# Not All Water Consumption Is Equal: A Water Stress Weighted Metric for Sustainable Computing

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# Computing is thirsty

- The rise of AI and computing comes with a hidden cost: **water consumption.**

**10~50 GPT-3 queries**
500 mL water

**A Google's datacenter**
3.7 million $m^3$ water

**1,500**

**Intel**
9.6 million $m^3$ water

**23,000**

**Water consumption is high across the entire computing stack.**

# How much do we understand water consumption?

# What is water consumption?

- **Water Withdrawal ≠ Water Consumption**
  Water Withdrawal: Total water taken from the environment
  Water Consumption: Water removed from the environment

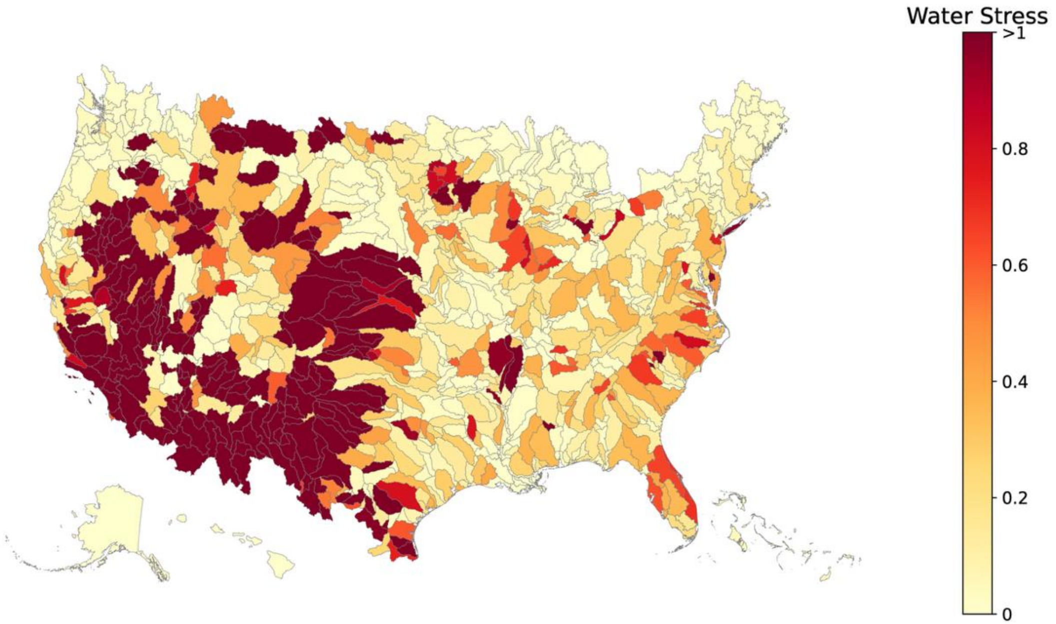
WATER CONSUMPTION = WATER WITHDRAWAL − WATER DISCHARGE

- **Water Consumption = On-site + Off-site**
  On-site consumption: Loss at facility (e.g., evaporation)
  Off-site consumption: Indirect consumption (e.g., power generation)

# Water consumption is location-sensitive

$$\text{Water stress} = \frac{\text{Water Demand}}{\text{Water Availability}} \quad [1]$$

Spatially, same amount of water consumption can lead to greater environment burden in arid regions than in water-abundant regions.




