

PAPER 4

TRANSFORMING CONVENTIONAL WASTEWATER TREATMENT INTO MULTIFUNCTIONAL WATER REUSE FACILITIES: THE ECREUSE APPROACH IN BUFFALO CITY

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ABSTRACT

Water reuse is a key strategy to enhance water security in drought-prone regions such as South Africa. The ecReUse project demonstrates how targeted, energy-efficient upgrades of existing wastewater treatment plants (WWTP) can unlock new reuse potentials while reducing operational costs. At the East Bank WWTP in East London, a modular demonstration plant was implemented to test and showcase three integrated measures: enhanced

primary treatment with anaerobic sludge digestion and biogas recovery, a containerized membrane bioreactor (MBR) for high-quality effluent production, and continuous sand filtration for agricultural reuse. Together, these modules aim to improve effluent quality, reduce energy demand, and provide up to 15m³/day of reuse-ready water. The flexible, small-scale setup allows real-world performance testing, supports operational training, and serves as a blueprint for scalable and locally adapted reuse solutions. The results will inform future strategies for sustainable wastewater reuse and capacity development in South Africa and similar urban contexts facing water stress and infrastructure challenges.

1. INTRODUCTION

South Africa is one of the most water-scarce countries in the world, with an average annual precipitation of approximately 450mm (Botai et al., 2018). Regional differences are stark: while the arid northwest receives less than 200mm per year, the wetter southeast can experience up to 1,000mm annually (Lynch, 2004). Historically, South Africa's rainfall patterns have followed long-period cycles of wet and dry periods (Malherbe et al., 2016; Du Plessis & Kibii, 2024). However, recent studies suggest that these cycles are becoming increasingly irregular due to climate change, with potentially severe consequences for water availability (Ndlovu et al., 2021; Kruger, 2025).

