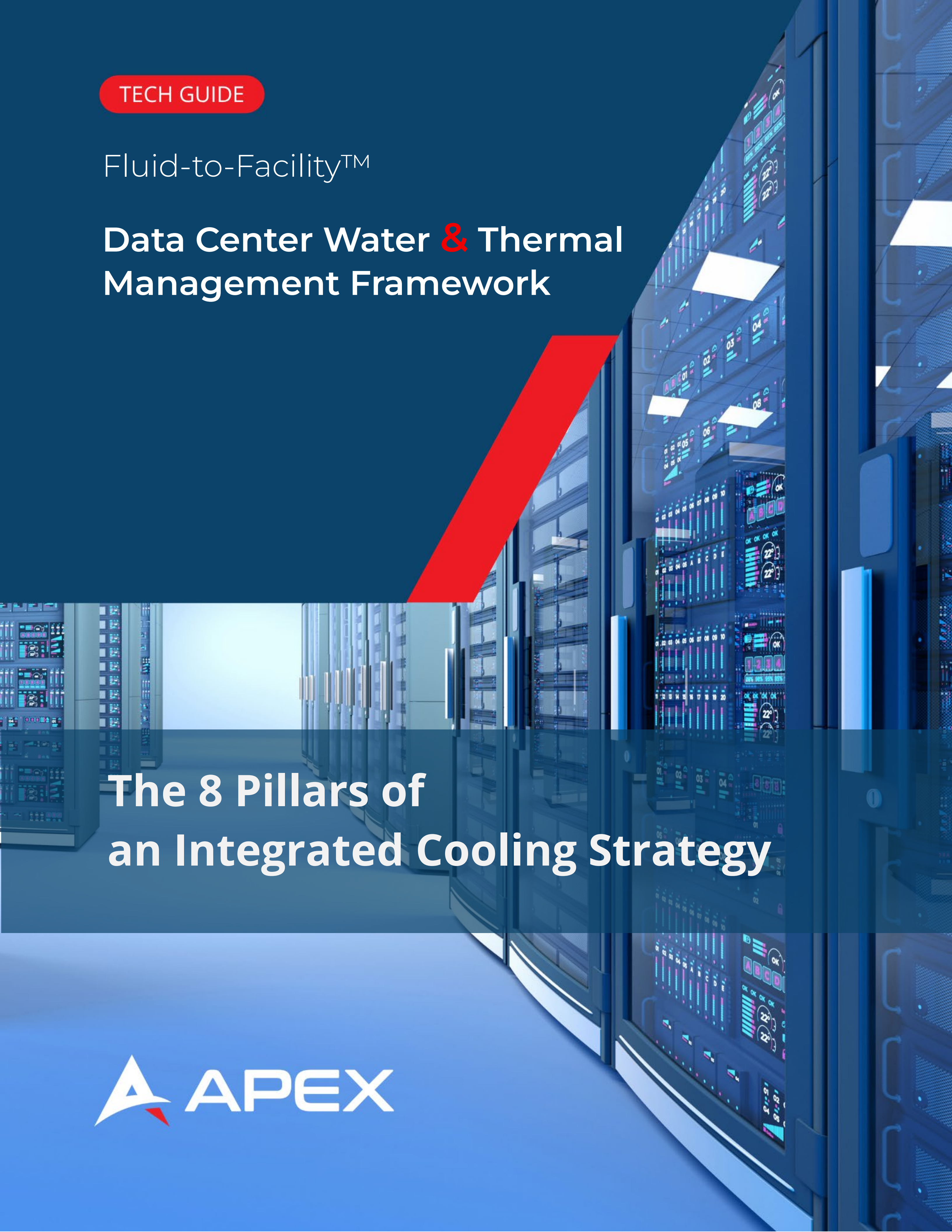
TECH GUIDE

Fluid-to-Facility™

Data Center Water & Thermal Management Framework



The 8 Pillars of an Integrated Cooling Strategy

APEX

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Executive Summary

Artificial intelligence is increasing rack densities, heat loads, and the operational importance of water and coolant systems. Data centers must now coordinate traditional heat-rejection infrastructure with closed-loop water and glycol systems, coolant distribution units, and direct-to-chip liquid cooling.

The **Fluid-to-Facility™** framework treats water and thermal management as one connected lifecycle strategy. Its central premise is that long-term cooling performance depends on decisions made during design, construction, startup, commissioning, operations, optimization, expansion, and retrofit—not on isolated treatment programs or individual pieces of equipment.

