Sustainable Asset Valuation of Wastewater Treatment Infrastructure in South Africa

An integrated assessment of infrastructure solutions for reducing nutrient-related pressures in the Hartenbos estuary

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Sustainable Asset Valuation of Wastewater Treatment Infrastructure in South Africa

An integrated assessment of infrastructure solutions for reducing nutrient-related pressures in the Hartenbos estuary

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Executive Summary

This study analyzes different wastewater treatment options for improving water quality in the Hartenbos estuary in South Africa. It also explores opportunities for reusing water for irrigation and related impacts on nutrient loads to the estuary.

The Hartenbos estuary is located in Mossel Bay, a municipality in South Africa's Western Cape Province. Every year, about 85,000 tourists visit Mossel Bay, and the lagoon is one of the attractions in the beach resort. However, water quality issues in the estuary strain the health and attractiveness of the ecosystem and are expected to worsen as population and tourist numbers grow. Most of the sewage from Mossel Bay is treated in a wastewater treatment plant in Hartenbos, and the cleaned effluent flows into retention ponds from which it is discharged into the lagoon. Even though the plant complies with national water quality standards, the discharged water contains high loads of nitrogen and phosphorus. The resulting high nutrient concentration in the estuary regularly leads to algae growth and fish kills due to lack of oxygen.

Further, water effluent quality is forecasted to worsen in the future due to increasing wastewater loads driven by population growth, tourism, and industry. The total amount of nutrients in sewage treatment plant (STP) effluent is projected to increase by around 50% between 2020 and 2060, leading to 6,600 kg of additional nitrogen (N) and 3,850 kg of additional phosphorus (P) per year being deposited in the estuary by 2060. This increase in loadings leads to an increase in concentration, with nutrient concentrations increasing from 1.61 mg N per litre and 0.91 mg P per litre in 2020 to 2.4 mg N per litre (+67% vs 2020) and 1.44 mg P per litre (+75.7% vs 2020) by 2060 respectively, highlighting the need for action.

For this assessment, the International Institute for Sustainable Development engaged with stakeholders from the Western Cape Government and Mossel Bay Municipality to co-develop the Hartenbos estuary assessment, customizing the Sustainable Asset Valuation (SAVi) method and tools to local circumstances and needs. These stakeholders were consulted for conceptualizing the analysis, outlining the scenarios to be simulated, and validating the results: they were involved throughout the development of the study.

This assessment analyzes the performance of wastewater treatment alternatives for reducing nutrient loads in the estuary. For this purpose, three distinct technologies have been assessed:

i) The installation of an improved treatment plant. For this grey infrastructure option, the existing wastewater treatment plant would be replaced with a more advanced conventional activated sludge reactor for increasing N and P removal.

ii) The installation of an Organica plant. This hybrid infrastructure combines conventional technologies with nature-based, biological wastewater treatment.

iii) The construction of an artificial wetland. The artificial wetland is used to treat the wastewater before reaching the Hartenbos river using a so-called vertical subsurface flow (VSF) system.

For this assessment, each of the water treatment technologies has been assumed to replace the existing treatment plant. Further, results are presented for the implementation of each technology in isolation to ensure a coherent comparison of results across scenarios. Given that it is common practice in South Africa to add new capacity and use it in conjunction with existing infrastructure, additional results in Appendix A present the change in nutrient loads if the new technology were to be installed in addition to the existing plant.

We analyzed these infrastructure options in comparison to a business-as-usual (BAU) scenario where no upgrade of the current treatment plant takes place. We conducted system dynamics and project finance modelling to identify, quantify, and interpret the economic, environmental, and social outcomes of using each of the three technologies considered.

The results of this assessment provide an overview of the societal costs and benefits of each water treatment option, considering outcomes for citizens, businesses, Mossel Bay Municipality, and the Western Cape Government. The comparative valuation provides several insights. Examples of research questions include: how efficient are the different technologies for treating the wastewater, and what contribution would they provide to the water quality of the Hartenbos estuary? Do the different options comply with national water quality standards? What would be the direct and indirect economic outcomes of improving water quality and recycling water? These questions (and more) are answered in this SAVi assessment.

Key Messages

- Wastewater treatment in Hartenbos needs to be improved to avoid a further deterioration of the estuary. Since the estuary is a highly sensitive ecosystem, it is important to reduce nutrient pollution and ensure that the installed treatment plant can address rising wastewater loads from residents, tourists, and industry in the future. Harvesting treated water before it reaches the estuary also benefits the sensitive ecosystem by diverting part of the nutrient-rich effluent.

- Based on the results obtained from this study, water recycling and reuse for agricultural production has the potential to create synergies with water treatment and would render all three water treatment investments economically viable. Recycling treated wastewater for irrigation offers considerable benefits for climate adaptation and the agriculture sector. Reusing 50% of the water by 2060 would cover the water demand of 330 additional hectares of agricultural land, resulting in higher water security, agricultural productivity, and job creation. Using average employment, water use, and value-added indicators per hectare, the cumulative benefits from water harvesting total around ZAR 453.7 million over the next 40 years.

- The hybrid infrastructure solution (Organica) is the cheapest option available for improving wastewater treatment. It exhibits the lowest cost per cubic metre (m^3) of water treated when considering the lifetime of the asset by 2060 (ZAR 4.28 per m^3). Treating water with the constructed wetland would cost instead ZAR 5.37 per m^3, on par with ZAR 5.38 per m^3 for the grey infrastructure upgrade.[1]

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[1] The values presented here correspond to around USD 0.2915 per m^3 treated (Organica), USD 0.3658 per m^3 treated (improved treatment), and USD 0.3664 per m^3 treated (constructed wetland), respectively.

- The hybrid Organica plant is the most effective option for removing N from wastewater. Using this technology, the 2060 N concentration in the estuary is around 55.6%[2] lower compared to the baseline, and the average cost per kg N removed is ZAR 77.04; this is relative to ZAR 100.92 per kg N for the improved treatment plant and ZAR 104.65 per kg N removed for the wetland. Considering the three treatment alternatives but no water recycling, the concentration of N is estimated at 2.22 mg N per litre (improved treatment), 1.06 mg N per litre (Organica), and 3.29 mg N per litre (wetland).

- The artificial wetland is instead the most effective solution for removing P from wastewater. Compared to the BAU scenario, the wetland prevents around 214.1 tons of P from reaching the estuary, which reduces P concentration to 0.64 mg P per litre (55.1% lower relative to BAU[3]). Alternatively, the concentration is estimated to be 0.87 mg P per litre (improved treatment) and 0.82 mg P per litre (Organica) in 2060.

- The economic viability of the wetland option depends on whether its implementation increases habitat quality and biodiversity, which in turn attracts additional tourists relative to the baseline. Practically, when ecological and tourism benefits are considered, the wetland is the most economical option; when these are excluded, it is the least economical option. Specifically, if the wetland is taken up as shelter by birds and other animals, it holds potential for the local tourism industry, indicating that it would attract more tourists than the other two options. The additional revenues could potentially be used to fund conservation efforts for the artificial wetland and secure its long-term sustainability; should these revenues not materialize, the economic performance of the wetland indicates a net cost and underperforms the Organica and the improved treatment plant.

- Water harvesting significantly benefits estuary nutrient concentration. N concentration in 2060 is indicated at 1.46 mg N per litre (improved treatment), 0.71 mg N per litre (Organica), and 2.15 mg N per litre (artificial wetland) in 2060, which is 39.3%, 70.5%, and 10.5% lower relative to BAU.

- The reductions in nutrients from water harvesting also apply to P. The P concentration in the estuary is indicated at 0.60 mg P per litre (improved treatment), 0.57 mg P per litre (Organica), and 0.45 mg P per litre (wetland), respectively. This is equivalent to a reduction between 58.6% (improved treatment) and 68.9% (wetland) relative to the BAU scenario in 2060.

- The results of the analysis illustrate that planners and policy-makers need to carefully consider the benefits and trade-offs of different infrastructure options for wastewater treatment. While the hybrid solution performs best for reducing nutrient pollution, the potential to create additional revenues from tourism through the implementation of the artificial wetland would result in even higher net benefits relative to the hybrid option.

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[2] If water harvesting is considered, the reduction in average estuary N loadings is 77% in 2060. The cost per kg of N removed from treatment remains the same, as the additional removal of N is achieved through exporting N to the field, which does not add to the cost of treatment.

[3] The P concentration by 2060 is around 68.9% lower relative to the baseline if the impacts of water harvesting are considered in addition to higher removal efficiency.

Summary of Results

Integrated Cost-Benefit Analysis

This report presents the outcomes of investing in three alternative options for wastewater treatment in the Hartenbos estuary: improved water treatment plant (grey option), Organica (hybrid option), and artificial wetland (natural infrastructure). Furthermore, given the interest of the Western Cape Government in increasing compliance with the national water harvesting mandate, additional water harvesting from the water treatment plant effluent is also considered. For the assessment, it is assumed that the additional water harvested would be used to expand agricultural production. Given the uncertainty related to the feasibility of additional water harvesting due to water quality issues such as heavy metal pollutants, the results for the replacement of treatment capacity—without the consideration of additional water harvesting—are presented first. Table ES1 presents the integrated cost-benefit analysis (CBA) conducted, without (ES1.1) and with water harvesting (ES1.2); Tables ES2 and ES3 present the results of the financial assessment.

Without considering the opportunity to recycle water for agricultural production, results indicate that only the Organica scenario results in a net positive result, with ZAR 31.9 million in net benefits. If no additional water harvesting is assumed, neither the improved water treatment option nor the wetland is economically viable, and both exhibit a net cost. Yet, the hybrid and grey alternatives generate higher avoided costs than the artificial wetland by further reducing nutrient discharge into the estuary. The hybrid option (Organica) exhibits the highest avoided cost (ZAR 631.6 million) and is the only option that generates a net benefit of ZAR 31.9 million between 2020 and 2060 (see Table ES1, Section ES1.1). The improved treatment plant and constructed wetland exhibit a net cost of ZAR 460.6 million and ZAR 652.4 million, respectively. If tourism revenues materialize, the wetland is projected to generate a net benefit of ZAR 173.1 million, becoming the most economical option, in that it both reduces costs and generates additional benefits.

Section ES1.2 in Table ES1 presents the results that consider the impact of additional water harvesting. The harvesting of water reduces the nutrient loads to the estuary due to the fact that water is diverted following treatment and does not reach the estuary. Reducing nutrient loads increases the avoided costs of nutrient discharge and generates ZAR 453.7 million in added benefits by unlocking water resources that allow for additional agricultural value added (ZAR 313.1 million) and labour income (ZAR 140.6 million) relative to BAU. The change in nutrient loads causes all three treatment technologies to exhibit a positive net result, with net benefits between 2020 and 2060 indicated at ZAR 693 million (Organica), ZAR 312.7 million (improved treatment) and ZAR 187 million (wetland, excluding tourism revenues). If additional tourism revenues were to materialize, the wetland would generate the highest net benefit with a total of ZAR 1.01 billion between 2020 and 2060.

Table ES1. Integrated CBA 2020–2060 without additional water harvesting (ES1.1) and with additional water harvesting (ES1.2), all values in undiscounted ZAR

Wastewater treatment capacity	Unit	ES1.1: Excluding water harvesting			ES1.2: Including water harvesting		
		Improved treatment	Organica	Wetland	Improved treatment	Organica	Wetland
Capital investment	ZAR million	223.2	162.5	502.0	223.2	162.5	502.0
Operation and maintenance (O&M) costs	ZAR million	530.6	437.2	249.3	530.6	437.2	249.3
Total cost	**ZAR million**	**753.8**	**599.7**	**751.4**	**753.8**	**599.7**	**751.4**
Avoided costs							
Cost of breaching	ZAR million	0.0	0.0	0.0	0.5	0.5	0.5
Cost of N disposed into estuary	ZAR million	46.3	347.5	-231.8	235.7	437.2	49.5
Cost of P disposed into estuary	ZAR million	229.8	247.7	320.0	340.5	352.4	400.8
Cost of N disposed into sea	ZAR million	2.8	20.9	-14.0	14.7	26.6	3.7
Cost of P disposed into sea	ZAR million	14.3	15.4	19.9	21.5	22.2	25.2
Total avoided costs	**ZAR million**	**293.2**	**631.6**	**94.2**	**612.8**	**839.0**	**479.8**
Added benefits							
Labour income, agriculture	ZAR million	0.0	0.0	0.0	140.6	140.6	140.6
Value added, agriculture	ZAR million	0.0	0.0	0.0	313.1	313.1	313.1

Wastewater treatment capacity	Unit	ES1.1: Excluding water harvesting			ES1.2: Including water harvesting		
		Improved treatment	Organica	Wetland	Improved treatment	Organica	Wetland
Value added, tourism	ZAR million	0.0	0.0	825.5	0.0	0.0	825.5
Carbon sequestration	ZAR million	0.0	N/A	4.8	0.0	N/A	4.8
Total added benefits	**ZAR million**	**0.0**	**0.0**	**830.3**	**453.7**	**453.7**	**1,284.0**
Net integrated benefits	**ZAR million**	**-460.6**	**31.9**	**173.1**	**312.7**	**693.0**	**1,012.5**
Total added benefits (excluding tourism)	ZAR million	0.0	0.0	4.8	453.7	453.7	458.6
Net integrated benefits (excluding tourism)	ZAR million	-460.6	31.9	-652.4	312.7	693.0	187.0

Source: Authors' own elaboration based on results obtained from SAVi.

Financial Analysis

Upon extending the integrated CBA to account for inflation as well as the time value of money, we estimated the net present value (NPV), internal rate of return (IRR), sustainable net present value (S-NPV), and sustainable internal rate of return (S-IRR) of the three alternatives. For these calculations, the NPVs and IRRs only account for the investment and maintenance costs and the added benefits associated with agriculture and tourism, whereas the S-NPVs and S-IRRs also consider avoided costs and other added benefits.[4] These avoided costs and other added benefits are accounted for as revenue streams of the project. These results are presented in Table ES2. Adding the avoided costs and other benefits to the calculation of the S-NPV improves results relative to the conventional NPV calculations across all three alternatives. Under these conditions, however, the only alternative that has a positive S-NPV is the wetland investment and only if the assumed tourism benefits materialize.

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[4] Avoided costs and other benefits include the carbon sequestration benefit and the avoided costs associated with breaching N into the estuary, P into the estuary, N into the sea, and P into the sea.

Table ES2. NPV, IRR, S-NPV, and S-IRR for the three alternatives without water harvesting being considered. All monetary values in 2020 million ZAR.[5]

Financial indicator	Improved treatment	Organica	Wetland
NPV	-619.7	-490.1	22.7
IRR	*	*	8.6%
S-NPV	-395.6	-7.4	99.3
S-IRR	*	8.3%	9.1%
NPV excluding tourism			-670.3
IRR excluding tourism			*
S-NPV excluding tourism			-593.8
S-IRR excluding tourism			*

Similar to the results above in Table ES2, when calculating the NPVs, IRRs, S-NPVs, and S-IRRs for alternatives in which additional water harvesting is considered, the water harvesting makes a significant difference when judging the viability of the alternatives. As shown in Table ES3, all proposed investment alternatives have positive S-NPVs. It remains notable that in both sets of calculations, when water harvesting was and was not considered, the inclusion of increased tourism was critical to the wetland alternative having higher S-NPVs (see Tables ES2 and ES3).

Table ES3. NPV, IRR, S-NPV, and S-IRR for the three alternatives with water harvesting being considered. All monetary values in 2020 million ZAR.

Financial indicator	Improved treatment	Organica	Wetland
NPV	-258.8	-129.3	383.6
IRR	2.5%	5.5%	10.5%
S-NPV	219.4	518.4	766.6
S-IRR	11.1%	15.9%	12.2%
NPV excluding tourism			-309.4
IRR excluding tourism			5.3%
S-NPV excluding tourism			73.6
S-IRR excluding tourism			9.0%

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[5] The asterisk denotes that IRRs and S-IRRs are incalculable because there are no net positive cash flows during the lifetime of the project.

The findings on water harvesting and related impacts on nutrient loads into the estuary indicate that water harvesting holds the potential to reduce nutrient loadings reaching the estuary by almost 50%. The assessment results provide a strong incentive to

i) Act swiftly, either by replacing or expanding water treatment capacity, to prevent future deterioration of habitat quality in the estuary.

ii) Start the process of amending the water reuse licence in parallel to the change in treatment capacity.

The latter is necessary to ensure that the harvesting of water can begin once operations of the different treatment plants commence or, alternatively, once an upgraded water reuse plant becomes operational.

Table ES4. How stakeholders and decision-makers can use the results

Stakeholder	Role in the project	How can the stakeholder use the results of the assessment?
Government	Design, implementation, and finance of nature-based infrastructure (NBI) projects	Government authorities can use the results to **raise awareness** of nature-based projects and to **justify investments** in integrated wastewater treatment solutions for estuary management. Specifically, the Organica plant shows the highest avoided cost in the scenario without water harvesting (Table ES1; Section ES1.1) and the highest net integrated benefit of around ZAR 693 million over the next 40 years, assuming that water harvesting is considered (Table ES1; Section ES1.2).
		The results presented in this report provide an integrated perspective on sewage treatment in the context of estuary management and can help government authorities to **provide funding and support** from different sources. For example, the use of nature-based technologies contributes to additional carbon sequestration (e.g., artificial wetland) or reduced energy use (Organica), highlighting the link between sewage treatment and **climate change mitigation**. NBI typically provides multiple benefit streams as compared to the single benefit provided by grey infrastructure, making it an enabler for more integrated system management and for reaching sustainable development goals. An increase in tourism numbers would benefit government tax revenues through additional spending and labour income. Interestingly, while the wetland and related tourism would increase revenues, making the asset economically viable, the Organica technology achieves economic viability through a reduction in costs rather than additional revenue generation.

Stakeholder	Role in the project	How can the stakeholder use the results of the assessment?
Government (continued)	Design, implementation, and finance of nature-based infrastructure (NBI) projects	Policy-makers can use the results to make decisions on **water management**, water harvesting and allocation, and potential additional investments that may be required for realizing additional benefits. For example, the information provided by this assessment can serve for revising the current water use licence to pave the way for increased water harvesting, which benefits the estuary by reducing nutrient loads. Finally, the results demonstrate the potential value of using nature-based approaches in **comparison to conventional solutions** for sewage. While the conventional treatment plant upgrade assessed in this study also reduces nutrient loads, the conventional plant performance is inferior relative to the nature-based options when looking at net benefits (see Table ES1, Sections ES1.1 and ES1.2).
Industry/ private sector	Project developers	Businesses, especially in agriculture but also other industries, can use the results for additional advocacy for increasing water harvesting and hence expanding **water supply** available for economic production. For example, the additional harvesting of water has the potential to unlock agricultural land for production. The use of this water allows for irrigating around 330 additional hectares of agricultural land (see Section 4.2). Tourism organizations can use the study to advocate for the implementation of the wetland due to its contribution in increasing natural land cover and maintaining or increasing natural capital, which may, in turn, attract more tourists.
Donors and funders	Funding of NBI projects	Donors can include the results in this report in their **reporting** to demonstrate the impacts of their investment. This report demonstrates that investments in hybrid and NBI for wastewater treatment generate net benefits of ZAR 1.16 and ZAR 1.35 per ZAR invested in treatment (based on Table ES1, Section ES1.2). The results can be used for **awareness raising** of the benefits of hybrid and nature-based options for wastewater treatment. This can help make the case for further NBI-based approaches to estuary management, as they can yield significant avoided costs and added benefits (see Table ES1; Sections ES1.1 and ES1.2.). For example, if the artificial wetland increases biodiversity and draws in additional tourists, additional revenues of around ZAR 825 million could materialize between 2020 and 2060.

