SAVi Sustainable Asset Valuation

An Application of the Sustainable Asset Valuation (SAVi) Methodology in Sri Lanka

Assessing the economic value of restoring the ecological health of Beira Lake in Colombo

SUMMARY OF RESULTS

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An Application of the Sustainable Asset Valuation (SAVi) Methodology in Sri Lanka: Assessing the economic value of restoring the ecological health of Beira Lake in Colombo

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ALTAIR

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About SAVi

SAVi is a simulation service that helps governments and investors value the many risks and externalities that affect the performance of infrastructure projects.

The distinctive features of SAVi are:

- Valuation: SAVi values, in financial terms, the material environmental, social and economic risks and externalities of infrastructure projects. These variables are ignored in traditional financial analyses.
- Simulation: SAVi combines the results of systems thinking and system dynamics simulation with project finance modelling. We engage with asset owners to identify the risks material to their infrastructure projects and then design appropriate simulation scenarios.
- Customization: SAVi is customized to individual infrastructure projects.

For more information on SAVi:

www.iisd.org/savi

Executive Summary

This report presents the results of the Sustainable Asset Valuation (SAVi) applied to Beira Lake in Colombo, Sri Lanka.

The MAVA Foundation and IISD built SAVi to identify and value the costs of risks along with the costs of the externalities of infrastructure projects, portfolios and policies. SAVi is a simulation methodology that combines the outputs of systems dynamics simulation with project finance modelling. It is also customized to each asset, portfolio or policy. It can thus provide exact intelligence on the costs of risks and externalities to determine if sustainable and resilient infrastructure can also bring the most attractive financial returns. See https://iisd.org/savi/ for further details.

In Sri Lanka—and indeed all over the world—policy-makers grapple with the costs of maintaining natural ecosystems, including wetlands, forests, freshwater lakes etc. As public budgets decline, decision-makers are often viewing such spending as an unaffordable luxury, especially in light of other seemingly more urgent upgrades in mobility, health care, education, transport, social housing and the like. However, natural ecosystems provide a range of "services"—i.e., ecosystem services such as water storage and supply, flood protection, prevention of erosion, reducing the impacts of heat and drought, and improving aesthetics and overall well-being. With the advent of climate change, natural ecosystems are also critical as they serve as buffers against catastrophic weather and the resulting floods, droughts, landslides and forest fires. However, what is the financial value of these services? Also, if policy-makers, investors and citizens were better informed on these services and their values, would they support the conservation and restoration of natural and nature-based infrastructure?

This SAVi assessment responds to these questions. Beira Lake, a civil-engineered freshwater lake in the centre of Colombo, is suffering from multiple pollution pressures and is in poor ecological condition. This SAVi assessment delivers a cost–benefit analysis of different restoration interventions for South-West Beira Lake. This cost–benefit analysis includes a valuation of water-quality impacts on property values and an estimation of the enhanced recreational value of a restored lake.

SAVi Results for Beira Lake

The SAVi assessment provides a range of key insights about the restoration value of South-West Beira Lake.

- The business-as-usual (BAU) scenario assumes no additional investments for restoring South-West Beira Lake. This will lead to a further deterioration of water quality. This assessment does not consider the market-driven appreciation of property values around South-West Beira Lake over time. As a consequence, Scenario 1 yields a net decrease of property values amounting to a negative value of slightly more than USD 170,000. No additional recreational visits to South-West Beira Lake by locals or tourists will occur due to the poor water quality. Consequently, the recreational value of the lake will not be enhanced under the BAU scenario.
- Reducing the inflow of nutrients from sewage drains is paramount to solving the eutrophication and algae bloom problems, as reflected by the results of the wastewater treatment scenario (Scenario 2). The reductions in phosphorus (P) and nitrogen (N) loadings improve water clarity in the long run and increase the economic value of properties surrounding South-West Beira Lake by more than USD 14 million by the end of year 2025. Likewise, spending on recreation will increase to more than USD 10 million between 2020 and

2025. The cost–benefit ratio indicates that benefits of this intervention are almost 40 times worth the expenditures for wastewater treatment upgrades.