Every cooling architecture must perform three essential functions: capture heat from IT equipment, transport that heat through the facility, and reject it to the environment. Reliability depends on maintaining suitable fluid chemistry, cleanliness, corrosion protection, heat-transfer performance, controls, and monitoring across every interface.

The framework organizes this work around eight pillars: lifecycle design; source water and pretreatment; cooling-tower optimization; closed-loop water and glycol protection; strategic water reuse; water safety; intelligent monitoring; and integrated water management.

Applied together, these practices help owners and operators improve uptime, control operating costs, extend equipment life, reduce water and energy consumption, strengthen operational visibility, and prepare facilities for evolving AI-driven cooling demands.

About This Framework

This framework is intended to provide a practical reference for designing, commissioning, operating, and optimizing water and thermal management systems throughout the data center lifecycle.

Rather than prescribing a single cooling technology or water treatment program, it presents a system-based approach that considers the interaction between source water, pretreatment, heat capture, heat transport, heat rejection, water reuse, monitoring, and operational performance.

The framework is organized around eight foundational pillars that support long-term reliability, resource efficiency, infrastructure protection, and operational resilience across a wide range of data center cooling architectures.

How to Use This Framework

The eight pillars presented in this document are interconnected and should be considered as components of a comprehensive lifecycle strategy rather than independent initiatives.

Organizations may use this framework to:

- Evaluate existing water and thermal management programs
- Guide design and commissioning decisions
- Identify operational improvement opportunities
- Support infrastructure modernization
- Strengthen cooling reliability and resilience
- Improve water and energy performance
- Develop long-term lifecycle planning strategies

Each section can be read independently, but together they provide a structured roadmap for integrating water management into every phase of the data center lifecycle.

Intended Audience

This publication is intended for:

- Data center owners and operators
- Design engineers and consulting engineers
- Mission-critical facility managers
- Commissioning authorities
- Mechanical contractors
- EPC firms
- AI infrastructure developers
- Sustainability and ESG leaders
- Water treatment and thermal management professionals

Overview

Artificial intelligence is reshaping data center design and making water treatment and management more important than ever.

As AI workloads increase rack densities and heat loads, operators are adopting a mix of evaporative cooling, closed-loop water and glycol systems, and direct-to-chip liquid cooling. Each approach uses water differently, but all depend on reliable heat capture, heat transport, and heat rejection.

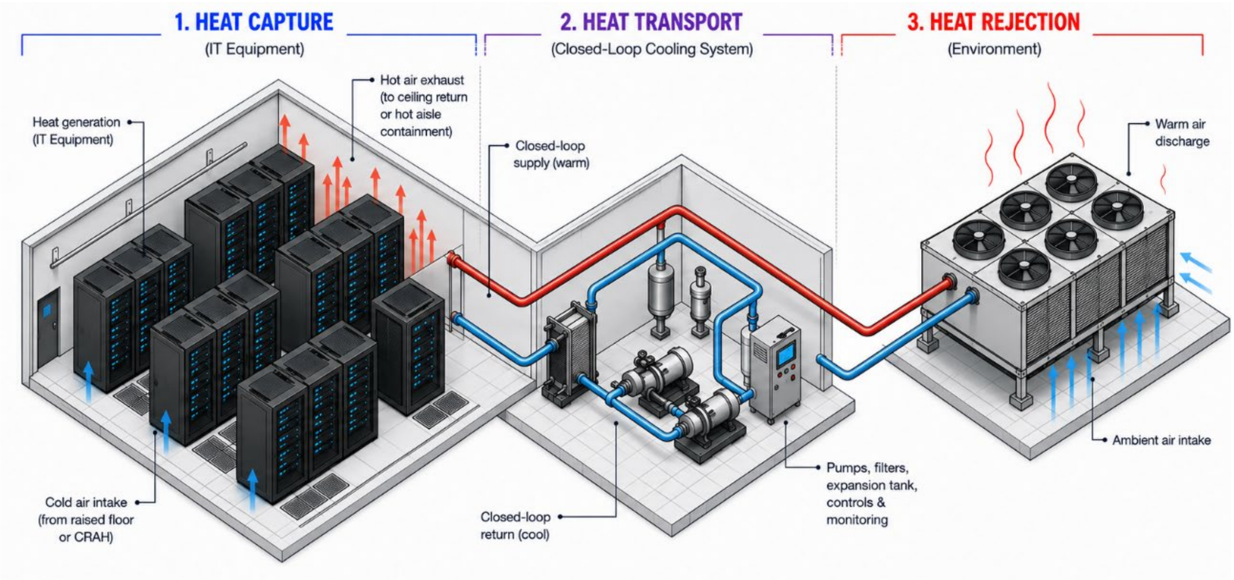
The challenge is not simply to reduce water use. It is to make water management a foundational part of the facility lifecycle—from initial design and construction through startup, commissioning, operations, optimization, expansion, and retrofit.