Stakeholder	Role in the project	How can the stakeholder use the results of the assessment?
Donors and funders (continued)	Funding of NBI projects	Further, donors can use this report to identify and **bring together relevant stakeholders** who could benefit from an integrated approach to wastewater treatment and estuary management. The proposed alternatives reduce the cost of estuary management and generate a net integrated benefit of between ZAR 1.01 billion for the nature-based alternative and ZAR 693 million in the case of the hybrid option.
Civil society organizations	Consultation with government on NBI projects	Civil society organizations can use the economic valuation of avoided cost and added benefits to **fine-tune sewage treatment** in eco-sensitive areas and to conduct more targeted **advocacy**. The results presented in this study provide avoided cost and added benefits of using NBI for sewage treatment (see Table ES1), highlighting the value added from using nature-based alternatives. Civil society organizations can also use the results to promote integrated solutions for sewage treatment. While an upgrade of treatment technology would contribute to alleviating nutrient pressures, the consideration of higher water harvesting yields shows the potential residing in reusing water for economic production. The fact that most nutrients reaching the estuary are currently originating from the treatment plant means that water harvesting reduces nutrient loads even further, improving water quality by preventing nutrients from reaching the estuary. Lastly, civil society organizations can use the results **to raise awareness of the value of NBI for integrated ecosystem management**. The combination of improved treatment and water harvesting generates system-wide benefits across multiple sectors, highlighting the value of a systemic approach for analyzing the cost and benefits of action and inaction.

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Glossary

Deep uncertainty: "A situation in which analysts do not know or cannot agree on (1) models that relate key forces that shape the future, (2) probability distributions of key variables and parameters in these models, and/or (3) the value of alternative outcomes" (Hallegatte et al., 2012, p.2).

Discounting: A finance process to determine the present value of a future cash value.

Indicator: Parameters of interest to one or several stakeholders that provide information about the development of key variables in the system over time and trends that unfold under specific conditions (United Nations Environment Programme [UNEP], 2014).

Internal Rate of Return (IRR): An indicator of the profitability prospects of a potential investment. The IRR is the discount rate that makes the net present value of all cash flows from a particular project equal to zero. Cash flows net of financing give us the equity IRR.

Integrated Valuation of Ecosystem Services and Trade-offs (InVEST): "A suite of models used to map and value the goods and services from nature that sustain and fulfill human life. It helps explore how changes in ecosystems can lead to changes in the flows of many different benefits to people" (Natural Capital Project, n.d.).

Methodology: The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).

Model transparency: The degree to which model structure and equations are accessible and make it possible to directly relate model behaviour (i.e., numerical results) to specific structural components of the model (UNEP, 2014).

Model validation: The process of assessing the degree to which model behaviour (i.e., numerical results) is consistent with behaviour observed in reality (i.e., national statistics, established databases) and the evaluation of whether the developed model structure (i.e., equations) is acceptable for capturing the mechanisms underlying the system under study (UNEP, 2014).

Net benefits: The cumulative amount of monetary benefits accrued across all sectors and actors over the lifetime of investments compared to the baseline, reported by the intervention scenario.

Net Present Value (NPV): The difference between the present value of cash inflows net of financing costs and the present value of cash outflows. It is used to analyze the profitability of a projected investment or project.

Optimization: A stream of modelling that aims to identify the policy or set of policies that deliver the best possible outcome from a set of alternatives, given a set of criteria (i.e., parameters to optimize) and/or constraints (i.e., available budget) (UNEP, 2014).

Robust decision: A decision that produces favourable outcomes under a range of possible scenarios (Hallegatte et al., 2012).

Scenarios: Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

Simulation model: Models can be regarded as systemic maps in that they are simplifications of reality that help to reduce complexity and describe, at their core, how the system works. Simulation models are quantitative by nature and can be built using one or several methodologies (UNEP, 2014).

Sustainable Internal Rate of Return (S-IRR): An indicator of the net benefit prospects of a potential investment. The S-IRR is the discount rate that makes the net present value of benefits from a particular project equal to zero.

Sustainable Net Present Value (S-NPV): The difference between the present value of benefits and avoided costs net of financing costs and the present value of cash outflows. It is used to analyze the net value of a projected investment or project.

1.0 Introduction

This study analyzes different wastewater treatment options for improving water quality in the Hartenbos estuary in South Africa. It also explores opportunities for reusing water for irrigation and related impacts on nutrient loads to the estuary.

The Hartenbos estuary is located in Mossel Bay, a municipality in South Africa's Western Cape Province. Every year, about 85,000 tourists visit Mossel Bay, and the lagoon is one of the attractions in the beach resort. However, water quality issues in the estuary strain the health and attractiveness of the ecosystem and are expected to worsen as population and tourist numbers grow. Most of the sewage from Mossel Bay is treated in a wastewater treatment plant in Hartenbos, and the cleaned effluent flows into retention ponds from which it is discharged into the lagoon. Even though the plant complies with national water quality standards, the discharged water contains high loads of nitrogen and phosphorus. The resulting high nutrient concentration in the estuary regularly leads to algae growth and fish kills due to lack of oxygen.

To allow for water exchange with the ocean, the municipality regularly breaches the strip of beach that often divides the estuary and ocean. While these breaches have positive effects on the ecosystem, they do not address the underlying causes for the nutrient overloads, and policy-makers are searching for alternatives.

Therefore, this assessment analyzes different options for upgrading the wastewater treatment infrastructure in Hartenbos. One possibility would be to extend the existing grey-built treatment plant to enhance its capacity. Another option would be to build a large plant using the so-called Organica technology, a hybrid treatment solution that combines grey and nature-based elements. Alternatively, policy-makers could decide to complement the existing treatment plant with a constructed wetland that treats the effluent before it reaches the estuary.

For each investment alternative, we calculate the costs, benefits, and avoided costs in an integrated valuation. For example, we model how the investments reduce nutrient loads in the estuary and how the improved water quality could attract more visitors.

The infrastructure investments would affect 268 hectares of the Hartenbos estuary and possibly create 20.4 hectares of artificial wetland. We assume that the improved wastewater treatment and ecosystem health could impact about 95,300 people living in Mossel Bay Municipality. The upgrades could also make enough water available to irrigate an additional 330 hectares of agricultural land.

Stakeholder Involvement and Policy Impacts

We conducted this valuation in collaboration with stakeholders from the Western Cape Government and Mossel Bay Municipality. The Department of Environmental Affairs & Development Planning of the Western Cape Government was closely involved in developing the model, defining scenarios, collecting data, and validating results. Similarly, we collaborated with the wastewater treatment managers of Mossel Bay Municipality.

The assessment is part of local efforts to better consider nature-based infrastructure (NBI) in infrastructure decisions. The Western Cape Government aims to promote infrastructure investments that deliver cost-effective services while contributing to climate adaptation, sustainable livelihoods, and a healthy environment. Assessments like this can help public authorities to better consider the life-cycle costs of infrastructure in their procurement decisions.

The valuation of wastewater treatment options in Mossel Bay can inform decisions in the Western Cape Province and beyond. It can serve as a case study on reducing the pollution of waterbodies. It also shows different infrastructure options for meeting the needs of a growing population. Moreover, the valuation could inform infrastructure funding guidelines and environmental policies, such as provincial water quality standards and estuary management plans.

2.0 Methodology

The Sustainable Asset Valuation (SAVi) assessment uses a systems approach to develop a project-specific integrated cost-benefit analysis (CBA) of sewage treatment options for the Hartenbos estuary. Information from multiple sources is integrated to allow for a cross-sectoral assessment and quantification of socio-economic as well as biophysical indicators.

The integrated CBAs presented in this report are based on the RCP 4.5 climate scenario obtained from the Copernicus Climate Data Store (CDS) (2021). Specifically, we use the Copernicus European Centre for Medium-Range Weather Forecasts Reanalysis 5th generation database for historical observations and the Coupled Model Intercomparison Project Phase 5 for projections.

2.1 Causal Loop Diagram

We developed and validated a Causal Loop Diagram (CLD) detailing the dynamics around the wastewater treatment issues in Mossel Bay, in collaboration with stakeholders from the Western Cape Government (Department of Environmental Affairs and Development Planning) and Mossel Bay Municipality (Municipal Infrastructure, Wastewater Treatment). A CLD is an analytical tool used to create an explicit representation of the dynamics of the system that should be considered for the assessment. It shows the interconnections between key socio-economic and environmental indicators and allows for a qualitative assessment of how potential project impacts unfold through the system.

The CLD created for the Hartenbos assessment is presented in Figure 1 and illustrates key drivers in form of balancing (B) and reinforcing (R) feedback loops that together create he dynamics currently observed in the system. While reinforcing loops, if regarded in isolation, lead to exponential growth or decline, balancing loops capture the limits to growth and carrying capacity of the system. For this assessment, six balancing loops were identified.[6]

At the Hartenbos estuary, nutrients originating from the sewage treatment plant (STP) have contributed to worsening water quality in the estuary. Population growth and an increase in annual visitors cause seasonal fluctuations in nutrient loads, which increase nutrient concentration in the estuary above sustainable levels (B1).

Algal blooms result in fish kills and make artificial breaching of the estuary necessary to reduce nutrient levels in the estuary (B2). The importance of the estuary not just for local tourism but also as a hatchery providing shelter for fish makes addressing water quality-related issues paramount for maintaining or improving the current level of ecosystem services.

Sewage system capacity and the installed treatment plant determine the total amount of nutrients removed during treatment and hence prevented from reaching the estuary (B3). Over the last couple of years, wastewater treatment works have mainly focused on upgrading the sewage system, increasing total system capacity to around 44 mega litres (ML); however, the reactor requires upgrading in the near future as well. The current STP capacity of 18 ML

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[6] For more information on CLDs and the way in which NBI assessments are carried out, visit the Training website of the NBI Global Resource Center: https://nbi.iisd.org/online-training-course-about-nature-based-infrastructure/

seems sufficient to process peak wastewater loads and to provide treatment services compliant with local water quality requirements. On the other hand, the current plant is quite old, and new technologies are more efficient in removing nutrients. A study of nutrient pressures on the estuary has shown that the majority of loadings discharged into the estuary come from the treated sewage that is discharged (Lemley et al., 2014), indicating that a change in treatment technology may yield additional water quality-related benefits.

There is a growing interest in assessing potential alternatives for reducing wastewater-related nutrient loads discharged into the estuary with an emphasis on using nature-based or hybrid alternatives. The upgrading of the treatment plant would ensure that both capacity and removal efficiency of STP operations are sufficient to address current pressures and pressures emerging over the lifetime of the technologies assessed (B4). Furthermore, investing in upgrading treatment technology may allow for increased water harvesting, which would reduce the amount of nutrients from treated sewage that reach the estuary. The potential reductions in total nutrient loads would, in combination with a steady water flow in the river, contribute to reducing the overall nutrient concentration in the estuary (B5). Depending on water levels in the estuary, the reduction in discharge quantities from the STP reduces total water loads into the estuary, reducing flood risk on the one (B6) hand while, ideally, reducing the need to breach the estuary as water loads decline and quality improves.

Figure 1. Causal Loop Diagram SAVi Hartenbos wastewater assessment

Source: Author diagram.

The following paragraphs provide a brief summary of the variables involved in each loop presented in the above narrative. The feedback loops highlighted in Figure 1 (marked B1 through B6) allow for an explanation of the historical pattern described above and demonstrate how interventions could contribute to alleviating the abovementioned pressures:

a) B1—population and tourism growth increase the nutrient loads for treatment and hence the nutrient loads reaching the estuary after treatment. An increase in nutrient loads leads to higher turbidity in estuary water, which reduces water clarity and thus the estuary's attractiveness for tourists, which in turn reduces nutrient loads.

b) B2—nutrient loads reaching the estuary provide nutrients for aquatic vegetation to grow. The resulting algal growths can cause hypoxia (oxygen deprivation of the water) in the estuary, with adverse impacts on local fish populations. This, in turn, reduces the biodiversity of the estuary and makes it less attractive for tourists to visit.

c) B3—wastewater loads increase wastewater treatment requirements, making it necessary to expand treatment infrastructure. Infrastructure sufficiency is important to ensure that nutrient removal is maintained, and nutrient loads to the estuary are minimized. The reduction in nutrients through treatment prevents adverse impacts on water quality and fish stocks, hence maintaining the attractiveness of the area for tourists.

d) B4—higher wastewater loads increase the required capacity necessary for sewage treatment and lead to capacity construction if capacity is below desired levels. The construction of treatment capacity increases total treatment capacity and hence ensures that the required capacity is installed.

e) B5—the more water is treated, the higher the amount of effluent that is discharged into the estuary. Given that most of the water in the estuary comes from the treatment plant, changes in effluent quantities and nutrient concentration affect the nutrient concentration in the estuary.

f) B6—higher water levels in the estuary increase flood risk, with potentially adverse impacts on tourism. This reduction in attractiveness leads to lower tourism numbers, which in turn reduces total wastewater loads for treatment and, hence, water discharged into the estuary from the treatment plant.

2.2 System Dynamics Model

The main purpose of the assessment is to analyze how nutrient pressures change under various wastewater treatment regimes and how potential water harvesting could reduce the need for artificial breaching and hence reduce associated costs. We developed a system dynamics (SD) simulation model to quantify the dynamics identified by the CLD in Figure 1.

Specifically, the model was set up to capture nutrient- and water flow-related pressures on the estuary as well as resulting impacts—in terms of nutrient concentration in the estuary—on the need for artificial breaching. For providing more nuanced information concerning the nutrient loads and their impact on the estuary, the following dynamics have been included in the model:

Social Dynamics Surrounding the Estuary

To forecast wastewater volumes and nutrient loads for treatment and entering the estuary, population and tourists are included in the model. Population is assumed to grow at a rate of 1% per year after 2013, and for tourists, historical growth rates are applied and a fixed growth rate is assumed moving forward. The calibration of population is aligned with the expected population indicated by Swartz et al. (2000). Tourists grow historically to reach the 86,000 visitors per year in 2017 (Mossel Bay Tourism, 2018); to capture the current reduction in visitors caused by the pandemic, a COVID shock is implemented that lasts from 2020 to 2023, after which tourists are assumed to recover to pre-pandemic levels. While tourism growth is set to zero between 2020 and 2023, the number of tourists visiting Mossel Bay is assumed to grow at 1.5% per year from 2023 onward.

Estuary Water Level and Water Flows Into the Estuary

Generating forecasts concerning water levels, the number of breaches, and the nutrient concentration of N and P in the estuary required the modelling of the waterbody. The water contained in the estuary and related dynamics, such as the release of treatment plant effluent, water inflow from the river, and required breaches, are informed by and calibrated based on the literature (Department of Water and Sanitation [DWS], 2016; Lemley et al., 2014, 2021; Swartz et al., 2000). The model considers the waterbody of the estuary and a nonlinear curve that relates water contained in the estuary to its water depth. Based on the estuary management plan (Anchor Environmental Consultants, 2016) and confirmed by Lemley et al. (2021), the model is calibrated to simulate a breach of the estuary (artificial opening of estuary mouth to release water into the sea) as soon as a water depth of 1.9 m is reached. Breaching depends on the water that flows into the estuary from the treatment plant and the river, leading to a slight variance in breaches based on seasonal precipitation.

Wastewater Treatment Dynamics and Nutrient Removal

Each of the wastewater treatment technologies considered was modelled using one stock that provides information about the installed capacity (in m^3/day) and with average removal efficiencies for total N and P. Based on the total water flow and the nutrients contained in the water reaching the treatment plant, the total amount of N and P is used to calculate the respective nutrient removal and to indicate the final amount of nutrients discharged into the estuary after treatment. Based on the water flow data of the treatment plant, it seems that the current effluent discharged per day is in the range of 8.5 ML. Water from population and tourism, as well as inflows from the sewers, was thus calibrated to ensure (i) that water flows are aligned with flow data and (ii) that water harvesting is consistent with the amount indicated in the current water use licence (DWS, 2016).

Water Harvesting From Treatment Plant Effluent

The model considers that a specific fraction of water is harvested from the treatment plant after treatment, based on the current water use licence (DWS, 2016). Over the course of multiple stakeholder meetings, it turned out that additional water harvesting was of particular interest for (i) reducing water loads into the estuary, which (ii) reduces nutrient pollution discharged into the waterbody and (iii) reduces the need for breaching the estuary mouth due to lower water loads, while (iv) providing additional water resources for agricultural production. The model provides the option to harvest additional water after treatment and captures changes in key output indicators, such as the required number of breaches, nutrients discharged into the estuary, nutrient concentration, and land unlocked through water harvesting, with related employment and value-added benefits.[7]

2.3 Integrated CBA

The integrated CBA estimates the costs, avoided costs, and added benefits related to each of the treatment alternatives considered. The CBA is set up at the level of Mossel Bay Municipality, due to the fact that the Hartenbos treatment plant is providing the largest share of the municipality's sewage treatment capacity. The estuary size was estimated at 29 hectares (River Health Programme, 2003), and the population of Hartenbos is calibrated based on Mossel Bay's socio-economic profile (Western Cape Government, 2020).

Intervention-related costs, avoided costs, and added benefits are estimated over a 40-year period, which is assumed to be the minimum lifetime of treatment alternatives. All values presented in the CBA hence cover the period from 2020 to 2060. An overview of valuation parameters used for the integrated CBA area is presented in Appendix A.

Intervention-related costs refer to the total **capital investment** and **operations and maintenance (O&M) expenditure** resulting from the implementation of the project over its lifetime. Capital costs are assumed to occur at the beginning of the project with the installation of capacity, after which only O&M costs incur from the operation of capacity.

The costs of breaching and the shadow cost of nutrient discharge are considered under avoided cost. Given the consideration of water harvesting as a policy option, the **costs of breaching** will be affected and are hence included in the assessment. Depending on the total water use of Mossel Bay Municipality as well as water loads from the river, water accumulates in the estuary at a slower or faster pace. Both the total amount of water as well as nutrient concentrations in the estuary determine the frequency at which artificial breaches become necessary. Breaches lead to the discharge of water (and nutrients contained) from the estuary into the open sea. The **shadow costs of nutrients discharged into the estuary and open sea** are used to attach a monetary cost to the nutrient streams in the absence of specific information on fish kills and other environmental impacts over time. The higher the efficiency of treatment technologies, the lower the shadow cost of nutrient disposal relative to the baseline scenario; hence the higher the avoided cost.

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[7] It should be noted that this assessment does not measure or forecast heavy metal pollution, which is one of the major ramifications for water harvesting under the current treatment regime. Further, the capital and operations costs for establishing additional water storage and conveyance infrastructure are not estimated in this study.

Added benefits are assumed to result (i) from the additional harvesting of water, increasing agricultural value added and labour income, and (ii) from the establishment of the wetland in the form of (potential) additional tourism revenues and the value of carbon sequestered by the wetland. The additional harvesting of water is assumed to unlock agricultural production that was constrained by water scarcity during the dry period. This study assumes that the higher availability of water diverted after treatment unlocks **additional agricultural value added and labour income** relative to the business-as-usual (BAU) scenario. Furthermore, if the artificial wetland contributes to higher biodiversity; for example, by providing shelter to birds and other animal species attractive to tourists, visitor numbers may be higher relative to the BAU, which in turn leads to additional **value added from tourism**. The **value of carbon sequestered** in the wetland is considered a co-benefit of this investment. The Organica plant (hybrid option) also provides some carbon sequestration from the use of plants for sewage treatment; however, the amount of carbon stored could not be determined due to the absence of data.

2.4 Financial Analysis

While the integrated CBA estimates the externalities (avoided costs/added benefits) and direct costs of the project, it does not consider how prices change over time, the time value of money, and the opportunity cost of the investment. To account for these aspects, we also conduct a financial analysis. We assume an inflation rate of 5.2%[8] for all modelled benefits and costs and use a discount rate of 8.5% per annum to determine the present value of costs and benefits at time of intervention. Our calculations are based on a 41-year lifetime of the intervention. These calculations allow us to assess the viability of the project and calculate the expected return on investment when the environmental, social, and economic benefits are considered. Traditionally, NBI projects, such as wetlands, do not generate revenue. However, as we can see from the CLD, they provide a range of benefits for different stakeholders as well as externalities in the form of avoided costs and added benefits.

