Aquifer Recharge: A New Approach from Italy and Croatia

Europe is facing a water paradox: while floods are becoming more extreme and frequent, droughts are also intensifying, putting enormous stress on water supply systems. Groundwater, which provides drinking water to three out of every four Europeans in some regions, is under particular pressure. Over-abstraction, nitrate and pesticide pollution, and saltwater intrusion are eroding this invisible reserve. The Blue Recharge project—a cross-border effort between Italy and Croatia—was launched to tackle this issue head-on by experimenting with managed aquifer recharge (MAR). MAR is a proactive approach that deliberately adds water back into aquifers, either by diverting surface water or reusing properly treated wastewater. The aim is not only to replenish depleted aquifers but also to improve water quality and strengthen resilience to climate change.

Who is behind it?

The Blue Recharge project brings together scientists, hydrologists, irrigation consortia, and wastewater utilities, alongside farmers and regional water authorities. This broad alliance ensures that the project's findings are both scientifically robust and practically relevant. Italian partners focus on wetland-based recharge, while Croatian teams test infiltration linked to wastewater treatment. Both share knowledge through workshops and data exchange, with the ultimate goal of producing guidelines and tools that any Mediterranean region can adapt.

What is happening?

Two contrasting pilot sites are at the heart of the work. In Italy's Emilia-Romagna plain, one of Europe's most productive agricultural regions, a managed wetland is being studied for its ability to filter and infiltrate water into shallow aquifers. In Croatia's southern Istria, where karst geology dominates and groundwater quality is fragile, a wastewater treatment plant doubles as a test site for recharge. By comparing such different environments—flat, alluvial farmland on one side and fractured carbonate rock on the other—the project aims to prove that MAR can be versatile and adaptable.

Where and When?

The Italian pilot is located at the Baldassari farm in Valle del Mezzano, in the Po River delta area, where drainage and irrigation infrastructure are well developed, but droughts are worsening. The Croatian pilot is centred on the Loborika Wastewater Treatment Plant, which serves the rapidly growing area around the city of Pula. Both sites have been operating since 2023, with field campaigns and monitoring still ongoing. The results gathered during 2024 and 2025 form the evidence base for future scale-up.

Why does it matter?

Aquifers are natural water banks. When they are full, they provide security in dry periods; when they are depleted, whole regions become vulnerable. Southern Istria is officially classified as being in poor chemical status, with nitrates above safe thresholds. In Italy, the Po basin is experiencing record-low flows, leading to conflicts between agriculture, energy production, and ecosystems. Climate change will only deepen these pressures. By testing MAR, the project shows that it is possible to both store more water locally and improve its quality. Importantly, MAR is also in line with the objectives of the EU Water Framework Directive and the Green Deal, which call for nature-based solutions and circular water use. It can reduce the need for costly inter-basin transfers, lower the energy footprint of pumping, and contribute to drought adaptation strategies.

Italy: Wetlands as Water Banks

The Italian pilot takes advantage of an 8-hectare wetland that can be managed by filling and draining. Three piezometers measure groundwater levels, while one of them also tracks conductivity. The data reveal a clear correlation between surface water levels and groundwater response, confirming that the aquifer is sensitive to managed inflows.

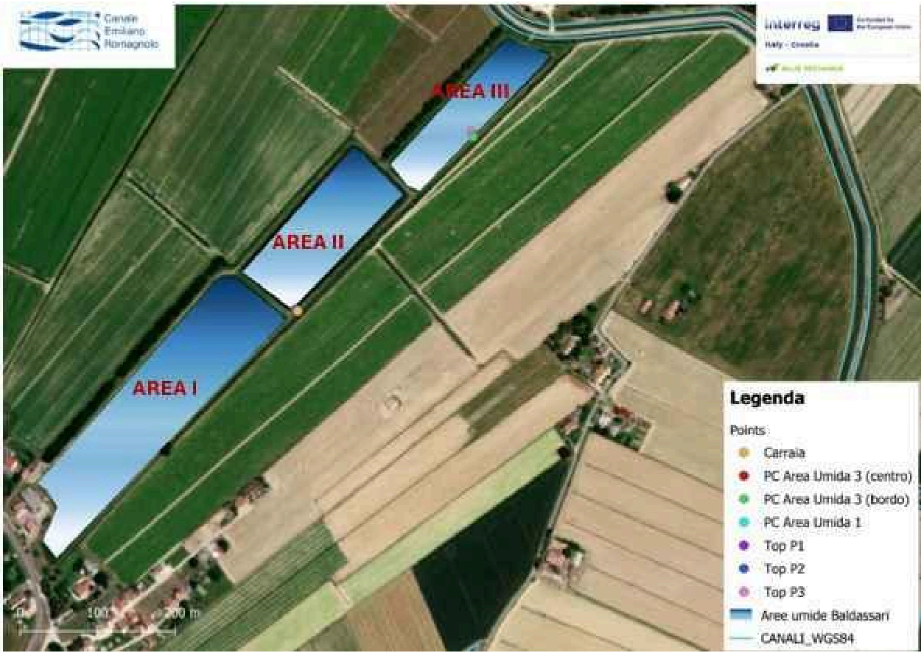

Figure 1. Wetland selected as a case study for the Blue Recharge project (Italian pilot).

