SUSTAINABLE DATA CENTERS ROADMAP

CHAPTER 5

Data Center Water Use

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As data center capacity grows globally and interest in AI surges, data centers' water use has emerged as a critical concern in some regions. In part, this concern is due to the location of some data centers in water-scarce regions such as the US Southwest and Persian Gulf. This concern reflects the fundamental importance of water as a natural resource. As nations, communities and companies manage data center demand growth, understanding these facilities' water use is critical to making sound investment and policy decisions.

Data on the water consumption of data centers are poor. The authors were unable to find standardized data sets for water use at these facilities at the national, state, county or municipal level. Much of the data that do exist lack regional context, including whether water resources at a data center are scarce. This lack of data can make it difficult to evaluate and select potential solutions to water-related challenges at data centers, whether at the site-specific, regional or global level.

This chapter provides background on data center water use, placing it in the context of water used by other sectors. The chapter discusses the challenges created by data center water use, corporate initiatives in this area, differences between data centers' direct and indirect water use and options to reduce data centers' water footprint. The chapter concludes with recommendations.

A. Definitions

i. Water usage effectiveness (WUE)

The most common measure of water consumed at a data center is water usage effectiveness (WUE)—a data center's water use divided by the energy its information technology (IT) equipment uses. WUE is typically expressed in liters per kilowatt-hour (L/kWh).[1] WUE is straightforward to estimate; however, like power usage effectiveness (PUE), it is an incomplete metric at best. For example, WUE provides no information on several important topics such as water consumed by off-site electricity generation used to power a data center (which can be substantial) or water scarcity in the region where a data center is located.

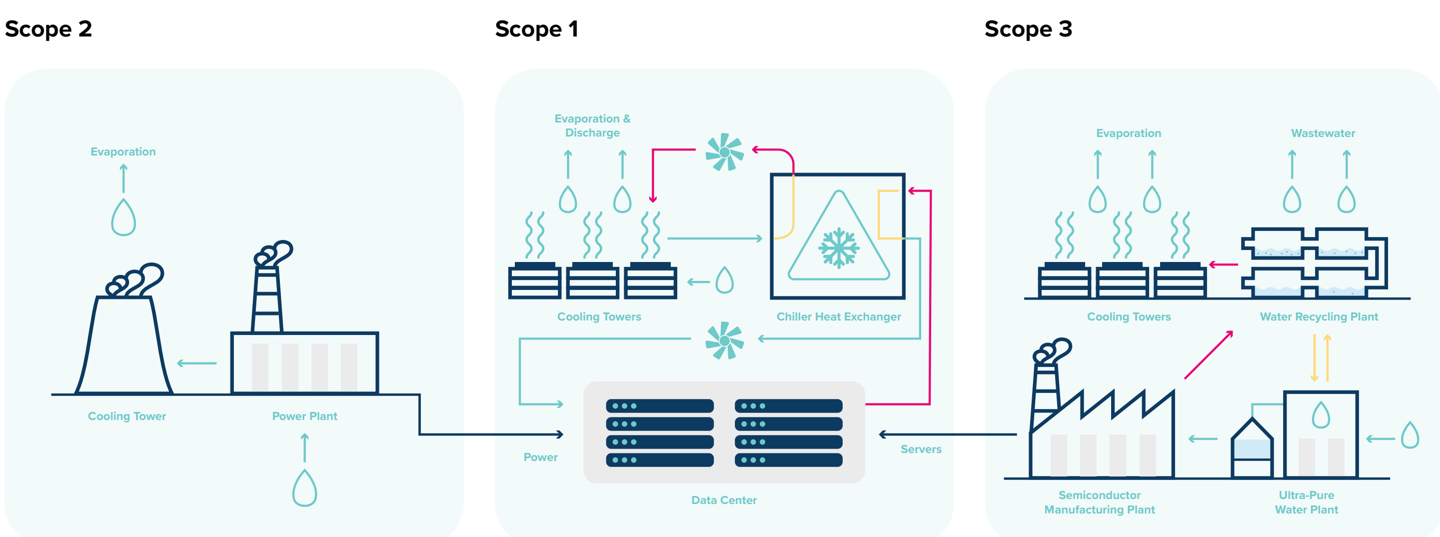
ii. Scope 1, 2 and 3 water use

Water use by data centers can be divided into three categories:

- **Scope 1:** Water used in direct operations (e.g., for cooling).
- **Scope 2:** Water used indirectly for power generation (e.g., evaporative cooling at thermal power plants).
- **Scope 3:** Water used indirectly in producing building materials, such as steel or cement ("embodied water").

These categories parallel the framework for emissions accounting under the Greenhouse Gas Protocol: Scope 1 (direct emissions), Scope 2 (energy-related emissions) and Scope 3 (embodied emissions).[2] See Figure 5-1.

Figure 5-1. *Scope 1, 2 and 3 water consumption.*



In general, direct water consumption at data centers (Scope 1) is modest. In contrast, indirect water consumption from thermal power generation for data centers (Scope 2) can be very large. (In most cases this occurs offsite at remote power stations.) Embodied water use (Scope 3) is likely to be minimal and distant from data center operations.

iii. Water use versus water consumption

Water use and water consumption are similar but distinct concepts.[3-5]

- Water use (often called water withdrawal) refers to freshwater taken from a watershed (ground water or surface water) and then used for purposes such as farming or drinking.

