

MANAGEMENT OF AGRICULTURAL SUBSURFACE DRAINED FLOW BY ARTIFICIAL WETLAND: WATER QUALITY AND BIODIVERSITY SUPPORT

GESTION DE L'ÉCOULEMENT DES EAUX DRAINÉES AGRICOLES SOUTERRAINES PAR DES ZONES HUMIDES ARTIFICIELLES : QUALITÉ DE L'EAU ET CONSERVATION DE LA BIODIVERSITÉ

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ABSTRACT

Agricultural intensification in northern France has generated diffuse pollution and landscape homogenization, threatening both water quality and biodiversity. In the Brie Nangissienne, a region characterized by intensive cereal production and widespread subsurface drainage, artificial wetland buffer zones—zones tampons humides artificielles (ZTHA)—were implemented to intercept drainage waters and promote mitigation of nitrates and pesticides. This study synthesizes a decade of hydrological, chemical, ecotoxicological, and ecological monitoring conducted on four ZTHA in Rampillon (Seine-et-Marne). Water-quality monitoring demonstrates average reductions of 11 mg/L in nitrate concentrations, 37% mean pesticide removal. Biodiversity surveys reveal 374 species across seven taxonomic groups, including amphibians, odonates, birds, mammals, reptiles, and insects, with species richness in ZTHA approaching that of regional natural wetlands. The results confirm that ZTHA simultaneously enhance water quality and support diverse biological communities, providing multiple ecosystem services. This article discusses the integrated functioning of ZTHA, their ecological and agronomic benefits, and the implications for regional water-resource management and agroecological transition.

Keywords: agrohydrological systems; soil conservation; gravity-based irrigation; runoff attenuation; terraced systems; climate adaptation

RESUME

L'intensification agricole au nord de la France a donné lieu à une pollution diffuse et une homogénéisation des paysages, menaçant à la fois la qualité de l'eau et la biodiversité. Dans la Brie Nangissienne, région caractérisée par une céréaliculture intensive et un drainage souterrain très répandu, des zones *tampons* humides artificielles (ZTHA) ont été mises en place pour intercepter les eaux de drainage et favoriser l'atténuation des teneurs en nitrates et en pesticides. Cette étude synthétise une décennie de suivi hydrologique, chimique, écotoxicologique et écologique mené sur quatre ZTHA à Rampillon (Seine-et-Marne). Le suivi de la qualité de l'eau montre une réduction moyenne de 11 mg/L des concentrations en nitrates et une élimination moyenne des pesticides de 37%. Les inventaires de la biodiversité ont révélé 374 espèces réparties en sept groupes taxonomiques, notamment des amphibiens, des odonates, des oiseaux, des mammifères, des reptiles et des insectes, la richesse en espèces des ZTHA se rapprochant de celle des zones humides naturelles régionales. Ces résultats confirment que les ZTHA rehaussent à la fois la qualité de l'eau tout en soutenant la diversité des communautés biologiques, fournissant ainsi de multiples services écosystémiques. Cet article examine le fonctionnement intégré des ZTHA, leurs avantages écologiques et agronomiques, ainsi que leurs implications sur la gestion régionale des ressources en eau et la transition agroécologique.

Mots-clés: Systèmes agrohydrologiques; Conservation des sols; Irrigation gravitaire; Atténuation d'écoulement; Systèmes en terrasses; Adaptation au changement climatique.

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1. INTRODUCTION

Diffuse agricultural pollution remains one of the most persistent environmental challenges in European temperate regions. The intensification of crop production, increased fertilizer inputs, and widespread use of synthetic pesticides have contributed to the degradation of aquatic ecosystems. In the Brie Nangissienne, a rural territory southeast of Paris, the combination of hydromorphic soils and intensive subsurface drainage accelerates the transfer of contaminants from fields to surface waters and Champigny's aquifer through sinkholes in karstic context. Two thirds of the recharge of the Champigny aquifer is constituted by a direct transfer from surface waters, including agricultural drainage. Simultaneously, agricultural landscapes have undergone structural simplification, leading to habitat loss, reduced ecological connectivity, and declines in biodiversity.

