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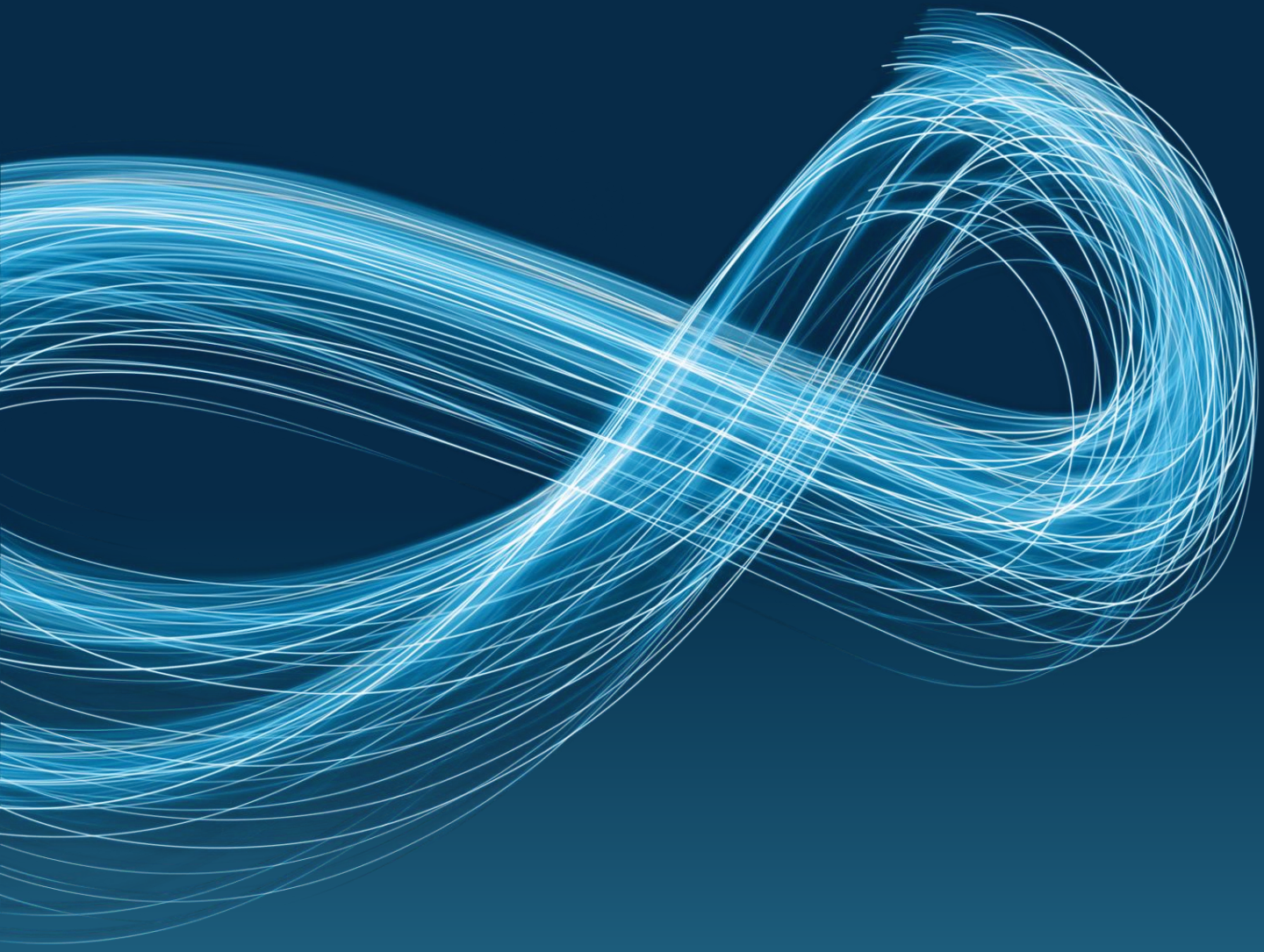

CESI Perspective:

Rethinking Water Infrastructure for a Climate-Stressed Future

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Water has always been central to Italy's economic development, territorial cohesion and industrial capacity.

