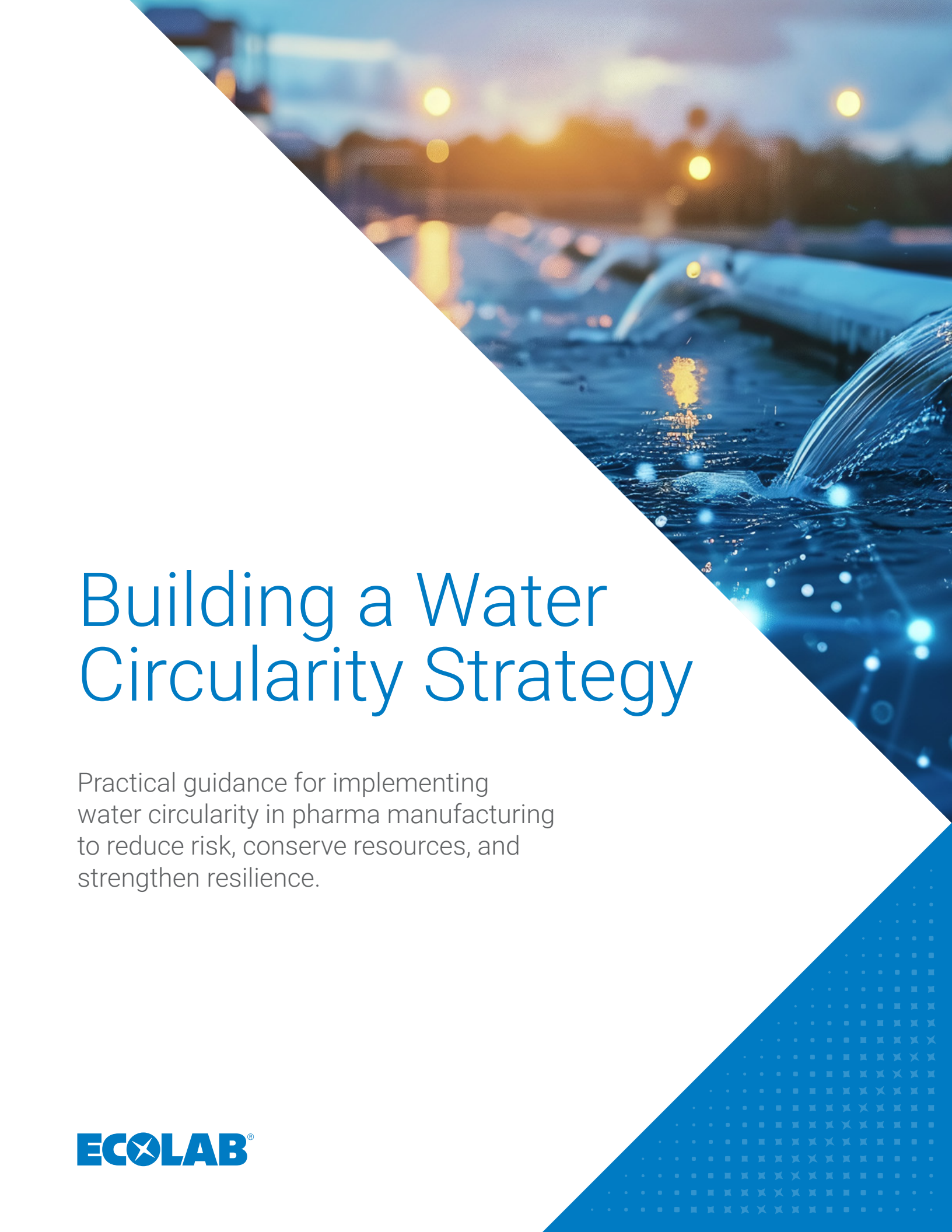




Building a Water Circularity Strategy

Practical guidance for implementing water circularity in pharma manufacturing to reduce risk, conserve resources, and strengthen resilience.

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Executive Summary

Water is becoming a strategic constraint in pharmaceutical manufacturing, shaped by scarcity, regulatory pressure, substances of concern, rising costs, and corporate sustainability commitments. As manufacturers look for practical ways to reduce freshwater demand and discharge volume, water circularity is increasingly viewed as both an operational resilience strategy and a sustainability lever.

This playbook provides a GMP-aligned, regulatory-grounded guide to water reduction, reuse, and recycling in pharma. It explains why circularity matters now, how the 3Rs maturity model can guide adoption, and how sites can identify, prioritize, and implement these opportunities without compromising quality or inspection readiness.

Moving from strategic context to practical execution, the playbook helps teams understand the regulatory considerations, opportunity mapping, readiness requirements, infrastructure needs, implementation steps, and validation and monitoring practices that shape a successful circularity program.

Together, these elements provide a clear path to building scalable water circularity strategies that reduce environmental impact and support business performance.



Why Water Circularity in Pharma

Water is one of the most critical – and most constrained – utilities in pharmaceutical manufacturing. It's essential to nearly every stage of production, from API synthesis and formulation to cleaning, sterilization, and utilities like cooling and steam.

Now is the time for pharmaceutical manufacturers to act on water circularity. Several factors are converging to make circularity both urgent and strategically valuable. Yet despite the momentum, real barriers to implementation remain.

Top Drivers



WATER SCARCITY

Growing pressure on water availability across global and regional hotspots.



ENVIRONMENTAL SAFETY

Increasing focus on removing substances of concern (APIs, PFAS, and other contaminants) to protect local communities.



REPUTATIONAL RISK

Brand exposure tied to public scrutiny of water usage, discharge practices, and environmental impact.



RIISING COST PRESSURE

Escalating costs associated with water acquisition, treatments, energy consumption, and wastewater discharge.



OPERATIONAL DEMANDS

Significant water volume required for cleaning-in-place (CIP), sterilization, purified water (PW), water for injection (WFI), and utilities.