To address these dual challenges, researchers and local stakeholders implemented artificial wetland buffer zones (*zones tampons humides artificielles*, ZTHA) designed to intercept drainage waters and promote biogeochemical processes that reduce pollutant loads. These nature-based solutions also create new habitats and stimulate a net biodiversity gain and other services which should be assessed in otherwise simplified agricultural landscapes.

This article synthesizes the coupled results of water-quality monitoring for more than 10 years, ecotoxicological assessments, and biodiversity surveys conducted on four ZTHA in Rampillon. It evaluates whether these engineered ecosystems can simultaneously improve water quality and support diverse biological communities, and discusses their role in agroecological transition and territorial water management.

1. MATERIALS AND METHODS

1.1 Study area

The study was conducted in the Brie Nangissienne, within the 355-ha basin of the Ru des Gouffres in Rampillon (Seine-et-Marne). The landscape is dominated by large-scale cereal production, with 93.5% of the basin surface occupied by large crops and minimal natural habitats. Due to hydromorphic soil (luvisol), subsurface drainage is ubiquitous, with pipes installed at 90 cm depth and 12 m spacing.

Following a shared dialog between stakeholders between 2005 and 2010, four ZTHA were constructed in 2010 (for details see Tourné et al., 2012) in : Les Vaux (2,000 m²), Montepot (2,400 m²), each connected to approximately 70ha upstream subcatchments, La Charité (500 m²) a restored old pond and Terminale (5,600 m²), the only collective ZTHA, located within a mosaic of woods, hedges, and ponds. The terminal ZTHA is the largest and most structurally complex, with three sub-zones: a sedimentation basin, a vegetated shallow zone, and a terminal basin.

1.2 Water-quality monitoring

To assess water quality improvement, a protocol was established continuous hydrological and chemical monitoring at the inlet and outlet of the terminal ZTHA. Measurements included: Hourly nitrate concentrations using spectro UV device; Hourly flow rates with Doppler device; Bi-monthly composite sampling proportional to volume, for analyzing of more than 100 pesticide molecules by a subcontractor laboratory.

1.3 Biodiversity monitoring

Seven taxonomic groups were surveyed using standardized protocols: Amphibians; Reptiles; Birds; Mammals; Bats; Odonates; Insects (including Lepidoptera). Surveys were conducted between 2016 and 2018. Species presence was compared to the regional CETTIA database for wetlands across 14 communes around (Milieu A, 9,537 ha). ZTHA biodiversity gathering observations of the 4 restored ZTHA (Milieu B, 2 ha) was compared using Jaccard similarity indices.



Figure 1. Map of Rampillon catchment and localization of the 4 restored ZTHA.

1.4 Ecotoxicological assays

To assess sublethal effects of contaminants at inlet and outlet of Terminal ZTHA, sentinel organisms *Gammarus* spp. were exposed in situ (caging experiments) during 2 weeks spring exposition periods. Biomarkers included in 2017: Feeding rate; Locomotion; Enzymatic activities (peroxidase, detoxification enzymes); Oxidative stress indicators. Details of methodology could be found in Persat et al. (2026).

2. RESULTS

2.1 Water-quality improvement

2.1.1 Nitrate attenuation

The ZTHA reduced nitrate concentrations by an average of 11 mg/L, decreasing exceedances of the 50 mg/L drinking-water threshold from 58% (inlet) to 23.7% (outlet). Mean nitrate retention in flux was 15%, primarily through denitrification at the water-sediment interface. Assimilation by plants is negligible compared to microbial denitrification. N₂O emission was estimated to be lower than 0.1% of nitrogen denitrified (Mander et al., 2021) leading to conclude that the ZTHA does not transform aquatic into atmospheric pollution. Minimum differences between inlet and outlet nitrate concentrations were observed during winter whereas maximum up to 100% during late spring.