- Water consumption is the difference between water withdrawal and water returned to the same watershed. Water consumed is "evaporated, transpired, incorporated into products or crops, or otherwise removed from the immediate water environment."[5]

iv. Water-stress

A water-stressed region is one where water resources are insufficient to meet demands of human consumption. This can be due to a combination of factors, including limited rainfall, high water needs or inadequate infrastructure.
There are several frequently used definitions of water-stress, each with strengths and weaknesses.[6] Estimates of people worldwide exposed to water-stress vary greatly by methodology, ranging from 0.5 to 4.3 billion people.[7]

- The Falkenmark Water-Stress Indicator[8] measures the amount of renewable freshwater available per person per year. While straightforward, this definition has significant limitations. For example, it fails to account for the accessibility of water resources (whether some water in a region is deep underground or heavily polluted). It also fails to include man-made sources of freshwater, such as desalination plants.

- The Withdrawal-to-Availability Ratio measures the ratio of water withdrawal in a region to the total available water (as the name implies). This approach also has limitations. Like the Falkenmark Indicator, it does not include man-made sources of freshwater, water reclamation or water recycling.

There are other definitions, many of which are limited because they are static—they fail to take account of conditions that may change the extent of water-stress in a region over time.[9] Analyses of population growth, agricultural trends, industrial development plans, potential climate change impacts and other factors are necessary to fully assess water-stress in a region.[10]

B. Putting Data Center Water Use in Context

Data center water use is tiny globally but can be significant locally.
A comparison with agricultural water use is striking. Agriculture accounts for 70% of freshwater withdrawals globally, using roughly 20.4 trillion liters (5.48 trillion gallons) per day.[11,12] Data centers, in contrast, are projected to use roughly 1.7 billion liters (~450 million gallons) per day globally by 2030.[13] **Current global water use by agriculture is therefore over 12,000 times greater than projected global water use by data centers in 2030.** Put differently, projected water use by data centers in 2030 is roughly 0.008% of water used by agriculture today.

Box 5-1

ChatGPT versus Hamburgers: Comparing Water Consumption

To help put data center water use in context, a comparison between the water consumed by ChatGPT and hamburgers may be helpful. Our research suggests that, using conservative assumptions:

- 19,000 ChatGPT-3 queries and the process of producing one hamburger consume roughly the same amount of water.

- ChatGPT-4o takes roughly 537 days—almost a year-and-a-half—to consume as much water as needed to produce the hamburgers McDonald’s sells in one day.

These estimates are based on the following.

- According to data in one study, roughly 328 liters (87 gallons) of water are consumed to produce one hamburger in the United States (mainly for growing feed). Data in another study suggest the figure is higher—roughly 580 liters[5] (153 gallons) per hamburger.

- A recent study found that a single ChatGPT-3 query in the United States used an average of roughly 17 milliliters of water, taking into account the water used in training and inference, as well as Scope 1 and Scope 2 emissions. The lower figure for water consumed to produce a hamburger just above (328 liters) and basic division (328 liters divided by 17 milliliters = 19,294) yields the first estimate: 19,000 ChatGPT-3 queries and one hamburger consume roughly the same amount of water.

- McDonald's sells roughly 6.5 million hamburgers each day.[13] The lower figure for water consumed to produce a hamburger just above (328 liters) and basic multiplication (6.5 million hamburgers x 328 liters) suggest that roughly 2.13 billion liters (565 million gallons) of water are consumed to produce the hamburgers McDonald's sells in one day.

- Another recent study found that GPT-4o's annual water consumption is roughly 1.45 billion liters (383 million gallons).[14] Comparing that figure to the rough annual water consumption needed for McDonald's hamburgers and doing basic division (2.13 billion liters divided by 1.45 billion liters = 1.47; 1.47 years = 537 days) yields the second estimate: ChatGPT4o takes roughly 537 days—almost a year-and-a-half—to consume as much water needed for the hamburgers McDonald's sells in one day.

Several caveats are required with respect to the foregoing estimates. First, the quality of data with respect to data center water use is poor, as emphasized at the beginning of this chapter. Second, the estimates above could understate ChatGPT's water consumption in comparison to hamburgers for several reasons. (For example, more recent large language models likely consume more water than ChatGPT-3.) On the other hand, the estimates above could also overstate ChatGPT's water consumption in comparison to hamburgers for several reasons. (For example, the estimates use a conservative assumption with respect to water consumed to produce hamburgers, given the study cited above that found that almost twice as much water is needed.)

We invite critiques of the ChatGPT/hamburger water consumption comparisons above. Yet even if the comparisons are off by an order of magnitude, they still provide insight into the rough scale of data center water use as compared to the water use of a familiar everyday product. More data collection, research and public dialogue on these topics are needed.

Comparing data center water use to natural water fluxes is helpful as well. Data centers represent a tiny fraction of natural water flows regionally.

The following comparisons provide context.