We demonstrate the investment worthiness of the three alternatives assessed through the calculation of the net present value (NPV) and internal rate of return (IRR) and by integrating the abovementioned externalities and calculating the sustainable net present value (S-NPV) and sustainable internal rate of return (S-IRR). This extension of traditional NPV and IRR calculations makes sense for decision-makers who want to take a more holistic approach when assessing whether the project would deliver value for money to society over its life cycle.

In wanting to present a more nuanced picture of the value of the project, we have also included a scenario in which we consider the investment opportunity cost. With any investment there is a cost associated with choosing one investment over all other investments. For example, while we consider the investment in the wetland in relation to other grey alternatives that may deliver similar environmental benefits, an analysis that includes the investment opportunity cost goes beyond this comparison. By including the investment

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[8] We calculated the average annual inflation in South Africa to be 5.2% from 2000 to 2020 (World Bank, 2021). We used a higher inflation rate of 6.2% (5.2% + 1% premium) per annum to calculate the value of the carbon storage benefit as we expect the value of carbon storage to increase more rapidly. This estimation is more conservative than the estimation made by Gollier (2021) that has carbon prices to grow at 4% plus inflation.

opportunity cost, we compare the investment in the alternatives against the increase in GDP that accrues to the economy when an average investment of the same size is made. This average investment is not sector specific and may have environmental benefits and costs that are quite different from the alternatives. To do so, we scale the investment amount by a fiscal multiplier of 1.6, the estimated multiplier that Ilzetzki et al. (2013) found for fiscal spending by governments in developing countries. This opportunity cost is spread over the 5 years following each capital investment. Despite the limitations of the method used and the limited comparability of investments for social and environmental outcomes with those that prioritize economic performance, it is important to compare the different investment allocation options available to the municipality.

3.0 Scenarios and Assumptions

The assessment was conducted with two main objectives:

i)   Assessing the nutrient regime within the estuary through the implementation of different treatment alternatives.

ii) Outlining the impacts of additional water exports for agricultural production.

For the assessment of different wastewater treatment technologies, a range of scenarios were simulated to conduct the assessment: a baseline scenario and three treatment scenarios. To analyze treatment technology-induced changes in the system, the three treatment scenarios are compared against the baseline scenario.

3.1 Scenario Assumptions and Technologies Considered

The assessment of treatment alternatives is done by using the SD model to simulate each of the technologies envisaged with and without additional water harvesting. The first four scenarios analyze the current situation and how it would change if a different treatment technology was introduced. For all technologies simulated, the total installed capacity is assumed to be 18 ML per day, which is the equivalent of the currently installed reactor. This scenario does not consider additional water harvesting and hence provides information on how water quality in the estuary changes based on a change in treatment technology.

The second set of scenarios envisages a change in treatment technologies in combination with increased export of water for agricultural reuse. The three alternative treatment options with additional water harvesting are compared to the BAU without additional water harvesting scenario, given water quality-related issues that currently prevent increased water harvesting. The results comparing baseline results with and without water harvesting are presented in a textbox at the end of the results section.

Table 1 provides an overview of the technologies considered in the four scenarios simulated. Cost- and performance-related data for the different scenarios are summarized in Appendix A.

Table 1. Overview of technologies considered in the scenarios simulated

Scenario	Description
BAU	The BAU scenario represents the no-action scenario. In the BAU scenario, the situation continues as is, without the upgrading of wastewater treatment facilities or the establishment of NBI. This scenario assumes that the current treatment plant remains in place with no changes in removal efficiencies or water harvesting.
Upgrade of grey treatment capacity (improved treatment)	The improved treatment scenario assumes the upgrade of the existing Hartenbos wastewater treatment plant and its replacement with a conventional activated sludge reactor. The existing plant is replaced with a more advanced version of the current treatment plant. Nutrient-removal parameters are based on a report by Murray & Roberts Water (MRW, 2019).
Hybrid infrastructure (Organica)	The hybrid treatment scenario envisages the installation of an Organica treatment plant of the abovementioned capacity. Organica plants have been shown to be more efficient in terms of space and energy requirements as well as showing reduced sludge production compared to conventional activated sludge systems (MRW, 2019). Organica plants are considered a hybrid approach, as treatment takes place in part using conventional technologies, using screening and grit-removal technologies for pre-treatment, after which biological treatment occurs.
Artificial wetland	The artificial wetland scenario assumes that an artificial wetland using a vertical subsurface flow (VSF) system will be established to treat wastewater before it reaches the Hartenbos river. The VSF wetland uses mechanical technologies for pre-treatment, using a rotating disk screen, settlement tanks, sludge digestion-stabilization tanks as well as open siphon tanks and multiple basins (Tsihrintzis et al., 2007). A VSF system was chosen as treatment technology for two reasons, (i) higher removal efficiencies, and (ii) lower space requirements compared to a free-water surface system (11.3 m²/m³/day for the VSF system vs. 25.5 m²/m³/day for a free water surface [FWS] system), in light of potential spatial constraints.

3.1.1 Investment, Avoided Costs, and Added Benefits

Data for the integrated CBA and the financial assessment of the scenarios presented in Table 2 are drawn from different sources. Each of the positions presented in the CBA is calculated based on biophysical flows included in the SD model. Table 2 hence provides an overview of key assumptions used for the calculation of investment, avoided costs, and added benefits. A full overview of parameters and source documents is provided in Appendix A.

Table 2. Indicators, assumptions, and data sources used for the integrated CBA

Indicator	Assumptions
Added benefits	
Labour income, agriculture	• Additional water harvesting provides water for expanding agricultural production. • Unlocked land is estimated assuming an average water use per hectare (5,874 m^3/ha/year). • The average employment per hectare is assumed at 0.468 people per hectare. • The average salary is assumed at ZAR 40,304 per person per year (Statistics South Africa, 2020).
Value added, agriculture	• Additional water harvesting provides water for expanding agricultural production. • Unlocked land is estimated assuming an average water use per hectare (5,874 m^3/ha/year). • The average value added per hectare unlocked is assumed at ZAR 41,993 per hectare per year.
Value added, tourism	• The installation of the wetland is assumed to increase tourism growth by 0.05% per year over the other treatment cases. • The average length of stay is assumed to be 5 days per person. • The average local income generated from tourism is assumed at ZAR 3,214 per person per day.
Carbon sequestration	• Carbon sequestration from the wetland is estimated based on surface area and a sequestration multiplier per hectare. • The average wetland size is estimated using a capacity of 11.3 m^3 per m^2 per day, equivalent to 0.0885 m^2 per m^3 of capacity installed. • Average sequestration per hectare is assumed at 13.35 tons CO_2e per hectare per year (de Klein & Van der Werf, 2013).

Indicator	Assumptions
Avoided costs	
Cost of breaching	• The need for breaching is simulated in the SD model, based on estuary volume and water inflows. The number of breaches is informed by Lemley et al. (2021). • Increasing water harvesting yields reduces water flow into the estuary and hence the need for breaching. • The average cost of breaching is assumed at ZAR 15,000 per breach (assuming equipment needs to be rented) (W. Manuel, personal communication, October 27, 2021).
Cost of N and P discharged into estuary	• The cost of nutrient discharge into the estuary is calculated based on the nutrient flows into the estuary and the shadow cost of nutrient discharge reported by UNEP (2015). • The average cost per kg N discharged is assumed at USD 65.2 (UNEP, 2015). • The average cost per kg P discharged is assumed at USD 103.4 (UNEP, 2015).
Cost of N and P reaching the open sea	• The cost of nutrient discharge into the sea is calculated based on the nutrients flushed from the estuary into the open sea during breaches and shadow costs of nutrient discharge into the open sea reported by UNEP (2015). • The average cost per kg N discharged is assumed at USD 4.6 (UNEP, 2015). • The average cost per kg P discharged is assumed at USD 7.5 (UNEP, 2015).
Investment and cost	

Capital investment	• Capital investment in new capacity is based on the assumption that an 18 ML plant will be installed.
	• Capital costs per m^3/day of capacity are assumed at
	  - Improved treatment: ZAR 12,400 per m^3/day
	  - Organica: ZAR 9,025 per m^3/day
	  - Wetland: ZAR 25,356 per m^3/day

O&M costs	• O&M costs of sewage treatment are calculated based on the projected m^3 of water to be treated.
	• O&M costs per m^3 treated are assumed at
	  - Improved treatment: ZAR 3.75 per m^3/day
	  - Organica: ZAR 3.09 per m^3/day
	  - Wetland: ZAR 1.76 per m^3/day

3.1.2 Inputs for Financial Model

Table 3 summarizes the inputs that were used during the financial analysis that were not included in the integrated CBA.

Table 3. Inputs to the financial model

Other relevant information

Inflation rate	• Future estimates of annual inflation in South Africa of 5.2% are based on average annual inflation in South Africa from 2000 to 2020 (The World Bank, 2021). • We used a higher inflation rate of 6.2% (5.2% + 1 % premium) per annum to calculate the value of the carbon storage benefit as we expect the value of carbon storage to increase more rapidly. This estimation is more conservative than the estimation made by Gollier (2021) which has carbon prices to grow at 4% plus inflation.
Discount rate	• A discount rate of 8.5% was used as the Development Bank of South Africa issued medium-term debt in 2020 with coupons slightly above and below 8% (Development Bank of South Africa, n.d.). We thought that a 0.5% premium on this rate was an appropriate adjustment.
Benefits and costs beyond time horizon	• We assume that maintenance costs, tourism benefits, and avoided costs will continue beyond the 41-year time horizon of the financial analysis. • Terminal values (the value of flows beyond the forecast) are calculated using the same discount rate and adjusted using the same inflation rate in perpetuity.

3.1.3 Climate Data Inputs

Climate data were obtained from the CDS (2021). The results presented in this report are based on the Representative Concentration Pathway (RCP) 4.5 scenario. Monthly precipitation forecasts used for the assessment are presented in Figure 2. The RCP 4.5 scenario was chosen for this assessment because it is the most likely climate scenario to occur given the current international ambitions to reduce greenhouse gas emissions.

For this assessment, monthly precipitation is used as a driver for total water loads entering the estuary. Total water loads are the sum of water flow in the river and STP effluent being discharged. Both river water flows and the amount of water reaching the treatment plant are affected by precipitation.

Figure 2. Monthly precipitation in the RCP 4.5 scenario
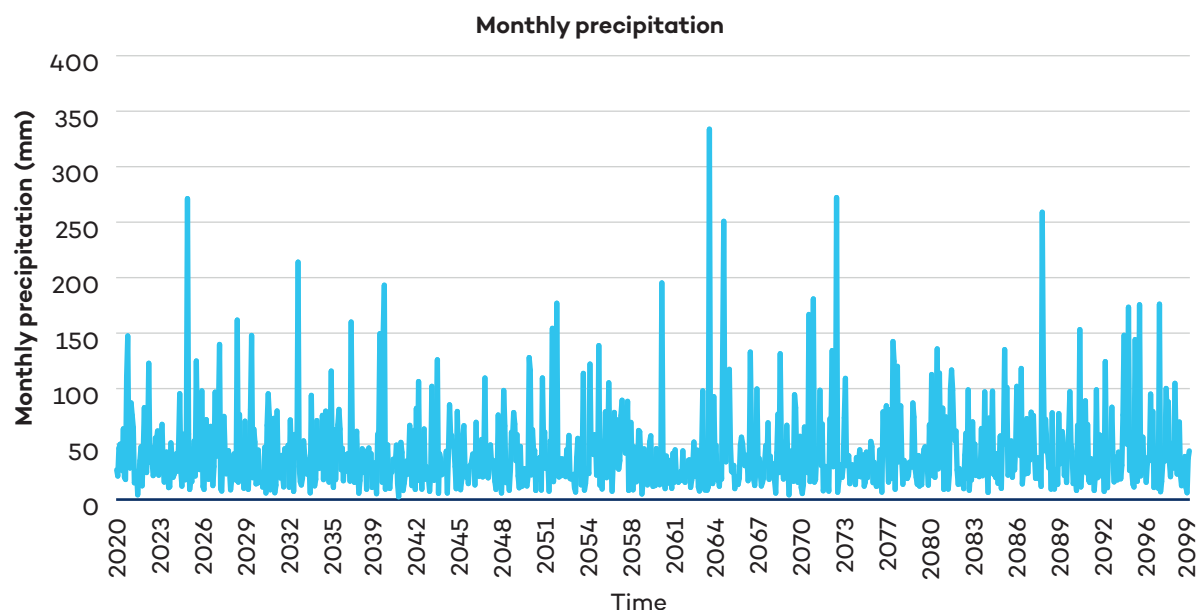
Source: Author diagram, using data from CDS, 2021.

3.2 Driving Forces

The driving forces considered for the nutrient loads in the estuary are wastewater loads from population and tourism, or, more specifically, the related nutrient loads to the treatment plant and, given a specific removal efficiency, nutrient discharge from the treatment plant.

3.2.1 Population and Tourism

A conservative estimate of 1% net population growth per year was assumed for the period 2020 to 2060. Concerning tourism, a 2020 report by the Western Cape Tourism, Trade and Investment Promotion Agency and the reported contraction of around 70% in total tourists was applied to affect the number of tourists for the years 2020 and 2021; a full recovery of visitors is assumed by 2023. The projected development of total population of the Mossel Bay Municipality and visiting tourists is presented in Figures 3 and 4. In the baseline, the total population increases to around 148,000 people by 2060, and the baseline number of visitors to Mossel Bay is projected to increase to 159,000 people per year, with visiting numbers of around 25,000 people per month during peak season (Mossel Bay Tourism, 2018).

Figure 3. Total population

Source: Authors' diagram based on SAVi simulations, March 1, 2022

Figure 4. Total number of tourists and seasonality of visitors
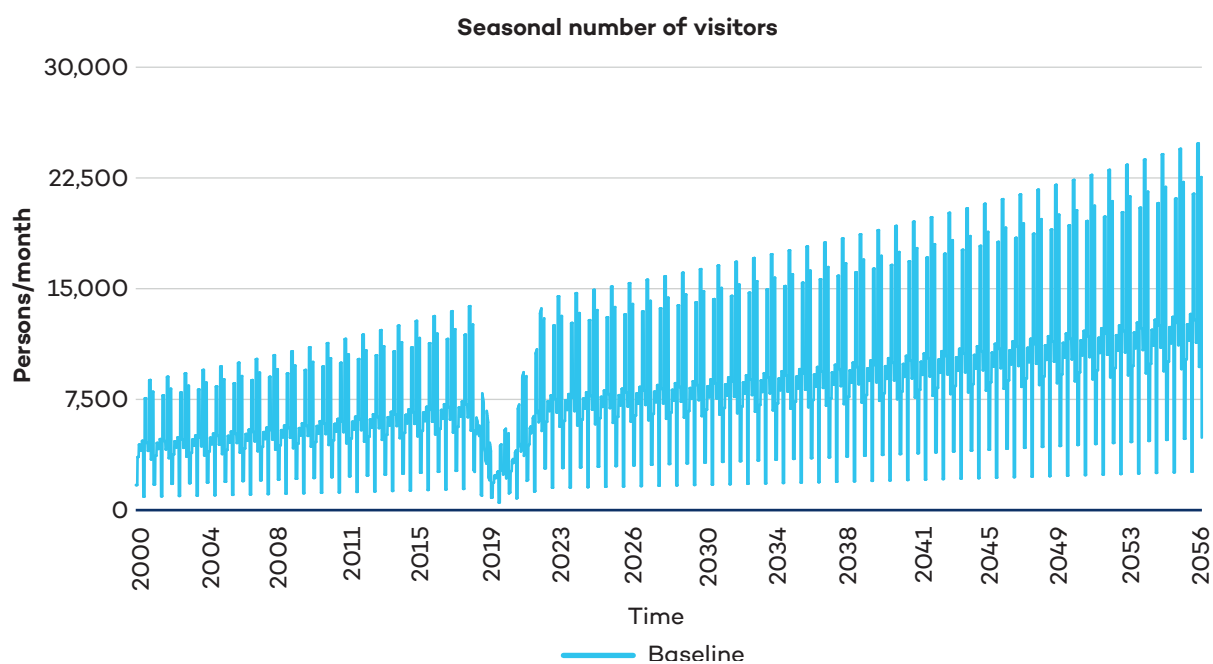
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

3.2.2 Wetland-Induced Tourism Growth

Between the four scenarios simulated, only the artificial wetland scenario induces a change in key drivers. While total population is assumed to be the same across all scenarios, the established wetland is assumed to have a beneficial impact on visitor numbers, due to increased biodiversity in the area. The total number of visitors across all scenarios is presented in Figure 5. The additional growth assumed for the artificial wetland scenario increases the total number of annual visitors to 164,300 by 2060 compared to 158,700 in the baseline, improved treatment, and Organica scenarios, which is 2% higher, for the former. Despite this increase in annual visitors, the change in total effluent discharge compared to the other scenarios is only 0.02%, due to the length of stay assumed and the fact that the number of additional visitors is evenly spread out across the year.

Figure 5. Total number of tourists and seasonality of visitors, all scenarios
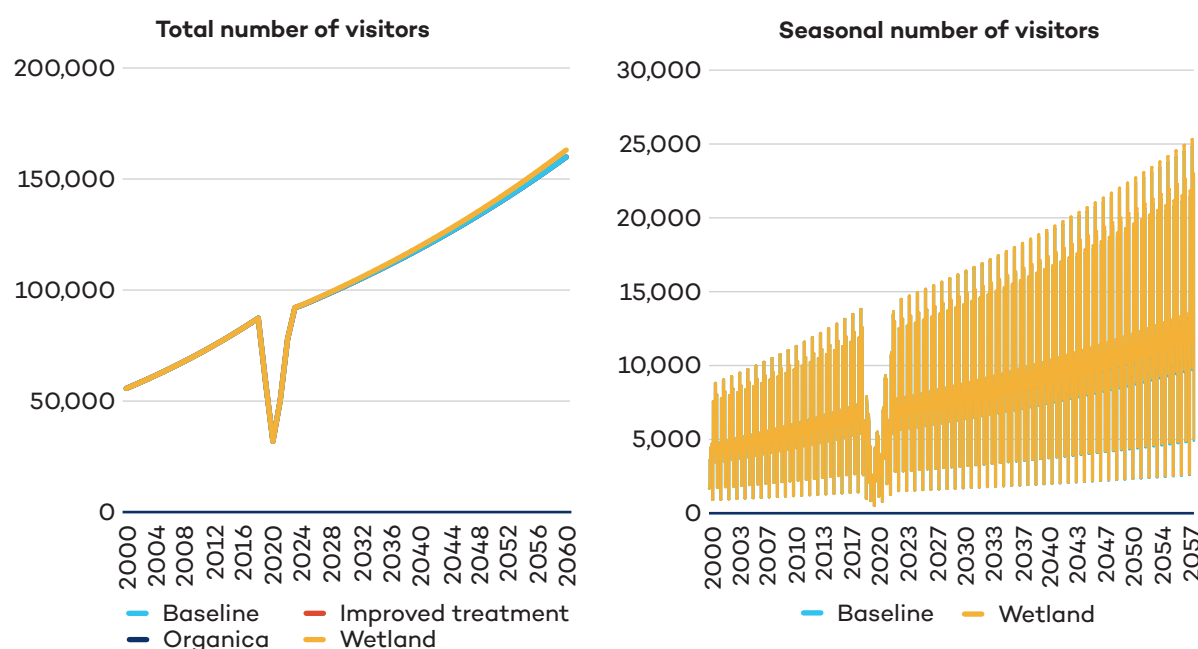
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

3.2.3 Wastewater Discharge and Water Harvesting

The resulting wastewater discharge into the estuary is presented in Figure 6. The total amount of wastewater discharged into the estuary increases as a consequence of increased population and visitor numbers from around 8 ML per day in 2016 to up to 11 ML per day in the year 2060, indicating that the currently installed reactor of 18 ML litres is sufficient to deal with incoming (average) loads over the next 40 years.

