

PARADOXES OF WATER REUSE: WHEN CIRCULARITY CONFLICTS WITH ENVIRONMENTAL AND GOVERNANCE PRINCIPLES

LES PARADOXES DE LA REUTILISATION DE L'EAU : QUAND LA CIRCULARITE ENTRE EN CONFLIT AVEC LES PRINCIPES ENVIRONNEMENTAUX ET DE GOUVERNANCE

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ABSTRACT

Water reuse is increasingly promoted as a key instrument of circular water management, especially in response to climate change, drought, water scarcity, and growing pressure on freshwater resources (VOULVOULIS, 2018). By transforming treated wastewater into an alternative resource, reuse is commonly presented as an inherently sustainable practice capable of reducing freshwater withdrawals, limiting discharges, and improving territorial resilience. However, this paper argues that water reuse also embeds structural paradoxes that challenge a simplified understanding of circularity.

The first paradox concerns the relationship between reuse and wastewater discharges. While reducing treated effluent discharges may appear environmentally beneficial at the local scale, it can have unintended consequences at the river basin scale. In highly anthropised systems, treated wastewater often contributes to low flows, dilution capacity, hydrological continuity, and downstream ecological conditions. Maximising reuse may therefore weaken certain hydrological balances, particularly during low-flow periods.

The second paradox is regulatory. Direct reuse of treated wastewater is often subject to strict quality standards, monitoring obligations, risk management requirements, and authorisation procedures. By contrast, indirect reuse through discharge into the environment and subsequent downstream abstraction may be legally simpler, even though it can be functionally similar from a hydrological perspective. This asymmetry may create incentives to preserve linear discharge-and-abstraction pathways rather than formally organise circular water reuse.

The paper argues that these paradoxes reflect deeper governance issues. Water reuse is frequently promoted through sectoral objectives such as agricultural supply, urban resilience, industrial efficiency, etc. without sufficient integration into basin-scale water planning. A genuinely circular approach should therefore assess reuse not only by the volume of water reused, but also by its effects on downstream flows, ecological needs, allocation conflicts, and regulatory coherence. The paper concludes by calling for a systemic reuse strategy that aligns direct and indirect reuse regimes, integrates downstream impacts, and embeds reuse policies within river basin management planning.

Keywords: Water reuse; Structural paradoxes; Wastewater discharges; Downstream impacts; River basin management.

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RÉSUMÉ

La réutilisation de l'eau est de plus en plus encouragée comme un outil clé de la gestion circulaire de l'eau, notamment pour faire face au changement climatique, à la sécheresse, à la pénurie d'eau et à la pression croissante sur les ressources en eau douce (VOULVOULIS, 2018). En transformant les eaux usées traitées en une ressource alternative, la réutilisation est généralement présentée comme une pratique intrinsèquement durable, capable de réduire les prélèvements d'eau douce, de limiter les rejets et d'améliorer la résilience territoriale. Cependant, ce papier soutient que la réutilisation de l'eau comporte également des paradoxes structurels qui remettent en cause une conception simplifiée de la circularité.

Le premier paradoxe concerne la relation entre la réutilisation et les rejets d'eaux usées. Si la réduction des rejets d'effluents traités peut sembler bénéfique pour l'environnement à l'échelle locale, elle peut avoir des conséquences imprévues à l'échelle du bassin fluvial. Dans les systèmes fortement anthropisés, les eaux usées traitées contribuent souvent aux débits d'étiage, à la capacité de dilution, à la continuité hydrologique et aux conditions écologiques en aval. Maximiser la réutilisation peut donc affaiblir certains équilibres hydrologiques, en particulier pendant les périodes de faible débit.

Le deuxième paradoxe est d'ordre réglementaire. La réutilisation directe des eaux usées traitées est souvent soumise à des normes de qualité strictes, à des obligations de surveillance, à des exigences en matière de gestion des risques et à des procédures d'autorisation. En revanche, la réutilisation indirecte au moyen d'un rejet dans l'environnement suivi d'un prélèvement en aval peut s'avérer juridiquement plus simple, même si elle peut être fonctionnellement similaire d'un point de vue hydrologique. Cette asymétrie peut inciter à préserver les filières linéaires de rejet et de prélèvement plutôt qu'à organiser formellement une réutilisation circulaire de l'eau.