Decisions made early can influence cooling reliability, water and energy efficiency, maintenance requirements, equipment life, and sustainability performance for decades. From source water pretreatment and cooling towers to technical fluid loops, water reuse, monitoring, and water safety, every system and lifecycle stage affects the next.

The highest-performing data centers manage the entire water and thermal ecosystem as one connected strategy to improve uptime, control operating costs, protect critical infrastructure, conserve resources, and strengthen long-term resilience.

Understanding Today's Data Center Cooling Ecosystem

Modern data center cooling is evolving rapidly to support AI workloads and increasingly dense computing environments. Regardless of the cooling technology, every data center must accomplish three fundamental functions:



1. **Capture heat** from the IT equipment.
2. **Transport heat** through the facility.
3. **Reject heat** to the environment.

These functions may use different technologies, but they work together as one integrated thermal and water management ecosystem. Optimizing only one part of the system is not enough. Long-term performance depends on managing the entire water lifecycle—from source water and coolant quality to heat rejection, reuse, monitoring, and system optimization.

1. Heat Capture: Direct-to-Chip Liquid Cooling

As AI workloads continue to increase rack densities, direct-to-chip liquid cooling is being adopted rapidly for high-density computing. Instead of cooling the surrounding air, coolant flows through cold plates attached directly to CPUs and GPUs, removing heat much more efficiently than traditional air cooling.

While direct-to-chip cooling significantly reduces reliance on room-level air cooling, it does not eliminate the need for water management. The captured heat must still be transferred to the facility cooling infrastructure through coolant distribution units (CDUs) and heat exchangers before it can ultimately be rejected to the environment.

Key water management priorities include:

- Coolant chemistry management
- Corrosion protection
- Fluid cleanliness
- Heat transfer performance
- Continuous monitoring
- Long-term coolant health

2. Heat Transport: Closed-Loop Water and Glycol Systems
Once heat is removed from the IT equipment, it must be transported throughout the facility. Closed-loop water and glycol systems serve as the backbone of modern data center cooling by transferring heat between servers, CDUs, heat exchangers, chillers, and heat rejection equipment.

Because these systems continuously circulate the same coolant, maintaining fluid quality and system integrity is essential for long-term reliability and thermal performance.

Key priorities include:

- Fluid chemistry management
- Corrosion inhibitor protection
- Contamination control
- Heat exchanger performance
- Filtration and system cleanliness
- Continuous coolant monitoring

Properly maintained closed-loop systems improve heat transfer efficiency, protect valuable equipment, and extend the life of critical cooling infrastructure.

3. Heat Rejection: Evaporative, Dry and Hybrid Cooling Systems
The final step is rejecting heat from the facility to the surrounding environment.

Many data centers use cooling towers or other evaporative cooling systems because they can provide highly energy-efficient heat rejection. Others rely on dry coolers or hybrid cooling systems to reduce onsite water consumption while balancing climate conditions, energy performance, and sustainability goals.

Regardless of the heat rejection technology, effective water management remains essential for maximizing performance and reliability.

For facilities using evaporative cooling, key priorities include:

- Source water quality
- Water pretreatment
- Cooling tower treatment
- Scale and corrosion control
- Microbiological control
- Blowdown optimization
- Water reuse and recycling

Facilities using dry or hybrid cooling systems may consume significantly less onsite water, but they still depend on well-managed closed-loop coolant systems and efficient heat transfer to maintain performance.

Myth vs. Reality: Can a Data Center Be "Water-Free"?

Low-water and water-free cooling strategies can significantly reduce or eliminate onsite evaporative water use. However, every data center must still reject heat through dry, evaporative, hybrid, or district cooling infrastructure, and the electricity powering the facility may carry an upstream water footprint.