REGULATORY SCRUTINY

Tightening discharge limits, environmental regulations, and evolving permitting expectations.



SUSTAINABILITY COMMITMENTS

Ambitious water stewardship, carbon reduction, and ESG targets tied to investor expectations and brand narratives.

Top Barriers



FINANCIAL JUSTIFICATION

Difficulty building a business case that competes with core manufacturing investments.



CAPEX & INFRASTRUCTURE

High upfront cost and limited site footprint, especially without onsite wastewater treatment.



REGULATORY MISCONCEPTIONS

Existing site permits, approved procedures, validation processes, and outdated regulatory submissions often represent implementation challenges.



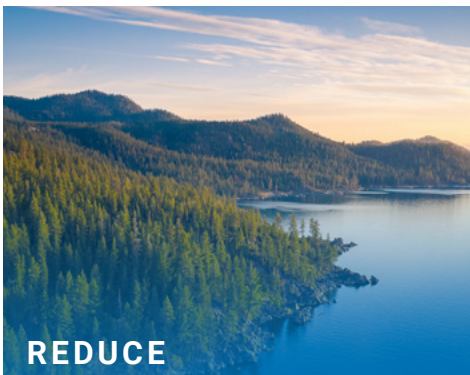
LOW RISK TOLERANCE

Uncertainty around API limits and a preference to stay “purer than regulations” for brand protection.

Water Circularity and the Conservation Framework

Water circularity is a holistic approach to water conservation based on the 3Rs framework – Reduce, Reuse, and Recycle – aimed at minimizing freshwater demand and maximizing the value of water resources. While reduction remains the most common conservation strategy, reuse and recycling often represent the greatest opportunities to improve water efficiency and resilience.

Strategic water management begins with establishing a clear baseline of current water use and water quality across all systems through monitoring, mapping, cost evaluation, and water quality analysis. With a baseline established, organizations can identify and prioritize opportunities that align with operational objectives, regulatory expectations, and sustainability goals.



REDUCE

Minimizing water consumption through conservation, efficiency improvements, and process optimization.

- Low capital cost, often reduces operating cost
- Simple, fast implementation
- Improves water use baseline
- Low to moderate conservation potential – efficiency constrained by performance requirements of specific water users
- May change quality requirements or effluent characteristics



REUSE

Using a water stream again for a different application with little or no additional treatment.

- Moderate capital cost, may reduce operating costs
- Moderate complexity and speed to implementation
- Moderate conservation potential – reuse constrained by water quality, volume alignments, and infrastructure complexity



RECYCLE

Treating a water stream to achieve a defined quality requirement before returning it to service.

- Highest impact potential – can supply recycled water to highest-demand users
- Highest complexity to implement
- High capital cost

It is critically important to understand how these three conservation strategies interrelate. Reduction projects may limit circularity potential. A single, large recycle project, though complex in itself, may prove to be simpler and more impactful than executing several smaller reuse projects. Reuse projects may capture thermal energy that would be lost through recycling.

Once all conservation opportunities have been identified, an overall conservation strategy should be developed that holistically optimizes the ROI across viable projects. A project manager should then oversee sequencing, execution, and value capture. Because water management is rarely a core competency in pharma, an experienced water partner helps accelerate progress and reduce risk.

Regulatory Landscape

Pharmaceutical water circularity, both reuse and recycle, is often perceived as a regulatory gray area. Increasingly, however, the frameworks set forward by governing bodies across regions are converging on a shared set of expectations: water used in manufacturing must be fit-for-purpose, controlled under the Pharmaceutical Quality System (PQS), and supported by risk-based decision-making.

In practice, the greater challenge may be existing permits, approved procedures, validated processes, or regulatory submissions that were developed around current operating conditions. Implementing water circularity may require updates to these site-specific commitments rather than overcoming a regulatory prohibition.

The themes below highlight where that alignment exists and where regional nuances still matter.

This section is intended as a thematic overview. It does not replace site-specific legal, permit, or compendial review.

Fit-For-Purpose Water Quality

Across the US, EU, and global frameworks, regulators do not prescribe a single source of water but rather prescribe a quality standard tied to water use. Published standards from USP (U.S.), Ph. Eur. (Europe), and WHO (global) define those quality requirements for Purified Water and Water for Injection. EMA's 2020 guideline reinforces that reused or recycled water must meet the same quality as any other water used at that point in the process.

Pharmaceutical manufacturing uses multiple water grades, including potable water, purified water (PW), and water for injection (WFI). The required water quality depends on its intended use, the stage of the manufacturing process, and the product being produced.

Fit-for-purpose means water must consistently meet the chemical, microbiological, and quality requirements for its specific application. Water quality must be defined beyond basic parameters such as COD to include the management of contaminants and low-level chemical residuals, which reuse can concentrate over time. The focus is not on where the water comes from, but whether it is appropriately treated, controlled, monitored, and proven to meet the required specifications.

This distinction is important. Regulations define the quality water must achieve for a given use, not the source of the water itself. As a result, recycled or reclaimed water can be used in pharmaceutical manufacturing when it is properly treated and demonstrated to be fit for its intended purpose.

The key principle is simple: water quality determines use – not water origin.

Environmental Discharge and Reuse

Environmental regulations frame the upstream and downstream boundaries of any circularity project. In the US, the Environmental Protection Agency's (EPA) NPDES program and 40 CFR Part 439 set effluent limits for pharmaceutical manufacturers. In the EU, the Water Framework Directive, Urban Waste Water Treatment Directive, and Regulation (EU) 2020/741 on water reuse establish a risk-based model that is increasingly referenced beyond its agricultural scope. Federal limits set a ceiling, not a floor: states, municipalities, and individual EU countries can require lower, contaminant-specific limits, but never less stringent ones. Because reuse can concentrate contaminants, this patchy landscape means circularity decisions are often best made at the plant level.