Le papier soutient que ces paradoxes reflètent des enjeux de gouvernance plus profonds. La réutilisation de l'eau est fréquemment encouragée par l'intermédiaire d'objectifs sectoriels, tels que l'approvisionnement agricole, la résilience urbaine, l'efficacité industrielle, etc., sans intégration suffisante dans la planification de l'eau à l'échelle du bassin. Une approche véritablement circulaire devrait donc évaluer la réutilisation non seulement en fonction du volume d'eau réutilisé, mais aussi en fonction de ses effets sur les débits en aval, les besoins écologiques, les conflits d'allocation et la cohérence réglementaire. Le papier conclut en appelant à une stratégie systémique de réutilisation qui harmonise les régimes de réutilisation directe et indirecte, intègre les impacts en aval et intègre les politiques de réutilisation dans la planification de la gestion des bassins fluviaux.

Mots-clés : Réutilisation de l'eau; Paradoxes structurels; Rejets d'eaux usées; Impacts en aval; Gestion des bassins fluviaux.

INTRODUCTION

Water reuse is increasingly promoted as a key component of circular water management. In a context marked by climate change, recurrent droughts, growing pressure on freshwater resources, and competing demands from agricultural, urban and industrial users, the reuse of treated wastewater appears as both a technical solution and a policy priority. It is commonly associated with multiple benefits: reducing freshwater withdrawals, securing non-potable uses, enhancing territorial resilience, limiting wastewater discharges, and supporting the transition from linear to circular resource management.

Within this narrative, treated wastewater is no longer regarded merely as an effluent to be discharged into the environment after treatment, but as a valuable alternative water resource. Reuse schemes are therefore often presented as inherently virtuous: they would close water loops, reduce pressure on conventional resources, and contribute to a more sustainable allocation of water. However, this contribution argues that such a representation, although relevant in principle, may obscure a series of

structural paradoxes. Water reuse is not automatically circular, nor is it necessarily environmentally beneficial in all contexts. Its impact depends on the spatial scale considered, the hydrological configuration of the river basin, the regulatory framework in place, and the governance arrangements through which reuse projects are implemented.

This paper therefore examines the paradoxes embedded in water reuse policies and practices. It argues that the more water reuse is framed as a local strategy for closing water loops, the more it may reveal or reinforce broader hydrological, legal and institutional dependencies inherited from linear water management systems. These paradoxes do not call into question the relevance of water reuse as such. Rather, they show that reuse should not be treated as an end in itself, but as one instrument among others within an integrated and systemic approach to water governance.

1. WATER REUSE AS A PROMISE OF CIRCULARITY

Water reuse forms part of a broader transformation in water policy. Traditional urban water systems have long been structured according to a linear model: water is abstracted from the environment, treated, distributed, used, collected as wastewater, treated again, and finally discharged into receiving water bodies (BIXIO *et al.*, 2006). This model has played a crucial role in improving public health and environmental protection, particularly through the development of wastewater collection and treatment infrastructures. Yet it is increasingly challenged by water scarcity, climate variability, drought events, and the need to reduce pressure on freshwater ecosystems.

Against this background, water reuse is often presented as a paradigm shift. Treated wastewater becomes a resource rather than a residual flow. It can be used for agricultural irrigation, landscape irrigation, street cleaning, industrial processes, aquifer recharge, urban non-potable uses, and, in some jurisdictions, even indirect or direct potable reuse under strict conditions. The underlying logic is one of substitution: water of a quality appropriate to a given use should replace conventional freshwater where high-quality water is not strictly necessary. In principle, this allows higher-quality resources to be preserved for uses that require them, especially drinking water production.

This approach is attractive because it appears to reconcile several policy objectives. It contributes to climate change adaptation, promotes water efficiency, reduces pressure on conventional resources, supports technological innovation, and aligns with broader circular economy principles. It also responds to the idea that flows once considered as waste can be transformed into usable resources. In this sense, water reuse has become one of the most visible symbols of circular water management.

However, substitution is not the one and only practice that occurs with water reuse. Two other situations can happen with various consequences, in which the expression “circular water management” is not clear. This is for example the case when a new activity requiring water is created, such as the creation of golf courses, extension of irrigation area etc. In that case, new needs can be covered with water reuse. Another situation can occur when climate conditions are forcing practice changes, such as irrigation of lands that did not need water under previous climate conditions.