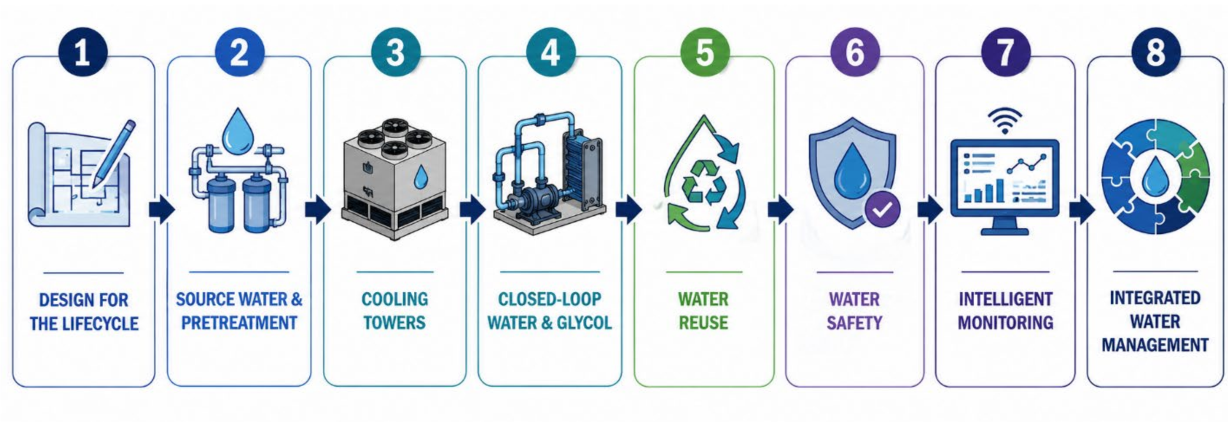
Water use may therefore be reduced onsite, eliminated from certain processes, or shifted elsewhere in the cooling and energy ecosystem.

Myth: *AI data centers can operate without water.*

Reality: *"Water-free" often means eliminating onsite evaporative water use—not eliminating water from the broader infrastructure supporting the facility. The more meaningful goal is to optimize water use, energy efficiency, and heat rejection together.*

The 8 Pillars of an Integrated Data Center Cooling Strategy

How an integrated water & thermal strategy strengthens
cooling reliability, resource efficiency, and long-term resilience.



Reliable data center cooling depends on far more than a cooling tower, a glycol loop, or a water treatment program. Every stage of the water lifecycle—from source water and pretreatment to heat rejection, water reuse, monitoring, and ongoing optimization—plays a critical role in maintaining cooling performance, protecting infrastructure, and supporting long-term sustainability.

The most successful owner-operators don't manage these systems independently. They take a lifecycle approach, recognizing that decisions made during design, construction, commissioning, operations, and future expansion all influence uptime, operating costs, water consumption, and energy efficiency. The following eight best practices provide a practical framework for building a resilient, high-performance water management strategy that supports today's mission-critical operations while preparing for tomorrow's AI-driven cooling demands.

Best Practice 1: Design for the Entire Lifecycle

The most successful data center water strategies don't begin at startup—they begin during design. Decisions made early in a project's lifecycle influence cooling reliability, operating efficiency, maintenance requirements, water consumption, and sustainability performance for decades to come.

Rather than treating water management as a series of independent tasks, leading owner-operators take a lifecycle approach that considers every phase of the facility—from initial design through long-term operations and future expansion.

Effective commissioning begins during design, not after construction is complete.

Water quality requirements, system materials, flushing and cleaning procedures, sampling locations, temporary filtration, chemical feed, controls, testing protocols, and acceptance criteria should be defined before installation begins.

Design
Water quality, cooling architecture, pretreatment, heat rejection, closed-loop systems, monitoring, and water reuse should be evaluated as an integrated system. Designing for maintainability, scalability, and operational flexibility helps reduce future risks while supporting evolving cooling technologies such as direct-to-chip liquid cooling.

Construction
Proper installation practices—including system cleanliness, flushing, passivation, pressure testing, and documentation—help ensure water systems perform as designed from day one. Addressing issues during construction is significantly less costly than correcting them after the facility becomes operational.

Startup & Commissioning
Commissioning verifies that water treatment programs, pretreatment equipment, cooling towers, closed-loop systems, sensors, controls, and monitoring platforms are operating together as intended. Establishing baseline water quality and system performance creates a valuable reference point for future optimization.

Key commissioning practices:

- Establish water-quality and coolant specifications
- Define flushing, cleaning, passivation, and disinfection requirements
- Identify sampling and monitoring locations
- Develop startup sequences and acceptance criteria
- Assign ownership for testing, documentation, and corrective action
- Plan for future expansion and system turnover

Operations
Routine water analysis, coolant monitoring, preventive maintenance, laboratory testing, and field service help maintain cooling efficiency while minimizing scale, corrosion, fouling, microbiological growth, and unplanned downtime.