GMP Control and Validation

GMP frameworks across the US, EU, and global regulatory bodies share one expectation: water systems must be designed, tested, monitored, and managed under change control. Water circularity extends that expectation to the recovery and treatment steps.

Risk Management Framework and Inspection Readiness

Global guidelines (ICH Q9, Q10, and Q12) provide a risk-based framework for quality risk management, the pharmaceutical quality system, and post-approval lifecycle change management – enabling predictable, science-driven manufacturing changes. Together, they provide the structure needed to justify circularity decisions, and the lens inspectors use to evaluate them. Inspector-facing tools, like PIC/S PI 009-4 and FDA ITG 46, reinforce this by setting clear expectations for how water systems are reviewed during inspections.

Dispelling the Myth: “Water Reuse Isn’t Allowed”

There is a strong foundation in current regulations to support water reuse and recycling.

Neither US nor EU laws and regulations prohibit the use of recycled water in the manufacturing of active pharmaceutical ingredients (APIs) and finished drug products, so long as the recycled water is processed in a manner that ensures it is fit-for-purpose.

The processing steps and acceptance criteria will depend on its intended use. For example, water used in finished drug product manufacturing may require additional processing and more stringent physical, chemical, and microbiological criteria than water used in API manufacturing.

A persistent barrier to progress is the assumption that water reuse is inherently prohibited. In practice, regulators do not prohibit reuse, but expect water used in GMP-relevant activities to be fit-for-purpose and controlled.

Organizations should also evaluate internal barriers such as SOPs, change control requirements, quality system expectations, permit conditions, and previously approved regulatory filings that may need revision to support circularity initiatives. Often, these site-specific commitments represent a greater implementation hurdle than regulatory requirements themselves.

Across global frameworks (FDA, EMA, WHO, PIC/S), the regulatory focus is consistent:

- Water must meet the quality requirements appropriate to its intended use
- Risks must be identified, assessed, and controlled
- Systems must be validated, monitored, and maintained in a state of control

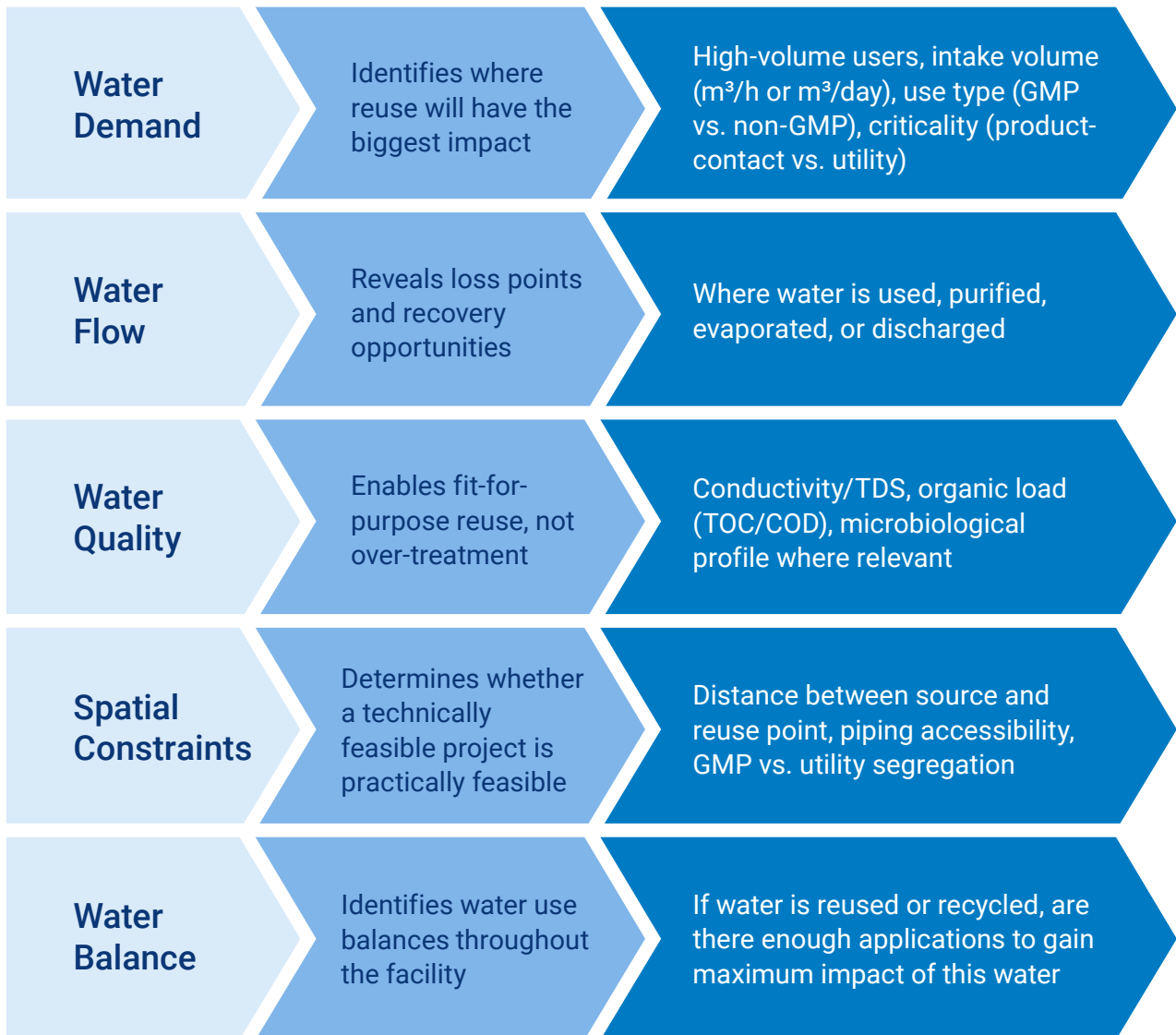
The source of the water – municipal, on-site treated, or reclaimed – is secondary to whether the quality and control strategy are scientifically justified. In many cases, properly treated reused water is more consistent and predictable than the incoming municipal supply.