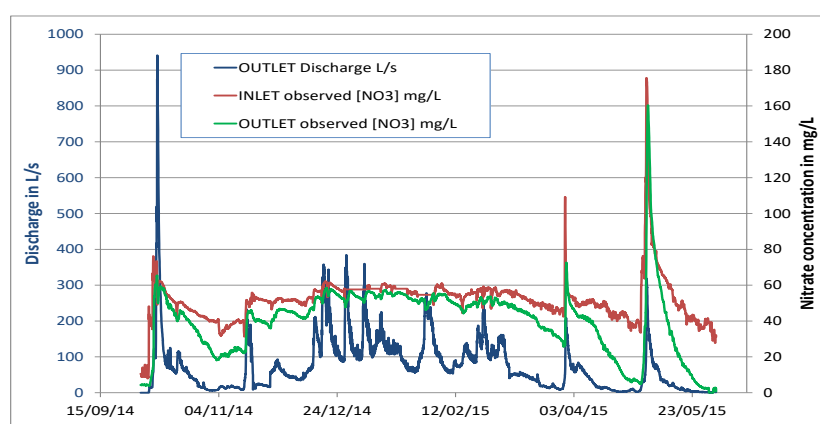


Figure 2. Hourly monitoring of Nitrate concentration, discharge at inlet vs outlet of Terminal ZTHA for the hydrological year 2014-2015.

2.1.2 Pesticide removal

The incoming pesticides fluxes correspond in average to 500g/year (1.5g/ha) all molecules together. Depending to subcontractor laboratory facilities, among the 92 applied pesticides per year, 41 pesticide molecules and 2 metabolites were regularly detected above the limit of 0.01µg/L. Comparing concentrations and fluxes at inlet vs outlet, mean removal efficiency was 37% over the 10 years, with strong variability (figure 3): Fongicides (–57%), Herbicides (–30%), Insecticides (–10%), Growth regulators (–100%).

Some molecules were fully removed (e.g., chlormequat), while others showed <10% attenuation (e.g., mesotrione).

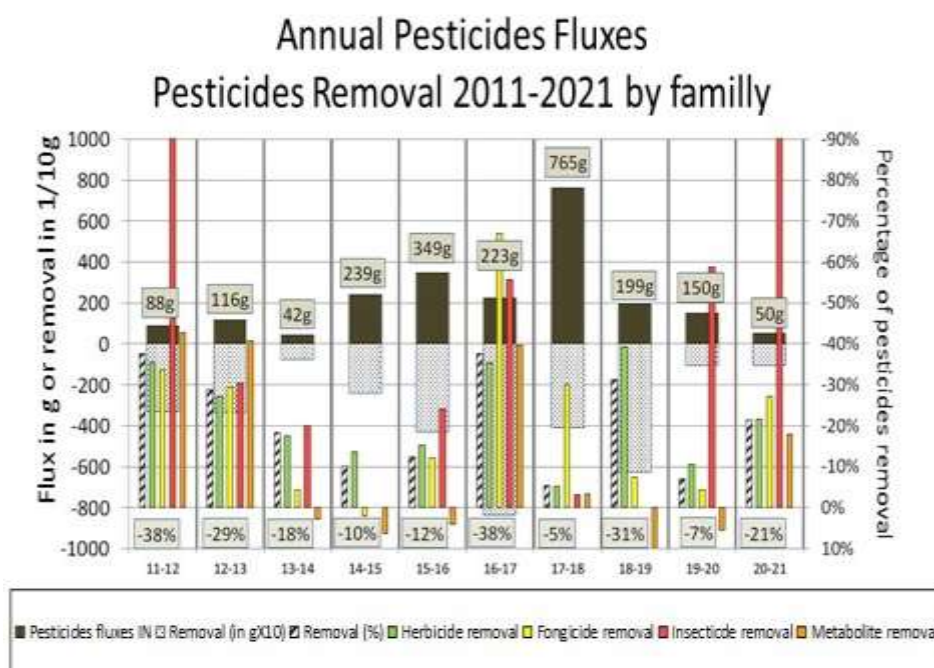


Figure 3: Pesticide removal by pesticide's family of terminal ZTHA between 2011 to 2021.

Sediment analyses revealed rapid adsorption of pesticides near the inlet, with concentrations in the ng/g range corresponding to less than 1g for the whole terminal ZTHA after 10 years. For example, fungicides such as tebuconazole and epoxiconazole enter the ZTHA during rainfall events following their application.

2.2 Biodiversity outcomes

Across all ZTHA, 374 species were recorded, including: 174 insect species, 20 species of patrimonial interest, numerous amphibians, odonates, birds, and mammals. The ZTHA are effectively supports of biodiversity in an agricultural context.