- Projected data center water demand globally in 2030 is roughly 0.02% of the Amazon River's daily discharge at its mouth.[12,17]
- Data centers in Northern Virginia, the largest global data center hub, use approximately 5.1 M gal/day[15]—0.07% of the Potomac River's daily flow (~7000 M gal/day) at Washington, D.C.[18] In Phoenix, Arizona, data centers consume roughly 177 M gal/day, roughly 1.36% of the Colorado River's average daily flow at Lees Ferry, Arizona and 22.2% of Maricopa County's daily water use.[23,24,25]
- A 20-50 MW facility can use 11-19 million liters per day (3-5 M gal/day), similar to the daily water use for a city of 30,000-40,000 people.[19]

The table below provides data on water use by data centers and total water flow in select regions. However, this context changes notably in regions of acute water-stress, as discussed below.

C. Data Centers in Water-Stressed Regions

Table 5-1. *Water flows in some geographies compared with water consumption from data centers.*

Region	Use Type	Average Daily Flow/Use in M L/day (M gal/day)
Global	**World's largest river by volume —Amazon River (at the river's mouth) (flow)**	**~14,679,600 (~3,877,800)[20]**
	Global data center 2030 forecast (use)	~3288 (~869)[13]
Virginia/Washington, D.C.	**Potomac River (at Washington, D.C.) (flow)**	**~26,498 (~7000)[21]**
	Virginia surface and groundwater withdrawals for agriculture (use)	**~121 (~32)[22]**
	Northern Virginia data centers (use)	~19 (~5)[18]

China	**Yangtze River (at Datong station) (flow)**	**~2,653,747 (~700,894)[20]**
	China's agricultural use (use)	**~1,055,616 (~278,880)[21]**
	China's data centers (use)	~3557 (~940)[22]
Phoenix/Maricopa County (Arizona)	**Colorado River Basin (at Lees Ferry, AZ) (flow)**	**~49,339 (~13,034)[23]**
	Phoenix/Maricopa County's residential and commercial (use)	**~3017 (~797)[24]**
	Phoenix/Maricopa County's data centers (use)	~670 (~177)[25]
Singapore	**Singapore's water consumption (use)**	**~1666 (~440)[29]**
	Singapore's data centers (use)	~134 (~35)[30]

Water scarcity is inherently a local issue. In water-stressed regions, even modest water demands from data centers can exacerbate local tensions.

Data centers are frequently clustered in dry areas due to land and energy availability. Two-thirds of data centers built or planned in the United States since 2022 are in high or extremely high water-stress areas. Almost three-quarters of these projects are in five US states: Virginia, Texas, Arizona, Illinois and California.[13] Under the Chinese government's East Data, West Computing program, many new data centers will be built in arid provinces, including Inner Mongolia, Gansu and Ningxia. Many of the world's regions with growing tech infrastructure, such as California's Central Valley, Arizona's Sonoran Desert and northern China, already face chronic water shortages.

In these regions, data centers sometimes compete with agricultural water demand, which can be significant. For example, California's Central Valley grows 20% of US agricultural production, and the agriculture sector overwhelmingly dominates water use. In California, recent and recurring droughts,[31] court-ordered constraints on water withdrawal,[32] state executive orders on water conservation[33,34] and climate change impacts[35] have magnified concerns about additional stressors, including data center demands.

In Arizona, though data centers account for <0.1% of the state's total water use (~9.5 M liters per day or ~2.5 M gal/day), they are concentrated in fast-growing suburbs where supply is under pressure. In Chandler, Arizona, city officials passed a 2015 ordinance to restrict data center water usage, reflecting tensions around limited groundwater.[36]

Similarly, northern China faces severe water-stress. Beijing's per capita water availability is far below the international water shortage threshold, intensifying the need to regulate industrial water usage strictly.[37] In Beijing, municipal and industrial daily water use totals around 6942 M L/day (1834 M gal/day).[38] While detailed local data-center-specific figures are not publicly available, national-level data indicate that 3557 M L/day (940 M gal/day) are used for all Chinese data centers, suggesting that the relative share of data centers in water-scarce regions like Beijing could be significant.[25] Indeed recent regulations in Beijing and surrounding provinces require data centers to enhance WUE significantly.[39] Such proactive policies help mitigate the additional water-stress posed by the rapidly expanding digital economy in these already strained areas.

In Singapore, a substantial share of freshwater is used by data centers in comparison to municipal uses. Due to limited freshwater availability, Singapore depends on desalination, water imports and advanced wastewater recycling.[30,40]

D. Direct Water Consumption (Scope 1)

Most on-site (direct) water is consumed by data center cooling.[41,42] High-quality data on direct water use are difficult to find. Individual facility estimates or direct data are very scarce. Estimates for direct water consumption come with high uncertainty and limited ability to extrapolate for many reasons:

- Data mixing: Direct and indirect (power related) water consumption is reported together without separation or distinction.[43-45]
- Poor transparency: Few operators—less than one third[1]—disclose data directly. For example, while both Microsoft and Google share these data each year, other US operators do not.
- Regulatory range: Data centers operate across a wide range of regulatory actors and jurisdictions. Most often, water is managed by cities and municipalities, yielding a wide range of mandates, requirements and standards. This makes aggregation difficult and disclosure enforcement spotty or difficult.
- Water source: WUE does not differentiate between municipal water, reclaimed water or desalinated water.[46]
- Diverse geography: Data centers operate across a wide range of geographies. Cool-climate data centers require less cooling and less water. The converse is true for warm climates, humid or dry.