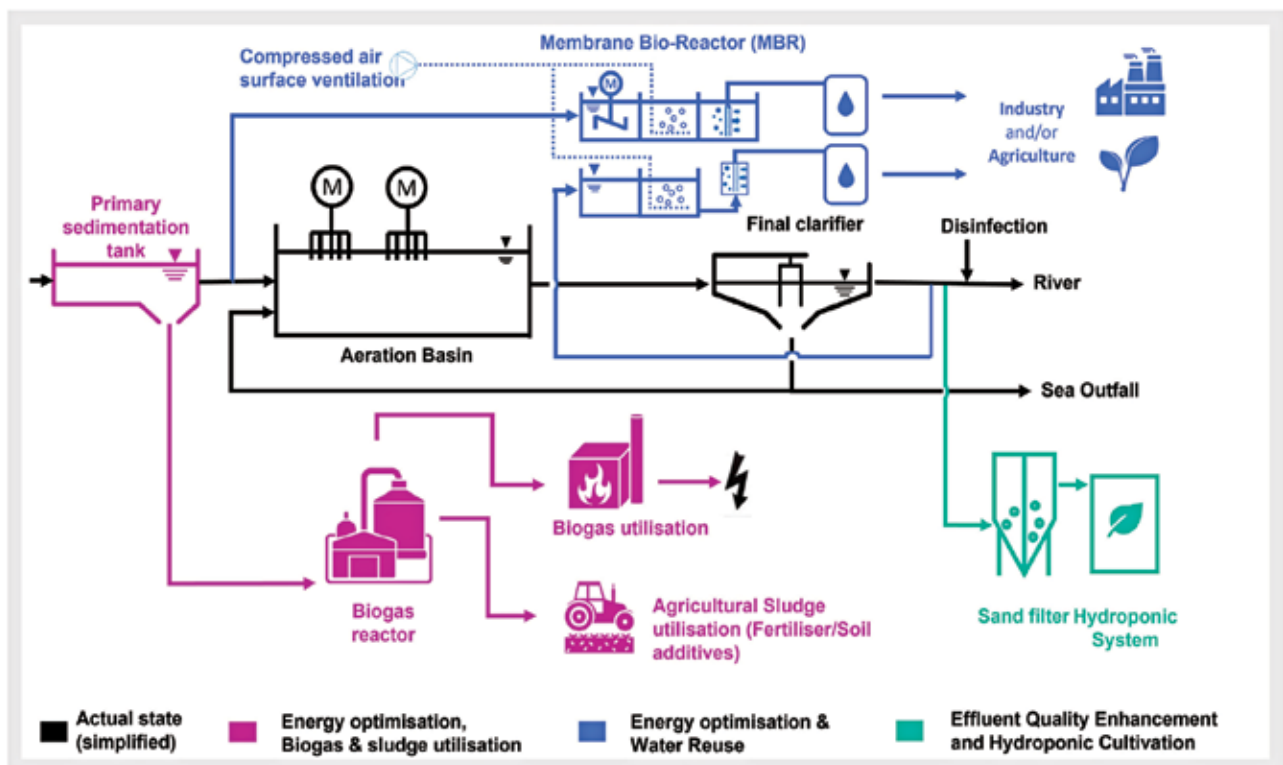


FIGURE 1: Process flow diagram of the East Bank WWTP showing the three optimization measures: (1) Energy optimization, biogas and sludge utilization; (2) Energy optimization and water reuse; (3) Effluent quality enhancement and hydroponic cultivation.

Regions highly dependent on surface water are particularly vulnerable. A prominent example is the Buffalo City Metropolitan Municipality (BCMM), whose water supply relies almost entirely on surface water sources (Buffalo City Metropolitan Municipality, 2022a). Rapid urban growth, ageing infrastructure, an unstable energy supply, and recurring droughts are putting the region's water security under mounting pressure. Structural and operational challenges in the wastewater sector can result in partially treated effluents reaching natural water bodies.

In this context, the reuse of treated wastewater is an increasingly promising strategy for enhancing the resilience of urban water systems. Technological advances in water treatment now enable the production of tailored water qualities—from agricultural irrigation water to ultrapure process water for industrial applications. Simultaneously, improvements in energy efficiency and the integration of on-site renewable energy generation (e.g., photovoltaic systems) offer opportunities to reduce operational costs and promote sustainable, circular use of local water resources.

The research and demonstration project ecReUse addresses these challenges by redesigning a conventional South African WWTP into an energy-efficient, multifunctional water reuse facility. The East Bank WWTP in Nahoon, East London, serves as the pilot site. Originally built in the 1980s, the plant has a design capacity of 40 million litres per day and operates using the widely adopted activated sludge process.

The ecReUse project focuses on targeted upgrades to increase both energy efficiency and water reuse potential of the East Bank WWTP.

Three key technical interventions are being piloted at a small scale:

- energy optimisation through primary sedimentation and anaerobic sludge digestion,
- advanced treatment using a MBR system,
- continuous sand filtration to produce irrigation-grade water.

All three components are implemented as modular pilot units to allow flexible testing and demonstration. The solutions developed and tested in ecReUse are intended to inform future upscaling, policy development, and the implementation of resilient, decentralised water reuse strategies in similar urban contexts.

2. METHODOLOGY

The technical transformation of the East Bank WWTP is structured into three key optimization measures, which are illustrated in the process flow diagram of the plant in Figure 1.

Existing Treatment Configuration

The existing WWTP comprises a conventional activated sludge system designed for municipal wastewater. The process line begins with inlet works that include mechanical screens and grit removal units, ensuring the removal of coarse solids and inert materials. Pre-treated influent then

flows into aeration basins equipped with surface mixers, which provide the necessary oxygenation and mixing for biological treatment. The effluent from the aeration stage is directed to final clarifiers for solid-liquid separation. A disinfection unit is installed downstream of the clarifiers to reduce pathogen loads before discharge into the receiving environment.

Energy optimization through primary sedimentation and biogas generation

The first measure addresses energy consumption, a major cost factor in many South African WWTPs operating with conventional activated sludge systems. In many such plants, the lack of primary sedimentation leads to excessive chemical oxygen demand (COD) in the biological treatment stage, increasing oxygen requirements and, consequently, electricity consumption. To address this, the ecReUse pilot at the East Bank WWTP includes a dedicated primary sedimentation tank to demonstrate the energy-saving potential of this measure and to evaluate its integration with downstream biogas production. The stainless-steel tank, with a volume of 10m³ and a hydraulic capacity of 10m³/h, enables the separation of settleable solids and the diversion of primary sludge into an anaerobic digester. The anaerobic reactor, with a volume of 2m³ and a hydraulic retention time of approximately 20 days, ensures effective sludge stabilization and a steady biogas production of around 600 litres per day.

To maintain optimal operating temperatures, the reactor is heated by an external electric unit wrapped around the vessel, while a high-performance thermal insulation layer minimizes heat loss. In addition, a time-controlled centrifugal pump ensures continuous internal circulation, promoting uniform temperature distribution and stable digestion conditions. The biogas generated can be used in a combined heat and power unit to partially offset the plant's electricity demand. By reducing the organic load entering the activated sludge tank, the oxygen demand for aerobic degradation is lowered, resulting in potential energy savings of up to 30%. The integration of anaerobic digestion further supports decentralized sludge management and resource recovery. Additionally, it reduces the amount of excess sludge and improves the dewaterability of the digested sludge.