- Dredging of the lake sediment (Scenario 3) yields a very slight increase in water clarity, but the problem of a high P concentration and resulting algae blooms persists due to continuous inflow of nutrients from wastewater that reach the lake untreated. While the valued benefits of Scenario 3 are twice as high as the required costs, the overall beneficial impacts of slight water clarity improvements are not as high. At the same time, these improvements won't last long. Therefore, investing only into the dredging of lake sediment is insufficient for restoring the ecosystem integrity of the lake and achieving long-lasting positive impacts for property values and the recreational value of South-West Beira Lake.
- Reducing nutrient inflows by improved wastewater treatment as well as investing into a one-time dredging of lake sediment (Scenario 4) achieves significant improvements in water clarity. This scenario provides by far for the greatest increase in economic value of properties surrounding South-West Beira Lake and significantly increases the total amount of recreational spending. The estimated property value increase amounts to more than USD 43 million by the end of year 2025 compared to the status quo. Recreational spending by locals and tourists increases cumulatively by USD 19.5 million between 2020 and 2025. The resulting benefit to cost ratio of Scenario 4 amounts to 9.92.

Table ES1 summarizes the cumulative costs of interventions and the beneficial impacts of a restored lake on property values and recreational spending under each assessed scenario between 2020 and the end of 2025. Results are expressed in relative numbers as required costs and resulting benefits of interventions are compared to the BAU scenario. Results are indicated in USD and a discount factor of 5 per cent is applied.

Table ES1. Cumulative costs and benefits per intervention scenario (2020 to 2025) relative to BAU, in USD and discounted

	Scenarios			
Costs and benefits (in USD, discounted)	**1. Business-as-usual (BAU)**	**2. Wastewater treatment upgrades**	**3. Dredging of lake deposits**	**4. Combined: wastewater treatment and dredging**
Costs				
Costs for wastewater treatment upgrades				
Nitrogen removal technology	\	479,314	\	479,314
Phosphorus removal technology	\	140,718	\	140,718
Cost of sediment removal	\	\	5,712,616	5,712,616
Total cost (2020 to 2025)	****	**620,032**	**5,712,616**	**6,332,648**

Costs and benefits (in USD, discounted)	Scenarios			
	1. Business-as-usual (BAU)	**2. Wastewater treatment upgrades**	**3. Dredging of lake deposits**	**4. Combined: wastewater treatment and dredging**
Benefits				
Property value net change by end of 2025*	(172,770)	14,266,034	5,098,886	43,221,392
Additional spending for recreation by local population	\	656,674	433,114	1,240,463
Additional spending for recreation by tourists	\	9,676,134	6,427,039	18,373,396
Total benefits (by end of 2025)	**(172,770)**	**24,598,842**	**11,959,039**	**62,835,251**
Net results	**(172,770)**	**23,978,810**	**6,246,424**	**56,502,603**
Benefit to cost ratio	**N/A**	**39.67**	**2.09**	**9.92**

**The calculated property value net changes do not account for the market-driven, organic appreciation of property values around South-West Beira Lake over time. For example, the negative value in the BAU scenario indicates solely the negative impact of deteriorated water clarity on property values.*

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Glossary

Causal loop diagram: A schematic representation of key indicators and variables of the system under evaluation that shows the causal connections between them and contributes to the identification of feedback loops and policy entry points.

Chlorophyll-a concentration: The concentration of planktonic algal chlorophyll per litre of lake water, typically measured in micrograms per litre. The higher the chlorophyll concentration per litre of water, the lower the water clarity. Chlorophyll concentration is often used as a proxy for eutrophication.

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

Feedback loop: “Feedback is a process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself” (Roberts et al., 1983).

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 (UNEP, 2014).

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 allow 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).

Natural infrastructure: Natural systems that are actively managed to provide infrastructure outcomes such as managed wetlands, riparian buffers or green roofs.