Water stress map of United States

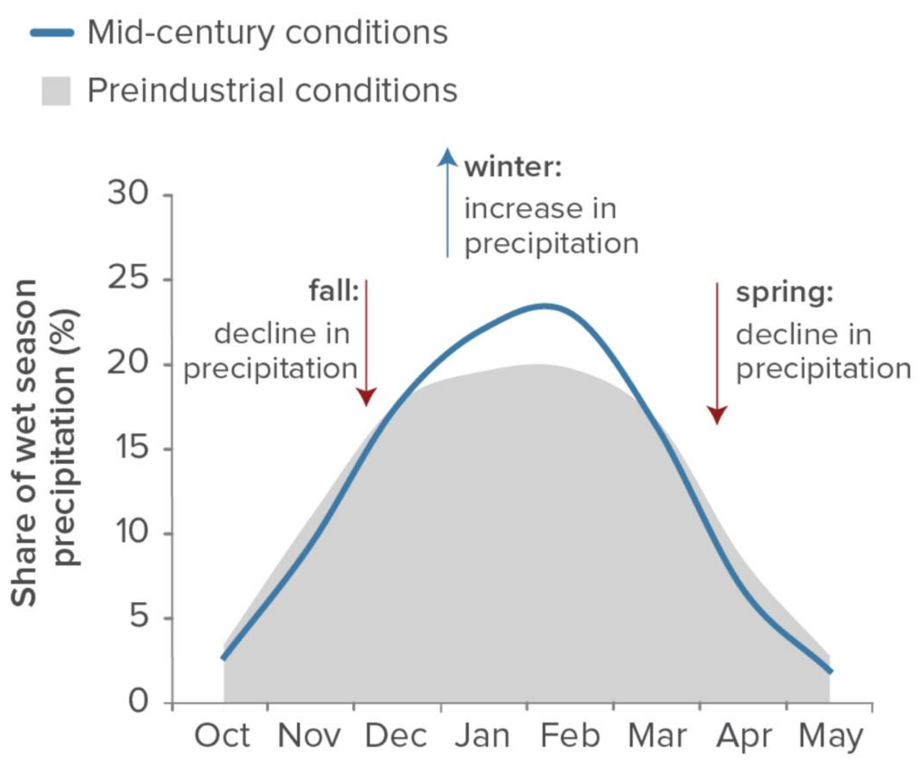


[1] Kuzma et al. Aqueduct 4.0: Updated decision-relevant global water risk indicators. WRI 2023.

# Water consumption is time-sensitive

- Water availability fluctuates over seasons
- Climate change influences water in long-term

Temporally, water supply fluctuates over time. We must account for both the **location** and **time** when analyzing water impact.




Seasonal Precipitation in California [2]



*[2] Swain et al. Increasing precipitation volatility in twenty-first-century California. Nat Clim Change 2018.*

# Our Contributions

- **Present SCARF:** Stress-Corrected Assessment of Water Resource Footprint, a general framework for water impact evaluation in computing.
  - **Incorporate spatial and temporal variations of water stress** to better evaluate water consumption impact.
  - **Introduce Adjusted Water Impact (AWI)** a unified metric combining water consumption with local water stress.
  - **Conduct three case studies** across LLM serving, datacenters, and semiconductor fabs

# Our method: SCARF

- **SCARF**: **S**tress-**C**orrected **A**ssessment of Water **R**esource **F**ootprint
- **Insight:** Incorporate spatial and temporal variations

1. Raw Water Consumption Modeling →
2. Spatial Mapping →
3. Temporal Water Stress Aggregation →
4. Adjusted Water Impact Calculation

# Our method: SCARF

- **SCARF**: <u>**S**</u>tress-<u>**C**</u>orrected <u>**A**</u>ssessment of Water <u>**R**</u>esource <u>**F**</u>ootprint
- **Insight:** Incorporate spatial and temporal variations

1 Raw Water Consumption Modeling → 2 Spatial Mapping → 3 Temporal Water Stress Aggregation → 4 Adjusted Water Impact Calculation

$$\text{Water Consumption} = W_{\text{on-site}} + W_{\text{off-site}}$$

- **On-site water consumption** directly consumed at the facility
- **Off-site water consumption** indirectly consumed through electricity generation

# Our method: SCARF

- **SCARF**: Stress-Corrected Assessment of Water Resource Footprint
- **Insight:** Incorporate spatial and temporal variations

1 Raw Water Consumption Modeling → **2 Spatial Mapping** → 3 Temporal Water Stress Aggregation → 4 Adjusted Water Impact Calculation

- **We retrieve regional water stress data from Aqueduct dataset.**


Water Stress Data:
- Baseline year,
- 2030,
- 2050,
- 2080

*[3] Linke et al. Global hydro-environmental sub-basin and river reach characteristics at high spatial resolution. Scientific Data, 2019.*

# Our method: SCARF

- **SCARF**: **S**tress-**C**orrected **A**ssessment of Water **R**esource **F**ootprint
- **Insight:** Incorporate spatial and temporal variations

1. Raw Water Consumption Modeling → 2. Spatial Mapping → 3. **Temporal Water Stress Aggregation** → 4. Adjusted Water Impact Calculation