Production of high-quality reuse water via containerized membrane bioreactor (MBR)

The second intervention focuses on the production of high-quality effluent suitable for reuse in industrial applications. For this purpose, a pilot-scale MBR is housed in a 40-foot high-cube shipping container. The system comprises two parallel treatment lines that differ in membrane configuration and biological pretreatment. In one line, a dry-installed ultrafiltration membrane is used, while the other features a submerged “seaweed-type” membrane module. Figure 2 illustrates the process flow of both MBR lines. The two configurations differ in terms of energy consumption, transmembrane

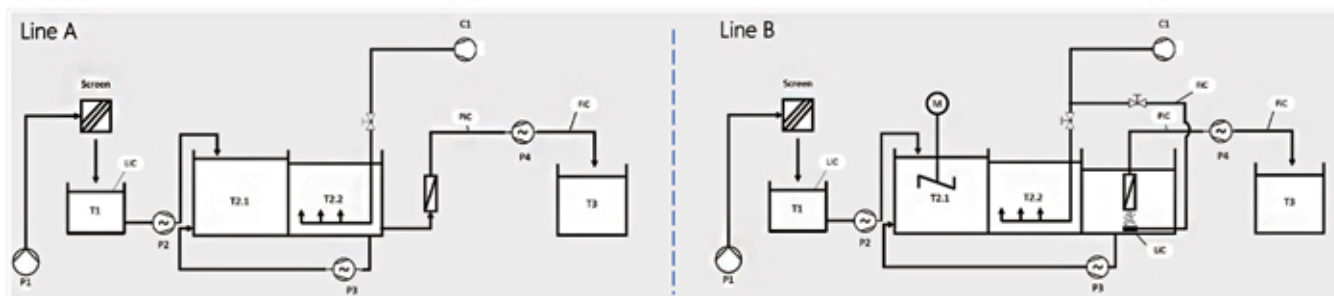


FIGURE 2: Process flow diagram of the two parallel MBR treatment lines installed in a 40-foot container. Line A uses a dry-installed ultrafiltration membrane, whereas Line B applies a submerged “seaweed-type” membrane. The setup allows comparative assessment of energy use, operating conditions, and membrane cleaning needs under realistic conditions.

pressure requirements, and membrane cleaning strategies. Their parallel operation enables direct performance comparisons under in situ conditions.

The treated water meets high-quality standards suitable for demanding industrial applications, such as boiler feed water or high-grade process water. Effluent quality is aligned with international reuse criteria, enabling safe and efficient reuse. Remote control and monitoring of the MBR system are enabled via an integrated control cabinet with both local and online access. In future extensions, the system could be complemented by a reverse osmosis (RO) unit, allowing the production of fully demineralized water (e.g. for ultrapure applications in automotive, energy or electronics industries).

Effluent quality improvement and Agricultural reuse via continuous sand filtration and hydroponic demonstration

To complement the industrial reuse pathway, a third line focuses on agricultural water reuse. A continuous sand filtration system is installed to produce effluent suitable for irrigation and hydroponic cultivation. The filter consists of a downward-flowing sand bed with integrated sand washing, which ensures continuous operation without the need for backwashing. This process provides a stable effluent quality, even under fluctuating influent loads, and can be enhanced with activated carbon to remove micropollutants such as pesticides or pharmaceutical residues.

On the premises of the treatment plant, a hydroponic demonstration system is set up to evaluate the feasibility and safety of agricultural reuse. The system allows for controlled cultivation of crops using the filtered effluent, enabling researchers to address several key questions: How can nutrients recovered from wastewater be effectively used in hydroponics? What are the risks related to water and food safety in recirculating agricultural systems? And what type of management, monitoring, and governance structures are required to ensure safe and acceptable reuse? Figure 3 shows an example of crop cultivation using a closed-loop hydroponic setup based on the Dutch Bucket system, implemented under arid conditions in Tunisia.

The aim is to develop a transferable model for the safe, water-efficient, and economically viable hydroponic reuse of treated wastewater. In addition to closing local nutrient cycles, the approach explores potentials to support urban agriculture and contribute to both food and fodder security under water-limited conditions.