In sandy soils, infiltration is rapid, while in finer soils the response is slower. This variability is critical knowledge for designing recharge systems: not all soils behave the same. Yet, across all areas, rises in groundwater are measurable, proving the effectiveness of wetland-based MAR.

Figure 2. Groundwater level trend in Piezometer 3 (Area II).

Regional monitoring adds another layer. Emilia-Romagna maintains more than 120 shallow wells that have recorded water levels for 25 years. Comparisons between these control wells and the pilot piezometers allow researchers to separate natural hydrological fluctuations from artificial recharge. This strengthens the evidence base, showing that the measured rises are not just weather-related but directly linked to wetland management.

Figure 3. Groundwater level trend in Piezometer 2 (Area III, edge of wetland).

Interestingly, in Area III, the water level sometimes rises above the piezometer top, meaning water temporarily ponds in the wetland. This confirms intense interaction between surface and groundwater, and highlights how wetlands can act as temporary buffers against drought.

Figure 4. Groundwater level trend in Piezometer 3 (Area III, inside the wetland).

Overall, the Italian pilot proves that productive farmland can host wetlands that provide dual services: maintaining biodiversity while recharging aquifers. The pilot also lays the foundation for Blue Credits, an innovative incentive scheme where farmers are rewarded for ecosystem services, aligning water protection with agricultural livelihoods.

Italy – Croatia

BLUE RECHARGE

Croatia: Wastewater Becomes a Resource

Croatia's pilot focuses on the Loborika WWTP, located in a karst landscape where groundwater flow is complex. Karst aquifers are vital but fragile: water travels quickly through conduits, making them vulnerable to contamination. This is why testing recharge here is so innovative—it combines engineering with nature's own filtration.

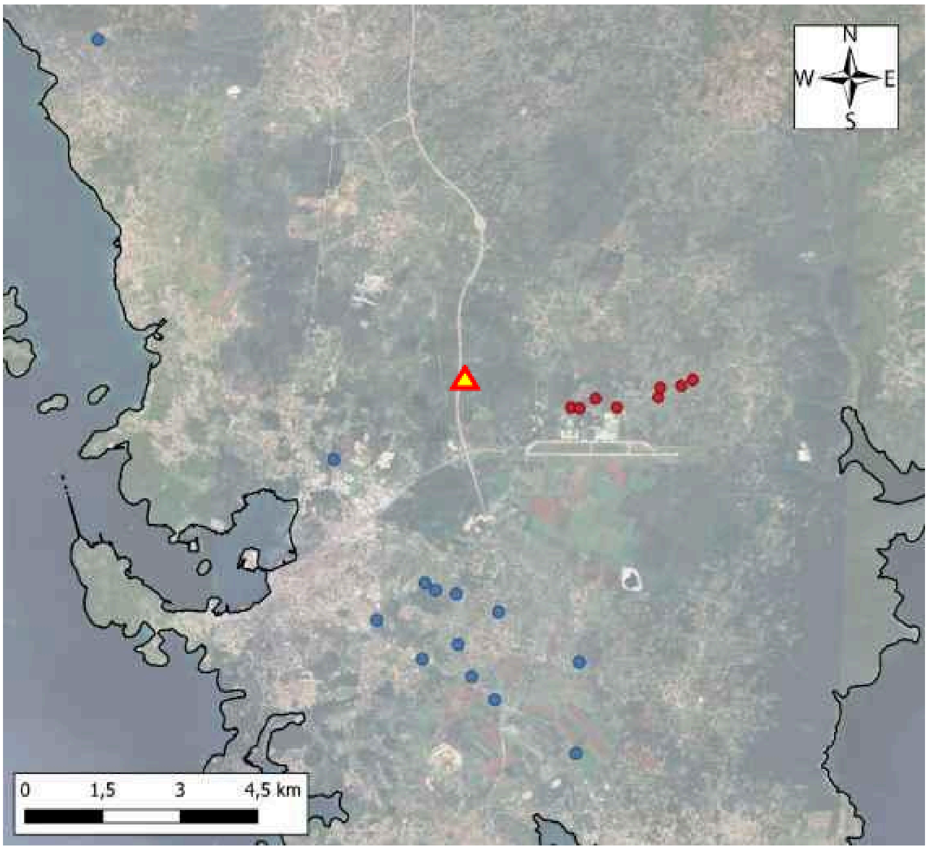

Figure 5. Location of wells (Vodovod Pula network – blue and red dots) and Loborika WWTP (triangle) in southern Istria (Croatian pilot).