Figure 6. Average monthly discharge into treatment plant
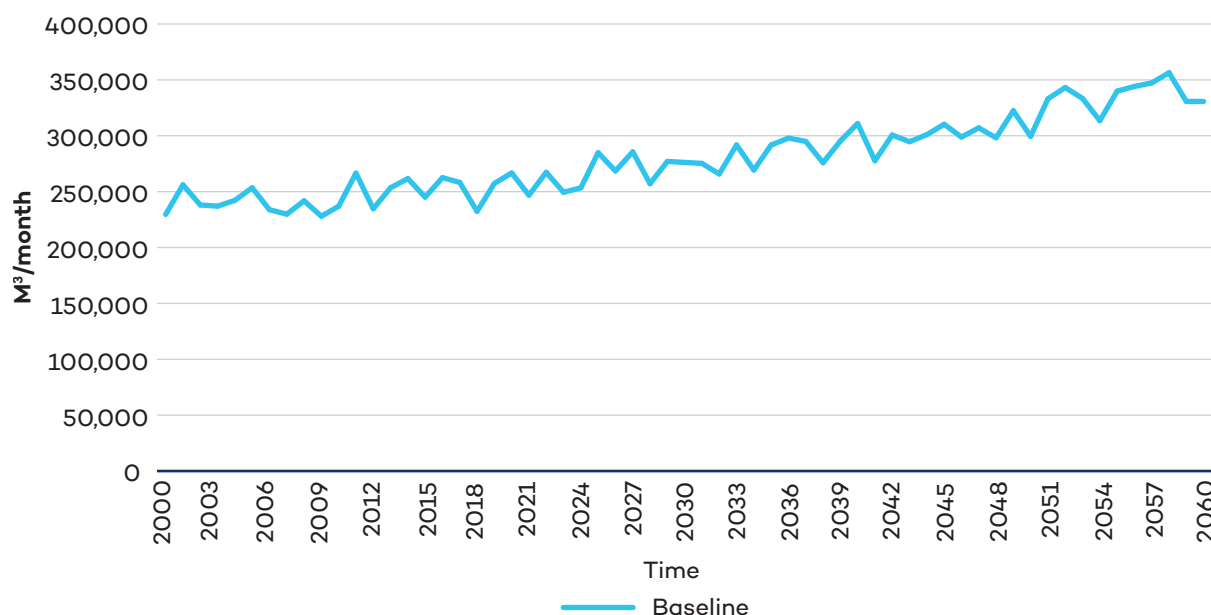
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

Water harvesting takes place in accordance with the water use licence, with approximately 45,700 m³ per year in water set aside and used for irrigation purposes (DWS, 2016). In 2060, water harvesting is equivalent to around 4,110 m³ per month on average. According to the licence, the area for discharging the harvested water is around 35 hectares. The projected development of water harvesting and agricultural land used for discharging harvested water is presented in Figure 7.

Figure 7. Water harvested after treatment and total area for irrigation water discharge
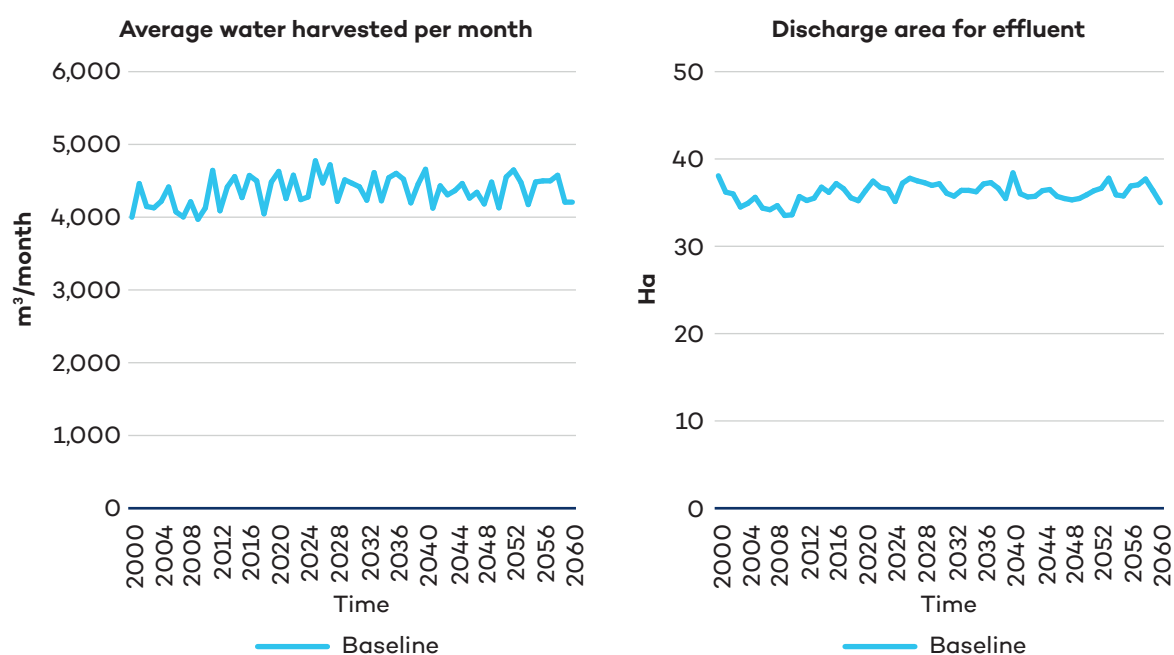
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

Considering the area-to-water harvesting relationship, each hectare of land receives around 1,310 m³ of harvested water, equivalent to around 7.7 m² of agricultural discharge area per m³ per year. A second indicator for agricultural land in relation to water harvesting was developed for this assessment, indicating the total amount of agricultural land that could be irrigated with the water harvested after treatment. For the calculation of this indicator, the total annual water harvested was divided by the average annual water use per hectare of agricultural land in Western Cape, indicated at 5,874 m³ per hectare per year (The Water Wheel, 2018). The resulting area thus indicates the total number of hectares for which water would be fully supplied from the treatment plant. This area will be used to estimate the marginal contribution of water harvesting to agricultural real GDP in the water harvesting scenario; the result for the total area that could be supplied with the current amount of water harvested is presented in Figure 8 for the scenarios without water harvesting.

Figure 8. Area fully supplied by water harvested
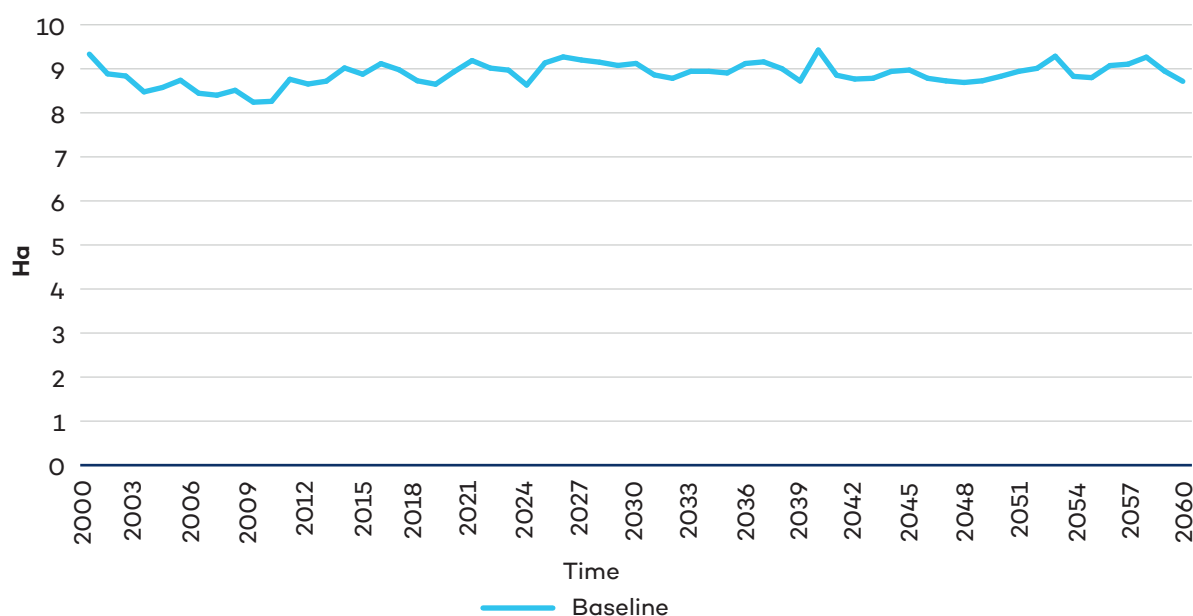
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

3.2.4 Additional Water Harvesting Relative to Baseline

Increasing the amount of water harvested after treatment leads to a reduction in sewage plant effluent into the estuary. For water harvesting, it is assumed that the share of effluent harvested for the three treatment scenarios assessed increases from 1.7% in 2020 to 25% in 2030 and 50% by 2060. As a result, the total amount of water harvested by 2060 increases from around 4,320 m³ per month in the baseline to 164,500 m³ per month in the water harvesting scenarios. The projected development of the average amount of water harvested per month is presented in Figure 9.

Figure 9. Average water harvested per month—water harvesting scenarios vs. baseline
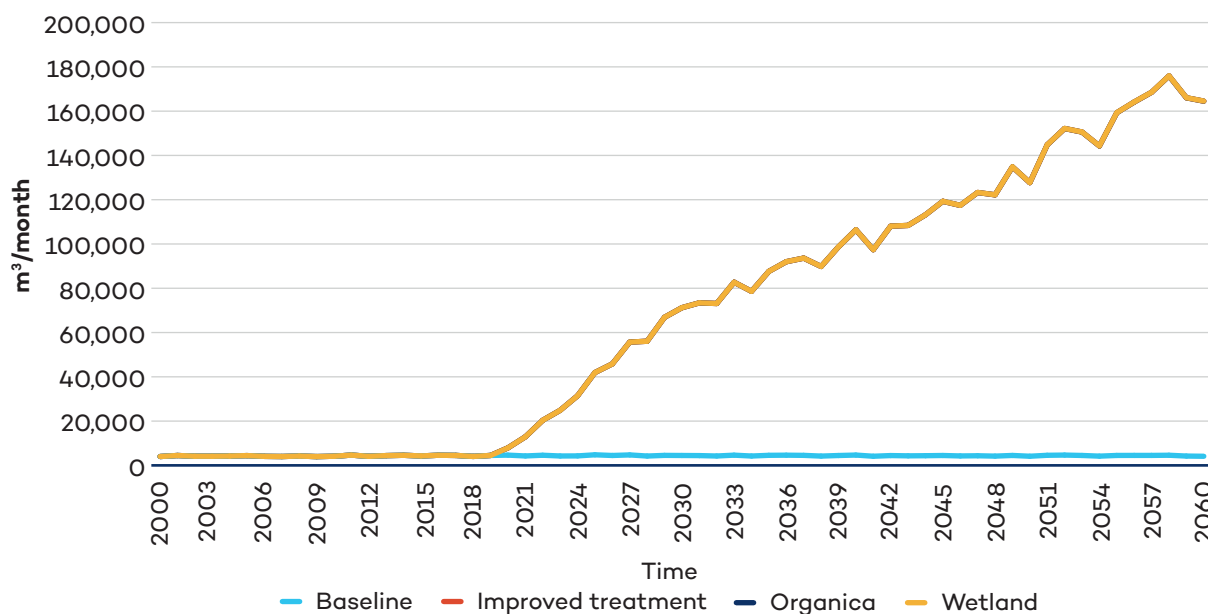
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

As a result of the increase in water harvested, there is an increase in the area for discharge and the total agricultural land that could be irrigated using the additional water harvested. The discharge area increases from around 35 hectares in the baseline to around 1,380 hectares in the water harvesting scenario. At the same time, the area for which the total irrigation requirements would be covered increases from around 9 hectares in the baseline to around 340 hectares by 2060. The projections for the total discharge area and the area fully supplied by water harvested are presented in Figure 10.

Figure 10. Discharge area for effluent and area fully supplied by water harvested— water harvesting scenarios vs. baseline
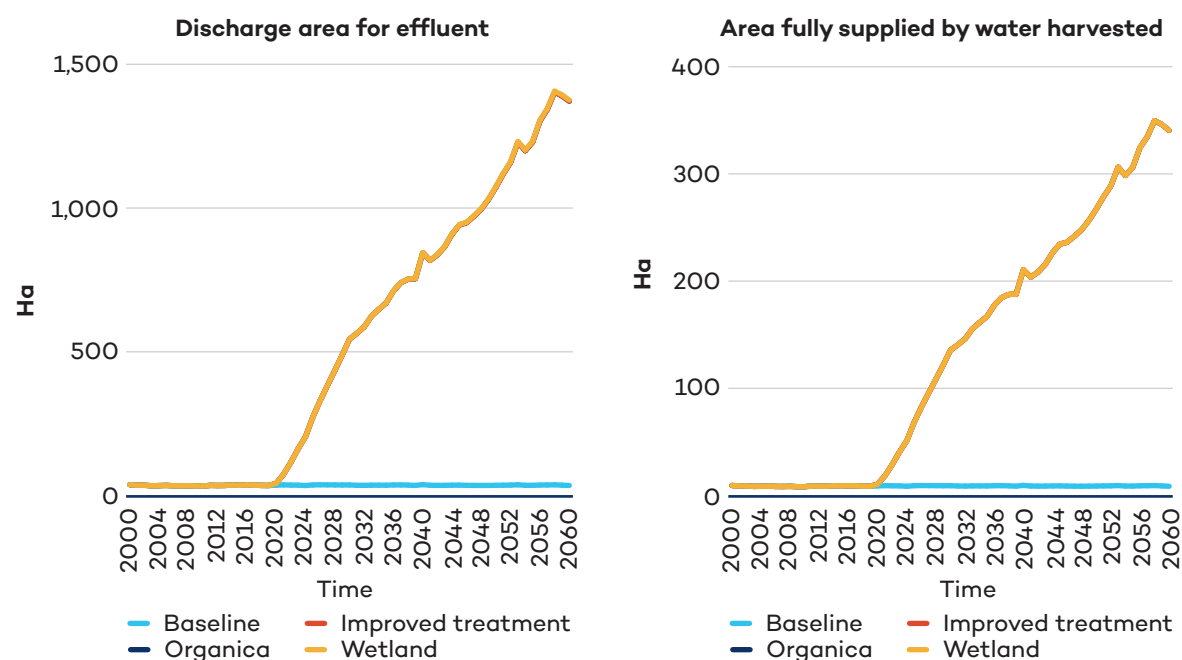
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

4.0 Results

This section presents the results generated for the three different treatment alternatives. The scenarios presented in Sections 4.1 and 4.2 focus on the current situation and existing solutions (i) without and (ii) with additional water harvesting. The first section provides results in which all impacts on nutrient loads and concentration are attributable to removal efficiency alone. The second section provides results that show the full impact of water treatment and diverting water for economic production after treatment, thereby illustrating the combined impact of improved treatment and water harvesting. The simulation of both cases allows for a more nuanced assessment and provides information about (i) the impacts of changing treatment technology in isolation and (ii) the combined impacts of change in treatment regime and additional water harvesting.

4.1 Upgrade of Treatment Capacity Without Water Harvesting

This section describes the results of the four abovementioned scenarios:

i)   Baseline, or BAU scenario

ii) Improved treatment scenario

iii) Organica scenario

iv) Artificial wetland scenario.

First, the impact of various treatment regimes on key drivers and the resulting water and nutrient loads entering the estuary—as well as their respective impacts on nutrient concentration in the estuary—are presented. The second part of this section focuses on the economic indicators related to the cost of treatment. Finally, an integrated CBA for the scenarios is presented. Due to the absence of baseline costs of treatment, the economic indicators are available only for the three intervention scenarios.

4.1.1 Nutrient Loadings and Concentrations Results

N LOADINGS AND CONCENTRATION

The total nutrient loads discharged into the estuary vary significantly across the three scenarios, with average annual N loadings being between 55.7% lower in the Organica scenario and 37.2% higher in the artificial wetland scenario by 2060. The main impacts on nutrients discharged stem from the fact that the treatment regimes assumed differ in their removal efficiency, which in turn impacts the total amount of nutrients discharged. The average annual N loads discharged in the four scenarios are presented in Figure 11.

Figure 11. Average annual N loads discharged into the estuary
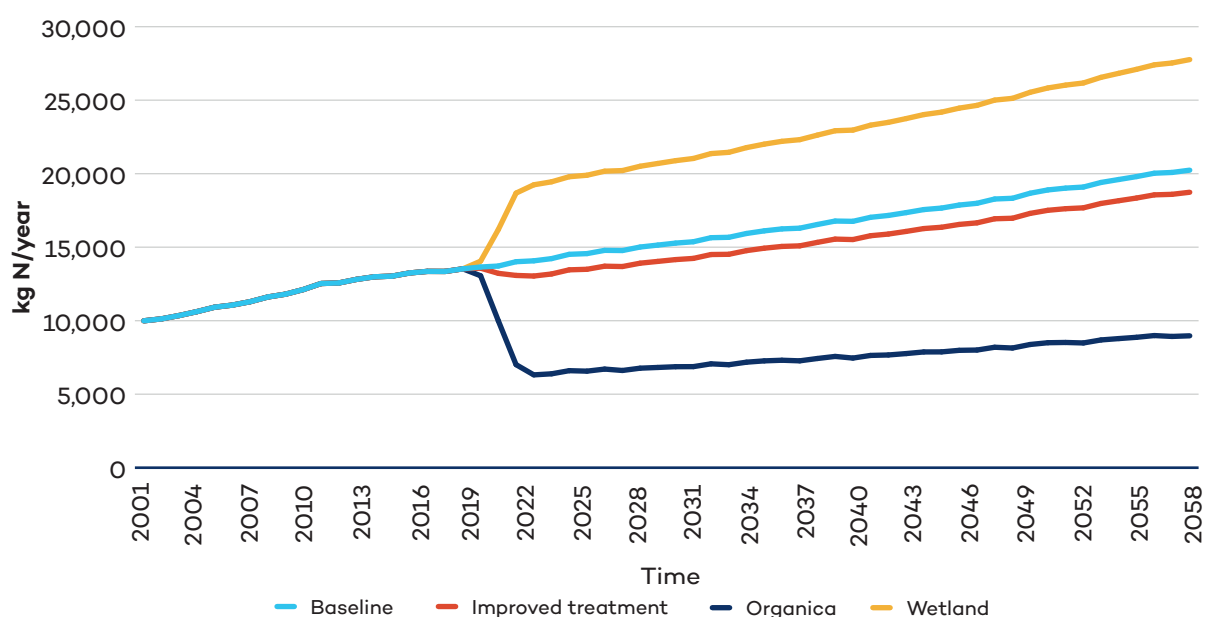
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

Total N loadings in the BAU scenario are projected to increase from 13,500 kg N per year in 2019 to around 20,240 kg N by 2060 and increase around 49.6% over the next 40 years, mainly driven by the increase in total population, but also the number of visitors. In the improved treatment scenario, total N loads are around 7.4% lower in the long run relative to the baseline due to higher N removal rates of the improved treatment plant. In the Organica scenario, the results suggest a reduction in total N loadings of up to 55.7% by 2060 compared to the BAU scenario, which is the highest reduction across the different treatment options assessed. An increase in total nutrient loadings discharged into the estuary is projected in the artificial wetland scenario. The slightly lower removal efficiency of the artificial wetland leads to a 37.2% increase in total N loadings discharged into the estuary by 2060 compared to the current treatment plant. An overview of results for total N discharge into the estuary is provided in Table 4 for selected years.

Table 4. Overview of total N loadings discharged into the estuary by scenario

N loadings entering estuary	Unit	2019	2030	2040	2050	2060
Baseline	kg N/Year	13,528	15,144	16,778	18,327	20,239
Improved treatment	kg N/Year	13,528	14,034	15,550	16,969	18,737
vs. BAU	%	*0.0%*	*-7.3%*	*-7.3%*	*-7.4%*	*-7.4%*
Organica	kg N/Year	13,528	6,819	7,570	8,141	8,972
vs. BAU	%	*0.0%*	*-55.0%*	*-54.9%*	*-55.6%*	*-55.7%*
Wetland	kg N/Year	13,528	20,695	22,920	25,124	27,762
vs. BAU	%	*0.0%*	*36.7%*	*36.6%*	*37.1%*	*37.2%*

Source: Authors' summary based on SAVi simulations, March 1, 2022.