2.2.1 Comparison with regional wetlands

From CETTIA inventory, Milieu A (regional wetlands) shows 146 species whereas the ZTHA (Milieu B) in only 2ha shows 135 species. Jaccard similarity index: 0.59, indicating ecological similarity between the large area and the only 2ha of restored wetlands.

We propose to calculate the taxon-specific ratios (ZTHA vs. regional wetlands, figure 4). This ratio shows the contribution of the ZTHA in term of number of species to the larger biodiversity for instance 96% of

odonates species were inventoried around the ZTHAs. For other taxons, the values are 89% for birds, 91% for lepidoptera: 91%, 73% for amphibians, 62% for mammals, 50% for reptiles and 26% for bats.

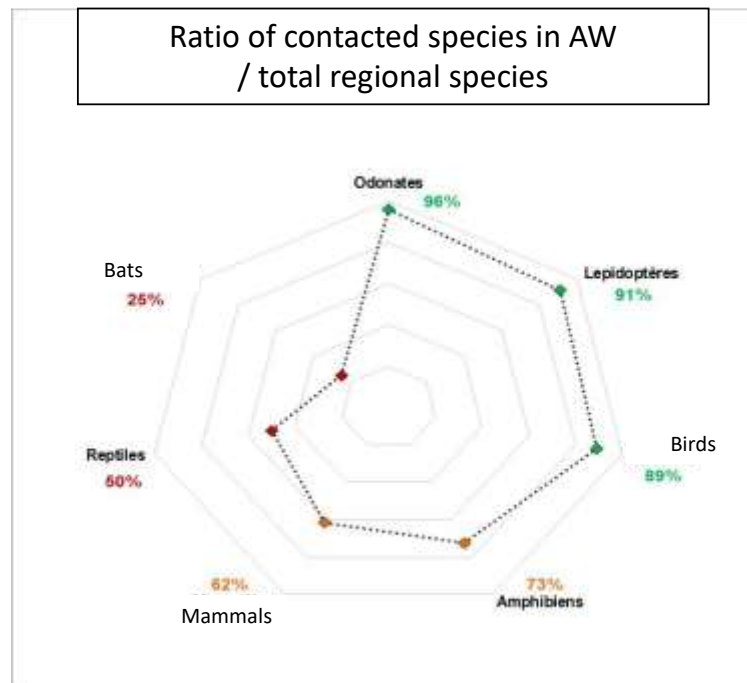


Figure 4. Ratio of inventoried species in the 4 ZTHA around Rampillon catchment on all species observed in CETTIA data base at regional scales.

2.2.2 Role of habitat diversity

The terminal ZTHA exhibited the highest species richness, attributed to its larger size and proximity to woods, hedges, and ZTHAs, showing that the diversity of habitats plays a preponderant role.

2.2.3 Agricultural auxiliaries

Among the 174 insect species: 40% were beneficial auxiliaries and 69% of individuals belonged to auxiliary species. Carabids, cantharids, and syrphids were particularly abundant.

2.3 Ecotoxicological effects

Caged *Gammarus* showed a reduced feeding rates upstream compared to downstream, and an altered antioxidant enzyme activities between inlet and outlet. Results highlight the evidence of stress from pesticide mixtures as mentioned in Pesce et al. (2025).

3. DISCUSSION

3.1 Coupled benefits for water quality and biodiversity

The Rampillon ZTHA demonstrate that engineered wetlands can simultaneously reduce nitrate and pesticides transferred by subsurface drainage, support diverse biological communities by providing habitat for species of conservation interest, enhance ecological connectivity in simplified landscapes. This dual functionality is central to nature-based solutions.

3.2 Hydrological and seasonal constraints

As shown by high frequency monitoring, the nitrate concentrations improvement varies along the years depending on water temperature as biogeochemical processes are stimulated by higher ones, flow regimes and particularly hydraulic residence time (HRT), lower during winter flow (less than 1 day), higher during late spring and summer (>1month). Moreover, Lemaire et al., (2024) showed that HRT is depending also from vegetation patches, generating hydraulic shortcuts.