However, this promise of circularity often rests on a simplified understanding of the water cycle. It tends to assume that reducing wastewater discharges and increasing reused volumes necessarily constitute environmental progress. Yet this assumption is not always valid. In some territories, treated wastewater discharges are not merely outputs from urban systems; they have become part of the hydrological functioning of rivers and streams. Reuse can therefore modify fragile balances that have already been shaped by human infrastructure. This gives rise to a first paradox.

2. FIRST PARADOX: REDUCING WASTEWATER DISCHARGES MAY WEAKEN HYDROLOGICAL BALANCES

The first paradox concerns the relationship between reuse and discharge. By definition, a reuse project diverts part of the treated wastewater flow from its usual discharge point and reallocates it to another use. From a local circularity perspective, this diversion is generally seen as positive. It reduces the volume of effluents discharged into the environment, limits the apparent loss of water from the urban system, and creates an additional resource for beneficial uses.

A hypothetical city approaching 100% water reuse could therefore appear to embody an ideal model of circular water management. It would drastically reduce freshwater withdrawals and almost eliminate treated wastewater discharges. At the scale of the city or the wastewater treatment plant, such a model may seem environmentally optimal. However, the picture becomes more complex when the analysis shifts to the river basin scale. In many highly anthropised systems, treated wastewater discharges contribute significantly to river flows, particularly during low-flow periods even though WWTP were not designed to support low-flow rates (LUTHY *et al.*, 2015). However, in the practice, these effluents may support base flows, maintain a minimum degree of hydrological continuity, contribute to the dilution of other pollutants, and sustain downstream ecosystems and uses. Although they originate from an artificial urban cycle, they can become structurally integrated into the functioning of the receiving environment. Moreover, low-flow rate is a crucial parameter regarding ecological status of water bodies, and UE law, especially Directive 2000/60/CE give objectives regarding good ecological status.

The substantial reduction or elimination of such discharges may therefore produce unintended consequences. On the one hand, it decreases the release of treated effluents into the environment. On the other hand, it may reduce downstream flows in some precise cases. It happens especially when abstraction of freshwater is done in a different source from where water is rejected after its treatment in WWTP. Effectively, downstream flow is impacted by reduced rejections, while it does not benefit from reduced abstraction (since abstraction is done in another water source in this precise case). However, water reuse does not affect downstream flow when abstractions from the same water source are reduced thanks to water reuse. That being said, in cases of real downstream flow alteration, apart from the quantitative perspective, it may also weaken dilution capacity, increase the relative concentration of residual pollution, and affect ecological conditions or downstream abstractions. The issue is not that reuse inherently creates environmental harm. Rather, it reveals the extent to which contemporary river regimes are already shaped by human infrastructure, including wastewater treatment systems.

This paradox highlights the need to distinguish between different scales of assessment. At the project or urban scale, reuse may appear as a successful closing of the water loop. At the basin scale, however, it may displace pressures, alter downstream availability, or affect environmental flows. Local circular efficiency may therefore conflict with integrated river basin management. A reuse strategy that maximises reused volumes without considering downstream hydrological effects risks transforming local performance into a collective constraint.

Consequently, the success of water reuse policies should not be measured solely by the volume of water reused or the percentage of treated wastewater diverted from discharge. It should also be assessed in relation to territorial water balances, seasonal flow conditions, ecological needs, downstream uses, and cumulative impacts within the basin. The relevant question is not only: how much water can be reused? It is also: where, when, for which use, and with what effects on the broader hydrological system?

3. SECOND PARADOX: DIRECT REUSE MAY BE MORE BURDENSOME THAN INDIRECT REUSE

A second paradox concerns the legal and regulatory framing of reuse. In many jurisdictions, direct reuse of treated wastewater is subject to a specific regulatory regime. Such regimes typically impose quality standards, monitoring obligations, risk management requirements, authorisation procedures, and clear

responsibilities for producers, distributors and users. This approach is justified. When treated wastewater is directly allocated to a specific use, public authorities must ensure that its quality is appropriate and that risks to human health and the environment are properly managed.

However, this creates a regulatory asymmetry. Treated wastewater that is directly reused for irrigation or other non-potable purposes may be subject to strict requirements. By contrast, treated effluents discharged into a water body and later abstracted downstream may fall under different legal regimes, often without being framed as reuse (BEARD *et al.*, 2019). In this second scenario, the water changes legal status through its passage into the environment. Dilution, natural attenuation and regulatory fragmentation obscure the functional continuity between the initial discharge and the downstream abstraction.