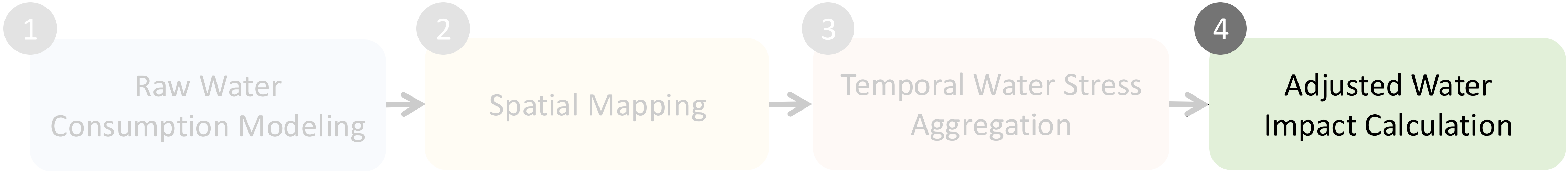
- **We introduce Water Stress Factor (WSF)**
  - Time-weighted aggregation
    → capture temporal variation in water stress
  - User-defined discount rate (γ)
    → reflect future uncertainty and potential impact

$$WSF_b^{\text{short}} = WS_{t_0,b} \qquad WSF_b^{\text{long}} = \sum_{t \in T} w_t \cdot WS_{t,b}$$

$$w'_t = \frac{1}{(1+\gamma)^{t-t_0}}, \quad w_t = \frac{w'_t}{\sum_{t' \in T} w'_{t'}}$$

# Our method: SCARF

- **SCARF**: Stress-Corrected Assessment of Water Resource Footprint
- **Insight:** Incorporate spatial and temporal variations




- **Our new metric for evaluating water consumption: Adjusted Water Impact (AWI)**

$$\text{AWI} = (W_{\text{on}} + W_{\text{off}}) \times WSF_b$$

# Evaluation

- Goal:
  - Show the **generalizability** of SCARF.
  - Quantify the hidden **environmental impact** of water consumption
  - Provide **actionable insights** for more water-sustainable deployment

- We apply SCARF across three case studies:
  - ✅ LLM Serving
  - ✅ Datacenters
  - ✅ Semiconductor Manufacturing

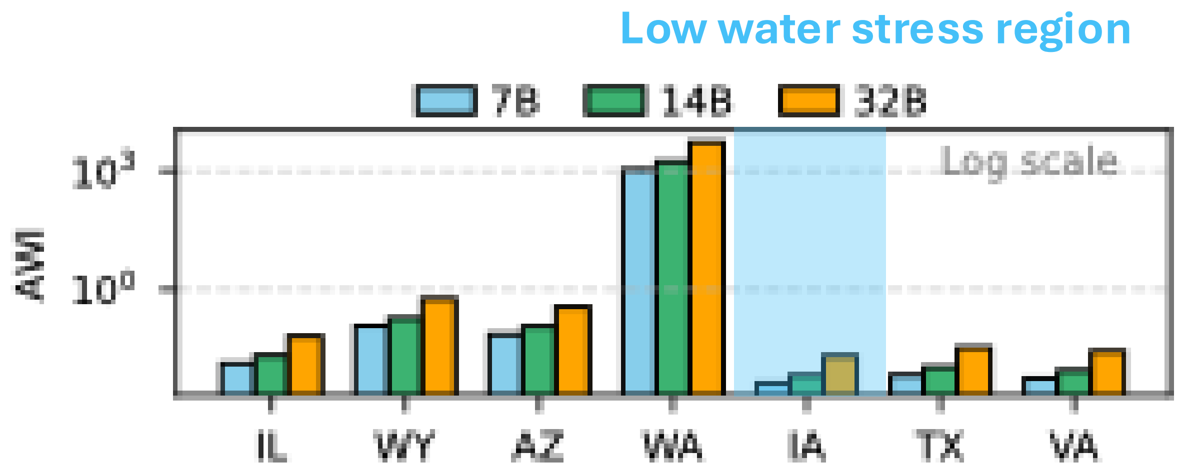
# Case Study I: LLM Serving

- **Models:** Three Qwen2.5 models — 7B, 14B, 32B [4]
- **Workload:** ShareGPT
- **On-site Water Consumption:**
  - Ramp up QPS, select peak throughput.
  - Measure GPU (H100) power during inference.
  - On-site Water Usage Effectiveness (WUE) from Microsoft reports [5].
- **Off-site Water Consumption:**
  - Estimate total energy from GPU power.
  - Regional electricity water intensity applied [6].
- **Short-term Water Impact Evaluation**