Yet today, the country faces a structural challenge that is both environmental and systemic: how to manage an increasingly scarce and volatile resource within an infrastructure network that is aging, under strain, and not fully aligned with emerging technological and climatic realities.

From the perspective of CESI, this is not simply a matter of environmental stewardship. It is a question of resilience, governance and long-term national competitiveness.

A Resource Increasingly Defined by Extremes

Recent data confirms the severity of the challenge. In 2022, Italy recorded the lowest level of renewable freshwater availability since 1951, with total volumes dropping by roughly one third compared to the previous year. The reduction amounted to approximately 36 billion cubic meters—equivalent to around sixty times the volume of Lake Trasimeno. The consequences were immediate and far-reaching: hydroelectric production fell to its lowest level since the mid-1950s, despite a reservoir system that is now three times larger than it was at that time.

The underlying issue is not only the quantity of rainfall, but its distribution. Italy receives roughly 300 billion cubic meters of precipitation annually. However, that rainfall is now increasingly concentrated in short, intense events, interspersed with prolonged periods of drought. This growing variability is placing stress on both natural systems and engineered infrastructure.

In this context, storage capacity becomes a critical metric. Italy's total nominal reservoir capacity stands at approximately 14 billion cubic meters—just over 200 cubic meters per inhabitant. This is significantly lower than in comparable Mediterranean countries, indicating a structural limitation in the country's ability to buffer climatic variability.

At the same time, demand remains high. Italy ranks first in the European Union for total freshwater withdrawals for potable use, with nearly 9 billion cubic meters abstracted annually. This reflects not only population density and economic activity, but also the central importance of water across the entire national system—from agriculture to industry and energy production.

The Weight of Legacy Infrastructure

Italy's water system is built on an extraordinary legacy of engineering. From the early development of industrial-scale hydropower in the late 19th century to the extensive network of dams, aqueducts and distribution systems that followed, the country has long demonstrated technical excellence in water management.

Today, however, that legacy comes with new responsibilities. The average age of large dams in Italy exceeds 60 years—among the highest in the world for comparable systems. While this does not imply an inherent safety risk, it does necessitate increasing levels of monitoring, maintenance and targeted upgrades.