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 intervention scenario.

Nitrogen (N) concentration: Refers to the amount of organic and inorganic nitrogen per litre of lake water. N concentration can contribute to eutrophication if it exceeds a critical threshold.

Nitrogen (N) loadings: The total annual amount of nitrogen from anthropogenic wastewater, fertilizers, stormwater and other pollution sources that reach the lake. N loadings serve to determine the N concentration in the lake water.

Optimization: A stream of modelling that aims at identifying 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).

Phosphorus (P) concentration: Refers to the amount of organic and inorganic phosphorus per litre of lake water. P concentration can contribute to eutrophication if it exceeds a critical threshold. This assessment uses P concentration to determine the growth of algae chlorophyll, as relevant P loadings and lake water recharge can be determined with relative certainty.

Phosphorus (P) loadings: The total annual amount of phosphorus from anthropogenic wastewater that reaches the lake. P loadings serve to determine the P concentration in the lake water.

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).

Secchi depth: A Secchi disk is a round plate that is painted black and white. The disk is attached to a rope and lowered into the lake water until it is at a depth where it can no longer be seen. Secchi depth helps to measure the clarity of the water and the general “health” of the lake.

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).

Stock and flow variables: “A stock variable represents accumulation and is measured at one specific time. A flow variable is the rate of change of the stock and is measured over an interval of time” (UNEP, 2014).

System Dynamics: A methodology developed by J. Forrester in the late 1950s (Forrester, 1961) to create descriptive models that represent the causal interconnections between key indicators and indicate their contribution to the dynamics exhibited by the system as well as to the issues being investigated. The core pillars of the system dynamics method are feedback loops, delays and non-linearity emerging from the explicit capturing of stocks and flows (UNEP, 2014).

Vertical/horizontal disaggregation of models: Vertically disaggregated models contain a high level of detail on sectoral level (i.e., energy), while horizontally disaggregated models focus on capturing the interconnections between several sectors and contain less detail on sectoral level (UNEP, 2014).

Wastewater treatment facility: Grey infrastructure component used for treating domestic sewage and other wastewater.

Abbreviations

BAU	business-as-usual
CBA	Cost–benefit analysis
CLD	Causal loop diagram
GPD	gallons per day
MCUDP	Metro Colombo Urban Development Project
MGD	million gallons per day
MMWD	Ministry of Megapolis and Western Development
N	nitrogen
O&M	operation and maintenance
P	phosphorous
SAVi	Sustainable Asset Valuation tool
TIN	total inorganic nitrogen

1.0 Introduction

Natural and bio-engineered ecosystems provide us with a range of services that are often undervalued in financial terms. Research and literature have evolved in quantifying their environmental, social and economic benefits. Conventional assessments account for revenues from ecosystem services such as carbon offsets, commercialization of biofuels by-products and others. The conventional investment case for nature-based assets remains a challenge, particularly with services that do not generate marketable revenues. However, natural assets often generate a range of positive environmental, social and economic externalities that, when financially valued, can strengthen the broader case for the conservation of natural ecosystems at large. For example, natural assets improve the aesthetic appearance of urban spaces and built structures, or enable us to reduce spending on the financing, building and maintaining of built assets.

The contribution of natural infrastructure as part of a system requires an integrated assessment to fully capture the range of services provided. This Sustainable Asset Valuation (SAVi) assessment focuses on valuing the aesthetic, recreational and associated economic benefits of a restored urban lake in Sri Lanka. However, other improved services resulting from a restored lake—such as the lake´s stormwater retention service—could be assessed in a second step.

IISD was invited by Indocean Developers (Pvt) Ltd., the project developer of the Altair real estate development project in Colombo, to use the SAVi methodology to quantify the economic value of a restored South-West Beira Lake. The objective was to value the economic benefits for the real estate sector as well as recreational benefits in Colombo resulting from the restoration of the South-Western part of the lake and according water-quality improvements. While acknowledging the current difficult business climate in Colombo, aggravated by the recent terrorism incidents in April 2019, these risk factors were not considered in the scope of this SAVi assessment. The objective was to demonstrate the economic value of a restored South-West Beira Lake under regular circumstances.