An additional module addresses the challenge of real-time process control in low-resource settings. A camera-based monitoring system is implemented at the outlet of the WWTP to track effluent quality and quantity, supporting remote operation and maintenance. This digital solution allows decentralized monitoring without permanent staff presence or grid dependency and contributes to the robustness and autonomy of the overall system.

Together, these upgrades form a comprehensive platform for evaluating technical performance, integration potential, and reuse viability. Beyond their immediate technological purpose, the pilot units are also used as

hands-on training environments for engineers, operators, and technicians. By embedding capacity development into the demonstration, ecReUse aims to foster long-term operational know-how and support the diffusion of innovative wastewater technologies across the region.

3. PROJECT STATUS & INITIAL PERFORMANCE EXPECTATIONS

3.1 Implementation Status

As of mid-2025, the core infrastructure of all four pilot modules – primary sedimentation and anaerobic digestion, MBR unit, continuous sand filtration, and off-grid monitoring – has been completed and is installed on site at the East Bank WWTP. The containerized MBR unit, including its dual membrane configuration, is fully assembled and placed on its designated platform. The prefabricated stainless steel sedimentation tank and the downstream anaerobic reactor have been constructed and hydraulically connected to the existing inflow line of the biological treatment stage. Similarly, the sand filtration unit has been delivered and is currently being integrated into the water reuse line for agricultural purposes.

The electrical installation and the integration of control and automation components across all modules are scheduled for completion in Q3/2025. This includes the setup of the camera-based monitoring system, which will be used to track key operational parameters – such as flow rates, and turbidity – without the need for constant on-site supervision. Once finalized, the system will undergo a phased commissioning process, including hydraulic testing, sensor calibration, and functional checks for all subsystems. In parallel, a hydroponic demonstration unit is under construction adjacent to the treatment plant. This system will serve as a practical testbed for evaluating the suitability and safety of reclaimed water in controlled agricultural applications. The design allows for modular planting beds with integrated monitoring of water quality and nutrient uptake.

The physical implementation of the demonstration modules is nearly complete, and the project is entering a crucial transition phase from construction to commissioning and pilot operation. Figure 4 shows the pilot units already installed on the designated platforms at the East Bank WWTP.

3.2 Expected Performance Gains

The pilot modules implemented in the ecReUse project target substantial improvements in both water quality and energy efficiency. Drawing on prior research, literature benchmarks, and design specifications, several performance gains are anticipated for each module.

Primary Sedimentation and Anaerobic Digestion: The installation of a compact primary sedimentation tank upstream of the biological treatment aims to assess the potential for reducing the organic load – expressed as biochemical oxygen demand (BOD) – prior to aeration. If applied at full scale, this could lead to a reduction in overall energy consumption of up to 30%,



FIGURE 3: Example of closed-loop hydroponic systems for crop production. The setup enables efficient nutrient and water use through recirculation and localized drip irrigation and is particularly suitable for semi- arid and arid conditions.



FIGURE 4: Pilot units installed at the East Bank WWTP: (a) MBR system, (b) primary sedimentation and anaerobic reactor, (c) continuous sand filter.

primarily by lowering the energy required for aeration. This figure remains theoretical and is subject to validation through pilot-scale experimentation. In the pilot setup, the separated sludge is further stabilized in an anaerobic reactor, which can generate up to 600L of biogas per day under optimal conditions. This biogas could potentially be used to offset auxiliary energy demands or, in future applications, be integrated into a combined heat and power (CHP) system.

Membrane Bioreactor (MBR): The containerized MBR unit features two interchangeable membrane lines that will be operated in parallel and compared in terms of energy demand, fouling behavior, and maintenance effort. Effluent quality is designed to meet relevant international and/or national standards for agricultural and industrial reuse applications, including target thresholds of <10mg/L BOD, <10mg/L TSS, and pathogen removal >5 log units. The expected specific energy demand ranges between 0.6 and 0.9kWh/m³, depending on membrane configuration and influent load.

Continuous Sand Filtration: As a tertiary polishing step, the sand filter provides additional particle and turbidity removal, stabilizing water quality for agricultural reuse. The unit is designed to maintain turbidity <1NTU and TSS <2mg/L under standard conditions. The filtration performance is being monitored, with optional capacity for granular activated carbon (GAC) addition to further reduce micropollutants and odors, if needed.

Hydroponic Reuse and Agricultural Application: The hydroponic demonstration unit will assess the safe and efficient use of reclaimed water in crop production. This includes monitoring nutrient availability (e.g., N, P, K concentrations), potential accumulation of contaminants, and overall system productivity (e.g., yield per m² per cycle). By recirculating nutrient-rich effluent, the system aims to reduce both water and fertilizer inputs, potentially improving water use efficiency by over 70% compared to conventional soil-based irrigation.