Given that the total amount of water in the estuary is the same across all scenarios, the changes in N discharged into the estuary impact the N concentration per litre of water. Figure 12 illustrates this change in average N concentration resulting for the four scenarios.

Figure 12. Average annual N concentration in the estuary
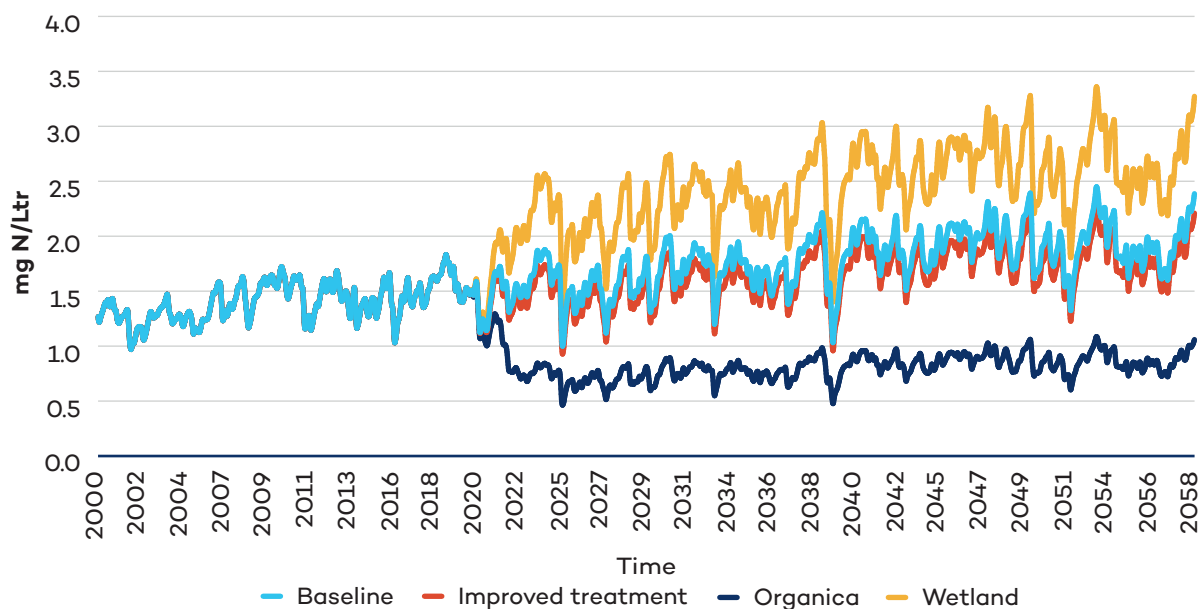
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

In the BAU scenario, the total N concentration per litre of water increases from around 1.61 mg N per litre in 2019 to 2.40 mg N per litre, which is a 49.2% increase. A doubling in N concentration is projected in the artificial wetland scenario, where N concentrations increase to an average of 3.29 mg N/litre. In the improved treatment and the Organica scenario, the total N concentration per litre declines to 2.22 mg N per litre (-7.4% vs BAU) and 1.06 mg N per litre (-55.6% vs BAU) by 2060, respectively.

P LOADINGS AND CONCENTRATION

The projected total amount of P discharged into the estuary across the four scenarios is presented in Figure 13. The analysis shows that all three technologies assessed lead to significant benefits in terms of P removal. The P removal efficiency of the alternatives assessed ranges from 47.9% for the improved treatment plant to 62% for the wetland, relative to 12% for the current treatment plant. This indicates the superiority of the alternatives assessed compared to the current plant and leads to significant reductions in P loadings reaching the estuary.

Figure 13. Average annual P loads discharged into the estuary
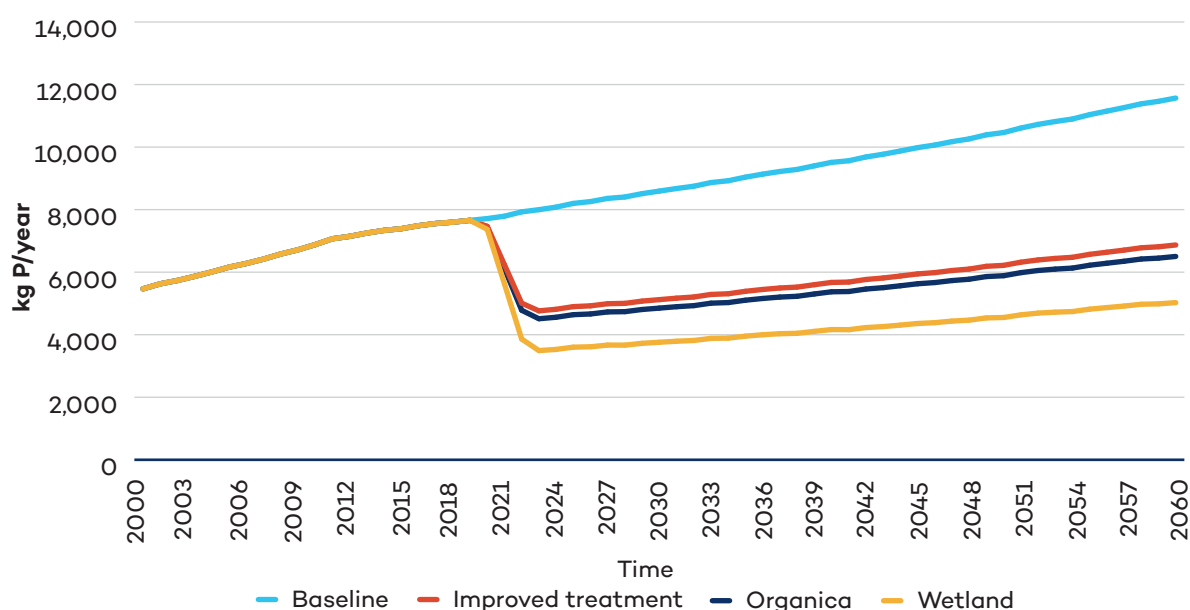
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

In the baseline scenario, total P loadings discharged into the estuary are projected to reach 11,570 kg P per year by 2060, compared to around 7,660 kg P in 2019. In the improved treatment scenario, the Organica scenario, and the artificial wetland scenario, the amount of P discharged into the estuary in 2060 totals 6,870 kg P per year, 6,500 kg P per year, and 5,030 kg P per year respectively. This is a reduction between 40.6% (improved treatment) and 56.6% (wetland) of baseline P loads. This highlights that it is highly recommended to maintain current practices for sludge after treatment in order to reduce nutrient pressures on the estuary. Table 5 presents an overview of the P loadings discharged into the estuary for selected years and all scenarios.

Table 5. Overview of total P loadings discharged into the estuary by scenario

P loadings entering estuary	Unit	2019	2030	2040	2050	2060
Baseline	kg P/Year	7,658	8,593	9,512	10,465	11,568
Improved treatment	kg P/Year	7,658	5,122	5,672	6,218	6,870
vs. BAU	%	*0.0%*	*-40.4%*	*-40.4%*	*-40.6%*	*-40.6%*
Organica	kg P/Year	7,658	4,851	5,372	5,886	6,503
vs. BAU	%	*0.0%*	*-43.5%*	*-43.5%*	*-43.8%*	*-43.8%*
Wetland	kg P/Year	7,658	3,758	4,164	4,551	5,026
vs. BAU	%	*0.0%*	*-56.3%*	*-56.2%*	*-56.5%*	*-56.6%*

Source: Authors' summary based on SAVi simulations, March 1, 2022.

The reduction in P loadings into the estuary leads to a decline in P concentration in the estuary relative to the BAU scenario. The resulting P concentration per litre is presented in Figure 14. In the baseline scenario, total P per litre of water is projected to increase by around 57.7% between 2019 and 2060, from 0.91 mg P per litre in 2019 to 1.44 mg P per litre in 2060. The P concentration for the three treatment technologies assessed is projected to decline to 0.87 mg P per litre in the improved treatment scenario, 0.82 mg P per litre in the Organica scenario and 0.64 mg P per litre in the artificial wetland scenario by 2060, respectively.

Figure 14. Average annual P concentration in the estuary
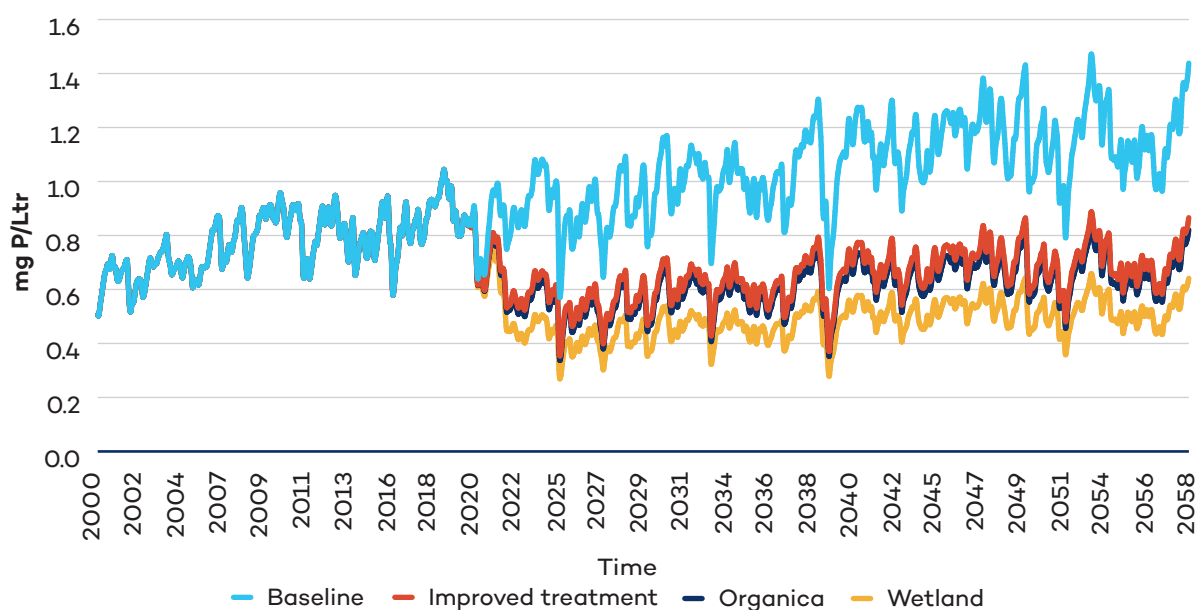
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

CHEMICAL OXYGEN DEMAND (COD) LOADINGS AND SLUDGE PRODUCTION

Total COD loadings in the effluent stream entering the treatment plants increase from around 4.63 kt in 2019 to 6.92 kt in 2060 across all four scenarios. In the artificial wetland scenario, the average COD loadings are 9 tons per year higher relative to the BAU, improved treatment, and Organica scenarios, due to the assumed increase in tourist numbers. The results for total COD loads after wastewater treatment are presented in Table 6 for all scenarios and selected years. In the BAU scenario, total COD loads after treatment increase to around 351 tons per year in 2060, proportional to the increase in total COD loads pre-treatment. In the improved treatment scenario and the artificial wetland scenarios, higher removal rates reduce total COD in STP effluent to 252.8 tons per year (-28% vs BAU) and 273.9 tons per year (-22% vs BAU), respectively. In the Organica scenario, COD loads in 2060 are projected to be 26% higher compared to the baseline, totalling 442.4 tons per year.

Table 6. Total COD loadings after treatment by scenario

COD after treatment	Unit	2019	2030	2040	2050	2060
Baseline	kg COD/Year	231,280	259,549	287,033	317,438	351,075
Improved treatment	kg COD/Year	231,280	186,876	206,664	228,555	252,774
vs BAU	*%*	*0.0%*	*-28.0%*	*-28.0%*	*-28.0%*	*-28.0%*
Organica	kg COD/Year	231,280	327,032	361,662	399,972	442,355
vs BAU	*%*	*0.0%*	*26.0%*	*26.0%*	*26.0%*	*26.0%*
Wetland	kg COD/Year	231,280	202,460	223,915	247,653	273,919
vs BAU	*%*	*0.0%*	*-22.0%*	*-22.0%*	*-22.0%*	*-22.0%*

Source: Authors' summary based on SAVi simulations, March 1, 2022.

Despite the increase in COD loadings in the Organica scenario, the projected sludge quantities resulting from the treatment alternatives assessed show a decline relative to the baseline. In the improved treatment and artificial wetland scenarios, total sludge production in 2060 is 44.6 tons per year (-28% vs BAU) and 34.9 tons per year (-21.9% vs BAU) lower compared to the baseline. In the Organica scenario, the treatment process leads to an even higher reduction, resulting in a total sludge reduction of 67.6 tons per year relative to the baseline in 2060, a reduction of 42.5%.

Figure 15. Total annual sludge production by treatment mode
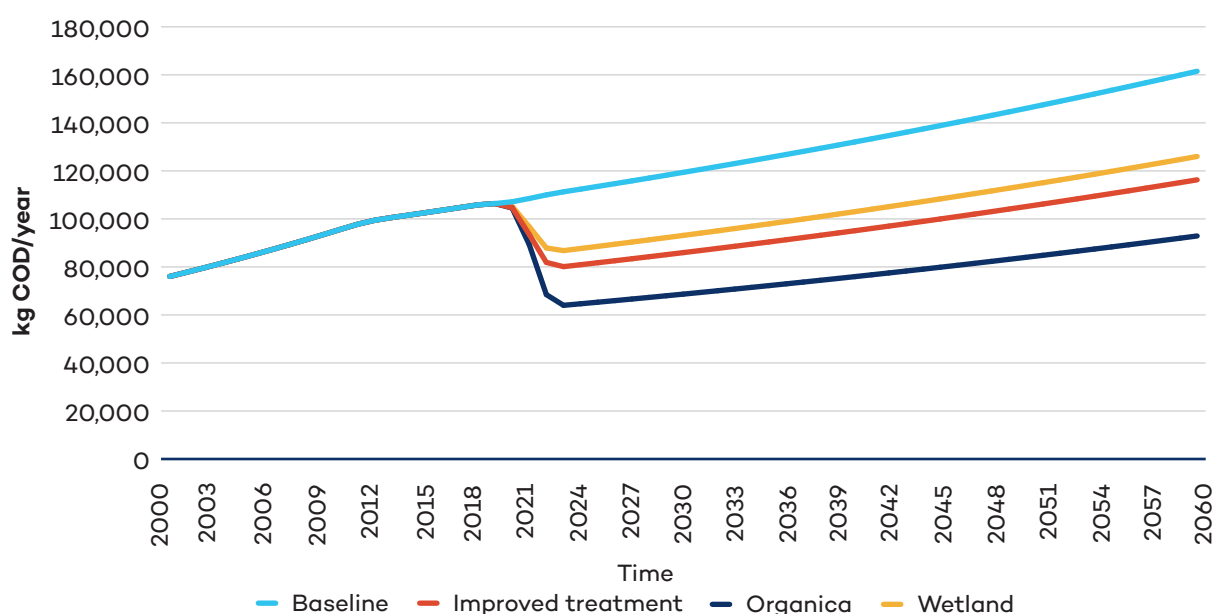
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

4.1.2 Wastewater Treatment Cost

The cost of treatment is assessed for three output indicators: (i) cost per m³ of water treated, (ii) cost per kg of N removed, and (iii) cost per kg of P removed. The resulting total cost per m³ of water treated in the three scenarios assessed is presented in Figure 16 and Table 8. The initial average cost per m³ treated is high in earlier years due to the relative weight of the total capital investment required and declines over time. Throughout the whole simulation, the Organica technology exhibits the lowest treatment cost per m³ of wastewater treated, with ZAR 4.28 per m³ treated by 2060. The artificial wetland and the improved treatment plant are on par by 2060, with ZAR 5.37 per m³ treated and ZAR 5.38 per m³ treated, respectively.

Figure 16. Average cost of treatment per m³ treated by treatment technology
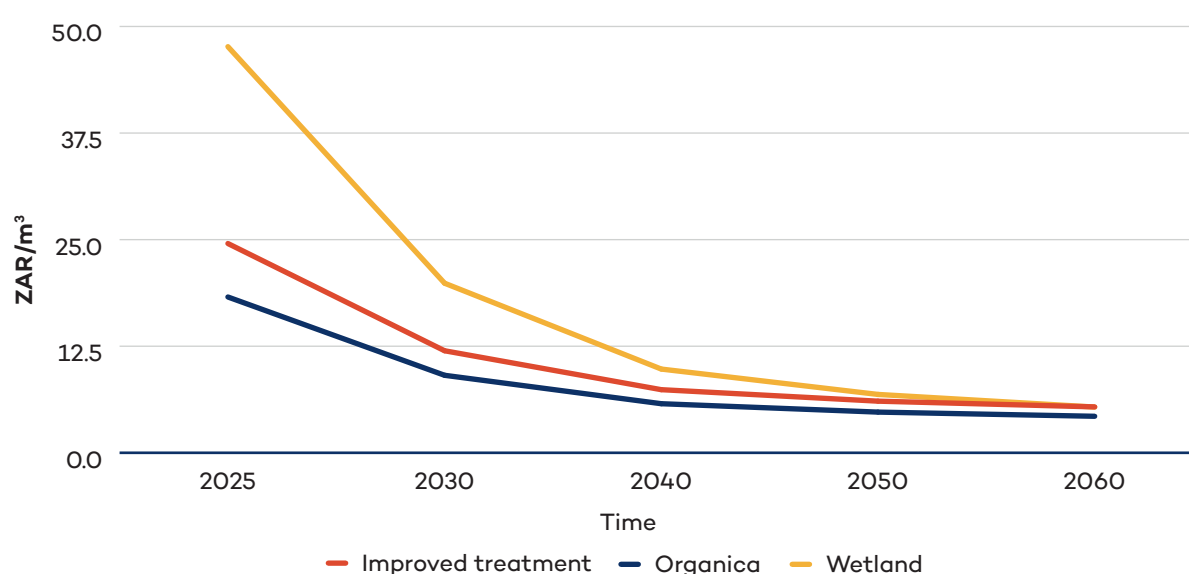
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

Table 7. Evolution of average cost per m³ treated over time by scenario

Average cost per m³ treated	Unit	2025	2030	2040	2050	2060
Improved treatment	ZAR/m³	24.54	11.97	7.40	6.05	5.38
Organica	ZAR/m³	18.27	9.09	5.76	4.77	4.28
Wetland	ZAR/m³	47.63	19.89	9.82	6.85	5.37

Source: Authors' summary based on SAVi simulations, March 1, 2022.

The average costs per kg of N and P removed are presented in Tables 8 and 9. The average cost per kg N removed by 2060 ranges from ZAR 77.03 per kg N in the Organica scenario to ZAR 105.21 per kg N removed in the artificial wetland scenario. This indicates that the Organica technology is the most cost-efficient alternative for N removal given the costs incurred for the 18 ML reactor, followed by the conventional activated sludge reactor and the VSF wetland.

When it comes to the cost of P removal, the cost per kg removed in 2060 is projected to range from ZAR 381.63 per kg P removed in the Organica scenario to ZAR 496.15 per kg P removed in the improved treatment scenario. The higher upfront cost of the artificial wetland is compensated for with lower O&M costs per m³ of water treated and the higher P removal efficiency, resulting in an average cost of ZAR 424.85 per kg of P removed by 2060.

Table 8. Overview of average cost per kg N removed over time by scenario

Average cost per kg N removed	Unit	2025	2030	2040	2050	2060
Improved treatment	ZAR/kg N	428.67	227.10	141.79	114.18	100.92
Organica	ZAR/kg N	306.26	165.53	105.81	86.37	77.04
Wetland	ZAR/kg N	865.37	392.67	195.67	134.31	104.65

Source: Authors' summary based on SAVi simulations, March 1, 2022.

Table 9. Overview of average cost per kg P removed over time by scenario

Average cost per kg P removed	Unit	2025	2030	2040	2050	2060
Improved treatment	ZAR/kg P	15,853.43	8,398.84	5,243.66	4,222.56	3,732.45
Organica	ZAR/kg P	11,151.41	6,027.19	3,852.78	3,144.73	2,805.26
Wetland	ZAR/kg P	23,764.31	10,783.33	5,373.32	3,688.21	2,873.73

Source: Authors' summary based on SAVi simulations, March 1, 2022.