SAVi applies a bottom-up integrated and technology-rich model. Several components of SAVi were combined for the systemic assessment of the South-West Beira Lake:

- SAVi Water Balance Model: To capture biophysical dynamics in a lake, which are influenced by water supply, nutrient uptake and effects from dredging interventions.
- SAVi Wastewater: To estimate both capacity and cost of upgrading wastewater treatment facilities required to treat and reduce nutrient loadings that reach a lake.

2.0 The Context of Colombo and Beira Lake

Beira Lake is a shallow artificial waterbody constructed in the 16th century in Colombo, Sri Lanka. It measures approximately 65 hectares and is located in the city centre close to the shoreline. The lake has a range of inlets and outlets and is connected to the Kelani river through the St. Sebastian canal. It is also connected to the Colombo Harbour via the McCallum lock gates and to the Indian Ocean by a drain channel (Ministry of Megapolis and Western Development [MMWD] et al., 2017). The lake consists of five compartments: the focus of this study is on South-West Beira Lake (highlighted in violet in Figure 1). The Altair building is located on the northern tip of this part of the lake.

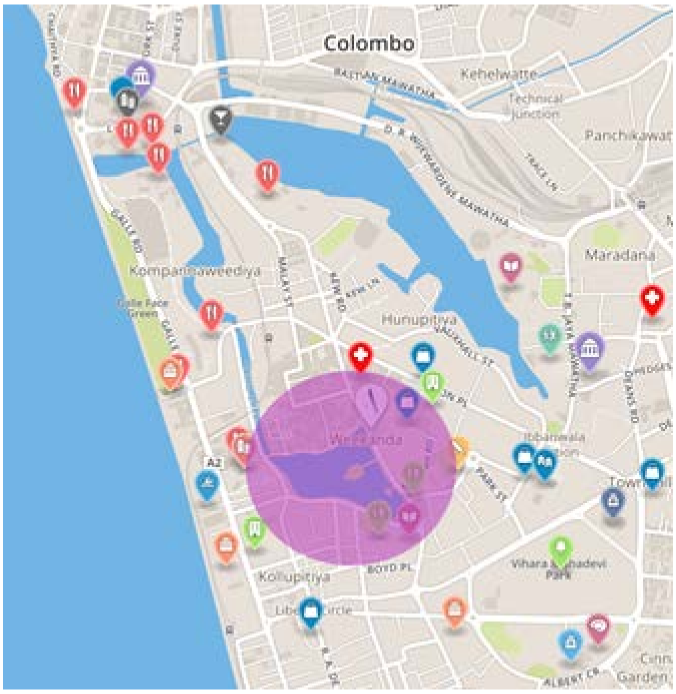

Figure 1. **Map of Beira Lake and highlighted area of investigation**

Source: Altair, 2019.

Its central location exposes the lake to transport and port infrastructure as well as to a diversity of residential, commercial, industrial, tourism-related and cultural activities. The sewage system and wastewater treatment facilities in the drainage area of Beira Lake are old and lack capacity to handle the current volumes and the likely increase of wastewater from the growing urban population (MMWD et al., 2017). Heavy rain events and flooding during the monsoon season cause overflows of wastewater treatment facilities and lead to untreated wastewater entering the lake (MMWD et al., 2017). Moreover, stormwater channels are illegitimately connected to the sewage system in certain areas and illegal settlements are reported in proximity to Beira Lake, release their wastewater directly into the lake. Aside from the pressures caused by untreated wastewater and stormwater from diverse sources, high volumes of solid waste are polluting the lake. Altogether, these diverse sources of pollution channel high nutrient loadings to Beira Lake (among other issues). These high levels of pollution have led to hypertrophic conditions, algae growth, poor water clarity, fish mortality and odour (Metro Colombo Urban Development Project [MCUDP], 2016; MMWD et al., 2017).