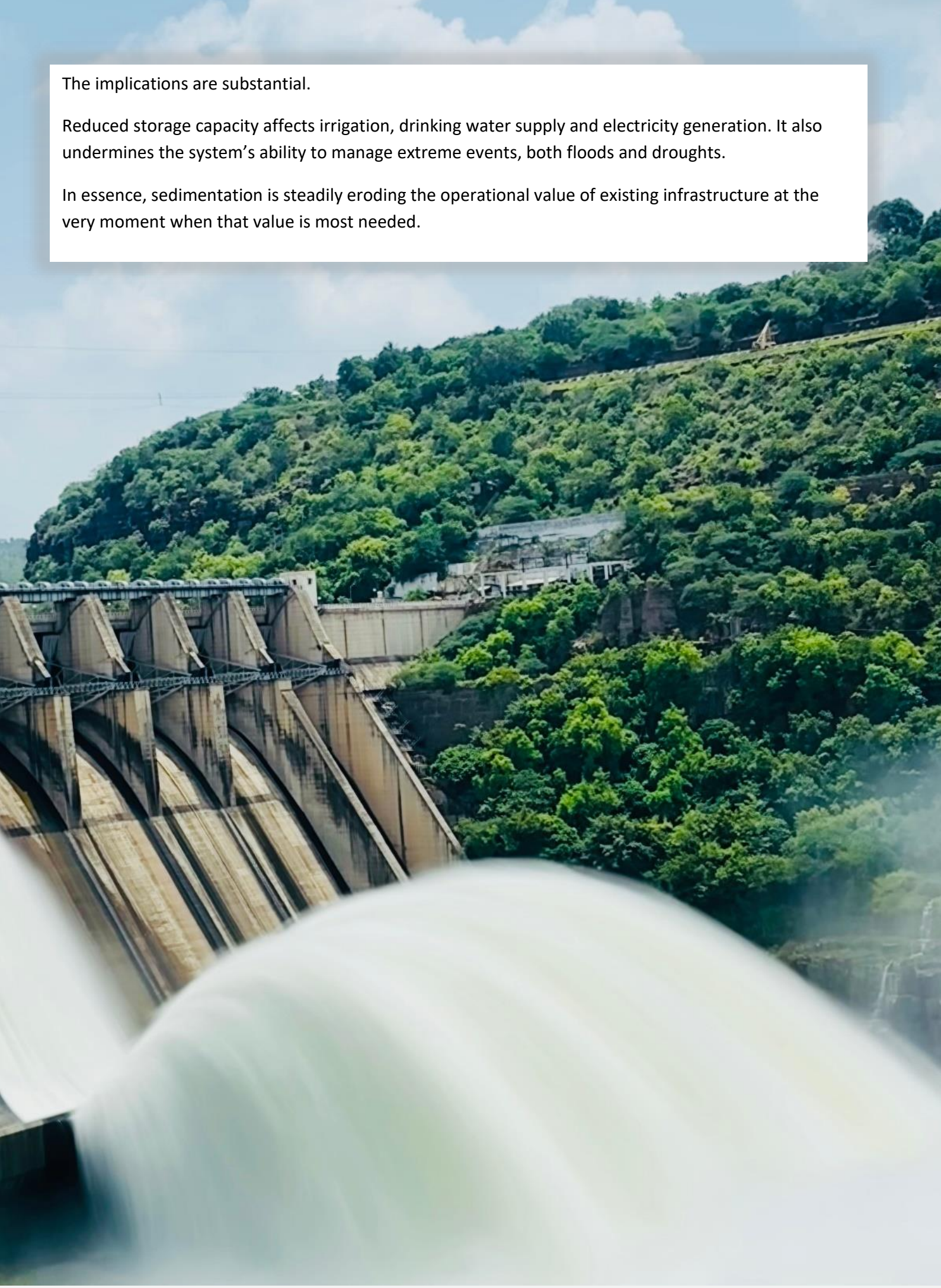
After decades of operation, infrastructure must be reassessed against conditions that differ significantly from those for which it was originally designed. Climate patterns have shifted, seismic risk assessments have evolved, and operational demands have intensified. Ensuring safety and performance requires a continuous process of verification and adaptation.