4.1.3 Integrated CBA

The integrated CBA for the three treatment alternatives is presented in Table 10. The results for the scenarios (considering that no additional water harvesting is assumed) indicate a net integrated cost of ZAR 460.6 million for the improved treatment scenario and a net integrated benefit of ZAR 31.9 million for the Organica scenario. The artificial wetland scenario indicates a net benefit of ZAR 173.1 million if tourism revenues materialize; without the additional revenues from tourism, the artificial wetland scenario incurs a net cost of ZAR 652.4 million.

The results show that, in terms of total investment and O&M costs, the Organica treatment plant exhibits the lowest total costs, with ZAR 599.7 million in cumulative capital and O&M expenditure between 2020 and 2060. The Organica plant is followed by the artificial wetland and the improved treatment plant with ZAR 751.4 million and ZAR 753.8 million in total cumulative capital and O&M costs by 2060, respectively.

Given that this scenario does not envisage additional water harvesting, the cost of breaching remains unchanged across the three scenarios. In the Organica, improved treatment, and wetland scenarios, the higher removal efficiency leads to a decline in the shadow cost of N and P entering the estuary, yielding a net avoided cost of ZAR 631.6 million (Organica), ZAR 293.2 million (improved treatment) and ZAR 94.2 million (artificial wetland),

respectively. Due to lower N removal efficiency of the wetland relative to the installed treatment plant, the additional N entering the estuary and open sea results in a net environmental cost of ZAR 231.8 million and ZAR 14 million, respectively, which is, however, compensated for through the avoided cost of P discharge.

In terms of added benefits, only the artificial wetland generates additional benefits from carbon sequestration and tourism revenues. Carbon sequestration in the wetland yields a net benefit of ZAR 4.8 million, while tourism revenues, if considered, generate an additional ZAR 825.5 million over the next 40 years.

Table 10. Integrated CBA of the three treatment alternatives assessed

Wastewater treatment capacity	Unit	Improved treatment	Organica	Wetland
Capital investment	ZAR million	223.2	162.5	502.0
O&M costs	ZAR million	530.6	437.2	249.3
Total cost	**ZAR million**	**753.8**	**599.7**	**751.4**
Avoided costs				
Cost of breaching	ZAR million	0.0	0.0	0.0
Cost of N disposed into estuary	ZAR million	46.3	347.5	-231.8
Cost of P disposed into estuary	ZAR million	229.8	247.7	320.0
Cost of N disposed into sea	ZAR million	2.8	20.9	-14.0
Cost of P disposed into sea	ZAR million	14.3	15.4	19.9
Total avoided costs	**ZAR million**	**293.2**	**631.6**	**94.2**
Added benefits				
Labour income, agriculture	ZAR million	0.0	0.0	0.0
Value added, agriculture	ZAR million	0.0	0.0	0.0
Value added, tourism	ZAR million	0.0	0.0	825.5
Carbon sequestration	ZAR million	0.0	N/A	4.8
Total added benefits	**ZAR million**	**0.0**	**0.0**	**830.3**
Net benefits	**ZAR million**	**-460.6**	**31.9**	**173.1**
Total added benefits (excluding tourism)	*ZAR million*	*0.0*	*0.0*	*4.8*
Net benefits (excluding tourism)	*ZAR million*	*-460.6*	*31.9*	*-652.4*

Source: Authors' summary based on SAVi simulations, March 1, 2022.

4.2 Upgrade of Treatment Technology With Additional Water Harvesting

This section describes the results of the four abovementioned scenarios:

    i) Baseline, or BAU scenario

    ii) Improved treatment scenario

    iii) Organica scenario

    iv) Artificial wetland scenario.

This section presents results capturing the combined impact of replacing treatment technology and additional water harvesting for agriculture. The resulting water and nutrient loads entering the estuary as well as their respective impacts on nutrient concentration in the estuary are presented in the first section. Finally, an integrated CBA for the scenarios is presented. Due to the absence of baseline costs of treatment, the economic indicators are available only for the three intervention scenarios.

4.2.1 Nutrient Loadings and Concentrations Results

N LOADINGS AND CONCENTRATION

Given that the majority of nutrient loads entering the estuary originate from treatment plant effluent, the harvesting of water not only has an impact on the total water loads entering the estuary, but also reduces nutrient loads relative to the scenarios in which no water is harvested. The average annual N loads entering the estuary and the average N loadings in the estuary in the water harvesting scenarios are presented in Figure 17, compared to the baseline scenario.

Figure 17. Average annual N loadings and N concentration—water harvesting scenarios vs. baseline

Average annual N loadings—water harvesting

Average N concentration—water harvesting
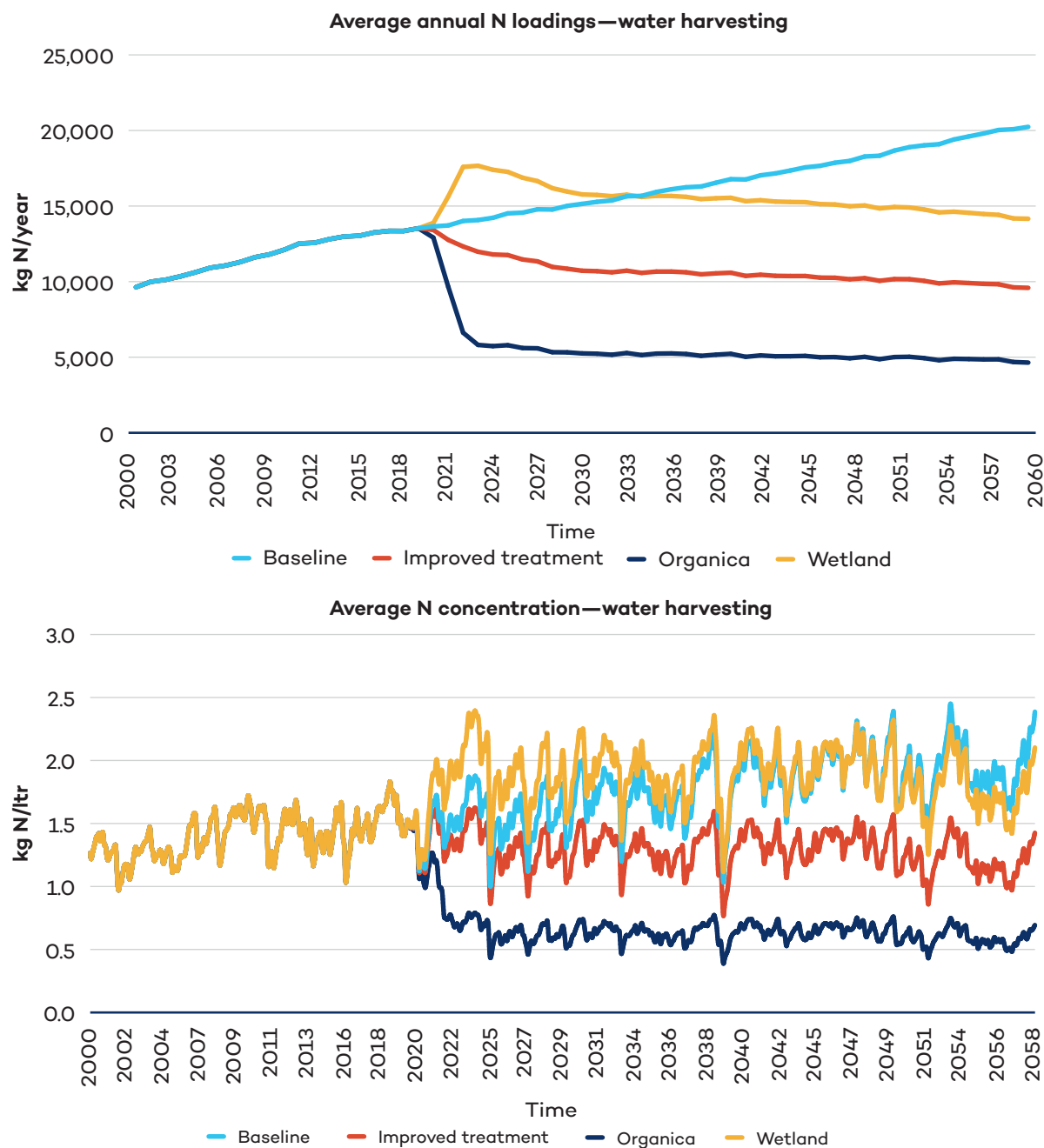
Sources: Authors' summary based on SAVi simulations, March 1, 2022.

While total baseline N loadings reach around 20,240 kg N per year by 2060, total N loads in the improved treatment and Organica scenarios decline below baseline levels right after implementation. In the case of the artificial wetland scenario, N loadings decline below baseline levels around 2040 and remain lower afterwards. By 2060, total annual N entering the estuary ranges from around 4,650 kg N per year in the Organica scenario (-77% vs BAU) to 14,160 kg N per year in the artificial wetland scenario (-30% vs BAU). As a result, the N concentration in the estuary in the waterbody declines proportional to the reduction in

loadings. In 2060, the N concentration in the waterbody is projected at 0.71 mg N per litre in the Organica scenario, 1.46 mg N per litre in the improved treatment scenario, and 2.15 mg N per litre in the artificial wetland scenario.

The reduction in N loadings and N concentration relative to the treatment cases without additional water harvesting is almost 50% and thus proportional to the increase in the share of water harvested. An overview of the projected N loadings discharged into the estuary and the average N concentration in the waterbody is presented in Table 11 for the three treatment scenarios assessed compared to the baseline.

Table 11. Average annual N loadings discharged into the estuary and estuary water N concentration for selected years—water harvesting scenarios vs. baseline

N loadings entering estuary	Unit	2019	2030	2040	2050	2060
Baseline	kg N/Year	13,528	15,144	16,778	18,327	20,239
Improved treatment	kg N/Year	13,528	10,720	10,591	10,055	9,590
vs. BAU	%	*0.0%*	*-29.2%*	*-36.9%*	*-45.1%*	*-52.6%*
Organica	kg N/Year	13,528	5,252	5,224	4,871	4,646
vs. BAU	%	*0.0%*	*-65.3%*	*-68.9%*	*-73.4%*	*-77.0%*
Wetland	kg N/Year	13,528	15,769	15,547	14,843	14,159
vs. BAU	%	*0.0%*	*4.1%*	*-7.3%*	*-19.0%*	*-30.0%*
N concentration per litre						
Baseline	mg N/Ltr	1.61	1.59	1.50	2.00	2.40
Improved treatment	mg N/Ltr	1.61	1.23	1.07	1.32	1.46
vs. BAU	%	*0.0%*	*-22.6%*	*-28.6%*	*-33.7%*	*-39.3%*
Organica	mg N/Ltr	1.61	0.60	0.53	0.65	0.71
vs. BAU	%	*0.0%*	*-62.1%*	*-64.7%*	*-67.6%*	*-70.5%*
Wetland	mg N/Ltr	1.61	1.81	1.57	1.95	2.15
vs. BAU	%	*0.0%*	*13.8%*	*4.8%*	*-2.3%*	*-10.5%*

Source: Authors' summary based on SAVi simulations, March 1, 2022.

P LOADINGS AND CONCENTRATION

A similar impact is observed for the total P loadings and P concentration in the estuary. The export of water, and hence the P contained in treated water, leads to a reduction in the three treatment scenarios relative to the scenarios without water harvesting. As for N, the decline in P loadings and concentration in the estuary water is around 50% (relative to the scenarios without additional water harvesting) and hence proportional to the increase in the amount of water harvested. While baseline average total P loadings discharged into the estuary total 11,600 kg P per year in the year 2060, total P loadings in the improved treatment scenario, the Organica scenario, and the artificial wetland scenario average 3,500 kg P per year, 3,320 kg P per year, and 2,570 kg P per year by 2060 respectively.

The above indicates that the average P concentration in the waterbody is lower in all three scenarios. In the improved treatment scenario, the average P concentration in 2060 is projected at 0.60 mg P per litre. For the Organica and artificial wetland scenarios, average P concentrations of 0.57 mg P per litre and 0.45 mg P per litre, respectively, are projected. The results for average annual total P loadings discharged into the estuary and the P concentration are presented in Figure 18 and Table 12.

Figure 18. Average annual P loadings and P concentration—water harvesting scenarios vs. baseline
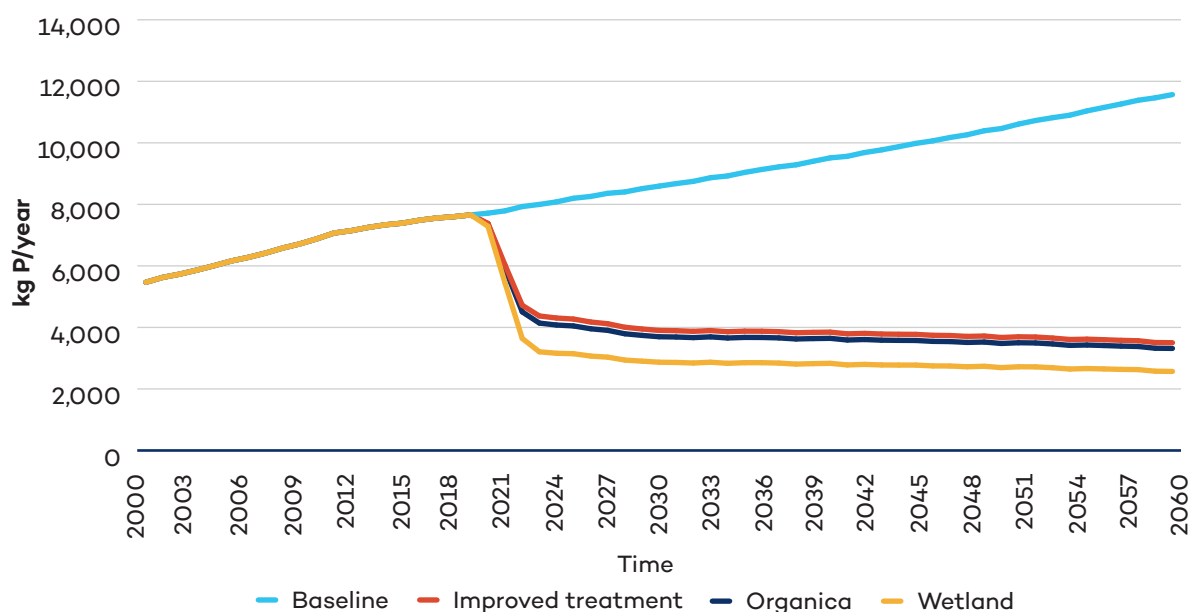
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

Table 12. Average annual P loadings discharged into the estuary and estuary water P concentration for selected years—water harvesting scenarios vs. baseline

P loadings entering estuary	Unit	2019	2030	2040	2050	2060
Baseline	kg P/Year	7,658	8,593	9,512	10,465	11,568
Improved treatment	kg P/Year	7,658	3,902	3,847	3,673	3,503
vs. BAU	%	0.0%	-54.6%	-59.6%	-64.9%	-69.7%
Organica	kg P/Year	7,658	3,697	3,645	3,478	3,318
vs. BAU	%	0.0%	-57.0%	-61.7%	-66.8%	-71.3%
Wetland	kg P/Year	7,658	2,869	2,833	2,694	2,570
vs. BAU	%	0.0%	-66.6%	-70.2%	-74.3%	-77.8%
P concentration per litre						
Baseline	mg P/Ltr	0.91	0.93	0.89	1.19	1.44
Improved treatment	mg P/Ltr	0.91	0.48	0.43	0.54	0.60
vs. BAU	%	0.0%	-47.8%	-51.8%	-55.0%	-58.6%
Organica	mg P/Ltr	0.91	0.46	0.41	0.51	0.57
vs. BAU	%	0.0%	-50.3%	-54.1%	-57.2%	-60.6%
Wetland	mg P/Ltr	0.91	0.37	0.32	0.40	0.45
vs. BAU	%	0.0%	-60.3%	-63.5%	-66.2%	-68.9%

Source: Authors' summary based on SAVi simulations, March 1, 2022.

COD LOADINGS AND SLUDGE PRODUCTION

Based on the assumption that water harvesting takes place after sewage has been treated, the total amount of COD loadings and resulting sludge production is not affected (see Section 4.1.1 for results).

4.2.2 Wastewater Treatment Cost

Given that there is no difference in the total amount of water treated, the cost of treatment considering additional water harvesting is identical to the cost of treatment presented in Section 4.1.2.

4.2.3 Integrated CBA

The integrated CBA for the three treatment scenarios including water harvesting is presented in Table 13. Compared to the CBA presented in Table 10, the improved treatment, the Organica, and the artificial wetland scenarios exhibit a positive net result of ZAR 312.7 million, ZAR 693 million, and ZAR 1.01 billion respectively.[9] If additional tourism revenues do not materialize, the net result exhibited for the artificial wetland is still positive, at ZAR 187 million.

The total investment and O&M costs of capacity remain unchanged, given that the water used for irrigation purposes is treated first. The total cost over the next 40 years is indicated at ZAR 753.8 million for the improved treatment scenario, ZAR 591.8 million for the Organica scenario, and ZAR 747.2 million for the artificial wetland respectively.

The increased water export onto agricultural fields reduces the total amount of nutrient loads, both N and P, that are reaching the estuary, which reduces the environmental cost assessed for this analysis. This additional removal further reduces the shadow cost of disposing N and P into the estuary and hence generates a higher net benefit relative to the scenarios without water harvesting. The results indicate avoided costs of ZAR 612.8 million for the improved treatment scenario, ZAR 839 million in the Organica scenario, and ZAR 479.8 million in the artificial wetland scenario. Across all three scenarios, the higher export of water for agricultural purposes leads to a reduction in breaching costs in the range of ZAR 0.5 million.

Furthermore, this scenario exhibits added benefits from higher water export volumes for agriculture, which increases the total area that can be irrigated using this water and hence related employment and value added. The additional water supply has the potential to generate ZAR 140.6 million in additional labour income and ZAR 313.1 million in additional value added across all three scenarios. The value of carbon sequestration in the wetland is indicated at ZAR 4.8 million. In addition, the results indicate that, if the wetland does increase the number of tourists visiting the area, the potential additional revenues from tourism are in the range of ZAR 825.5 million over the next 40 years.

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[9] It should be mentioned that the additional cost of water conveyance and storage infrastructure required are not included in the investment and O&M costs indicated for each technology.

Table 13. Integrated CBA of the three treatment alternatives assessed with water harvesting

Wastewater treatment capacity	Unit	Improved treatment	Organica	Wetland
Capital investment	ZAR million	223.2	162.5	502.0
O&M costs	ZAR million	530.6	437.2	249.3
Total cost	**ZAR million**	**753.8**	**599.7**	**751.4**
Avoided costs				
Cost of breaching	ZAR million	0.5	0.5	0.5
Cost of N disposed into estuary	ZAR million	235.7	437.2	49.5
Cost of P disposed into estuary	ZAR million	340.5	352.4	400.8
Cost of N disposed into sea	ZAR million	14.7	26.6	3.7
Cost of P disposed into sea	ZAR million	21.5	22.2	25.2
Total avoided costs	**ZAR million**	**612.8**	**839.0**	**479.8**
Added benefits				
Labour income agriculture	ZAR million	140.6	140.6	140.6
Value added agriculture	ZAR million	313.1	313.1	313.1
Revenues from tourism	ZAR million	0.0	0.0	825.5
Carbon sequestration	ZAR million	0.0	N/A	4.8
Total added benefits	**ZAR million**	**453.7**	**453.7**	**1,284.0**
Net integrated benefits	**ZAR million**	**312.7**	**693.0**	**1,012.5**
Total added benefits (excluding tourism)	*ZAR million*	*453.7*	*453.7*	*458.6*
Net integrated benefits (excluding tourism)	*ZAR million*	*312.7*	*693.0*	*187.0*

Source: Authors' elaboration based on SAVi simulations, March 1, 2022.