These lake conditions have been apparent for a couple of decades and negatively affect the surrounding natural environment, human health, economic activities and property prices. Despite the implementation of some conservation measures in the past, a restoration project for the South-West part of Beira Lake in 2004, long-lasting water-quality improvements has yet to be implemented. Essentially, external pollution loads continue to accumulate in the lake water and are emerging to the lake surface, causing an increase of sediment pollution (MCUDP, 2016; MMWD et al., 2017). The external and internal pollution sources make ongoing lake cleanup activities insufficient, while making effective and preventative restoration interventions difficult.

3.0 Scenarios and Assumptions

The SAVi assessment estimates the value of economic benefits for the real estate sector in Colombo and improvements in the recreational value of South-West Beira Lake resulting from water-quality improvements. The assessment of net changes in property values does not account for market-driven, organic appreciation of property values in Colombo over time—it assesses solely the beneficial impacts of water-quality improvements on property values. Moreover, the SAVi assessment estimates the required costs for a variety of technical interventions to achieve desired water-quality improvements. Table 1 provides a description of a business-as-usual (BAU) scenario and three intervention scenarios simulated for South-West Beira Lake.

Table 1. Overview of assumptions per scenario

Scenario	Description
1. Business-as-usual (BAU)	The BAU scenario assumes the continuation of historical trends such as: • Insufficient wastewater treatment: Only 80 per cent of wastewater reaching South-West Beira Lake is treated. Consequently, high P and N loads reach the lake over time. It is assumed that public service provision continues, which ensures that 80 per cent of the population's wastewater in the drainage area of South-West Beira Lake will be treated at any point in time. • Untreated stormwater containing P and N loadings will continue reaching the lake. • Lake sediment is not dredged, and P is continuously redistributed into the lake water from this source. • Population growth: The estimated population in the drainage area of South-West Beira Lake is 13,500 in 2017. This population increases to 17,000 by 2050.
2. Wastewater treatment upgrades	The wastewater treatment upgrade scenario assumes an increase of wastewater reaching South-West Beira Lake treated in wastewater treatment facilities. It also assumes increased effectiveness of the wastewater treatment process. Both the share of treated wastewater and the treatment effectiveness linearly increase between 2020 and 2025. This incremental improvement over time instead of an immediate improvement is assumed because planning, tendering, implementing and testing will require time until the upgraded treatment plants are fully operational. Other assumptions remain the same. • Increased volume of wastewater treated: The scenario assumes additional investment for wastewater treatment upgrades on top of historical trends. Investments between 2020 and 2025 will serve for incremental technology upgrades of the wastewater treatment capacity in the drainage area of South-West Beira Lake. This will allow the provision of wastewater treatment to all residents and industries in the drainage area of South-West Beira Lake by 2025. • Improved effectiveness of wastewater treatment: The technology upgrades between 2020 and 2025 also incrementally improve the effectiveness of nutrient removal during the wastewater treatment from 80 per cent to 96 per cent. • Stormwater that is not channelled to wastewater treatment facilities continues to reach the lake untreated. • Lake sediment is not treated and P is continuously redistributed into the lake water from this source. • Population growth: Same assumption as in the BAU scenario.

Scenario	Description
3. Dredging of lake deposits	The dredging scenario assumes the removal of P deposits in South-West Beira Lake by removing 180,000 m^3 of lake sediment. Other assumptions remain the same. • Dredging of lake sediment: Dredging and removing lake sediment containing P deposits reduces internal P loadings that could otherwise re-enter the lake from the bottom layer. The dredging intervention increases the water storage volume of the lake by 180,000 m^3 and increases the average water depth from 1.50 metres to 2.40 metres. All dredging activities are assumed to take place in 2021. • Insufficient wastewater treatment: Same assumption as in the BAU scenario, only 80 per cent of wastewater reaching South-West Beira Lake is treated over time. • Untreated stormwater containing P and N loadings will continue reaching the lake. • Population growth: Same assumption as in the BAU scenario.
4. Combined: Wastewater treatment and dredging	The combined scenario assumes a combination of interventions described for Scenario 2 and Scenario 3: Additional investments for wastewater treatment upgrades on top of historical trends and investments for the dredging of lake sediment. Assumptions regarding nutrient loadings reaching the lake due to stormwater and population growth remain unaltered.