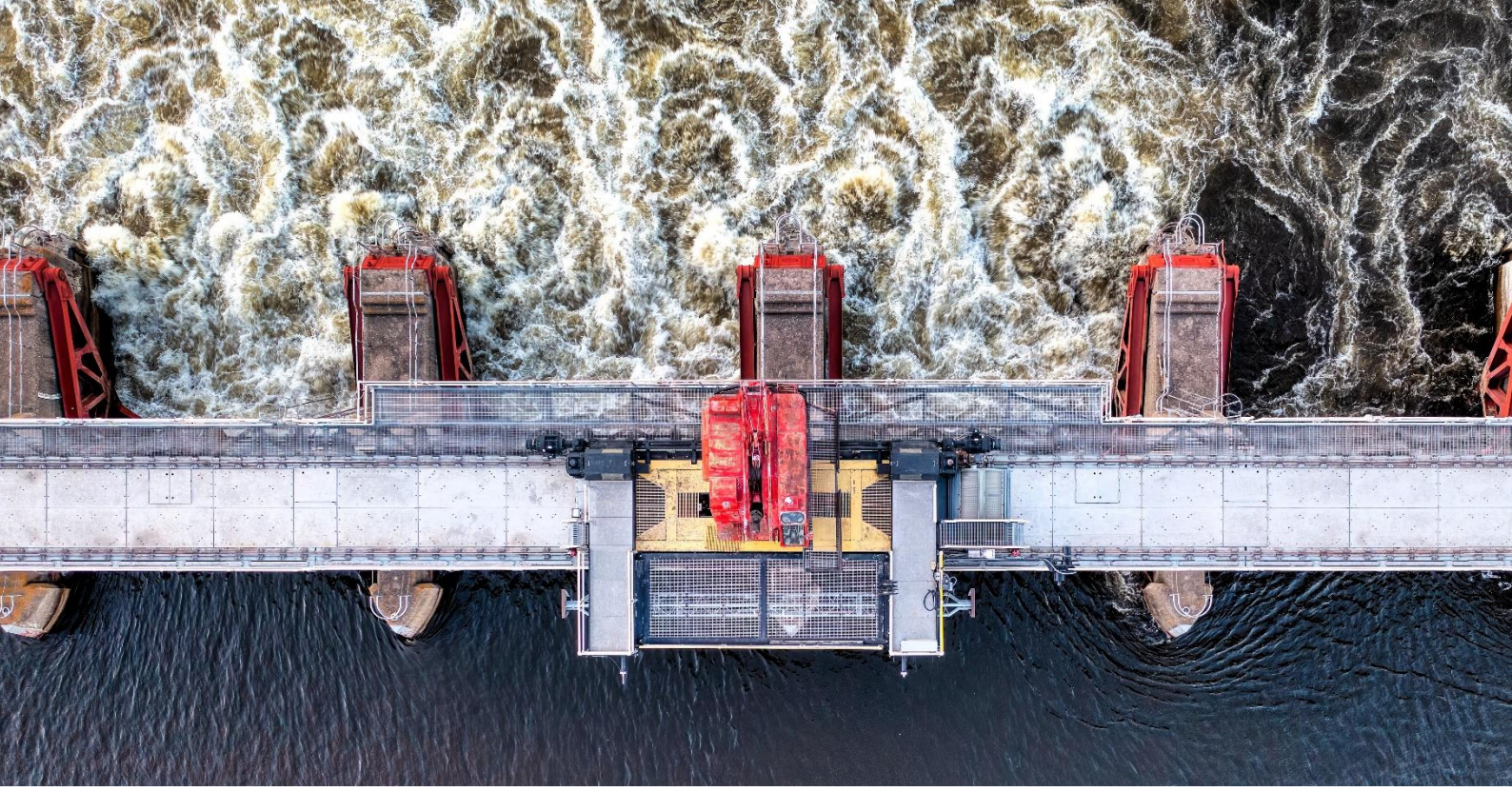
One of the most significant, yet often underappreciated, challenges is sedimentation. Over time, reservoirs accumulate sediments that reduce their effective storage capacity. According to sector analyses, nearly half of Italy's major reservoirs show significant levels of sedimentation, with capacity losses in some cases reaching 30 to 40 percent of their nominal volume.

The implications are substantial.

Reduced storage capacity affects irrigation, drinking water supply and electricity generation. It also undermines the system's ability to manage extreme events, both floods and droughts.

In essence, sedimentation is steadily eroding the operational value of existing infrastructure at the very moment when that value is most needed.





A Complex Regulatory Landscape

Addressing these issues is not solely a technical matter. In Italy, reservoir management—particularly sediment removal—is governed by a complex regulatory framework involving multiple authorities and layers of approval.

Over the past three decades, environmental protection has rightly become more stringent, introducing detailed requirements for the characterization, handling and disposal of sediment materials. While these measures have contributed to safeguarding ecosystems and landscapes, they have also increased the procedural complexity and timelines associated with intervention.

Each project must reconcile environmental sustainability, economic feasibility and operational urgency. This balancing act is especially challenging in a context where delays can translate directly into further loss of storage capacity and increased vulnerability to water stress.

Looking ahead, the absence of effective intervention strategies risks leading to a gradual but irreversible reduction in the usable volume of many reservoirs. Building new large-scale storage infrastructure is not a straightforward alternative. The most suitable sites have largely been developed, and new projects often face significant challenges in terms of environmental impact assessments and public acceptance.

The logical path, therefore, is to preserve and enhance the assets already in place.