Continuous Optimization
Water quality, cooling loads, utility conditions, and operational demands evolve over time. Continuous monitoring, performance trending, and periodic optimization help improve heat transfer, reduce water and energy consumption, extend equipment life, and support changing AI workloads.

Expansion & Retrofit
As computing density increases and facilities transition to liquid cooling, existing water infrastructure must often be upgraded to support higher thermal loads. Expanding pretreatment capacity, integrating CDUs, optimizing closed-loop systems, adding water reuse technologies, or modernizing monitoring and controls can improve performance while protecting previous infrastructure investments.

A Lifecycle Partner for Mission-Critical Cooling
Managing water across the entire facility lifecycle requires expertise that extends beyond chemical treatment alone. It demands an understanding of cooling systems, fluid management, commissioning, monitoring, laboratory services, and long-term operational support.

By taking a lifecycle approach—from design and construction through commissioning, optimization, expansion, and retrofit—data center owners can reduce project risk, maximize cooling reliability, improve resource efficiency, and build resilient infrastructure ready for the next generation of AI.

Best Practice 2: Start with Source Water and Pretreatment

Every successful water management program begins before water ever reaches the cooling system. During startup, pretreatment systems should be validated against design conditions before treated water is introduced to cooling towers, closed loops, or technology-side systems.

Municipal water quality varies dramatically by region and can fluctuate throughout the year. Hardness, silica, chlorides, iron, suspended solids, and biological contaminants all affect downstream performance.

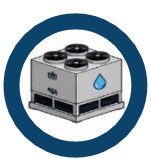
Depending on source water quality, cooling architecture, reuse objectives, and equipment requirements, pretreatment may include:

- Multimedia filtration
- Cartridge or automatic filtration
- Water softening
- Reverse osmosis (RO)
- Ultrafiltration (UF)
- Activated carbon
- Deionization (DI)
- Advanced monitoring and automation

Effective pretreatment helps:

- Reduce scaling potential
- Protect cooling equipment
- Improve chemical treatment performance
- Extend equipment life
- Reduce maintenance
- Improve heat transfer efficiency

Rather than over-treating downstream systems, many operators achieve better performance by delivering cleaner water from the start. The right pretreatment strategy can reduce downstream treatment demands, improve system performance, and lower lifecycle operating costs.



Best Practice 3: Optimize Cooling Tower Performance

Cooling towers remain one of the largest onsite water users in many data centers, but they can also provide highly energy-efficient heat rejection when properly designed and managed.

Cooling towers should not be considered commissioned until mechanical operation, water chemistry, controls, blowdown, biological control, and baseline thermal performance have all been verified.

When properly managed, they maximize cooling capacity while minimizing water consumption. When neglected, they become major sources of:

- Scale
- Corrosion
- Biofilm
- Fouling
- Water waste
- Energy loss

An optimized cooling tower program should include:

Continuous Monitoring
Real-time conductivity, pH, ORP, and makeup water monitoring allow operators to identify issues before they impact operations.

Deposit Control
Even thin layers of scale dramatically reduce heat transfer efficiency, forcing chillers and pumps to work harder.

Biological Control
Effective microbiological control protects both equipment performance and water safety.

Side-Stream Filtration
Removing suspended solids reduces fouling, improves heat exchanger performance, and lowers maintenance requirements.

Routine Inspection and Cleaning
No chemical treatment program can replace physical cleaning and preventive maintenance.

Together, these practices maximize heat transfer, extend equipment life, reduce water consumption, and lower energy use.