The trajectory is clear: emerging regulations are increasingly encouraging water circularity, signaling a shift toward acceptance rather than restriction.

Developing a Circularity Plan

Circularity feasibility is always site-specific. It depends on where water is used, the quality required at each point, the physical layout of the site, and the GMP considerations that apply. Identifying the right opportunities for water circularity starts with understanding the relationships between water sources and users, and the volumes and quality profiles that connect them. The five steps below provide a structured way to build that view and prioritize where to act first.

Step One: Build the Site Water Map



Step Two: Identify Reusable Water Sources

Focus on high-volume, moderate-to-high quality streams that can be captured with minimal effort. Typical sources include:

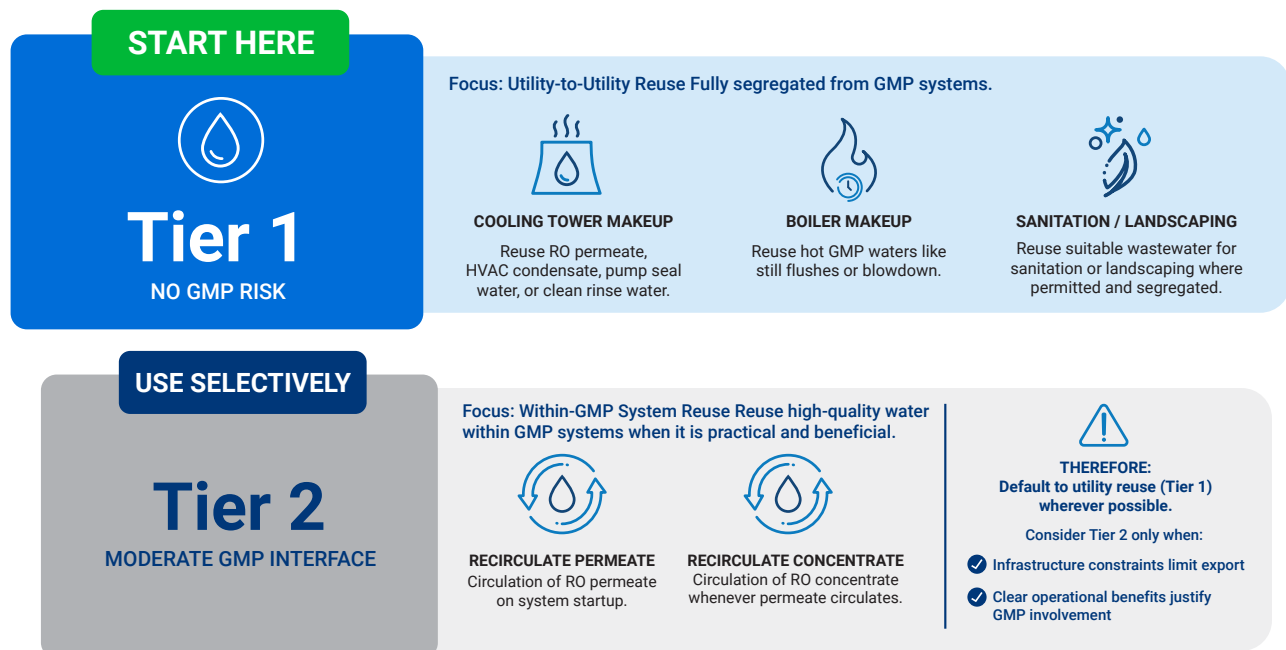
- ✓ GMP system reject streams (RO concentrate, still blowdown)
- ✓ GMP rinse waters (vial washing, final CIP rinses)
- ✓ Once-through cooling and seal water
- ✓ HVAC condensate

These streams tend to be consistent and reliable – a strong starting point for early reuse projects.

Step Three: Prioritize Low Risk, High Impact Pathways

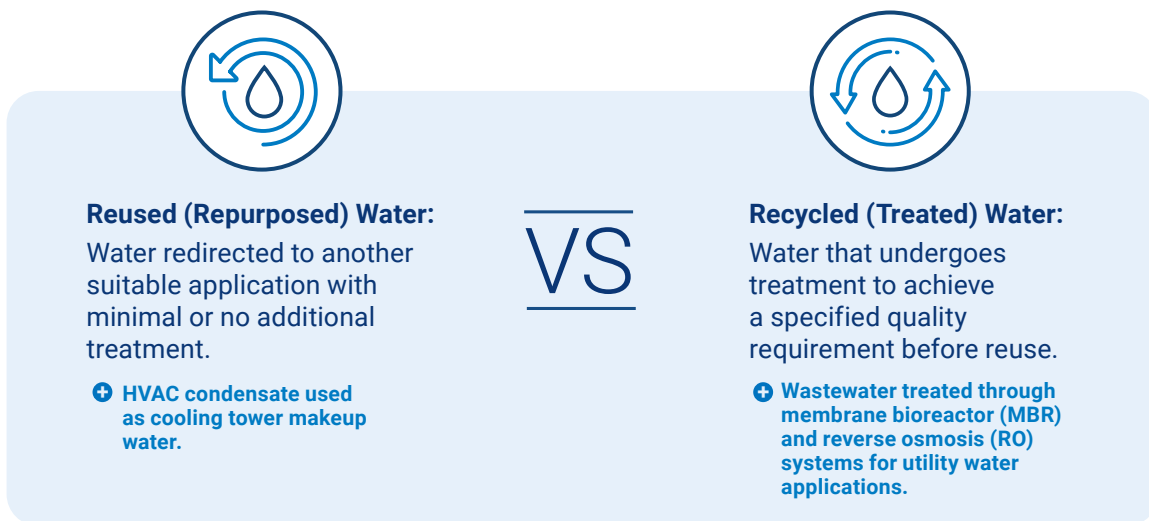
In pharma, adoption is driven by risk tolerance as much as technical feasibility. The most successful projects share three traits:

- ✓ The reuse pathway sits outside GMP-critical processes
- ✓ The project meaningfully reduces freshwater demand or discharge
- ✓ The reuse loop fits within existing piping, footprint, and segregation requirements



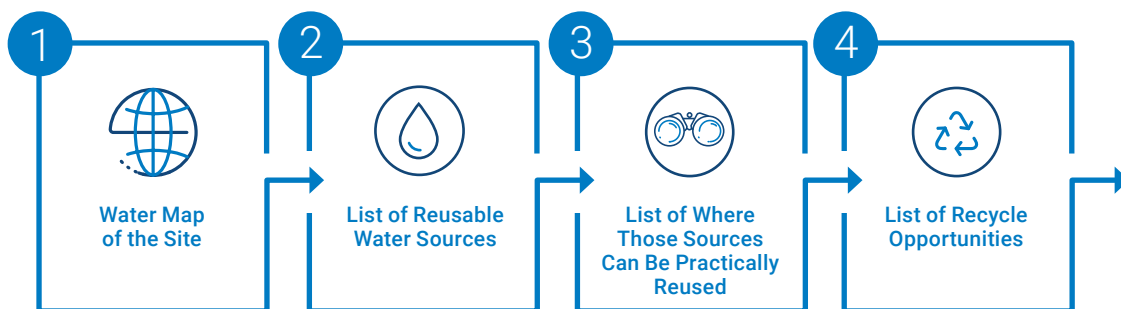
Step Four: Evaluate Recyclable Water Sources

Most often the ROI is greatest and effort lowest when reusing effluent water from one application as source water for another. However, recycling opens more possibilities for conservation by disconnecting quality and volume constraints. Through technology, high volumes of unusable water can be transformed into usable water. The capital costs for doing so can be high, but the ROI can also be surprisingly fast, especially where water or sewer services are expensive or where wastewater already undergoes biological treatment. Most facilities with Membrane Bioreactor (MBR) treatment already have “recycle ready” wastewater.



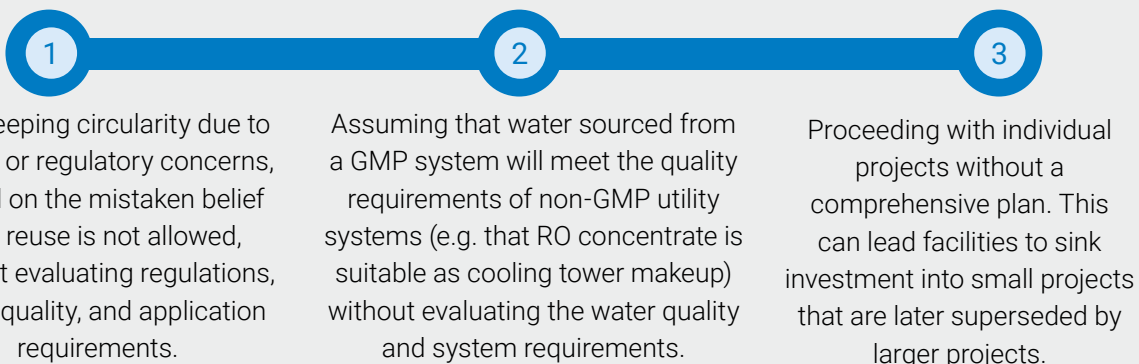
Step Five: Develop a Comprehensive Circularity Plan

The above steps have established the following:



In this step, compare the costs, benefits, and interrelationships between each opportunity to develop a comprehensive, prioritized list of circularity projects. Some of these opportunities may be mutually exclusive. For instance, recycling site wastewater may eliminate the benefits of many reuse projects. There may be multiple listed reuse applications for a single water stream. Priority should account for investment required, ease of implementation, volume impact, need for GMP validation, infrastructure limitations, etc.

Avoid Common Pitfalls



Circularity Readiness Assessment

After developing a circularity plan to identify priority circularity projects, the next step is determining whether the site is prepared to act on those opportunities.

A structured circularity readiness assessment helps pharmaceutical sites translate water circularity ambition into actionable, compliant opportunities. The goal is to determine where reuse or recycle can be implemented safely, compliantly, and with clear operational value.

Successful water circularity projects often require alignment across Environmental, Quality, Operations, Engineering, and Regulatory functions. Early engagement of these stakeholders helps identify documentation, validation, permitting, and procedural changes needed to support implementation.

This assessment focuses on water system maturity, GMP interface, infrastructure feasibility, and organizational alignment to identify low-risk, high-impact entry points – typically starting with utility reuse before progressing to more complex applications.

1. Water System Visibility & Baseline

- Do we have a clear map of all water inflows, uses, and discharge points?
- Which processes use the most water, and how consistent is that demand?
- What data do we have on water quality across different streams?
- Are major reject streams (e.g., RO concentrate, rinse water, condensate) well understood?

2. Fit-for-Purpose Water Use

- How are we defining water usage by required quality (potable, PW, WFI, utility)?
- Where are we using higher-quality water than necessary?
- Which applications could safely use reclaimed or lower-grade water?
- What opportunities align with low-risk, utility-focused reuse?

3. GMP Interface & Quality Risk

- Where could reuse intersect with GMP or product-contact systems?
- What risks (chemical, microbial, cross-contamination) need to be controlled?
- Do we have a structured process to assess and document these risks?
- What validation or requalification would be required?

