage.

For example, a water-cooled chiller with a water-usage effectiveness (WUE) of 2.8 L/kWh for a 150-MW data center consumes approximately 2.7 million gallons of water per day, equating to 970 million gallons annually. This is equivalent to filling roughly 388 Olympic-sized swimming pools. In contrast, an IT liquid cooling system with a dry cooler for a similar-sized data center, operating at a WUE of 0.2 L/kWh, uses approximately 190,000 gallons per day, or 69 million gallons per year. This is comparable to 27 Olympic-sized swimming pools. These estimates, while subject to variation based on climate and site-specific factors, underscore the potential of innovative cooling methods to reduce water consumption by over 90% in some cases.

COOLING SYSTEMS [4]

While traditional cooling methods have many years of proven use, emerging cooling technologies may offer significant opportunities to address the sustainability challenges posed by water-intensive cooling methods.

Most Common Traditional Cooling Methods

- **Direct Expansion System**: Also known as computer room air conditioners (CRACs), these systems circulate a refrigerant through indoor coils to cool the data center air. Typically used in small- to mid-sized data centers.
- **Air-Cooled Chiller**: These systems employ air-cooled condensers to remove heat from the system and are widely used in data centers of varying sizes. They minimize on-site water consumption.

- **Water-Cooled Chiller**: These systems use water-cooled condensers to extract heat from the system, then release it to the environment via cooling towers. They are highly efficient but require significant water consumption.

Newer Cooling Methods

- **Airside Economizer and Adiabatic Cooling (Air- or Water-Cooled Chiller)**: Harnesses outside air or evaporative cooling with water mist to enhance efficiency, significantly reducing energy consumption in favorable climates.
- **IT Liquid Cooling**:
  - **Dry Cooler**: Circulates liquid coolant through IT equipment, cooled by ambient air via dry coolers, minimizing water use while maintaining efficiency.
  - **Waterside Economizer**: Uses cool water from external sources to absorb heat from IT equipment, reducing energy costs but dependent on water availability.
- **Immersion Cooling**: Submerges IT equipment in dielectric fluid to efficiently dissipate heat, lowering both energy and water usage compared to traditional systems.
- **Evaporative Cooling**: Employs water evaporation to cool air, providing energy savings in arid regions but consuming water during operation.

CONCLUSION

Long-term sustainability of data centers in water-stressed areas depends on effectively balancing energy and water efficiency. While there is a trade-off between energy and water efficiency in traditional cooling technologies, advanced cooling solutions tailored to regional conditions can encourage reclaimed and recycled water use, while balancing electricity and water demands holistically.

For example, data center facilities can undertake measures to ensure sustainability and could adopt innovative cooling solutions to minimize reliance on freshwater sources, such as utilizing alternative water sources like municipal effluent instead of potable water.

Data centers also have opportunities to employ alternative cooling technologies that are less water intensive and with a lower impact on the local water supplies.

WHAT'S NEXT

EPRI plans to further investigate the water-energy trade-offs of advanced cooling systems, including quantifying potential water savings from widespread adoption of innovative cooling technologies. Future research will also explore regional siting strategies, integration with non-potable water sources, and the implications of AI-driven power demand on sustainable data center operations.

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