Higher variabilities are shown for pesticide decontaminations. Several factors are involved: timing of pesticide applications (autumn versus spring), pesticides properties (sorption and degradation). As methodology is based on comparison between inlet and outlet fluxes, dissipation could be attributed to one or other processes. Nevertheless, Bahi et al., 2023, by developing the model PESTIPOND, showed that sorption should be the first one meaning a possible storage in ZTHA's sediment. After 10 years of functioning, analyses did not show a generalized contamination. The second process would be biodegradation by co-metabolism leading to the production of metabolites. Generally, vegetation uptake or phytoextraction is negligible for pesticides.

Seasonality and residence time are factors that cannot be controlled. Larger ZTHA with longer residence times correspond to 1.6% of upstream area performs better for both nitrate and pesticides pollution (Bahi et al., 2023).

3.3 Landscape connectivity and species dispersal

Aerially mobile taxa (birds, odonates, insects) colonize ZTHA rapidly. Terrestrial taxa (reptiles, small mammals) are limited by the absence of corridors. The richest combo is constituted by a complementary ecological system Forest and constructed wetland like the Terminal one. By creating habitats by a network of multifunctional ZTHAs, connectivity could be restored and be planned following the Japanese Steps concept (Préau et al., 2022).

Nevertheless, while ZTHAs reduce contaminant loads, they also accumulate pollutants in sediments, creating potential long-term risks: The sediment could become a reservoir of pesticides due to sorption as main mitigation process. As consequence, benthic organisms could be more exposed. Sublethal effects observed in *Gammarus* highlight the need to pursue monitoring and in situ evaluation. Michel et al., (2025) underlines that the ZTHA could then change from refuge to ecological trap.

3.4 Ecosystem services

Complementary to experimental studies, the ZTHAs of Rampillon contribute to widespread advantages of nature based solution. In the frame of previous projects, an educational pathway around terminal ZTHA, was created to make the invisible visible (such as water quality, and biodiversity). Several visits are organized by scientists, every year, for students, local stakeholders, farmers for dissemination.

Finally, ZTHAs provide multiple ecosystem services (figure 5) for all categories and more specifically to the regulation services by nitrate and pesticides mitigations, support biodiversity and provide cultural services (education, recreation and reconnection to landscape legacy). Because water storage is low, ZTHAs' role for flood regulation is negligible.

These services strengthen the case for integrating ZTHA into territorial planning for diffuse pollution from agricultural subsurface drained flows (Tournebize et al., 2017) and restoring biodiversity refuge and connectivity (Préau et al. 2022). Then ZTHA answers the criteria defined by UICN standards for nature based solutions (UICN, 2020). Studies are on progress on carbon balance (carbon storage in sediment and vegetation, net ecosystem exchange based on CO₂ monitoring and greenhouse gas emissions, including CH₄).

Rampillon Artificial Wetland's Services	
1→ Support	
Soil	Mitigate TSS
Nutrient	Stimulate nutrient cycle
Biodiversity	Diversification of genetic resources
2→ Regulation	
Water	Water purification and flood regulation
Climate	Temperature regulation and carbon storage
Crop	Crop protection auxiliaries
3→ Cultural	
Aesthetics	Landscape diversification
Educational	Educational path stimulates citizen interaction
Recreational	Trekking activities
Sociological	Stimulate farmers – citizen discussions
4→ Provisioning	
Sediments	Reallocation of trapped sediment back to crop field
Fresh Water	Fresh water storage
Fuelwood	Macrophyte harvest
Wood and fiber	Willow cutting
Food	Refuge for wild food chain

Figure 5. Ecological services provided by ZTHA mitigating agricultural drained flows (in green positive services, in blue neutral services, and in red probably negative services).

4. CONCLUSION

The Rampillon artificial wetland buffer zones demonstrate that nature-based solutions can effectively address diffuse agricultural pollution while enhancing biodiversity in intensively farmed landscapes. Over a decade of monitoring shows significant reductions in nitrate, pesticide, alongside the establishment of rich biological communities comparable to regional natural wetlands. However, performance depends on hydrological conditions, landscape context, and contaminant mixtures. Future efforts should focus on improving ecological connectivity, optimizing ZTHA design for longer residence times, and assessing long-term ecotoxicological risks. As multifunctional infrastructures, ZTHA represent promising tools for agroecological transition and integrated water-resource management in subsurface drainage context.

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