4. Infrastructure & Treatment Feasibility

- Are water streams physically separated to enable safe reuse?
- What infrastructure constraints (piping, storage, space) limit reuse?
- What level of treatment would be needed for target applications?
- Can reuse be implemented without disrupting validated systems?

5. Regulatory & Permitting Context

- How would reuse impact discharge permits or regulatory obligations?
- Are there regional drivers (scarcity, regulations) increasing urgency?
- What documentation would be needed to support inspection readiness?
- Are current monitoring practices sufficient to demonstrate control?

6. Organizational Readiness

- Are Engineering, QA, EHS, and Sustainability aligned on reuse priorities?
- Is there clear ownership for water circularity initiatives?
- Is QA engaged early in evaluating reuse opportunities?
- What internal barriers (risk perception, cost, resources) could slow adoption?

7. Value & Prioritization

- Which opportunities provide the highest impact with lowest risk?
- Where can reuse deliver the most meaningful reduction in water use or discharge?
- Can we pilot or phase implementation to build confidence?
- How does reuse align with broader sustainability or business goals?

Infrastructure and Treatment Considerations

Water circularity is only as strong as the infrastructure and treatment systems that support it. The right design choices determine what reuse is possible, what quality can be achieved, and what can be validated and scaled. This section outlines the principles that should guide infrastructure and treatment decisions for both new builds and retrofits.

Design for Circularity

The biggest determinant of long-term success is whether infrastructure is *engineered* for circularity or *adapted* to it after the fact.

New Builds	Retrofits
Treat circularity and thermal energy recovery as early design priorities. Systems like wastewater heat recovery, heat-recovery chillers, and thermal networks reduce cooling tower demand and align water and energy reuse in a single resilient design.	Map existing water streams, identify recovery points, and prioritize changes that integrate cleanly with validated systems. Avoid solutions that require parallel infrastructure where existing assets can be repurposed.

Build the Core Components

Three components form the backbone of any circular water system:

- 1 Segregation and Distribution:** Physically separate high-purity, utility, and wastewater streams with dedicated piping and storage. Segregation is what makes fit-for-purpose reuse possible.
- 2 Storage and Buffering:** Buffer tanks and equalization systems absorb variability in flow and contaminant load, decoupling generation from reuse, so downstream treatment stays stable.
- 3 Utility Integration:** Connect reuse streams to cooling, boiler, CIP, and steam systems without disrupting validated processes. The cleanest reuse pathways extend existing utility loops rather than create new ones.

Match Treatment Complexity to Need

Treatment systems should follow a multi-barrier approach sized to the source water, the contaminant profile (organics, inorganics, APIs, PFAS), and the target reuse application.

The simpler the reuse path, the lower the cost, the smaller the risk, and the faster the payoff. Reduce first, cascade second, reuse clean streams third – and only invest in advanced treatment when the simpler options can't deliver the quality or quantity of savings you need.

Plan for Validation and Monitoring

In GMP environments, infrastructure must be designed to support validation from day one. That means:

- Repeatability and consistent output quality built into system design
- Defined operating parameters with continuous monitoring and documented protocols
- Sampling points, instrumentation access, and system integration designed in
- Auditable records for performance, deviations, and remediation actions

Changes to validated systems typically trigger revalidation, so flexibility and lifecycle cost must be considered upfront.

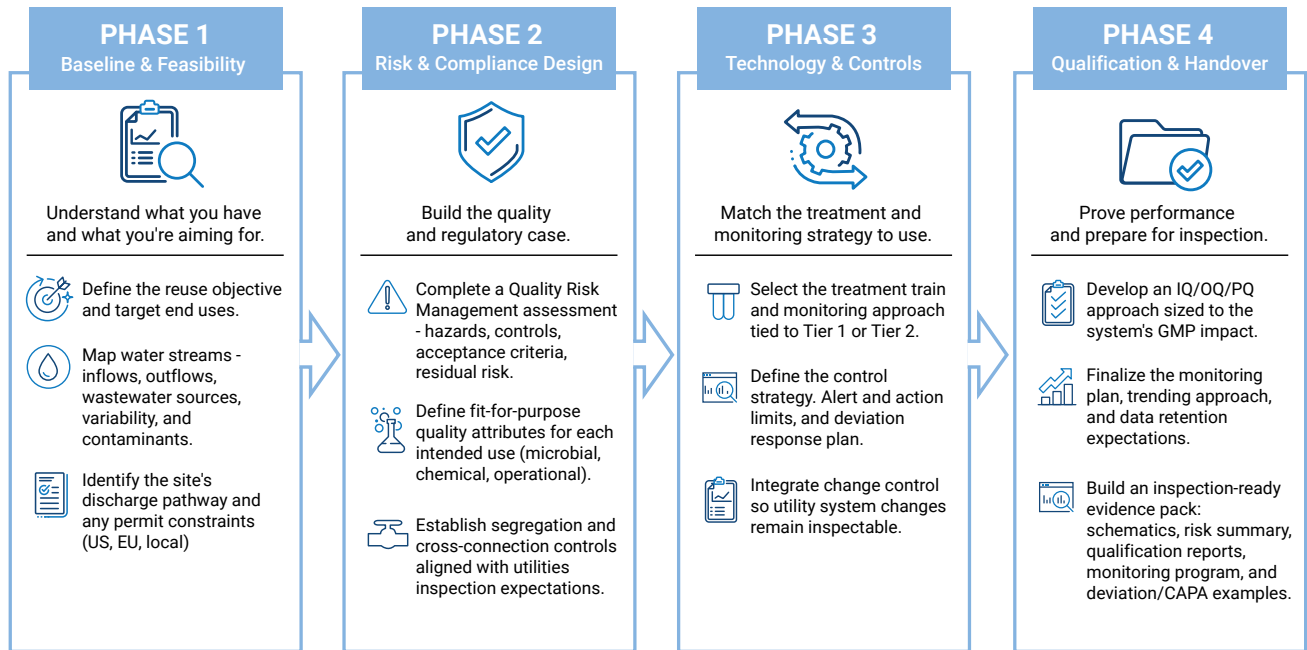
Anticipate Technical Challenges

- 1 **Water Quality Variability:** Wastewater streams vary by source and process. Treatment design must be flexible, with robust buffering to absorb swings.
- 2 **Targeted Contaminant Removal:** Treatment selection must match the reuse target, regulatory limits, and process sensitivity – not the highest available quality by default.
- 3 **Stability for Validated Systems:** Utility water variability can cascade into validated production. Reuse systems must deliver stable supply quality with minimal impact downstream.