3.3 Technological Innovations and Integration Potential

The ecReUse project demonstrates how upgrades and optimization of WWTPs can address water scarcity, energy inefficiency, and aging infrastructure – key challenges in South Africa and other water-stressed regions. While currently containerized for flexible testing, the concept can be adapted for integration into existing plants. Stakeholders from agriculture and industry have shown strong interest, particularly in stable water supply and potential cost savings. Future success will most likely depend on factors beyond technology, including reuse regulations, operational robustness, and user acceptance. Open questions remain regarding long-term performance, economic viability, and concentrate management. To address these, the next phase includes system commissioning, performance monitoring, and

training. A monitoring plan will track energy use, effluent quality, membrane durability, and nutrient recovery, while the pilot also serves as a local capacity-building platform.

3.4 Dissemination and Capacity Building

To ensure that the pilot's lessons and technical know-how are effectively shared and adopted, we developed a structured dissemination and capacity-building strategy comprising four key activities. First, the pilot units will be commissioned in close collaboration with the municipal wastewater operations team. During the startup phase, local staff will receive intensive, hands-on training on each demonstration module and will then assume primary responsibility for day-to-day operation. Second, a comprehensive suite of documentation – including slide decks for training sessions, step-by-step operating procedures, safety guidelines, and user manuals—will be provided to the local team. These materials will support both the commissioning process and long-term plant operation.

Third, dissemination will be tailored to the main stakeholder groups—municipal plant operators, water management decision-makers, industrial end-users, and the international technical community. Once installation and staff training are complete (scheduled for Q1 2026), the pilot plant will enter a three-month performance testing phase. Following this evaluation period, insights and performance data will be shared through innovation forums and hands-on technical workshops aimed at representatives from interested utilities and industry partners. These events will feature guided site tours, system demonstrations, and interactive sessions on topics such as WWTP energy-optimization strategies, anaerobic digestion, best practices in MBR and sand-filtration, and plant operation and maintenance. In parallel, specialized operator training courses will be developed for personnel from other utilities, equipping them with the skills needed to replicate and scale the ecReUse approach. Finally, project results will be published in peer-reviewed journals and presented at international conferences, ensuring broad accessibility for researchers and practitioners.

4. CONCLUSION

The ecReUse project demonstrates how modular, integrative upgrades can transform conventional WWTPs into resource-efficient water reuse systems. By combining established technologies – such as primary sedimentation, MBR, and continuous sand filtration – in an energy-optimized configuration, the project addresses both environmental and operational challenges in the South African context. While the modular layout reflects the pilot character of the current setup, the implemented solutions are fully scalable and adaptable to a wide range of treatment plants and reuse scenarios. With commissioning now underway, the demonstration site at East Bank is set to become not only a testbed for innovative reuse technologies, but also a long-term training platform for engineers, plant operators, and technicians. This hands-on training component is essential to build local expertise,

ensure operational continuity, and facilitate broader adoption of advanced treatment and reuse strategies.

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6. REFERENCES

Botai, C. M., Botai, J. O., De Wit, J. P., Ncongwane, K. P., & Adeola, A. M. (2018). Drought characteristics over the Western Cape Province, South Africa. *Water*, 10(4), 386. <https://doi.org/10.3390/w10040386>

Buffalo City Metropolitan Municipality. (2022). *Integrated Development Plan 2022/2023*. <https://www.buffalocity.gov.za>

Du Plessis, J. A., & Kibii, J. K. (2024). Does rainfall trends and patterns of South Africa for the past century demonstrate climate change? Paper presented at the 2024 IMESA Conference, Cape Town.

Kruger, A. C. (2025). Analysis of rainfall trends in South Africa: 1921–2022. *Climatic Change*, 173(1), 45–62.

Lynch, S. D. (2004). *Development of a raster database of annual, monthly and daily rainfall for Southern Africa* (WRC Report No. 1155/1/04). Water Research Commission.

Malherbe, J., Dieppois, B., Maluleke, P., Van Staden, M., & Pillay, D. L. (2016). South African droughts and decadal variability. *Natural Hazards*, 80(2), 657–681. <https://doi.org/10.1007/s11069-015-1989-y>

Ndlovu, N., Hadebe, S. T., & Dube, T. (2021). Climate variability and water security in South Africa: Emerging evidence and future directions. *Journal of Water and Climate Change*, 12(3), 475–489. <https://doi.org/10.2166/wcc.2020.242>