Table 2 summarizes the quantitative assumptions for technical lake restoration interventions per scenario. The amount of sediment for dredging is estimated based on the 1996 lake rehabilitation study conducted by the World Bank (Dissanayake & Pereira, 1996). This study estimates that 600,000 m^3 must be dredged to clean the entire lake of contaminated sediment. We assume a proportional share of sediment (30 per cent) based on the size of South-West Beira Lake. Hence, the amount of sediment to be removed is 180,000 m^3 covering an area of 19.5 hectare.

Table 2. Assumptions for restoration interventions

	Share of wastewater treated		**Nutrient removal efficiency (N and P)**		**Sediment removal**
Scenario	**2020**	**2025**	**2020**	**2025**	**2021**
1. Business-as-usual (BAU)	80%	80%	80%	80%	–
2. Wastewater treatment upgrades	80%	100%	80%	96%	–
3. Dredging of lake deposits	80%	80%	80%	80%	180,000 m^3
4. Combined: Wastewater treatment and dredging	80%	100%	80%	96%	180,000 m^3

Table 3 summarizes the costs of each intervention. It needs to be noted that costs for wastewater treatment technologies as well as for sediment dredging vary widely. Costs for wastewater treatment depend on the technologies and processes chosen for increasing treatment capacity and effectiveness. For this assessment, average costs across different wastewater treatment technologies were chosen (see Annex I). All technologies that were considered can remove both from the wastewater, N and P. Nutrient removal costs are estimated based on average values across various treatment technologies (Tetra Tech, 2011). An overview of cost assumptions is provided in Annex 1.

Costs of dredging vary depending on location, geography of the waterbody, accessibility and the proximity of land for storing dredged materials. Table 3 indicates which costs assumptions have been considered—they stem from a study conducted in a different region of the world. The SAVi assessment can easily be done with adjusted cost figures to assess how outcomes (costs and benefits) change.

Table 3. Data sources for lake restoration interventions

Intervention	Variable	Parameter value	Source
Wastewater treatment[1]	Cost of inorganic nitrogen removal	USD 57.36/kg N	Tetra Tech (2011)
	Cost of phosphorus removal	USD 68.38/kg P	Tetra Tech (2011)
Dredging of lake deposits	Cost for dredging, dewatering and other works	USD 35/m^3	Amaro & Thomas (2012)

Aside from wastewater treatment upgrades and dredging of lake sediment, there is a third restoration intervention currently being explored for South-West Beira Lake. To reduce algae growth and improve water clarity, the direct chemical treatment of lake water with ionic cupric copper is being suggested. This form of copper is characterized by high bioavailability and consequently can have toxic impacts on species like fish, crustaceans and algae. They are much more sensitive than mammals to this form of copper. In particular, algae are 1,000 times more sensitive to the toxicity of ionic cupric copper (Solomon 2009). Principally, this variety in sensitivity to the toxic effects of copper would allow the treatment of waterbodies that suffer from nuisance algae with a very low dosage of ionic cupric copper. However, there is a risk that such a treatment adversely effects other species if the dosage is not accurate. Moreover, algae are at the bottom of the aquatic ecosystem food chain. If they are significantly reduced and natural waterbodies are treated with such aggressive substances, there is a risk that the composition of ecosystems will be completely altered, including the biodiversity of insects and reproduction rates of fish species (Solomon, 2009).