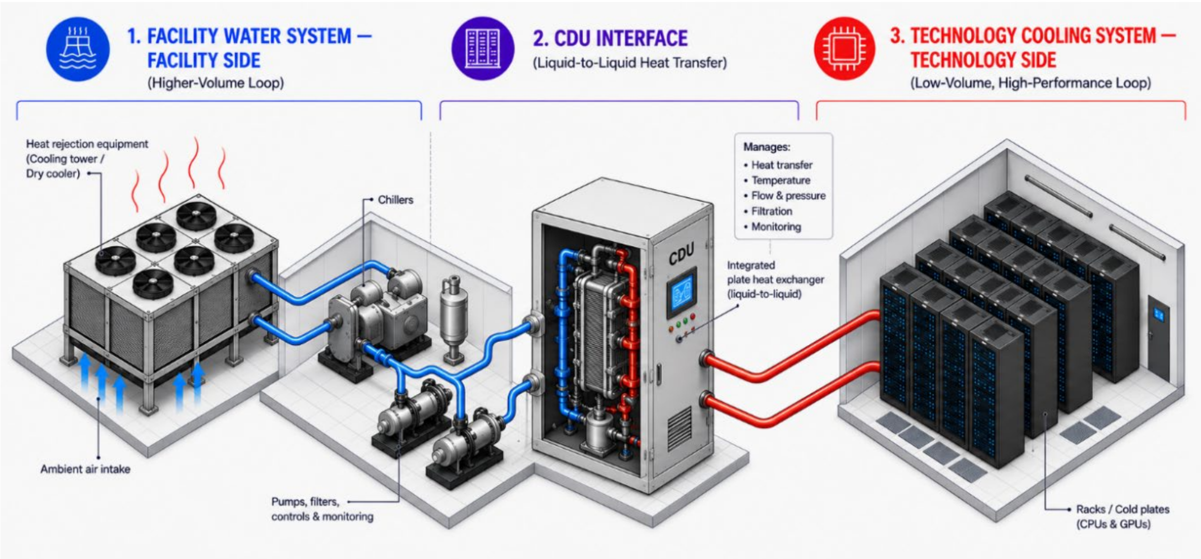
Best Practice 4: Protect Closed-Loop Water and Glycol Systems

Closed-loop systems form the critical thermal bridge in modern AI and high-density data centers. Effective management begins with understanding the distinct roles and fluid requirements of the facility-side and technology-side cooling loops.

Facility Water System—Facility Side: Circulates water or inhibited glycol between chillers, heat-rejection equipment, heat exchangers, and Coolant Distribution Units. These higher-volume loops transport heat across the facility.

Technology Cooling System—Technology Side: Circulates manufacturer-specified coolant between the CDU and the racks or cold plates serving CPUs and GPUs. Depending on the equipment design and materials of construction, the fluid may be treated water, deionized water, inhibited glycol, refrigerant, or another engineered coolant.

The CDU Interface: In common liquid-to-liquid configurations, the CDU transfers heat from the technology cooling system to the facility water system while keeping the fluids hydraulically separated. It also manages temperature, flow, pressure, filtration, and monitoring.



Closed-loop reliability is often determined before the system enters normal operation. Proper cleaning, flushing, filtration, air removal, final fill, chemistry verification, and baseline testing are essential to prevent construction contamination from becoming a long-term operating problem.

Because closed loops are sometimes treated as "fill-and-forget" assets, changes in fluid chemistry, contamination, corrosion, or fouling can go undetected until they reduce heat transfer or threaten critical equipment.

A proactive management program should include:

- Routine coolant analysis and fluid-quality monitoring
- Chemistry verification based on metallurgy and OEM requirements
- Corrosion inhibitor testing where applicable
- Contamination and particulate monitoring
- Filtration and system-cleanliness verification
- Pressure, leak, and expansion-control inspections
- CDU heat-exchanger performance and pressure-drop trending
- Documentation of fluid condition, corrective actions, and service history

Whether managing facility-side water and glycol or technology-side coolant, maintaining the proper chemistry, cleanliness, and operating conditions helps preserve heat-transfer performance while protecting pumps, valves, heat exchangers, cold plates, and other liquid-cooling infrastructure.

Best Practice 5: Treat Water Reuse as a Strategic Resource

Many new hyperscale campuses are being built in regions facing increasing water stress.

As a result, water reuse is becoming a competitive advantage rather than simply a sustainability initiative.

Opportunities may include:

- Cooling tower blowdown recovery
- Reverse osmosis reject reuse

- Condensate recovery
- Rainwater harvesting
- Process water recycling
- Wastewater reclamation

Modern reuse systems can dramatically reduce freshwater demand while lowering wastewater discharge.

These projects not only improve sustainability metrics but also reduce long-term operating costs and improve resilience where municipal water supplies are constrained.

Best Practice 6: Design Water Safety into Every System

Water safety should be incorporated wherever data center operations involve open recirculating cooling systems, stored water, domestic water, or conditions that may support microbiological growth.