In addition, modern data centers, including those under construction, come equipped with a diverse set of cooling options with dramatically different water consumption indexes: open-loop cooling, closed-loop cooling, adiabatic cooling, air cooling or advanced cooling technologies (see Chapter 2.3 of this Roadmap). Some systems also recover direct-use water. Most estimates based on power consumption or PUE do not represent this range of technology or water efficiency at all.

Table 5-2. *Estimated water consumption by data centers*

Data Center	Estimated direct water (total consumed)	Estimated WUE (rate)	Additional notes
Microsoft: 2022,[47] 2023[48]	6.9 B L/year (1.7 B gal/year)	0.3 L/kWh	~40% reduction from 2021–2023
Google: self-reported, 2021[49]	620 M L/year (164 M gal/year)		
Amazon Web Services: self-reported, 2024[50]		0.15 L/kWh	~40% reduction from 2021–2024
Meta: self–reported, 2024[51]		0.20 L/kWh	~33% reduction from 2020–2023
Industry average WUE in 2024[52]		1.85 L/kWh	
Practical range of WUE in 2024[41]		0.0–2.5	
Google: GSERB[53]	16.3 B		Unclear if this also includes indirect (power-related) water
2015 vintage[54] 1-MW data center	25 M L/year (6.75 M gal/year)		An extreme case for an old system; it does not include efficiencies of scale
Northern Virginia in 2023[18]	7 B L/year (1.85 B gal/year)		Approximately 50 data centers, not all
Japan in 2025[55]	89 B L/year	53 L/kWh	Very high estimated WUE–unclear if correct; most likely includes both indirect and embodied water in estimate across
UK in 2024[56]	~10 B L/year (~2.6 B gal/year)		231 data centers
Global estimate in 2023[18]	~720 B L/year (~190 B gal/year)		Data source: Bluefield Research[57]

The range of estimates complicates the task of estimating the likely on-site (“Scope 1”) water use for a 200 MW data center.

- One estimate of average 2024 WUE is 1.85 L/kWh.[52] Using this WUE, an average 200 MW data center would consume ~3.1 M L/year (0.82 M gal/year).

- The IEA published an estimate for a typical US data center.[58] However, they did not separate direct and indirect water consumption in their calculation:
    - The inclusive estimate (i.e., including direct, indirect and embodied water use) was 2 M L/year (~0.5 M gal/year) for a 100 MW facility or 4 M L/year (~1.1 M gal/year) for a 200 MW facility. Assuming a 95% capacity factor, this would be a WUE of 2.5 L/kWh.

    - In IEA’s figure of 5.27, cooling consumed roughly 20% of the total consumption in 2023. This would yield an estimate of direct water use of 0.8 M L/year (~0.2 M gal/year) for a 200 MW facility, or a WUE of 0.5.

- Using their published number (WUE of 0.3 L/kWh), an average 200 MW Microsoft facility with a 95% capacity factor would consume 0.5 M L/year (0.14 M gal/year).

- Meta, LuxConnect and Amazon claim an average of 0.2 L/kWh or less. An average 200 MW data center for one of these firms would consume ~0.33 M L/year (~0.09 M gal/year) or less.

Chapter 2.3 of this Roadmap describes a range of technologies that could reduce direct water consumption at data centers. Innovation in this space, driven by industrial priorities, is both rapid and profound. Before designing any targeted research, development and demonstration (RD&D) program, a government census of current technologies and their likely water resource benefit would help avoid investment in wasteful efforts and dead ends. This effort would require data sharing from companies and greater transparency—a priority for decision makers.

E. Indirect Water Consumption - Energy-Related (Scope 2)

i. Background

Water use from power generation cooling represents a significant portion of the indirect water footprint for data centers. This Scope 2 water use can account for the majority of a data center's total water impact, especially in fossil-fuel dominated grids.[59] Thermal power plants (coal, nuclear and natural gas generation) consume significant water volumes for cooling. Air cooling systems consume relatively little water but represent a small fraction of existing plants and an equally small fraction of recent power generation.

In general, generation withdraws and consumes freshwater, commonly from rivers, lakes and groundwater, although most coastal power plants withdraw seawater for cooling. Water withdrawals are commonly much larger than water use; for example, US thermal power withdrawals in 2015[50] were roughly 500 B L/day (133 B gal/day) but consumption was only 10.2 B L/day (2.7 B gal/day). Decision makers should take care in distinguishing between these two in data and analysis.

Transitioning from thermal to renewable energy sources can dramatically cut the indirect water use associated with data centers. Wet-cooled thermal power plants, for example, typically consume approximately 2900-3000 liters (766-793 gallons) per megawatt-hour,[61] while renewables consume virtually none (Table 5-3). This highlights renewables' dual climate and water conservation benefits.