This gives rise to a paradoxical situation: indirect reuse through discharge and subsequent abstraction may be legally simpler and economically more attractive than a formal direct reuse scheme, even though the two situations may be functionally close from the scheme. In both cases, water originating from an urban wastewater cycle may contribute to a subsequent beneficial use. Yet in the direct reuse scenario, this continuity is explicit and therefore regulated. In the indirect reuse scenario, the continuity is fragmented and less visible from a legal point of view.

Such asymmetry may create counterproductive incentives. Actors may be encouraged to rely on conventional discharge-and-abstraction pathways rather than develop formally regulated reuse projects, especially where authorisation procedures, treatment requirements, monitoring costs or liability concerns make direct reuse complex. The law may therefore unintentionally favour linear water management practices: discharge, dilute, reabstract, and reuse implicitly, rather than explicitly organising circularity.

This paradox reveals a deeper tension between two regulatory logics. The first is a use-specific and risk-based approach, focused on water quality, exposure pathways and the intended use. This logic is essential for protecting health and the environment. The second is a system-based approach, focused on hydrological continuity, basin-scale interdependencies and cumulative effects. The problem is not the existence of strict rules for direct reuse. Rather, it is the lack of equivalent attention to indirect forms of reuse and to the way dilution can function as an implicit regulatory mechanism.

A coherent circular water policy should therefore address not only the safety of direct reuse schemes, but also the broader legal distinction between discharge, dilution, abstraction and reuse. Otherwise, formal reuse may remain more constrained than functional reuse, and circularity may be discouraged precisely where it is made visible.

4. THIRD PARADOX: CIRCULARITY MAY REINFORCE FRAGMENTED WATER GOVERNANCE

A third paradox is institutional. Water reuse is often presented as an integrated solution capable of connecting water supply, sanitation, agriculture, urban planning, industry, environmental protection and climate adaptation (RIAZI *et al.*, 2022). In practice, however, reuse often reveals the fragmentation of water governance. It lies at the intersection of several policy domains, each with its own objectives, authorities, technical standards and risk perceptions.

Reuse projects involve many actors: wastewater treatment plant operators, local authorities, water utilities, environmental agencies, health authorities, farmers, industrial users, urban planners, engineering firms, financing bodies and final users. Each actor approaches reuse through a different lens. Health authorities focus on exposure and sanitary risk. Environmental authorities consider receiving water bodies, ecological flows and discharge permits. Users seek reliable and affordable water. Local authorities pursue resilience, economic development and compliance with environmental obligations. Technology providers emphasise treatment performance and innovation.

This plurality is not problematic in itself. On the contrary, water reuse requires interdisciplinary and multi-actor coordination. Yet it may lead to fragmented decision-making if no integrated framework is in place. Each sector may promote reuse as a solution to its own problem: agriculture sees an additional resource, cities see a resilience tool, industries see an efficiency measure, and environmental policies see a way to reduce discharges. But the accumulation of sectoral interests does not automatically produce a coherent basin-wide strategy.

Reuse also involves allocation choices. Water reused in one location is no longer available in the same form elsewhere. A discharge avoided upstream may alter flows downstream. A use prioritised today may affect future options. Reuse therefore does not eliminate water scarcity or competition; it redistributes them. It also redistributes responsibilities, costs and risks. Who should pay for additional treatment? Who is responsible if water quality deteriorates during storage or distribution? Who accounts for downstream impacts? Who decides whether irrigation, urban uses or ecological flows should be prioritised? If circularity is understood only as a technical process of valorising water, it may obscure these political and institutional questions. It may create the impression that better resource efficiency is sufficient to resolve water conflicts, whereas reuse projects often require difficult choices about allocation, responsibility and territorial solidarity. A genuinely circular water strategy should therefore make these choices explicit rather than hide them behind the language of innovation and efficiency.

5. TOWARDS A LESS PARADOXICAL WATER REUSE STRATEGY

The paradoxes identified above do not undermine the relevance of water reuse. Instead, they point to the conditions under which reuse can genuinely contribute to sustainable and circular water management. Reuse should be governed not as an isolated technical solution, but as part of a broader strategy for managing water flows, risks and responsibilities at the appropriate scale.