Strategic Direction and National Initiatives

Italy has begun to move in this direction. National programs aimed at improving the safety and efficiency of large dams include objectives to safeguard billions of cubic meters of water resources and to recover significant volumes that are currently unusable. Such initiatives reflect a broader

recognition that water infrastructure must be treated as a strategic asset. They also underscore the importance of coordinated action between central government, regional authorities and local stakeholders.

Yet even the most well-designed programs depend on effective implementation. This requires not only funding but also streamlined governance mechanisms capable of reducing fragmentation and accelerating decision-making processes.

The Emerging Nexus: Water, Energy and Digital Infrastructure

A less visible but rapidly growing dimension of the water challenge is linked to technological transformation. The expansion of digital infrastructure, particularly large-scale data centers, is introducing new and significant demands on water resources.

Hyperscale data centers can consume up to two million liters of water per day, comparable to the needs of a town of 10,000 people. At a global level, the water footprint of data centers has reached trillions of liters annually and is expected to grow sharply in the coming years.

The reason lies in a fundamental physical constraint: heat. Whether in power generation or data processing, the management of heat is a central issue, and water remains the most efficient medium for cooling systems at scale.

This creates a direct link between two domains that are often considered separately: digitalization and water management. As societies become increasingly reliant on data-intensive services, the pressure on water systems will intensify, requiring integrated planning across sectors.

Technological Pathways: From Monitoring to Prediction

In this context, innovation is not optional—it is essential. Advances in sensor technology, data analytics and modelling are opening new possibilities for managing water infrastructure more effectively.

Continuous monitoring systems can track structural conditions, hydrological parameters and operational performance in real time, enabling early detection of anomalies. Predictive models, supported by large datasets, can simulate the behavior of reservoirs under extreme conditions such as sudden floods or prolonged droughts.

One of the most promising tools is the concept of the digital twin: a virtual representation of a physical asset that evolves dynamically based on real-world data. By integrating historical information, current measurements and predictive algorithms, digital twins allow operators to test scenarios, optimize interventions and reduce uncertainty.

These technologies shift the paradigm from reactive to proactive management. Instead of responding to crises after they occur, operators can anticipate risks and implement preventive measures, improving both safety and efficiency.

From Challenge to Opportunity: Practical Applications

Concrete examples demonstrate how these approaches can be applied. In central Italy, studies are underway to recover reservoir capacity through innovative sediment management techniques that combine engineering solutions with environmental considerations.

The objective is not only to remove accumulated material, but also to reintegrate it into the system where possible, in line with principles of circular economy. Such interventions have the potential to restore significant volumes of water storage while minimizing ecological impact.

At the same time, broader programs are being developed to upgrade and monitor dozens of dams across the country. These initiatives involve the deployment of advanced control systems and predictive diagnostics—essentially providing each structure with a “digital health check”.