Table 5-3. *Water consumption by generation type—US average data*

Units are L/kWh, which are equal to m^3/MWh and tonne/MWh. Units in parentheses are gallons per MWh. Data sources: Thunder Said Energy[62] and National Renewable Energy Laboratory (NREL).[5]

Generation Type	Thunder Said Units: L/kWh (gal/MWh)	NREL, median value Units: L/kWh (gal/MWh)
Nuclear	2.1 (554)	2.54 (672)
Coal	2.0 (528)	2.6 (687)
Gas – natural gas combine cycle (NGCC)	1.2 (317)	0.7 (198)
Gas – open cycle	0.1-0.2 (26-54)	--
Solar photovoltaic (PV)	0.01-0.1 (2.6-26)	0.1 (26)
Wind	0.0000001 (0.000026)	0 (0)

Table 5-4. Power-related water consumption by data centers in key nations. Units are billions of liters (in parentheses are billions of gallons)

Country	Annual water consumption Billions of l (billions of gals)	Daily water consumption Billions l/day (billions g/day)	National % of daily water use (for power)
United States	~5280 (~1390)	14.5 (3.8)	~12%[63]
China	~12,700 (3350)	34.8 (9.2)	~23%[64,65]
India	~5920 (1563)	16.2 (4.3)	~18%[66]
France	~855 (225)	2.3 (0.6)	~10[67]
United Kingdom	~292 (77)	0.8 (0.2)	~9[67]

In cases where data center loads receive power from new generation, water use will depend on the technology being used. This varies significantly by country and region. New US thermal generation is mostly gas, for example, while new Chinese thermal generation is mostly coal, on top of renewable generation.

Estimates of US data center power consumption vary widely. The IEA (2025) estimate is 175 TWh total in 2023, reflecting significant recent growth (see Chapter 1 of this Roadmap for details).

ii. Local regulatory constraints on water use for power generation

Global regulatory approaches vary widely by region, but they often focus on three key levers:

- **Incentives or mandates for adopting more water-efficient cooling systems**, such as dry or hybrid cooling as opposed to traditional once-through cooling, aim to lower water consumption.
- **Limits on water discharge temperatures** aim to minimize adverse thermal impacts on local aquatic life.
- **Restrictions on water withdrawals** have become critical for protecting water bodies and aquatic ecosystems, especially during periods of heat waves and droughts.

The following sections detail significant restrictions on how water withdrawals and total consumption for thermal power generation are regulated and restricted. These restrictions do not apply directly to water withdrawals and consumption for data centers per se. However, they could affect data centers indirectly if their power supply comes from thermal generation.

United States: In the United States, federal regulations under the Clean Water Act 316(a) and 316(b) provide a comprehensive framework that helps guide the location, design and operation of water cooling structures in power generation. Section 316(a) limits water discharge temperatures, while 316(b) mandates that Best Technology Available (BTA), including closed-cycle cooling systems, water reuse, recirculating systems and other technologies, be adopted to minimize adverse environmental impacts from water cooling systems.[68] Additionally, 316(b) requires National Pollutant Discharge Elimination System (NPDES) permits for withdrawal for larger facilities, and the US Environmental Protection Agency's (EPA's) 2004 Phase II rule required existing power plants to reduce withdrawals to levels comparable to closed-cycle systems. Furthermore, during periods of high heat and drought, regulations become even more restrictive. These restrictions can limit both access to cooling water and its use, especially for power generation.

These federal regulations are reinforced at the state level, and regulations vary considerably by state. For example, California's 2010 Once-Through Cooling Policy banned once-through cooling at coastal power plants to reduce water consumption.[69] The state also strictly regulates discharged cooling water, requiring that it not exceed receiving water temperatures by more than 20 °F (11.1 °C).[70]

China: China's heavy dependence on thermal power generation exacerbates regional water-stress, sometimes significantly. This has resulted in stringent power plant water-use regulations. Since the mid-2000s, China has required new coal-fired power plants in water-stressed regions to adopt dry-cooling technologies, resulting in 70-80% reductions in water use compared to conventional wet-cooling systems.[71] The 2013 Water Allocation Plan for Coal Bases introduced regional caps on water use and accelerated wastewater recycling in the power sector in water-scarce regions.[72] China's 2015 Water Pollution Prevention and Control Action Plan also mandates discharge temperature limits, typically <35 °C or ≤3-5 °C above intake levels.[73] Further, China's Three Red Lines national policy sets binding limits on water use, withdrawal efficiency and wastewater discharge for power generation.[74] Finally, many provinces, like Hebei and Guangdong, have added restrictions in more densely populated or ecologically sensitive regions.

India: In India, 40% of thermal power plants are in regions with high water-stress.[75] Since 1999, India has required that all thermal power plants using freshwater to meet withdrawal limits and adopt closed-cycle cooling systems to reduce water use and thermal pollution.[76] India's Central Pollution Control Board (CPCB) limits the temperature of condenser cooling water from thermal power plants to a maximum of 7°C above ambient water temperature for new coastal plants and 10°C above the temperature of inlet water for existing plants.[77] These rules are particularly important in water-stressed states like Maharashtra and Rajasthan, where water demand for agriculture, energy and municipal supply already exceeds availability.

As these regulatory frameworks evolve, they shape the sustainability of data centers' indirect water use by influencing the water-efficiency of local power generation. This underscores the importance of grid decarbonization, not just for emissions, but for water security as well.