The tracer test carried out in 2025 proved a direct hydraulic connection between the infiltration and observation wells, with the tracer arriving after 14 hours. No tracer was detected at more distant wells, underlining the compartmentalised character of karst systems. This result is key for risk management, showing both the potential and the limits of MAR in such geology.

Figure 6. Fluorometric analysis at the Loborika observation well (April–May 2025).

Isotopic monitoring showed groundwater composition closely matches rainfall, proving recharge is locally driven. The radon analysis demonstrated considerable variability across different wells, reflecting distinct differences in mean water residence times. This information helps assess the sustainability of abstractions.

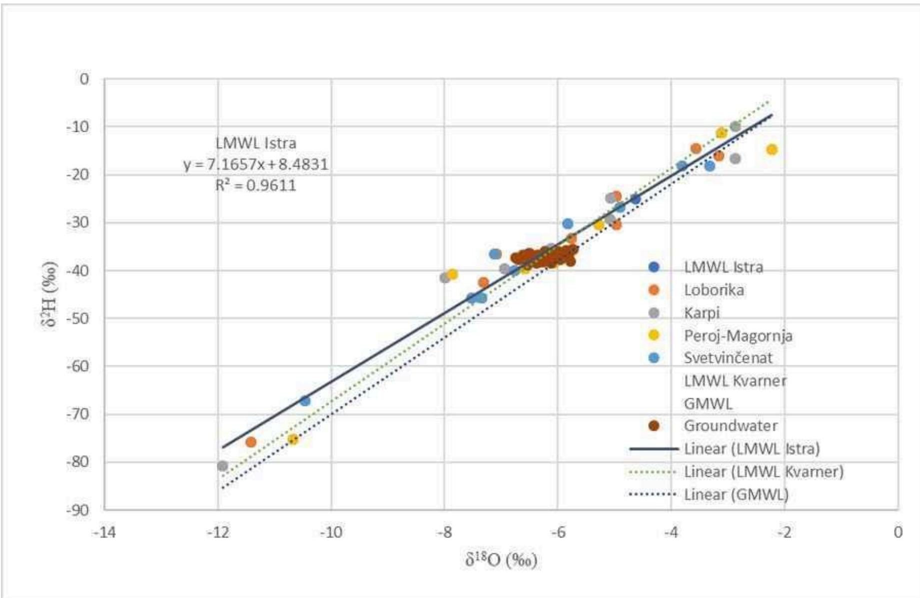

Figure 7. δ^2H vs $\delta^{18}O$ correlation for precipitation and groundwater (Istria LMWL).

The pilot treatment columns tested at Loborika WWTP achieved impressive purification levels: nitrate reduced by 82%, bacteria by 94%. This proves MAR can serve a dual role in Croatia: improving groundwater quality while storing additional resources for dry periods.

Figure 8. Installation of pilot treatment columns at the Loborika WWTP site.

Economically, MAR reduces reliance on expensive long-distance transfers of both treated as well as untreated water and postpones or even cancels completely some investment in new infrastructure. By linking MAR to a Blue Credits market, Croatia’s pilot also shows how innovative finance can reward water sustainability, just as carbon credits do for climate.

How do these approaches connect?

At first glance, wetlands in Italy and wastewater infiltration in Croatian karst seem worlds apart. Yet, both contribute to the same goals: recharging depleted aquifers, filtering pollutants, and providing water security. Together, they prove MAR is adaptable across geologies and uses. They also supply the scientific backbone for a Blue Credits system, creating economic incentives for recharge. This links well with EU strategies on circular economy, farm-to-fork, and climate adaptation, showing how water management can deliver multiple co-benefits.

What's next?

The pilots are not ending here. Monitoring will continue for several years to track seasonal cycles and long-term performance. The Italian case will refine how wetland management can balance biodiversity, farming, and recharge. The Croatian case will optimise wastewater treatment and test market-based water credits. Both will feed results into national policies and EU dialogues on drought resilience. Ultimately, replication across other Mediterranean basins is expected, where water scarcity has already developed into a crisis.

Conclusion

Groundwater is invisible but essential. Without it, agriculture, industry, and communities would collapse in times of drought. The Blue Recharge pilots prove that with smart management, aquifers can be actively replenished. Wetlands in Italy show how farmers can be part of the solution; wastewater in Croatia shows how infrastructure can double as a recharge tool. Together, they chart a path where ecological resilience and economic incentives go hand in hand. By quantifying recharge and turning it into Blue Credits, these projects make groundwater protection a tangible, tradable service—opening the way for a new era of water sustainability.