There are no robust studies that provide information on the dosage requirements and costs of ionic cupric copper as well as evidence about its effectiveness. There is also a lack of data on ecosystem

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[1] For this assessment, the cost per kg of N removed was calibrated based on reports from Tetra Tech (2011) and Berry (2016) and corresponds to the use of physical removal. The SAVi Wastewater model is, on the other hand, equipped with three different wastewater treatment technologies (physical removal, ultrafiltration and reverse osmosis) and is parametrized based on Iglesias et al. (2010). The standard values used in the SAVi Wastewater model are consistent with cost assumptions used in the SAVi Canada assessment. The N removal efficiency of the different treatment methods is assumed to be 70 per cent for physical removal, 80 per cent for ultrafiltration and 95 per cent for reverse osmosis, respectively.

composition of Beira Lake available to estimate the potentially adverse effects of this sort of intervention and value them for the purpose of an integrated CBA. This is why the ionic cupric copper treatment was not included as an intervention scenario in this SAVi assessment. More research on ionic cupric copper would be required to state whether it is a viable lake restoration option. The risks of adverse toxic effects on ecosystems of natural waterbodies should not be underestimated.

4.0 Results of the SAVi Assessments

This chapter presents the results of the SAVi assessments on restoring South-West Beira Lake. It first discusses the results of assessed biophysical parameters for the different scenarios. Quantitative figures for indicated time periods are expressed as annual averages to eliminate biased results caused by seasonal variability and extreme events. This discussion of biophysical parameters is followed by a presentation of valuation results per scenario, including net changes in economic values of properties surrounding South-West Beira Lake and changes in recreational spending volumes by the local population and tourists.

4.1 Assessment Results of Biophysical Parameters of South-West Beira Lake

NITROGEN AND PHOSPHORUS LOADINGS

Table 4 displays the scenario results of the development of N and P loadings over time. The table compares the volume of N and P loadings before (2017–2019) and after the implementation of a restoration intervention (2025–2027). For these two time periods, annualized values for N and P loadings reaching the lake are expressed in kilogram per year.

The analysis considers external P and N loadings that affect the water quality of the South-West Beira Lake. External P and N loadings stem from untreated wastewater discharged into the lake through stormwater drains, sewage from latrines being channelled to the lake and the overflow of wastewater treatment facilities during times of erratic rainfall and flooding. It is assumed that external P loadings are entirely caused by wastewater from population located in the drainage area of South-West Beira Lake. N loadings reaching the lake are instead assumed to stem not only from untreated wastewater but also from other pollution sources. The other sources are organic matter in stormwater drains that accumulates during the dry season, the depositing of N from the air and solid waste dumped into water columns. None of these other sources of N loading are explicitly captured in the assessment and are also not affected by assessed interventions.

The analysis also investigates the changes in internal P loadings. These internal loadings emerge when P deposits at the bottom of the lake are being resuspended into the lake water. These resuspended nutrients become available as sources for algae and other plant growth.

Table 4. Annual nitrogen and phosphorus loadings before and after restoration interventions

	Nitrogen loadings (kg/year)			Phosphorus loadings (kg/year)		
Scenarios	**2017–2019**	**2025–2027**	**% difference**	**2017–2019**	**2025–2027**	**% difference**
1. Business-as-usual (BAU)	33,557.4	34,338.6	2.3%	4,351.3	4,589.4	5.5%
2. Wastewater treatment upgrades	33,475.4	21,486.4	(35.8%)	4,351.3	731.3	(83.2%)
3. Dredging of lake deposits	33,557.4	34,338.6	2.3%	4,351.3	4,327.4	(0.5%)
4. Combined: Wastewater treatment + dredging	33,475.4	21,486.4	(35.8%)	4,351.3	460.1	(89.4%)

The BAU scenario assumes a continuation of historical trends—details are indicated in Table 1 of Part 3. As a consequence of population growth, N and P loadings reaching the lake will slightly increase over time. Scenario 2 implies an incremental increase of wastewater being treated effectively before it enters the lake instead of being discharged directly into it. This intervention reduces the amount of external P and N loadings reaching the lake. As external P loadings are solely associated with wastewater while N loadings also stem from other sources, Scenario 2 yields a reduction in P loadings of 89 per cent while N loadings are reduced by only 35.8 per cent.