First, legal regimes for direct and indirect reuse should be better aligned. This does not mean that all indirect reuse pathways should be regulated in the same way as direct reuse schemes. Such an approach would be neither realistic nor necessarily proportionate. However, legal frameworks should recognise that the distinction between discharge, dilution, abstraction and reuse may sometimes obscure functional continuity. Where downstream abstraction depends significantly on upstream treated effluents, this relationship should be taken into account in planning, permitting and risk assessment.

Second, reuse should be prioritised where it provides genuine substitution benefits. Not all reuse projects have the same environmental value. Some replace withdrawals from stressed resources and contribute directly to resilience. Others may be costly, energy-intensive or mainly symbolic. A coherent strategy should distinguish between reuse that reduces pressure on vulnerable resources and reuse that merely shifts water within an already constrained system. The objective should not be to maximise reuse for its own sake, but to maximise its contribution to sustainable water allocation. The objective is not to use more water than before simply because it is water reuse.

Third, governance arrangements should clarify responsibilities across the reuse chain. Treated wastewater reuse involves several stages: production, additional treatment, storage, distribution, application and monitoring. Each stage may involve different actors. Legal uncertainty over responsibility can discourage projects, while unclear accountability can create risks for health, the environment and public trust. A robust governance framework should define who is responsible for water quality, infrastructure operation, monitoring, incident management and communication with users.

Fourth, circularity should be understood as a systemic principle rather than a purely technological objective. Advanced treatment, disinfection, real-time monitoring and dedicated distribution systems are essential tools. But they are insufficient without institutional coordination, coherent regulation, financing mechanisms, public acceptance and integration with basin-scale planning. Reclaimed water is not merely a technical product. It is also a legal, territorial and political object.

CONCLUSION

Water reuse is one of the most promising instruments for adapting water management to climate change, scarcity and increasing pressure on freshwater resources. It can contribute to resilience, reduce reliance on conventional sources, and support the transition towards circular water management. However, it should not be equated automatically with circularity.

This contribution has identified three structural paradoxes. First, reducing wastewater discharges may weaken hydrological balances in basins where treated effluents contribute significantly to low flows. Second, direct reuse may be more strictly regulated than indirect reuse through discharge and downstream abstraction, creating incoherent incentives. Third, the circularity narrative may obscure fragmented governance, allocation conflicts and responsibility gaps. The central challenge is therefore not whether water reuse should be developed, but under what conditions it can genuinely support sustainable water governance (BERBEL *et al.*, 2023). A coherent reuse strategy should be assessed through three key questions: does it effectively substitute for problematic freshwater withdrawals? Does it preserve ecological and hydrological needs at the basin scale? Does it operate within a legal and institutional framework capable of managing risks, responsibilities and downstream effects?

Water reuse should thus be understood not simply as the closing of a local loop, but as the reorganisation of water flows within a broader hydrological and institutional system. Circular water management does not mean reusing as much water as possible in every context. It means reducing overall pressure on aquatic environments, avoiding the transfer of impacts downstream, and making visible the interdependencies between urban systems, users and ecosystems. Only under these conditions can water reuse become not merely a technically attractive solution, but a genuine instrument of sustainable water governance.

REFERENCES

- Beard, J. E., Bierkens, M. F. P., & Bartholomeus, R. P. (2019). Following the water: Characterising de facto wastewater reuse in agriculture in the Netherlands. *Sustainability*, 11(21), 5963.
- Berbel, J., Exposito, A., Gutierrez-Martin, C., & Mateos, L. (2023). Challenges for circular economy under the EU 2020/741 wastewater reuse regulation. *Water*, 15.
- Bixio, D., Thoeye, C., De Koning, J., Joksimovic, D., Savic, D., Wintgens, T., & Merlin, T. (2006). Wastewater reuse in Europe. *Desalination*, 187(1-3), 89-101.
- Luthy, R. G., Sedlak, D. L., Plumlee, M. H., Austin, D., & Resh, V. H. (2015). Wastewater effluent-dominated streams as ecosystem management tools in a drier climate. *Frontiers in Ecology and the Environment*, 13(9), 477-485.
- Riazi, F., Turvani, M. E., & Mazzetto, F. (2022). Governance arrangements for water reuse: assessing the potential of inter-municipal cooperation. *Water*, 14(18), 2789.
- Voulvoulis, N. (2018). Water reuse from a circular economy perspective and potential risks from an unregulated approach. *Current Opinion in Environmental Science & Health*, 2, 45-51.