F. Indirect Water Consumption - Embodied (Scope 3)

Much less water is used in manufacturing materials for data centers than for direct cooling of a data center or for cooling the thermal generation used by data centers. In part, this is because the physical materials going into a data center are functional for years (chips) or decades (concrete, structural steel, rebar).

Even given these characterizations, the embodied water use at data centers merits greater understanding and attention in light of these facilities' growth, size and rate of deployment. This analysis focuses on four elements of embodied water consumption: concrete, structural steel, rebar and chips. To simplify, the unit we consider is a 200 MW data center. Physical footprints of data centers vary chiefly by energy density, with low-energy density footprints of ~120,000 m^2 (~1.3 million ft^2) and high-energy density footprints of ~60,000 m^2 (~650,000 sq ft). Numbers will also vary somewhat by geography and vintage of production.

i. Concrete

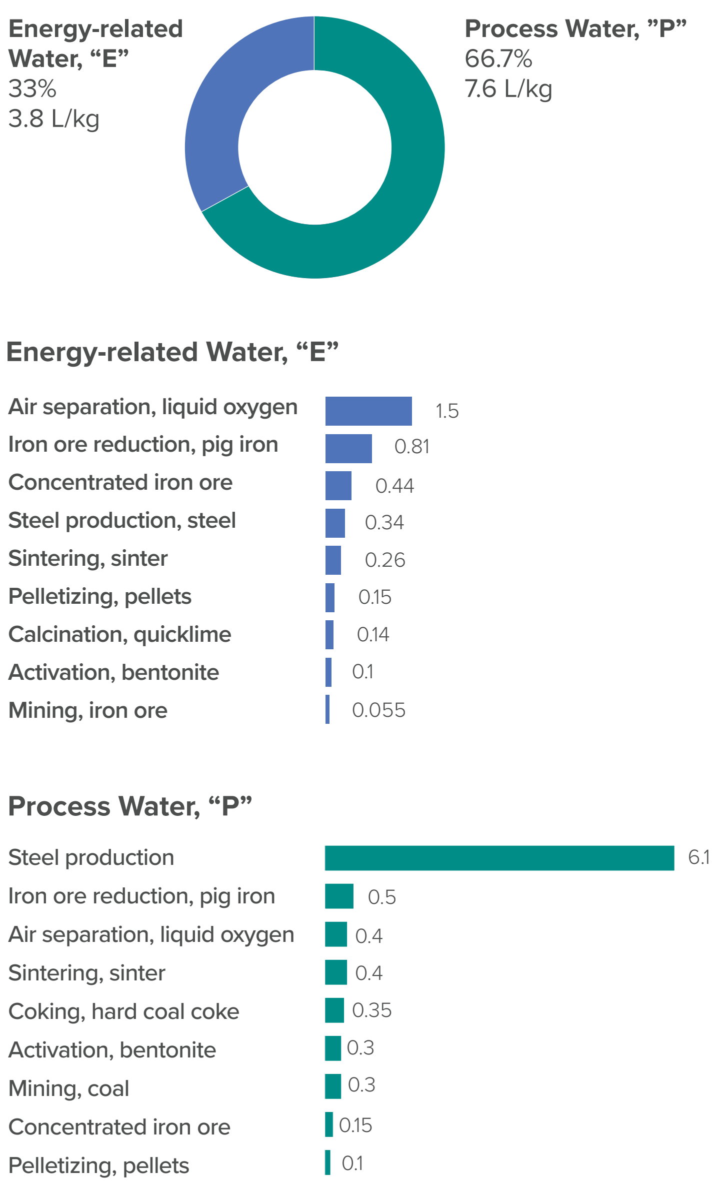
Concrete production and use require significant water.[78] Estimates range from 2000-2500 liters per m^3 of concrete. This includes ~500 L/ton for production of clinker, limestone mining and washing as well as a significant fraction (up to 80%) as mixing water, which is necessary to convert raw Portland cement into the binder of concrete.[78]

A 200 MW data center can require a wide range of concrete volumes as a function of building code, seismic requirements and design. Estimates range between 55,000 and 500,000 m^3. Assuming 300,000 m^3 of concrete for the physical plant, including foundations, walls, slabs and service areas, a data center will use roughly 700 million liters of water for concrete (ranging from 110-1250 million liters), equivalent to roughly 2% of the water consumed by US data centers in a single day.

ii. Steel: structural steel and rebar

Primary steel production requires significant water inputs.[78] For conventional blast-furnace/basic oxygen furnace operation (BF-BOF), water is consumed in mining, upgrading ores, oxygen production for blast furnace use, cooling and energy inputs. Although iron ore mining occurs in water-stressed regions (e.g., Australia, South Africa), most steel is produced in water-abundant areas (e.g., Hubei province, China, Japan, Korea and Germany) and most of the water consumption is associated with production.[78] On average, primary production consumes 11.8 liters of water per kg of steel (11.8 m^3/tonne or 3.1 gal/tonne).