Water reallocation in the BAU

Given that additional water harvesting under current treatment conditions is unfeasible, the results presented in this report compare the water harvesting scenarios to a no water harvesting baseline. For illustration purposes, a BAU scenario with additional water harvesting was simulated using the same assumptions as for the treatment scenarios described above (25% by 2030, 50% by 2060). The resulting impacts on the average monthly water discharge and the average water harvested are presented in Figure 19. Total discharge into the estuary is projected to be 161,800 m³ per month lower (-48.9%) in the scenario with water harvesting, declining to around 168,900 m³ per month on average by 2060.

Figure 19. Water discharged into estuary and water harvested—baseline with water harvesting vs. baseline
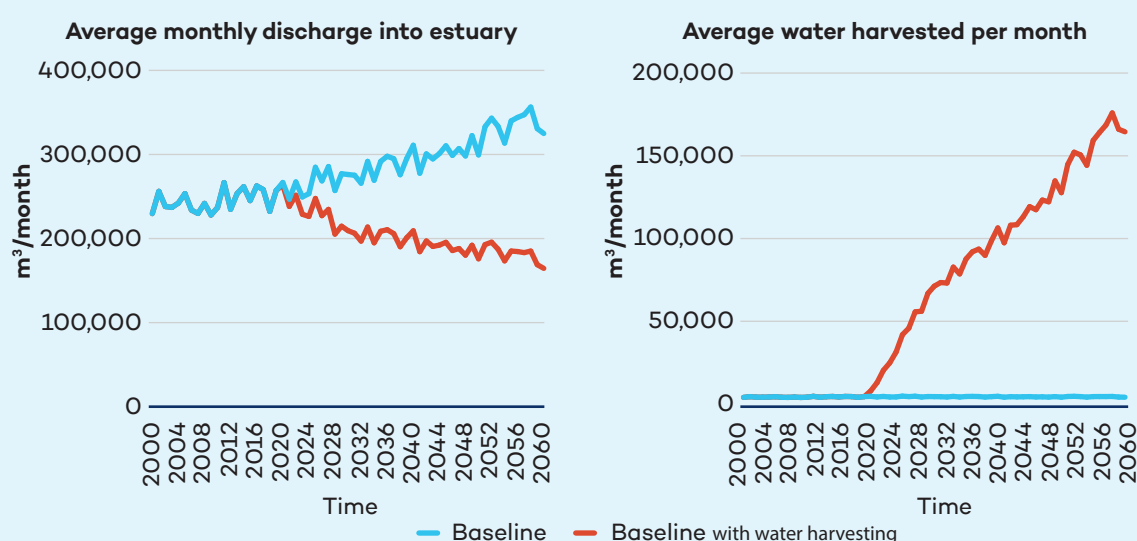
Source: Authors' summary based on SAVi simulations, March 1, 2022.

This reduction in effluent discharged to the estuary also reduces related N and P loads that are discharged into the estuary. The projected N and P loadings discharged into the estuary as well as the resulting impacts on nutrient concentration in the estuary are presented in Figure 20. Compared to the baseline scenario, the additional water harvesting reduces total N and P loadings discharged by around 49%. By 2060, this difference amounts to average avoided nutrient loadings of 9,900 kg N per year and 5,700 kg P per year, respectively. As a consequence, the average N concentration declines from 2.40 mg N per litre to 1.57 mg N per litre (-34.5%) and the average P concentration from 1.44 mg P per litre to 0.98 mg P per litre (-32.2%). This highlights that the additional reuse of effluent for agricultural purposes in itself holds a high potential for mitigating the nutrient pressures on the estuary in addition to generating additional benefits, such as higher water availability for agriculture and reduced cost of breaching.

Figure 20. Impact of water harvesting on nutrient loadings and concentration in the baseline
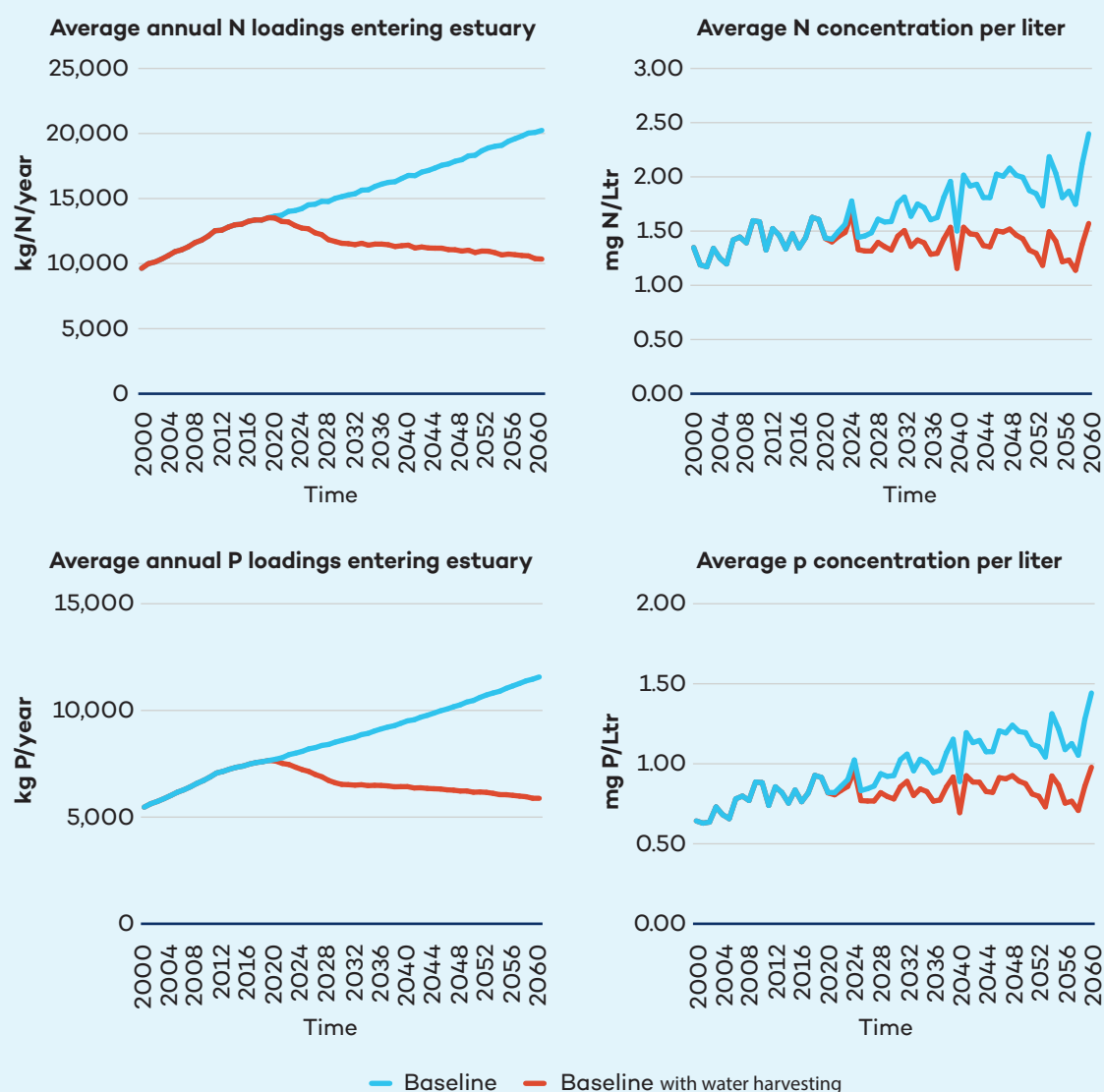
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

4.3 Financial Analysis

Similar to the undiscounted results in the integrated CBAs presented in Table 10 and Table 13, the realization of the tourism benefit is critical to the wetland being the best alternative from a financial perspective. If we were to assume that the tourism benefit is not realized, the Organica alternative and the improved water treatment alternative are better financial alternatives than the wetland since the upfront capital cost of the Organica alternative is one-third that of the wetland, and the cost of upgrading the water treatment plant is half the cost of the wetland.

4.3.1 Financial Analysis Without Water Harvesting

The results of the financial analysis, when accounting for inflation and applying a discount rate of 8.5%, highlight the importance of the tourism benefit. From the results presented in Table 14, it is evident that the wetland is the superior alternative if the tourism benefit is realized but will have the least value if this were not the case. As the present value associated with the estimated tourism benefit is ZAR 693 million, the wetland project needs to realize almost all of that to deliver on its promise of having the most value among the alternatives.

Table 14. NPV, IRR, S-NPV, and S-IRR for the three alternatives without water harvesting being considered. All monetary values in 2020 million ZAR.[10]

Financial indicator	Improved treatment	Organica	Wetland
NPV	-619.7	-490.1	22.7
IRR	*	*	8.6%
S-NPV	-395.6	-7.4	99.3
S-IRR	*	8.3%	9.1%
NPV excluding tourism			-670.3
IRR excluding tourism			*
S-NPV excluding tourism			-593.8
S-IRR excluding tourism			*

Source: Authors' summary based on SAVi simulations, March 1, 2022.

As the traditional NPV and IRR values calculated in Table 14 account for only the investment and maintenance costs and the added benefits associated with agriculture and tourism, it is unsurprising that the NPV is negative in most cases. It is only when the tourism benefits are included that one of the alternatives, the wetland, has a positive NPV and IRR.

When looking at the S-IRR, it is interesting to note that the Organica alternative offers a compounded average annual benefit of 3.9% while the wetland has an S-IRR of only 2.8%. Despite this estimation, the S-NPV is a superior calculation for these types of projects as it provides a calculation of the absolute value of a project based on an estimated rate of financing (the discount rate).

Given that the investment in improved water treatment and the investment in a wetland without tourism benefits do not have net positive annual cash inflows to offset the upfront investment costs, S-IRRs cannot be calculated.

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[10] The asterisk denotes that IRRs and S-IRRs are incalculable because there are no net positive cash flows during the lifetime of the project.

4.3.2 Financial Analysis With Water Harvesting

When calculating the NPVs, IRRs, S-NPVs, and S-IRRs for alternatives in which additional water harvesting is considered, the water harvesting makes a significant difference when judging the viability of the alternatives. As shown in Table 15, the NPV of the wetland alternative and S-NPVs of all proposed investment alternatives are positive. It remains notable that in both sets of calculations, when water harvesting was and was not considered, the inclusion of increased tourism was critical to the wetland alternative NPV and S-NPVs among the alternatives.

Table 15. NPV, IRR, S-NPV, and S-IRR for the three alternatives with water harvesting being considered. All monetary values in 2020 million ZAR.

Financial indicator	Improved treatment	Organica	Wetland
NPV	-258.8	-129.3	383.6
IRR	2.5%	5.5%	10.5%
S-NPV	219.4	518.4	766.6
S-IRR	11.1%	15.9%	12.2%
NPV excluding tourism			-309.4
IRR excluding tourism			5.3%
S-NPV excluding tourism			73.6
S-IRR excluding tourism			9.0%

Source: Authors' summary based on SAVi simulations, March 1, 2022.

As when considering the S-IRRs of the alternatives without considering water harvesting, the S-IRRs tell a conflicting tale. Despite the wetland having the highest S-NPV, it has the second-highest S-IRR behind the Organica alternative. The reasons for this are documented above, and we would continue to suggest that stakeholders rely on S-NPV when confronted with conflicting results.

4.3.3 Financial Analysis Considering Investment Opportunity Cost

As mentioned in Section 2.4, in wanting to present a more nuanced picture of the value of the project, we have also included a scenario in which we consider the investment opportunity cost. With any investment there is a cost associated with choosing one alternative over another. By using the estimated multiplier that Ilzetzki et al. (2013) found for fiscal spending by governments in developing countries, we estimated the opportunity cost of money being spent on this project as opposed to other projects. Obviously, the multiplier used in calculating the opportunity cost would change depending on the sectors of the alternative investment considered; however, the government multiplier provides an estimate.

Table 16 shows that when these costs are taken into consideration, the Organica alternative provides the best value—even more value than the wetland with realized tourism benefits. However, we note that this finding should be interpreted with caution. The Organica alternative has a lower upfront cost than the wetland; thus, when the investment opportunity cost is added to the analysis, the Organica alternative adds less investment opportunity cost than the wetland. This increased addition of cost alters the findings from Section 4.5.2.

Table 16. S-NPV and S-IRR for the three alternatives with opportunity costs considered. All monetary values in 2020 million ZAR.[11]

Financial indicator	Improved treatment	Organica	Wetland
Without water harvesting			
S-NPV	-687.0	-219.6	-556.4
S-IRR	*	4.8%	6.3%
S-NPV excluding tourism			-1,249.4
S-IRR excluding tourism			*
With water harvesting			
S-NPV	-72.1	306.3	-582.0
S-IRR	7.9%	11.2%	5.9%
S-NPV excluding tourism			111.0
S-IRR excluding tourism			8.8%

Source: Authors' summary based on SAVi simulations, March 1, 2022.

It is important to remember that by including the investment opportunity cost, we are comparing the investment in the alternatives against the increase in GDP that accrues to the economy when an average investment of the same size is made. This average investment is not sector specific and may have environmental benefits and costs that are quite different from the alternatives. We highlight this fact to reiterate that the investment opportunity cost is an estimate of a potential lost benefit somewhere else in society: it is not a cash flow and is highly dependent on the assumption that the capital used for these projects would have actually been deployed in other GDP-enhancing projects.

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[11] The asterisk denotes that IRRs and S-IRRs are incalculable because there are no net positive cash flows during the lifetime of the project.

5.0 Conclusions

We conducted this valuation in collaboration with stakeholders from the Western Cape Government and Mossel Bay Municipality. The Department of Environmental Affairs & Development Planning of the Western Cape Government was closely involved in developing the model, defining scenarios, collecting data, and validating results. Similarly, we collaborated with the wastewater treatment managers of Mossel Bay Municipality.

The assessment is part of local efforts to better consider NBI in infrastructure decisions. The Western Cape Government aims to promote infrastructure investments that deliver cost-effective services while contributing to climate adaptation, sustainable livelihoods, and a healthy environment. Assessments like this can help public authorities to better consider the life-cycle costs of infrastructure in their procurement decisions.

The valuation of wastewater treatment options in Mossel Bay can inform decisions in the Western Cape Province and beyond. It can serve as a case study of how to reduce the pollution of waterbodies. It also shows different infrastructure options for meeting the needs of growing populations. Moreover, the valuation could inform infrastructure funding guidelines and environmental policies, such as provincial water quality standards and estuary management plans.

The SAVi model and scenarios simulated are fully customized to the local context, highlighting the flexibility and scalability of this approach. They also highlight the benefits and disadvantages of each approach for managing nutrient flows and, hence, water quality.

Application of Results

The results of this assessment provide the Wastewater Treatment department and the Western Cape Government with overview of systemic costs and benefits of each alternative treatment option. The results generated in the course of this assessment provide insight into the outcomes of using different water treatment options, each characterized by different treatment efficiency (compliance with water quality standards for N and P), potential for water recycling (national water recycling mandate) and resulting in a range of indirect and induced impacts, such as potential additional production from agriculture and related employment from higher water availability.

The design of the assessment provides a blueprint to inform the infrastructure planning discussions of other municipalities that face similar issues. While the local context always provides a unique set of circumstances, the approach used for this study can be replicated in other locations.

The findings on water harvesting and related impacts on nutrient loads into the estuary provide a strong incentive to both (i) act swiftly, either by replacing or expanding water treatment capacity, to prevent future deterioration of habitat quality in the estuary and (ii) start the process of amending the water reuse licence in parallel to the change in treatment capacity. Given the beneficial impacts of water reuse on nutrients discharged into the estuary,

the amendment of the licence is necessary to ensure that the harvesting of water can begin once operations of the different treatment plants commence. Alternatively, until there is clarity on the post-treatment level of heavy metals and other pollutants, the amendment of the licence can be postponed until more detailed assessments of water quality have been conducted and water deemed feasible for agriculture use.

Next Steps Following the Assessment

The results presented in this study suggest that the hybrid treatment plant is the most cost-efficient option per m³ of water treated while exhibiting the higher N removal rates of all treatment alternatives assessed. **This assessment illustrates that hybrid alternatives are not just cost-competitive when it comes to the cost of treatment, but also outperform grey alternatives in terms of treatment efficiency.** It also shows that, for this specific case study, while the wetland is not as effective in reducing water pollution, it can generate new value by stimulating tourism. As a next step, the approach used in this study could be replicated in other locations where the stakes of improving water quality are high, such as, for example, other estuaries that are facing similar pressures.

The results can be disseminated across relevant stakeholders and institutions to raise awareness of integrated approaches for assessing the value of wastewater treatment and the importance to also consider hybrid and nature-based approaches.

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Appendix A. Main Parameters Used for the SD Model

Table A1. Overview of key assumptions used for the SAVi Hartenbos assessment

Indicator	Value	Data source/comment
Socio-economic data		
Population Mossel Bay 2018	95,255 People	WCG (2020)
Employment Mossel Bay (2018)	37,055 People	WCG (2020)
Value added Mossel Bay (2016)	ZAR 7,716.3 million	WCG (2020)
Estuary data		
Estuary size	29 Ha	Assumed based on River Health Programme (2003)
Average estuary depth	1.5m	Assumption
Number of breaches	Simulated endogenously, around five breaches per year	Approximated based on Lemley et al. (2021)
Estuary volume	493,000 m³	Assumption, estimated based on the above
Estuary water inflow	Varies by month	Based on Lemley et al. (2014) and DWS (2016)
Water quality data		
Estuary N concentration	Time series, based on MBM Estuary data	Provided by the local team
Estuary P concentration	Time series, based on MBM Estuary data	Provided by the local team
N concentration of STP effluent	Mean value is 4.7 mg N/ltr	For validation only; Lemley et al. (2014)
P concentration of STP effluent	Mean value is 2.67 mg P/ltr	For validation only; Lemley et al. (2014)
N concentration of river water	Mean value is 0.07 mg N/ltr	Assumption based on Lemley et al. (2014)

Indicator	Value	Data source/comment
P concentration of river water	Mean value is 0.017 mg N/ltr	Assumption based on Lemley et al. (2014)
Nutrient-related parameters		
Average N loadings per capita	2.2 kg N per capita year	Assumption, based on calibration
Average P loadings per capita	0.5 kg P per capita year	Assumption, based on calibration
Average COD loadings per capita	62 kg COD per capita per year	Based on Swartz et al. (2000)
Wastewater treatment-related parameters		
Average employment per ML of capacity	0.5277 jobs/ML/day	Based on UN (2003)
Average labour income	ZAR 23,526 per month	Statistics South Africa (2021)
Current treatment plant		
N removal efficiency	92%	Estimated based on Swartz et al. (2000) and Lemley et al. (2014)
P removal efficiency	12%	Based on inputs from the Mossel Bay Municipality Wastewater treatment team
COD removal efficiency	95%	Estimated based on Swartz et al. (2000)
Sludge produced per kg COD	0.46 kg dry sludge/kg COD	MRW (2019)
Improved treatment plant (conventional activated sludge)		
Capital cost per m^3	ZAR 12,400 per m^3/day of capacity	MRW (2019)
Capital cost per m^3	ZAR 3.75 per m^3	MRW (2019)
N removal efficiency	92.6%	MRW (2019)
P removal efficiency	47.9%	MRW (2019)
COD removal efficiency	96.4%	MRW (2019)
Sludge produced per kg COD	0.46 kg dry sludge/kg COD	MRW (2019)