A comprehensive water safety strategy includes:

- Risk assessments
- Proper flow management
- Temperature management
- Microbiological monitoring
- Secondary disinfection where appropriate
- Cooling tower hygiene
- Routine validation
- Documentation and trending

Effective microbiological control helps protect people, maintain cooling performance, and support responsible cooling-tower operation.

Best Practice 7: Connect Everything Through Intelligent Monitoring

Modern data centers generate enormous amounts of operational data.
Water systems should be no different.

Integrated monitoring platforms can combine information from:

- Cooling towers
- Closed-loop systems
- Direct-to-chip cooling infrastructure
- Pretreatment systems
- Chemical feed systems
- Water quality sensors
- Utility water consumption
- Laboratory testing
- Remote equipment monitoring

Instead of reacting to failures, operators gain earlier warning of changing conditions and actionable performance trends that support timely intervention, treatment optimization, and lifecycle planning.

Automation also improves documentation, supports ESG reporting, simplifies operational decision-making, and helps optimize both water and energy performance.

Best Practice 8: Adopt an Integrated Water Management Strategy

The biggest opportunity isn't improving one cooling tower or one glycol loop. It's optimizing the entire water ecosystem.

An integrated strategy considers:

- Source water

- Water pretreatment
- Cooling towers
- Closed-loop water systems
- Closed-loop glycol systems
- Direct-to-chip cooling
- Heat exchangers
- High-purity water
- Wastewater
- Water reuse
- Water safety
- Automation
- Laboratory validation
- Lifecycle services

When these systems are managed together rather than independently, operators gain:

- Greater uptime
- Lower operating costs
- Longer equipment life
- Reduced water consumption
- Lower energy use
- Improved sustainability performance
- Better operational visibility
- Reduced project risk

The Future of Data Center Cooling

As AI infrastructure expands, water will become an increasingly strategic part of data center performance.

Regardless of the cooling architecture, heat must be captured, transported, and rejected. The priority is not eliminating one technology, but selecting and managing the right combination of water, energy, coolant, and heat-rejection strategies for each facility.

By integrating pretreatment, cooling optimization, closed-loop management, monitoring, reuse, and lifecycle support, operators can improve uptime, control costs, extend equipment life, and protect critical water resources.

The most resilient data centers will manage water, energy, and thermal performance as one connected system—delivering the reliability, efficiency, and computing capacity required for the next generation of AI.

Frequently Asked Questions

What is a closed-loop cooling system?

A closed-loop cooling system continuously circulates the same water, inhibited glycol, or engineered coolant to transport heat throughout a data center. Unlike open cooling systems, the fluid remains contained within the piping network, minimizing water loss while protecting pumps, heat exchangers, Coolant Distribution Units (CDUs), and other critical cooling equipment. Routine monitoring of fluid chemistry, cleanliness, and corrosion protection is essential to maintain long-term reliability and heat transfer performance.

Why are cooling towers still used in AI data centers?

Cooling towers remain one of the most energy-efficient methods for rejecting heat from large data centers. While AI workloads are accelerating the adoption of direct-to-chip liquid cooling and closed-loop coolant systems, the heat removed from servers must still be transferred to the environment. In many climates, evaporative cooling towers provide the lowest energy consumption and highest cooling capacity, making them a preferred solution for hyperscale and AI facilities. Dry coolers and hybrid systems may be used where water availability, climate, or sustainability goals favor reduced onsite water consumption.

Do liquid-cooled data centers eliminate water use?

Not necessarily. Direct-to-chip liquid cooling significantly reduces the need for room-level air cooling and can reduce onsite evaporative water use when paired with dry cooling systems. However, the heat generated by IT equipment must still be rejected to the environment through dry, evaporative, hybrid, or district cooling infrastructure. In addition, electricity generation may carry an upstream water footprint. Rather than striving for "zero water," leading operators optimize water use, energy efficiency, and heat rejection together.

What is the difference between the facility water loop and the technology cooling loop?

Modern liquid-cooled data centers typically use two separate cooling loops connected by a Coolant Distribution Unit (CDU) or liquid-to-liquid heat exchanger.

Facility Water Loop

- Circulates water or inhibited glycol throughout the facility.

- Connects chillers, pumps, heat rejection equipment, heat exchangers, and CDUs.
- Transfers heat across the building.
- Designed for high-volume heat transport.

Technology Cooling Loop

- Circulates the manufacturer-specified coolant through CDUs, manifolds, cold plates, CPUs, and GPUs.
- Operates with fluid chemistry specified by the equipment manufacturer.
- Optimized to protect sensitive IT hardware while maximizing cooling performance.