*[4] Yang et al. Qwen2.5 Technical Report. arXiv preprint arXiv:2412.15115, 2024.*
*[5] Microsoft. https://datacenters.microsoft.com/sustainability/efficiency. 2024.*
*[6] Siddik et al. Spatially and temporally detailed water and carbon footprints of US electricity generation and use. Water Resources Research, 2024.*

# Case Study I: LLM Serving

- Evaluate *per-request* Adjusted Water Impact (AWI) of 7B, 14B and 32B Qwen 2.5 model **in different regions.**



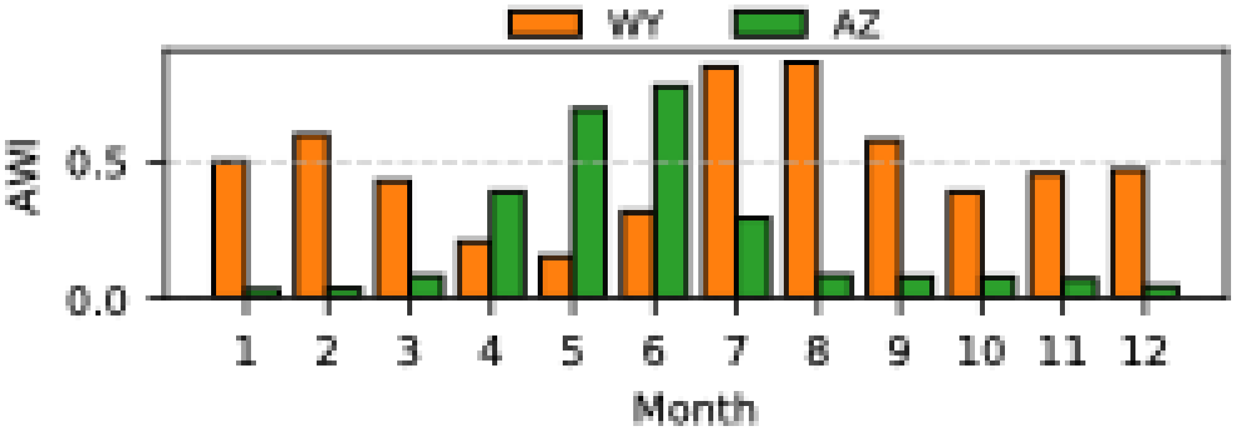

The adjusted water impact of deploying LLMs is highly **location-sensitive**. Same workloads can have 1000× differences depending on where they are served.



* *More results can be found in paper.*

# Case Study I: LLM Serving

- Evaluate *per-request* Adjusted Water Impact (AWI) of 32B Qwen2.5 in **different months** but same regions (AZ vs WY).




Even in the same location, seasonal changes can significantly affect adjusted water impact. **When we deploy matters**—not just where.



** More results can be found in paper.*

# Case Study II: Datacenters

- **On-site Water Consumption:**
  - From Google's public sustainability reports [7].

- **Off-site Water Consumption:**
  - Estimate datacenter power capacity using *DataCenters.com*.
  - Assume 70% average utilization, 24/7 operation.
  - Regional electricity water intensity applied [6].