Figure 5-2. *Water consumption in steel production.*



Wedges labeled "P" are primary production (direct water consumption) and wedges labeled "E" are water consumed by energy inputs (indirect). Source: Gerber-Leenes et al., 2018,[78] including supplemental material.[79]

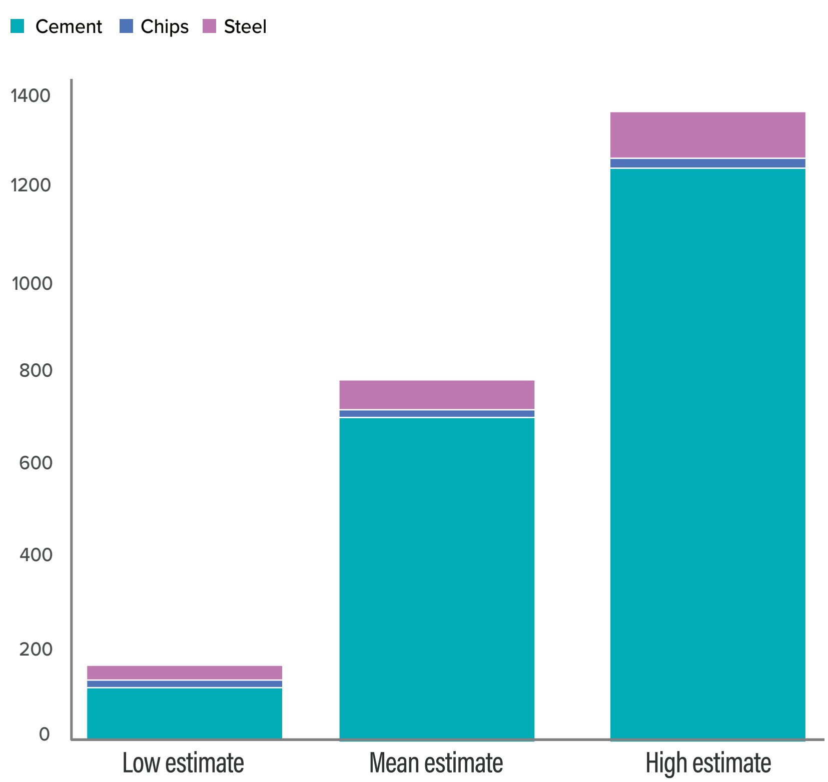
Robust, validated estimates for structural steel and rebar use in data centers are scarce. Assuming 50-75 kg/ft^2 of floor (535-802 kg/m^2), estimates of steel water footprint would range from ~34 million to ~98 million liters (9 to 26 million gallons) of water per 200 MW data center.

iii. Chips

Advanced semiconductor production (chips) consumes significant water resources. An integrated circuit can require 2200 liters per unit, with a large chip fabrication facility ("fab") consuming as much as 18.2 million L/day (4.8 million gal/day) to produce 40,000 wafers each month. In addition, much of this water must be "ultra-pure" water, which itself consumes water to produce (ultrapure water is used[80] to rinse wafers, cool special manufacturing equipment and dilute chemicals for manufacturing). Published estimates indicate that 1400-1600 liters of water[81] are needed to produce 1000 liters of ultrapure water, with 1500 liters per unit of ultrapure water needed to produce a single 30-cm wafer.

Assuming 5000-6000 wafers are needed to stock a 200 MW data center, roughly 2.3-3.3 million liters (580,000-870,000 gallons) are required to provide the initial set of chips. If each set of chips lasts 3-5 years[82] and a data center operates for 15 years, then 4 times that much water is needed, not including the water requirements for mining high-grade silica or copper, transportation, or upgrading of ores. This is a conservative estimate, since graphics processing units (GPUs) are replaced with higher frequency (2-3 years).

Figure 5-3. *Summary estimate of water (liters) required for building a 200 MW data center, high range and low range by material.*



G. Corporate Initiatives

Some tech firms self-report water usage. In 2023, Microsoft reported that 42% of its water withdrawals company-wide came from stressed areas, and Google reported 15%.[76] However, many other tech companies do not self-report.

Beyond reporting, key data center buyers and operators have made specific commitments regarding water use:

- Microsoft has committed to being “net water positive” by 2030, meaning it will generate or return a greater volume of water than is consumed

- Google has made a similar commitment, declaring its intent to produce or return 20% more water than it consumes by 2030.[77]

- Amazon Web Services (AWS) began sharing its annual WUE in 2022[78] and has also committed to being “net water positive” by 2030.[79]

Not all companies have been as proactive. A 2022 analysis[80] concluded that only 16% of data center operators have declared plans to manage water-stress. Although leading companies have reported low WUE values, the industry average is significantly higher (see Table 5-2)

H. Options for water footprint reduction

Companies (e.g., Microsoft,[81] Amazon Web Services[45] and Meta[82,83]) are demonstrating significant improvements in managing water consumption today, including reducing WUE. In most cases, these improvements come from applying advanced cooling technologies and increasing purchases of low-carbon electricity. At the same time, growing demand is increasing the volume of direct data center water consumption, which adds water-stress locally, while increasing use of natural gas and coal generation, which adds water-stress to some regions and communities. New, expanded and restarted nuclear facilities will consume significant water volumes and might add to regional water-stress.

These changes are driven by a combination of internal corporate policies, market demands, economic and operational trade-offs, and infrastructure limits. Given these dynamics, companies, governments and regulators have a relatively modest list of options to consider:

- **Siting:** Water is consumed where data centers, thermal generation or manufacturing operate, so siting plays an outsized role in water planning.