The CDU transfers heat between the two loops while keeping the fluids hydraulically separated, preventing contamination and allowing each loop to operate with the chemistry best suited for its application.

How often should closed-loop glycol be tested?

Testing frequency depends on system criticality, manufacturer recommendations, operating conditions, and facility standards. For most mission-critical data centers, an annual comprehensive glycol analysis is considered the minimum, while many operators perform testing every six months or quarterly for high-value AI and liquid-cooling infrastructure.

Routine testing should verify:

- Glycol concentration
- Freeze protection
- Corrosion inhibitor levels
- pH
- Fluid cleanliness
- Metals and contamination
- Heat-transfer performance indicators

Regular testing helps identify degradation before it impacts cooling performance or damages critical equipment.

What is Water Usage Effectiveness (WUE)?

Water Usage Effectiveness (WUE) is a sustainability metric developed by The Green Grid that measures the amount of water a data center consumes relative to the IT equipment energy it delivers.

It helps operators evaluate how efficiently a facility uses water for cooling and other operations while supporting comparisons between different cooling technologies and site designs.

Improving WUE often involves a combination of:

- Cooling tower optimization
- Source water pretreatment
- Closed-loop cooling systems
- Water reuse and recycling
- Intelligent monitoring and controls
- Selecting the most appropriate heat rejection technology for the local climate

Because water and energy are closely linked, the lowest WUE does not always represent the most sustainable solution. The most resilient data centers balance **water consumption, energy efficiency, cooling reliability, and long-term community water stewardship** to achieve the best overall operational and environmental performance.

How Team Apex Supports Each Lifecycle Phase

Plan
Consulting, source-water analysis, feasibility studies, water-risk assessment, cooling-fluid strategy, and lifecycle planning.

Design
Pretreatment design support, cooling-tower water strategy, closed-loop fluid requirements, instrumentation planning, maintainability reviews, and commissioning criteria.

Build
Construction support, system-cleanliness planning, flushing, cleaning, passivation, temporary filtration, and equipment protection.

Startup and Commissioning
Pressure-test support, final cleaning, water and glycol filling, air purging, chemistry verification, controls validation, baseline laboratory analysis, and turnover reporting.

Operate
Water treatment, coolant management, laboratory services, remote monitoring, water safety, field service, and preventive maintenance.

Optimize
Performance assessments, water reuse, treatment optimization, energy and WUE improvement, system health trending, expansion planning, and retrofit support.

Partner with Apex

From source water pretreatment to cooling towers, closed-loop water and glycol systems, facility-side water and thermal support for direct-to-chip cooling, high-purity water, wastewater reuse, automation, laboratory services, and ongoing optimization, Apex helps data centers manage the complete water and thermal lifecycle.

Whether you're designing a new AI campus, expanding an existing facility, or optimizing operating performance, Apex's expert team can help reduce project risk, improve cooling reliability, optimize water and energy use, and support long-term sustainability.

Learn More: https://teamapex.com/industries/datacenter/

Technical Disclaimer

The information contained in this publication is provided for educational and informational purposes only. While every effort has been made to ensure technical accuracy, the guidance presented is not intended to replace engineering judgment, applicable codes and standards, manufacturer requirements, or project-specific design criteria.

Actual system design, water chemistry, coolant selection, operating conditions, treatment programs, and maintenance practices should be developed by qualified professionals based on the specific requirements of each facility and the recommendations of equipment manufacturers.

References to cooling technologies, products, processes, or standards are provided for informational purposes and should not be interpreted as endorsements or guarantees of performance.

Vendor Neutrality Statement

This framework discusses a broad range of water and thermal management practices used throughout the data center industry. The principles presented are intended to be technology-agnostic and applicable across multiple cooling architectures, manufacturers, and operating environments.

Although Apex provides engineering, water treatment, commissioning, laboratory, monitoring, and lifecycle support services, the recommendations contained in this document are based on recognized engineering principles and industry best practices rather than any specific product or proprietary technology.

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DOWFROST™ Service Provider

Apex provides integrated water, fluid, and thermal management solutions across the data center cooling lifecycle. As an authorized distributor and service provider for DOWFROST™ Heat Transfer Fluids, Apex combines proven glycol technology with expertise in direct-to-chip cooling, commissioning, field service, and facility-wide water management.

Through Fluid-to-Facility™, Apex helps data centers improve uptime, efficiency, reliability, and scalability for AI-driven growth.

Learn more

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