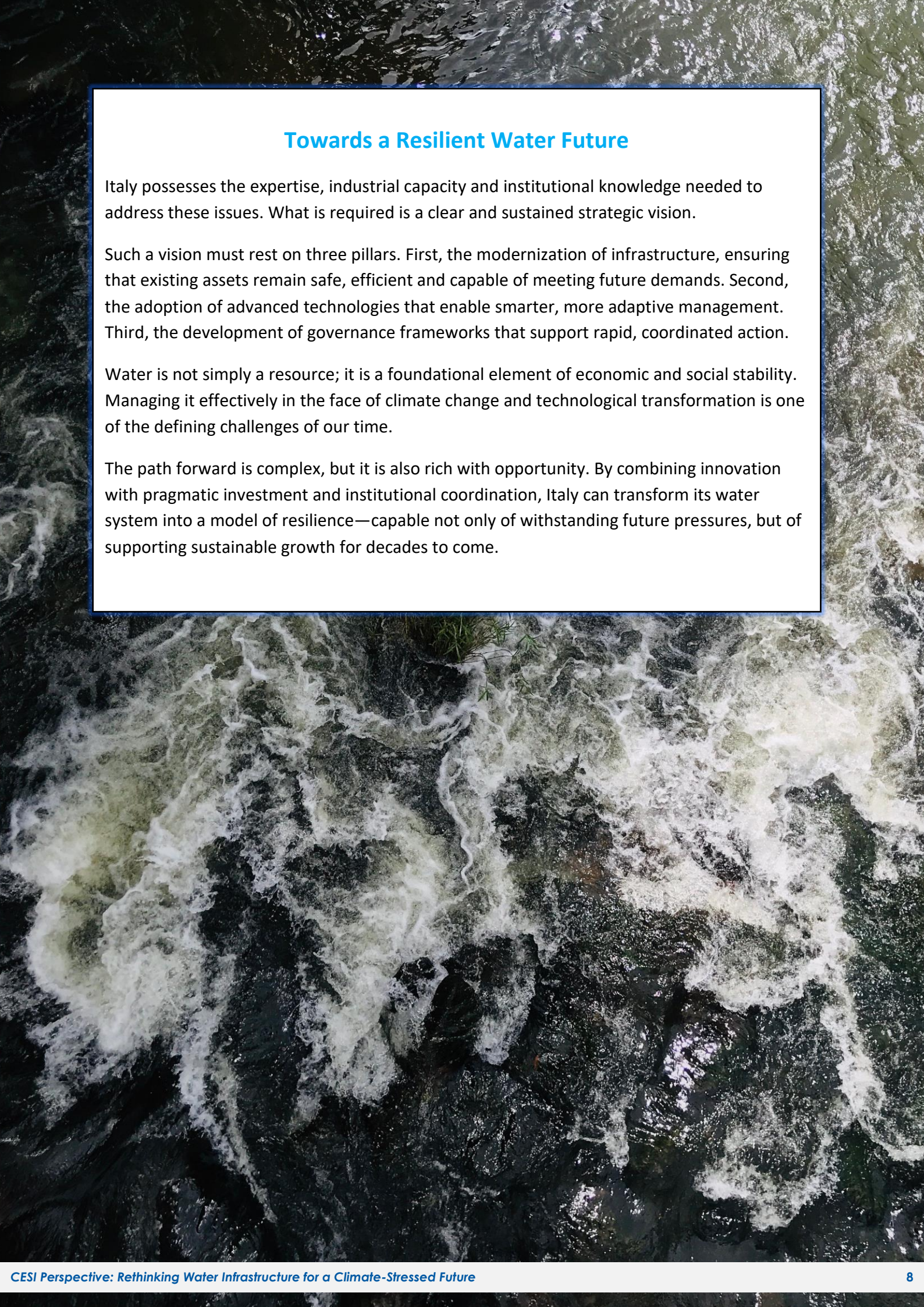
The benefits are multiple: extended asset lifespans, reduced risk of failure, improved operational performance, and enhanced resilience of the overall water system.

Governance and Technology: A Dual Imperative

Ultimately, the effectiveness of these solutions depends on the alignment between technology and governance. Technical capabilities alone are not sufficient if they are constrained by fragmented regulatory frameworks or prolonged approval processes.

A coordinated approach is required, one that enables timely intervention while maintaining high environmental standards. This involves not only simplifying procedures, but also fostering collaboration among institutions, operators and local communities.

In many respects, water management illustrates a broader principle: complex challenges cannot be addressed through isolated actions. They require integrated strategies that combine engineering, policy and societal engagement.