Indicator	Value	Data source/comment
Organica		
Capital cost per m³	ZAR 9,025 per m³/day of capacity	MRW (2019)
Capital cost per m³	ZAR 3.09 per m³	MRW (2019)
N removal efficiency	96.5%	MRW (2019)
P removal efficiency	50.7%	MRW (2019)
COD removal efficiency	93.7%	MRW (2019)
Sludge produced per kg COD	0.21 kg dry sludge/kg COD	MRW (2019)
Artificial wetland		
Capital cost per m³	USD 1,727 per m³/day of capacity	Based on Tsihrintzis et al. (2007)
Capital cost per m³	USD 0.12 per m³	Based on Tsihrintzis et al. (2007)
Exchange rate ZAR to USD	14.6819 ZAR/USD	Oanda (2021)
N removal efficiency	89%	Based on Tsihrintzis et al. (2007)
P removal efficiency	62%	Tsihrintzis et al. (2007)
COD removal efficiency	96.1%	Tsihrintzis et al. (2007)
Sludge produced per kg COD	0.46 kg dry sludge/kg COD	Assumed same as currently installed, based on MRW (2019)
Average space requirements per m³ treated	0.001133 ha per m³/day of capacity	Based on Tsihrintzis et al. (2007)
Tourism		
Number of tourists	~86,000 in 2018	Based on Mossel Bay Tourism (2018)
COVID impacts on tourism	-80% in 2020, -70% in 2021	Impact based on WESGRO (2020), recovery assumed by 2023
Seasonality of visitors	Depends on months	Based on Mossel Bay Tourism (2018)
Tourism growth rate after 2023	1.5% per year	Assumption

| Indicator	Value	Data source/comment
Additional tourism growth induced by wetland	0.05% per year	Assumption
Average length of stay	5 days per person	Informed by Cape Town Routes Unlimited (2007)
Average daily spending	ZAR 3,214 per person-day	Informed by Champion Traveller (2021)
Parameters for calculating externalities		
Average cost of breaching	ZAR 15,000 per breach	W. Manuel (personal communication, October 27, 2021)
Average water use per hectare of agriculture land	5,874 m^3 per hectare per year	The Water Wheel (2018)
Average value added per hectare	ZAR 41,990 per hectare per year	Based on Statistics South Africa (2020) and WCG (2020)
Average employment per hectare of agriculture land	0.468 person per hectare	Based on Statistics South Africa (2020) and WCG (2020)
Average salary per person working in agriculture	ZAR 40,304 per person per year	Based on Statistics South Africa (2020)
Average cost per kg of N discharged into estuary	USD 65.2 per kg N	Shadow price for nutrient discharge into eco-sensitive areas (UNEP, 2015)
Average cost per kg of P discharged into estuary	USD 103.4 per kg P	Shadow price for nutrient discharge into eco-sensitive areas (UNEP, 2015)
Average cost per kg of N discharged into sea	USD 4.6 per kg N	Shadow price for nutrient discharge into open sea (UNEP, 2015)
Average cost per kg of P discharged into sea	USD 7.5 per kg P	Shadow price for nutrient discharge into open sea (UNEP, 2015)
Carbon sequestration per ha of wetland	13.35 ton CO_2e per ha per year	Based on de Klein & Van der Werf (2013)
Social cost of carbon	31 USD per ton	Nordhaus (2017)
Exchange rate	14.6819 ZAR/USD	Based on Oanda (2021)

Appendix B. Assessment Results Assuming Supplementary Installation of Treatment Technologies

This section describes the results of the three treatment technologies discussed in this paper: (i) the improved treatment scenario, (ii) the Organica scenario and the (iii) artificial wetland scenario, assuming that the respective treatment technology is installed in addition to the baseline treatment plant. While the main report provides insight into the impact of replacing the current plant against one of the three technologies assessed, it is common practice in South Africa to keep older assets operational and supplement them with newer technologies. This appendix provides results about the change in nutrient loads and concentration that would occur if the current sewage treatment works are supplemented with an additional treatment plant.

The results obtained for total N loadings and N concentration resulting from the additional implementation of treatment capacity are presented in Figure B1 and results for selected years are presented in Table B1. By 2060, the results indicate that N loadings entering the estuary are reduced by between 88.1% (artificial wetland) and 95.5% (Organica) relative to the BAU scenario. Total N discharged into the estuary is reduced to 1,700 kg N per year, 910 kg N per year and 2,413 kg N per year respectively, depending on whether an improved treatment plant, an Organica plant, or an artificial wetland is used to supplement the current treatment capacity. This is in comparison to an annual N discharge of 20,250 kg in the BAU scenario in 2060 without any additional intervention.

Figure B1. N loadings and concentration assuming supplementation of current treatment
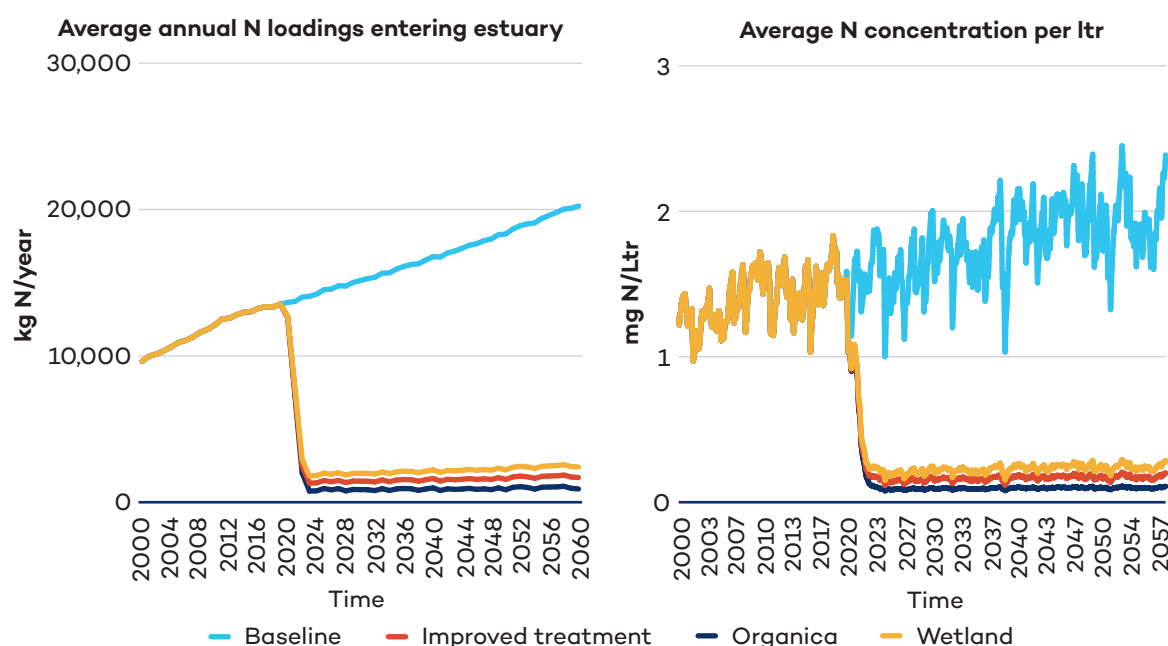
Source: Authors' diagram based on SAVi simulations, March 1, 2022.

As a result, the N concentration in 2060 declines to 0.2 mg N per litre (BAU+improved treatment), 0.11 mg N per litre (BAU+Organica) and 0.29 mg N per litre (BAU+Wetland) respectively, which is between 88% and 95.4% lower relative to the baseline scenario with 2.40 mg N per litre in 2060 and hence a significant improvement concerning the removal of N from wastewater before it is discharged into the estuary.

Table B1. N loadings and concentration assuming supplementation of current treatment, for selected years

Indicator	Unit	2019	2030	2040	2050	2060
N loadings entering estuary						
Baseline	kg N/Year	13,528	15,144	16,778	18,327	20,239
Improved treatment	kg N/Year	13,528	1,440	1,620	1,559	1,691
vs BAU	%	*0.0%*	*-90.5%*	*-90.3%*	*-91.5%*	*-91.6%*
Organica	kg N/Year	13,528	863	981	853	909
vs BAU	%	*0.0%*	*-94.3%*	*-94.2%*	*-95.3%*	*-95.5%*
Wetland	kg N/Year	13,528	1,973	2,209	2,212	2,413
vs BAU	%	*0.0%*	*-87.0%*	*-86.8%*	*-87.9%*	*-88.1%*
N concentration per litre						
Baseline	mg N/Ltr	1.61	1.59	1.50	2.00	2.40
Improved treatment	mg N/Ltr	1.61	0.15	0.15	0.18	0.20
vs BAU	%	*0.0%*	*-90.5%*	*-90.2%*	*-91.1%*	*-91.6%*
Organica	mg N/Ltr	1.61	0.09	0.09	0.10	0.11
vs BAU	%	*0.0%*	*-94.3%*	*-94.0%*	*-95.0%*	*-95.4%*
Wetland	mg N/Ltr	1.61	0.21	0.20	0.25	0.29
vs BAU	%	*0.0%*	*-87.0%*	*-86.7%*	*-87.6%*	*-88.0%*

Source: Authors' summary based on SAVi simulations, March 1, 2022.

A similar trend is observed for total P loadings and concentration, for which results are presented in Figure B2 and Table B2. The installation of a second treatment plant holds the potential to reduce P loadings reaching the estuary in 2060 by between 47.7% (BAU+improved treatment) and 61.7% (BAU+wetland). While total P loadings in the BAU scenario reach 11,600 kg P per year in 2060, the supplementation of treatment with an improved treatment plant, an Organica plant or an artificial wetland reduces annual P loadings to 6,050 kg P per year, 5,730 kg P per year, and 4,430 kg P per year respectively.

Figure B2. P loadings and concentration assuming supplementation of current treatment

Source: Authors' diagram based on SAVi simulations, March 1, 2022.

The P concentration in the estuary declines by between 46.7% (BAU+improved treatment) and 60.5% (BAU+wetland) as a consequence of the reduction in loadings. Estuary water P concentration in the year 2060 is lowest if an artificial wetland is built in addition to the current plant, with 0.57 mg P per litre in 2060, followed by the Organica plant (0.73 mg P per litre), and the improved treatment plant (0.77 mg P per litre).

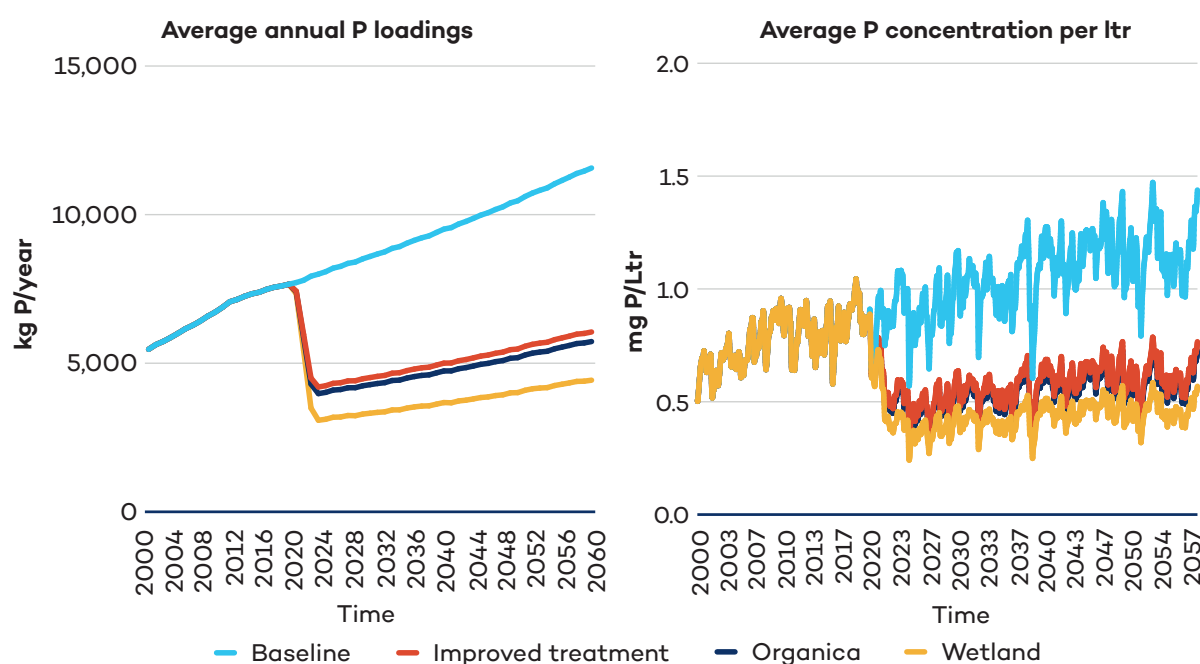**Table B2.** P loadings and concentration assuming supplementation of current treatment, for selected years

Indicator	Unit	2019	2030	2040	2050	2060
P loadings entering estuary						
Baseline	kg P/Year	7,658	8,593	9,512	10,465	11,568
Improved treatment	kg P/Year	7,658	4,517	5,003	5,478	6,051
vs BAU	%	*0.0%*	*-47.4%*	*-47.4%*	*-47.7%*	*-47.7%*
Organica	kg P/Year	7,658	4,279	4,739	5,186	5,729
vs BAU	%	*0.0%*	*-50.2%*	*-50.2%*	*-50.4%*	*-50.5%*
Wetland	kg P/Year	7,658	3,318	3,676	4,011	4,429
vs BAU	%	*0.0%*	*-61.4%*	*-61.3%*	*-61.7%*	*-61.7%*
P concentration per litre						
Baseline	mg P/Ltr	0.91	0.93	0.89	1.19	1.44
Improved treatment	mg P/Ltr	0.91	0.51	0.48	0.64	0.77
vs BAU	%	*0.0%*	*-45.3%*	*-45.8%*	*-46.4%*	*-46.7%*
Organica	mg P/Ltr	0.91	0.48	0.46	0.61	0.73
vs BAU	%	*0.0%*	*-48.0%*	*-48.5%*	*-49.1%*	*-49.5%*
Wetland	mg P/Ltr	0.91	0.38	0.36	0.48	0.57
vs BAU	%	*0.0%*	*-58.7%*	*-59.3%*	*-60.0%*	*-60.5%*

Source: Authors' summary based on SAVi simulations, March 1, 2022.

To put the results presented in this appendix in perspective alongside the results presented in the main body of the report, the benefit of installing an additional treatment plant is clearly the additional reduction in N loads discharged to the estuary. If the results in Table B1 and Table B2 are compared to the results presented in the main report (see Table 4 for N and Table 5 for P), the results suggest that the installation of an additional treatment plant has the potential to reduce N loadings by between 89.9% (Organica) and 91.3% (artificial wetland) relative to using the respective treatment plant in isolation. For example, while total N loadings discharged to the estuary in 2060 are indicated at around 18,740 kg N per year for the improved treatment scenario, the utilization of the current plant in combination with an improved treatment plant reduces N loadings to around 1,700 kg N per year. The same applies to the Organica and artificial wetland, for which N loadings decline from 8,970 kg N per year and 27,800 kg N per year in 2060 to 910 kg N per year and 2,400 kg N per year respectively.

For P, on the other hand, the reductions resulting from a combination of two plants are in the range of 12% across the three technologies assessed (see Table 5). The artificial wetland exhibits the lowers P loadings discharged to the estuary in 2060 of all interventions assessed. If a wetland is constructed in addition to the current treatment plant, P loadings decline from 5,030 kg P per year in the artificial wetland scenario to 4,430 kg P per year in the combined scenario. This is equivalent to an additional reduction of around 600 kg P per year on average in 2060 relative to the wetland in isolation. The Organica and improved treatment scenarios also see a decline in total P discharged to the estuary. Combining the current treatment plant with an additional Organica plant will reduce P loadings in 2060 by around 775 kg P per year, to 5,730 kg P per year (compared to 6,500 kg P per year in the Organica only scenario) and using an improved treatment plant leads to reductions of around 820 kg P per year compared to the improved treatment only scenario, with 6,050 kg P per year discharged compared to 6,870 kg P discharged in the improved treatment scenario.

These results suggest that there is a definite upside to installing a new plant in addition to the existing one. The additional reduction induced by the installation of the extra plant is significant and will benefit the estuary by reducing nutrient loads significantly. On the other hand, given that the costs of current treatment are not available, no statement can be made concerning the economic impacts.

Appendix C. Detailed Financial Analysis

Table C1. S-NPV and S-IRR of the three investment alternatives. All values in 2020 thousand ZAR.

	With no water harvesting			
	Improved water treatment plant	**Organica plant**	**Wetland**	**Wetland with tourism**
PRESENT VALUE of ADDED BENEFITS and AVOIDED COSTS				
Added benefits				
Agriculture wages	-	-	1	1
Agriculture value added	-	-	1	1
Tourism value added	-	-	-	693,016
	-	-	2	693,017
Avoided costs and other benefits				
Carbon sequestration benefit	-	-	4,522	4,522
Avoided cost of breaching	-	-	-	-
Avoided cost of nitrogen into estuary	35,400	265,494	-	-
Avoided cost of phosphorus into estuary	175,583	189,278	244,505	244,505
Avoided cost of nitrogen into sea	2,142	16,062	-	-
Avoided cost of phosphorus in sea	11,024	11,884	15,352	15,352
	244,148	482,718	264,379	264,379
Total added benefits and avoided costs	**244,148**	**482,718**	**264,381**	**957,397**
PRESENT VALUE of COSTS				
Investment and operation costs				
Capital costs	213,051	155,064	479,215	479,215
Annual maintenance cost of intervention	406,636	335,068	191,071	191,071
Investment opportunity cost	619,688	490,132	670,286	670,286
Other costs				
Investment opportunity cost	291,495	212,157	655,658	655,658
Cost of nitrogen into estuary	-	-	177,134	177,134

	With no water harvesting			
	Improved water treatment plant	Organica plant	Wetland	Wetland with tourism
Cost of nitrogen into sea	-	-	10,716	10,716
	291,495	212,157	843,507	843,507
Total costs	**911,183**	**702,288**	**1,513,793**	**1,513,793**
S-NPV (no investment opportunity cost)	-395,539	-7,414	-593,754	99,261
S-NPV (all benefits and costs)	-687,034	-219,571	-1,249,412	-556,396
S-IRR (no investment opportunity cost)	* 12	8.3 %	*	9.1 %
S-IRR (all benefits and costs)	*	4.8 %	*	6.3 %

Table C2. S-NPV and S-IRR of the three investment alternatives with water harvesting. All values in 2020 thousand ZAR.

	With water harvesting			
	Improved water treatment plant	Organica plant	Wetland	Wetland with tourism
PRESENT VALUE of ADDED BENEFITS and AVOIDED COSTS				
Added benefits				
Agriculture wages	111,853	111,853	111,870	111,870
Agriculture value added	249,005	249,005	249,044	249,044
Tourism value added	-	-	-	693,016
	360,858	360,858	360,914	1,053,930
Avoided costs and other benefits				
Carbon sequestration benefit	-	-	4,522	4,522
Avoided cost of breaching	430	430	430	430
Avoided cost of nitrogen into estuary	185,830	336,851	65,348	65,348
Avoided cost of phosphorus into estuary	263,511	272,500	308,751	308,751
Avoided cost of nitrogen into sea	11,646	20,577	4,421	4,421

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12 Asterisk denotes that S-IRR is incalculable because there are no net positive cash flows.

	With water harvesting			
	Improved water treatment plant	Organica plant	Wetland	Wetland with tourism
Avoided cost of phosphorus in sea	16,764	17,318	19,552	19,552
	477,751	647,246	402,594	402,594
Total added benefits and avoided costs	**839,039**	**1,008,534**	**763,939**	**1,456,955**
PRESENT VALUE of COSTS				
Investment and operation costs				
Capital costs	213,051	155,064	479,215	479,215
Annual maintenance cost of intervention	406,636	335,068	191,071	191,071
Investment opportunity cost	619,688	490,132	670,286	670,286
Other costs				
Investment opportunity cost	291,495	212,157	655,658	655,658
Cost of nitrogen into estuary	-	-	19,003	19,003
Cost of nitrogen into sea	-	-	1,024	1,024
	291,495	212,157	675,685	675,685
Total costs	**911,183**	**702,288**	**1,345,970**	**1,345,970**
S-NPV (no investment opportunity cost)	219,352	518,403	73,627	766,642
S-NPV (all benefits and costs)	-72,143	306,246	-582,031	110,984
S-IRR (no investment opportunity cost)	11.1 %	15.9 %	9.0 %	12.2 %
S-IRR (all benefits and costs)	7.9 %	11.2 %	5.9 %	8.8 %