Infrastructure determines what is physically possible. Treatment determines what quality can be achieved. Design and validation determine what is acceptable and scalable. Successful water circularity requires all three to be designed together to deliver consistent, fit-for-purpose water across every reuse pathway.

Implementation Framework

Once a circularity opportunity has been identified and the site is ready to act, the work shifts to execution. The four-phase framework below supports both project delivery and inspection readiness. Each phase should align with the site's specific permits and GMP requirements.



Inspection Readiness

The implementation framework, infrastructure design, and validation strategy all feed into the same outcome: a system that can withstand inspection. Inspectors look for clear evidence that the site understands its water system, controls it consistently, and can document every decision behind it.

Key Inspection Areas

System Clarity

A clear description of the water system, its boundaries, and how it interfaces with GMP water.

Qualification Evidence

Risk-based, justified qualifications (IQ, OQ, and PQ) where appropriate.



Ongoing State of Control

Monitoring data and trend reviews that demonstrate the system is performing as intended.

Change Control Discipline

Documented control over components, setpoints, treatment chemistry, and piping changes.

Managing the Change to Recycled Water

Introducing recycled water, whether as a partial source or a full substitute, is a change that must be managed through the site's quality system. The path follows five steps:

- 1 **Assess the Change:** Evaluate the proposed use of recycled water under the change management system, with input from subject matter experts.
- 2 **Conduct a Risk Assessment:** Identify potential impacts on product quality, define the control strategy, and determine what additional testing, requalification, or revalidation is required before implementation.
- 3 **Validate the Treatment and System:** If the recycled water is treated before reuse, the treatment process must be validated to confirm it consistently delivers water that meets the quality required for its intended use. If recycled water is fed into the existing water system, validate the full system across the expected range of flow and contaminant conditions. Validation includes DQ, IQ, OQ, PQ, and validation maintenance.
- 4 **Implement and Confirm:** After the change is in place, confirm the objectives were achieved and that product quality was not affected.
- 5 **Monitor on an Ongoing Basis:** Routine monitoring of both the recycled water and the products made with it confirms continued compliance with all applicable specifications.

Validation and Ongoing Monitoring

Regulatory, Water, and Digital Intersection

Modern reuse programs succeed when three disciplines work together: regulatory expectations, treatment technology, and digital oversight. Each strengthens the others, and together they make consistent compliance achievable at scale.

Three Critical Intersections:

- **Monitoring and Trending:** Continuous data on system performance demonstrates ongoing state of control — the foundation of any inspection-ready program.
- **Data Integrity and Visibility:** Reliable, accessible data supports both day-to-day decisions and the evidence pack inspectors expect to see.
- **Predictive Insights:** Early signals enable proactive maintenance and risk reduction before issues affect water quality or production.

Digital tools don't replace validation or risk assessment; but make both stronger by enabling faster detection, deeper evidence, and sustained compliance.

Use Cases and Proof Points

Across the pharmaceutical industry, water circularity is moving from concept to measurable outcomes. The examples below demonstrate how the 3Rs framework translates into impact and ROI.

Reduce

- **The Opportunity:** Cleaning-in-place (CIP) rinse steps are among the most water-intensive operations in pharma manufacturing and one of the easiest places to capture quick wins without affecting GMP-validated processes.
- **The Approach:** By replacing the traditional three full-volume rinses with four rinses at 25% volume, total cleaning water consumption is reduced to roughly one-third of the baseline while still achieving the same cleaning efficacy.
- **The Result:** Up to 67% reduction in rinse water consumption per cleaning cycle, with shorter rinse times and no capital investment required.

Reuse

- **The Opportunity:** A pharmaceutical manufacturing site evaluated its full water balance – across utilities, production, environmental, wastewater treatment, and fiber dilution – to identify reuse pathways and reduce freshwater demand.
- **The Approach:** Through a structured water balance and circular design, the site captured high-quality streams for internal reuse, applied targeted in-process water reductions, and routed appropriate streams back into utility systems.
- **The Result:** Of 90,199 m³ of total water entering the site, 18,395 m³ was reused internally and an additional 4,189 m³ was eliminated through in-process reductions, meaningfully lowering both freshwater intake and wastewater discharge volume.

Recycle

- **The Opportunity:** A global pharmaceutical manufacturer committed to a 25% reduction in environmental impact by 2030, with cooling system performance as a key focus area.
- **The Approach:** Ecolab deployed 3D TRASAR™ technology to combine real-time monitoring, automated chemistry dosing, and digital oversight across the site's cooling operations – delivering continuous visibility and proactive optimization without disrupting validated production.
- **The Result:** The program delivers more than \$1.5M in Total Value Delivered each year, including 98 million gallons (370,970 m³) of water saved, 273 million kWh of energy avoided, and a reduction of 19,000 metric tons of CO₂e in greenhouse gas emissions.

Lessons Learned

Across the industry, water circularity is adopted as a phased journey, not a single leap to full recycling. Most sites begin with initiatives to stabilize or reduce water demand. Followed by reuse-focused initiatives in utility systems where GMP risk is lowest. Finally, full-scale recycling initiatives are pursued primarily by large, global manufacturers facing scarcity, reputational risk, or permit pressure.