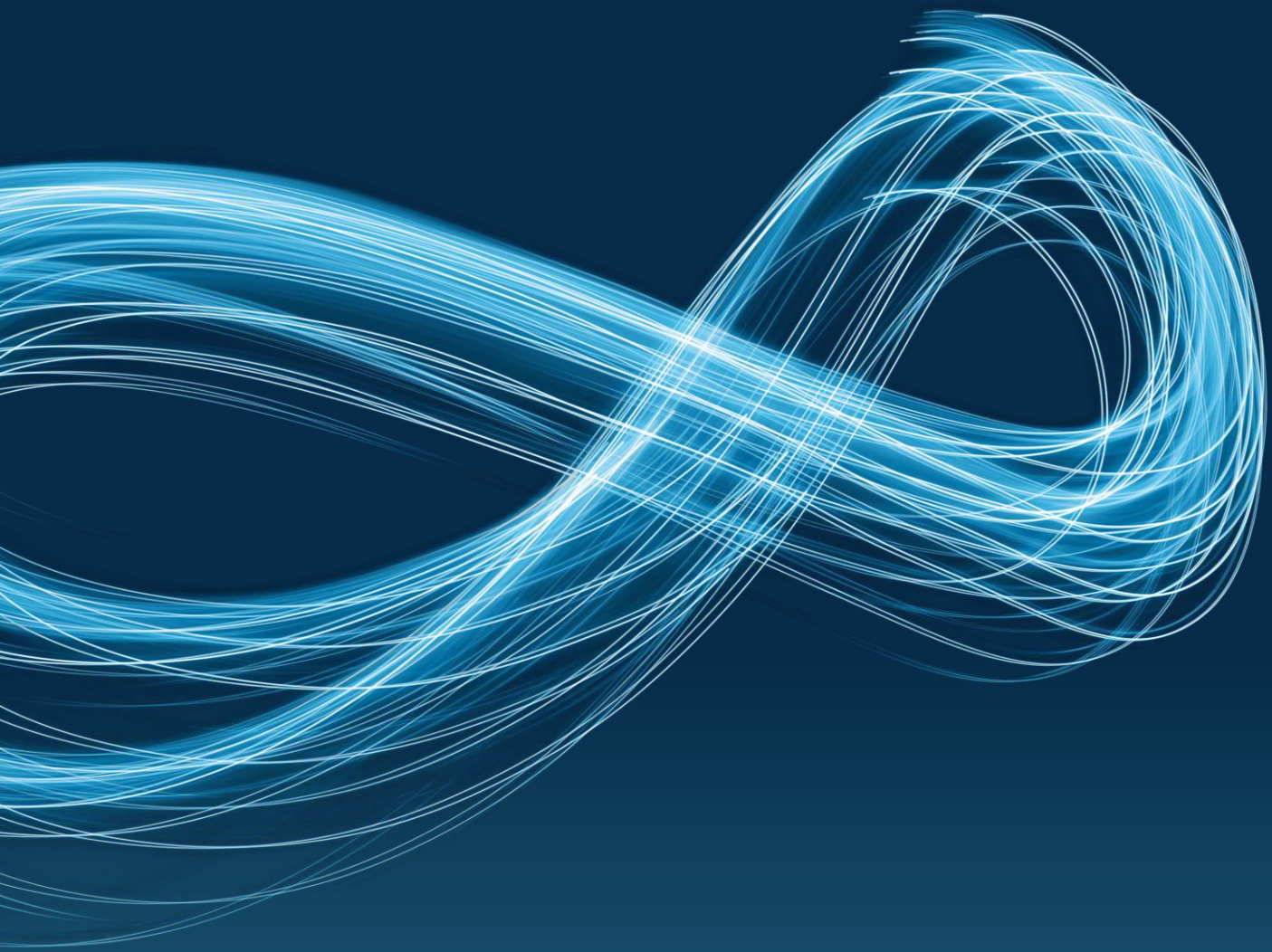
Towards a Resilient Water Future

Italy possesses the expertise, industrial capacity and institutional knowledge needed to address these issues. What is required is a clear and sustained strategic vision.

Such a vision must rest on three pillars. First, the modernization of infrastructure, ensuring that existing assets remain safe, efficient and capable of meeting future demands. Second, the adoption of advanced technologies that enable smarter, more adaptive management. Third, the development of governance frameworks that support rapid, coordinated action.

Water is not simply a resource; it is a foundational element of economic and social stability. Managing it effectively in the face of climate change and technological transformation is one of the defining challenges of our time.

The path forward is complex, but it is also rich with opportunity. By combining innovation with pragmatic investment and institutional coordination, Italy can transform its water system into a model of resilience—capable not only of withstanding future pressures, but of supporting sustainable growth for decades to come.



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