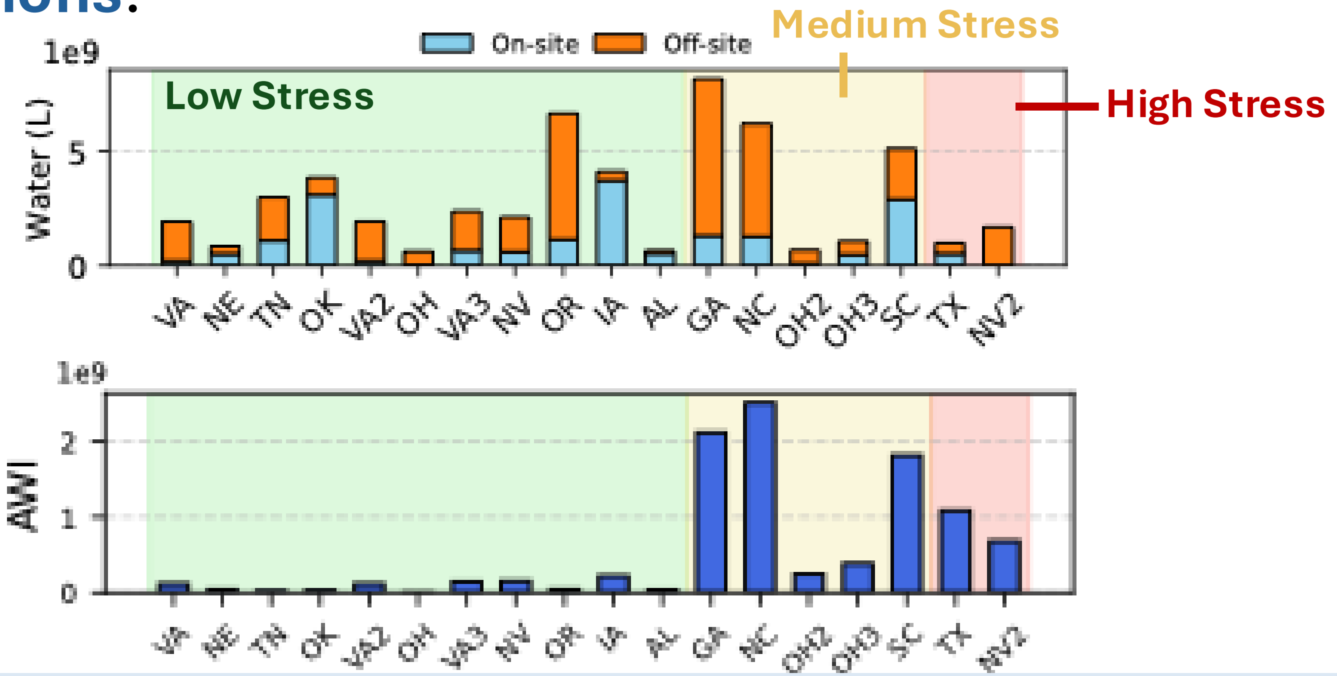
- **Long-term Water Impact Evaluation**



*[7] Google. https://www.gstatic.com/gumdrop/sustainability/google-2024-environmental-report.pdf. 2024.*

# Case Study II: Datacenters

- Evaluate *annual* Adjusted Water Impact (AWI) of datacenters in **different regions**.