What Works

- Starting with fit-for-purpose use cases that match site readiness
- Engaging QA early and framing reuse as a quality decision, not an engineering one
- Using established GMP risk frameworks (ICH Q9) rather than building new ones
- Anchoring discussions in inspection readiness from the outset
- Running pilot programs and using data to build confidence before scaling

What Slows Progress

- Treating reuse as an engineering project without QA ownership
- Over-engineering early stages before baseline data is understood
- Avoiding reuse entirely based on perceived regulatory risk rather than assessed risk
- Pursuing the highest-quality opportunity instead of the lowest-risk, highest-impact one

How Ecolab Supports the Journey

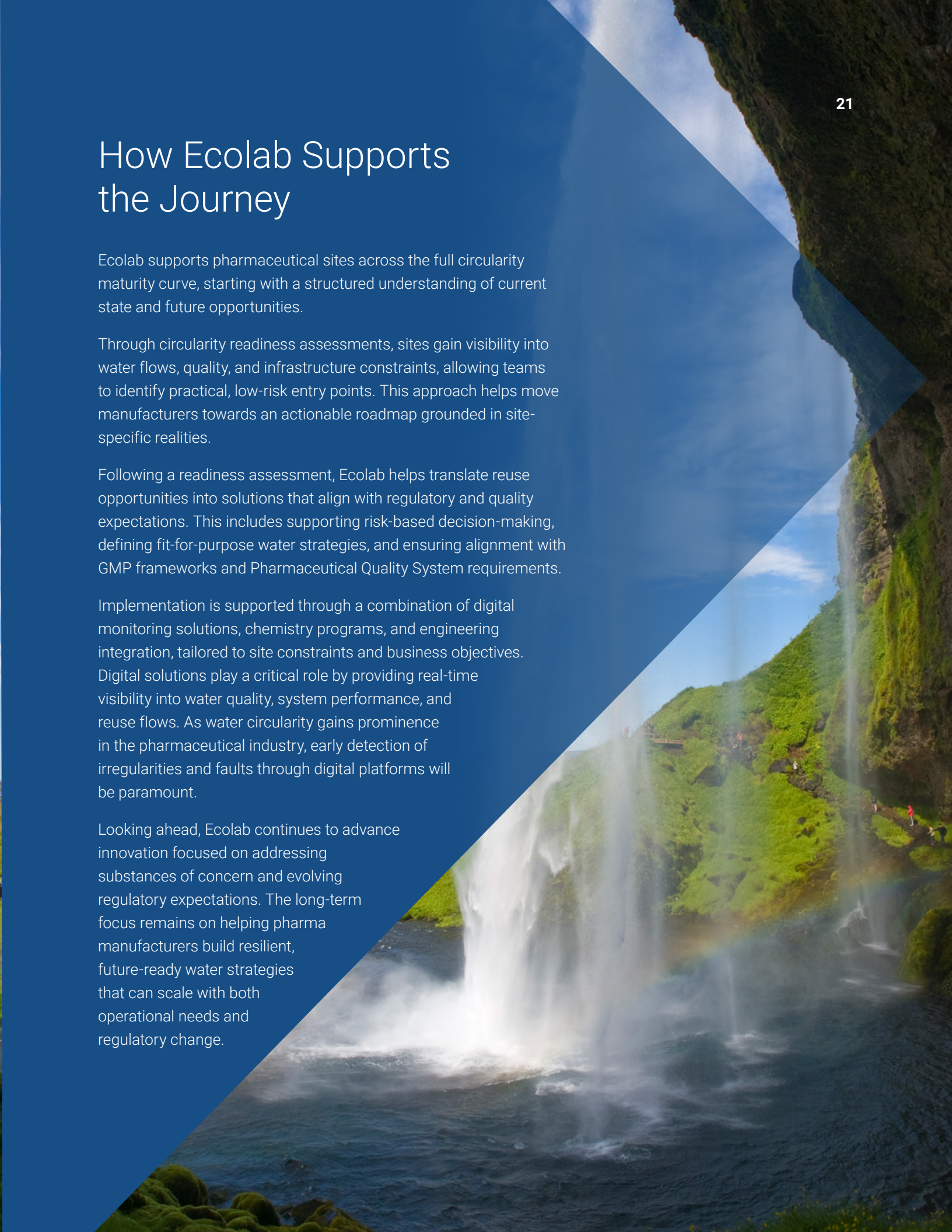
Ecolab supports pharmaceutical sites across the full circularity maturity curve, starting with a structured understanding of current state and future opportunities.

Through circularity readiness assessments, sites gain visibility into water flows, quality, and infrastructure constraints, allowing teams to identify practical, low-risk entry points. This approach helps move manufacturers towards an actionable roadmap grounded in site-specific realities.

Following a readiness assessment, Ecolab helps translate reuse opportunities into solutions that align with regulatory and quality expectations. This includes supporting risk-based decision-making, defining fit-for-purpose water strategies, and ensuring alignment with GMP frameworks and Pharmaceutical Quality System requirements.

Implementation is supported through a combination of digital monitoring solutions, chemistry programs, and engineering integration, tailored to site constraints and business objectives. Digital solutions play a critical role by providing real-time visibility into water quality, system performance, and reuse flows. As water circularity gains prominence in the pharmaceutical industry, early detection of irregularities and faults through digital platforms will be paramount.

Looking ahead, Ecolab continues to advance innovation focused on addressing substances of concern and evolving regulatory expectations. The long-term focus remains on helping pharma manufacturers build resilient, future-ready water strategies that can scale with both operational needs and regulatory change.



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Contact your Ecolab sales representative to learn more about how we can help you increase efficiency while reducing water, energy, greenhouse gas emissions and more.

The results in the case studies included in this document are specific to the individual customers and may vary for other customers based on factors and circumstances in their operations.



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