Many considerations affect siting choices, including economics, infrastructure access, climate and community concerns. Potential water-stress should factor into siting decisions as well.

- Unsurprisingly, placing key manufacturing sites (e.g., chip fabs) and large data centers in water scarce regions can stress natural resources and create political and economic challenges. Conversely, placing these facilities outside of water scarce regions minimizes regional stresses and friction.

- Secondary water supply options may help siting decisions, such as potential for water reclamation and reuse.[81] Similarly, companies may be able to make arrangements with agricultural or municipal water users to help reduce the companies' water consumption through interventions.

- **Direct:** Since the overwhelming majority of direct water consumption is associated with cooling during data center operations, the primary vector for water footprint reduction is alternative cooling pathways. (See Chapter 2.3 of this Roadmap.)

- **Indirect:** Since the majority of indirect water consumption is associated with using thermal electricity generation, the primary vector for water footprint reduction is to use non-thermal water sources, chiefly wind and solar with battery support. (See Chapter 3.2 of this Roadmap.)

- **Embodied:** Concrete, steel and chips all consume significant amounts of water (including ultra-pure water for chip-making). Producing these goods using water-saving approaches and technologies would help reduce water-stress. For example, this could include use of reclaimed water (e.g., in concrete mixing operations and at chip fabs).[81] Specifically for concrete, mixing water is an enormous part of the water used. Technologies that use CO_2 for binding concrete (e.g., CarbonCure or CarbonBuilt) can significantly reduce use of mixing water. Similarly, advanced steel production technologies, such as direct reduction of iron with electric arc furnace (DRI+EAF) production, would reduce water use in general. Ultimately, supply chain standards and procurement policies could help reduce embodied emissions.

The majority of these approaches involve economic and operational trade-offs. For example, water scarce regions often have lower land costs, which is a significant economic component of facility siting costs. Similarly, procuring building materials and chips with low-water footprints may involve paying a green premium or accessing limited supplies. Absent regulation or policy-based incentives, it may take considerable time for new technologies to enter the market and replace existing kit.

I. Conclusion

Significant gaps in data availability and quality limit understanding of data center water use. Estimates are often inconsistent, incomplete and lack a local or regional context, which hinders investors, policy makers and civil society in making sound decisions regarding data center water use. The scale and kinds of water demands from data centers must be considered in the context of other water demands in a region or nation, such as agricultural or municipal use. Similarly, tracking and quantifying the direct, indirect and embodied water consumption of data centers is important in developing management plans.

Technologies, such as improving efficiency, reclaiming and reusing water, and prioritizing renewable power over thermal electricity generation, can help reduce water-stress from data centers. Especially in regions of water scarcity and high water-stress, data center operators should prioritize the use of advanced cooling technologies and develop procurement standards for low-water footprint building materials and chips to minimize water impacts and strain. Finally, in-depth, systems-level analyses can identify the most useful technology or regulatory options and reveal the costs and trade-offs between water-conserving options. These analyses can serve as the basis for policy and private sector solutions.

J. Recommendations

1. *Governments should **assemble and share data** related to direct, indirect and embodied water consumption from data center construction and operation. Data center owners and operators should volunteer to **share site-specific water use and consumption data** proactively and invite third-party review. If necessary, governments should require disclosure of this information.*

2. *All stakeholders should **recognize that data center water use is tiny in relation to water use by other sectors globally but can be very significant in water-scarce regions.***

3. ***Before siting data centers**, data center owners and operators should **assess likely water impacts**, including in particular by consulting with local stakeholders. In water-scarce regions, companies should consider several steps to reduce likely water impacts:*

   a. ***Apply advanced cooling approaches*** *to reduce direct water use, with potential additional expense.*

   b. ***Assess the cost and viability of water reclamation and reuse*** *and of increasing water supply (e.g., through desalination).*

   c. ***Maximize non-thermal power supplies****, including solar, wind and batteries, including potential overbuilding of variable renewable resources and hybrid load balancing using a mix of thermal and non-thermal generation.*

   d. ***Develop procurement standards*** *for building materials and chips with low-water footprints. Where possible, procure low-water footprint materials, including the cost of a modest green premium.*

4. *Governments should* ***support the development of advanced technologies*** *that limit the water footprint associated with AI use.*

   a. *Most importantly, governments should* ***support replacing fossil generation*** *with non-thermal generation and should encourage use of air cooling in existing facilities, both of which would dramatically reduce indirect water use.*

   b. *Similarly, governments should* ***support novel cement, concrete and steel technology*** *that would reduce water consumption, as well as CO_2 emissions. Where possible, companies should accelerate adoption and procurement of low-water pathways.*

   c. *Governments should* ***undertake a cost-benefit analysis*** *based on the lifetime of operation and seek support to reduce risk and cost.*

5. *Governments* ***should undertake initial and then systematic analysis to understand the technology options, costs and trade-offs between water-conserving options****. These analyses can serve as the basis for policy, including regulation or incentives. Data center builders and operators should share their data with government agencies to help identify low-cost, large-volume options for water footprint reduction.*

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