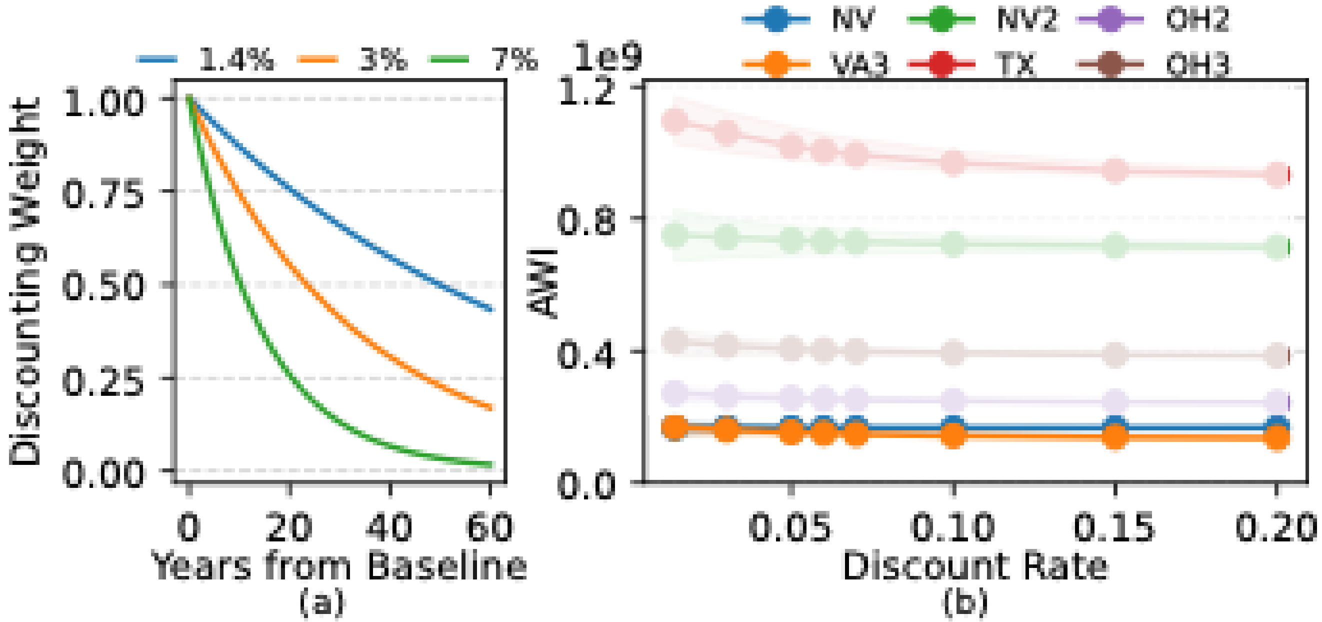

Water stress alone is not sufficient to capture true water impact. High water consumption in medium-stress regions can cause greater impact than expected.



** More results can be found in paper.*

# Case Study II: Datacenters

- Evaluate *annual* Adjusted Water Impact (AWI) of Google's datacenters with **different discount rates**.




Different planning perspectives lead to different sustainable decisions.

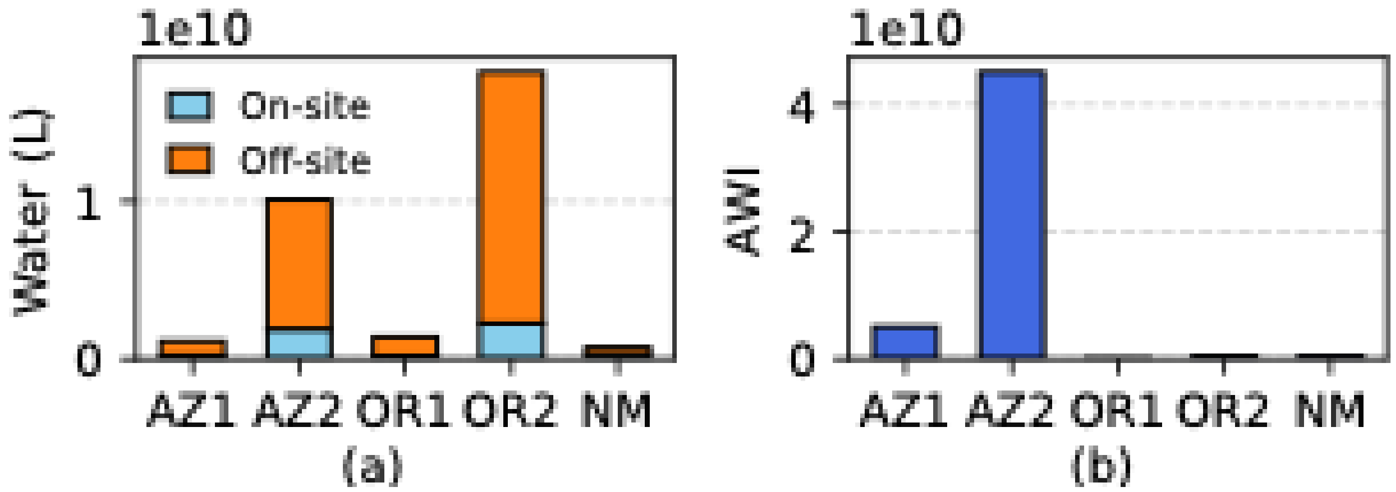
# Case Study III: Semiconductor Fabs

- **On-site Water Consumption:**
  - From Intel's public sustainability report [7-8].
- **Off-site Water Consumption:**
  - Power consumption from Intel's reports.
  - Regional electricity water intensity applied [6].
- **Long-term Water Impact Evaluation**

*[7] Intel. https://csrreportbuilder.intel.com/pdfbuilder/pdfs/CSR-2023-24-Full-Report.pdf. 2024.*
*[8] Intel. https://www.exploreintel.com/*

# Case Study III: Semiconductor Fabs

- Evaluate *annual* Adjusted Water Impact (AWI) of Intel’s fabs in **different regions**.




Semiconductor fabs consume a large amount of water. Building fabs in water-scarce regions like Arizona causes higher environmental burdens.

# Take Home Messages

SCARF quantifies water impact based on spatial and temporal variations in water stress.

- **Region matters.**
  Water stress level varies dramatically across regions.
- **Time matters.**
  Water stress shifts with seasons and long-term climate change.
- **Amount matters.**
  Large water consumption amplifies water impact even in low-stress area.
- **How we value the future matters.**
  Different priorities for future can reshape sustainability decisions.