In the dredging scenario (3), only P deposits in the lake's sediment are removed, while external P and N loadings remain at BAU levels. Hence, overall no reductions in N loadings are observed over time. There is a slight 0.5 per cent decline of P loadings compared to a situation before dredging interventions. However, when compared to BAU (which leads to an overall 5.5 per cent increase in external and internal P loadings over time) the dredging scenario leads to a reduction of 6 per cent of total P loadings.

Scenario 4 includes both wastewater treatment upgrades as well as dredging. It yields significant reductions in N and P loadings. The reduction in P loadings amounts to 89.4 per cent and hence is even higher than in Scenario 2 due to the reinforcing effects between reduction of external P loadings resulting from wastewater treatment upgrades and reduction of internal P loadings due to sediment dredging.

NITROGEN AND PHOSPHORUS CONCENTRATION LEVELS

The nutrient concentration in the lake water is an indicator for water quality and depends on the nutrient loadings reaching the lake, the water retention time and the amount of water in the lake. Table 5 displays the scenario results of the development of N concentration over time. It compares the volume of N concentration before (2017–2019) and after the implementation of a restoration intervention (2025–2027). For these two time periods, annualized values for N and P concentration in South-West Beira Lake are expressed in milligram per litre of lake water.

Table 5. Nitrogen and phosphorus concentration in South-West Beira Lake before and after restoration interventions

	Nitrogen concentration (mg/litre)			Phosphorus concentration (mg/litre)		
Scenarios	**2017–2019**	**2025–2027**	**% difference**	**2017–2019**	**2025–2027**	**% difference**
1. Business-as-usual (BAU)	10.94	11.18	2.1%	1.27	1.34	5.5%
2. Wastewater treatment upgrades	10.92	7.25	(33.6%)	1.27	0.23	(82.3%)
3. Dredging of lake deposits	10.94	10.09	(7.8%)	1.27	1.16	(8.9%)
4. Combined: Wastewater treatment + dredging	10.92	6.37	(41.7%)	1.27	0.13	(90.1%)

The BAU scenario assumes a continuation of historical trends. Since N and P loadings slightly increase over time, the same effect can be observed for N and P concentration in the lake water. Caused by a reduction of N and P loadings after the upgrades of wastewater treatment facilities (Scenario 2), the nutrient concentrations in the lake water are reduced proportionally. N concentration is reduced by 33.6 per cent, whereas the P concentration is lowered more effectively—by 82.3 per cent.

Dredging of lake deposits (Scenario 3) affects internal P loadings by removing P deposits at the bottom of the lake. Moreover, dredging increases the average water depth of South-West Beira Lake from 1.50 metres to 2.40 metres. Consequently, P loadings and N loadings are diluted in higher water volumes, leading to a reduction of P concentration by 8.9 per cent and a reduction of N concentration by 7.8 per cent after the dredging intervention. However, the absolute P and N concentrations in South-West Beira Lake remain relatively high in Scenario 3 because external P and N loadings from untreated wastewater continue to flow into the lake water. The external P loadings determine approximately 95 per cent of total P dissolved in the lake water of South-West Beria Lake.

In Scenario 4, the pollution pressures for South-West Beira Lake are effectively mitigated since external nutrient loadings as well as internal P loadings are reduced. The combined interventions yield by far the highest reductions in N and P concentration in the lake water. After the interventions are implemented, N concentration is reduced by almost 42 per cent and the P concentration is reduced by 90 per cent.

Figure 2 presents the effectiveness of reducing P concentration in the lake water over time. Clearly, interventions assessed in Scenarios 2 and 4 are most effective as shown by the steady decrease of P concentration between 2020 and 2025. The upgrade of wastewater treatment facilities and dredging of lake deposits are accomplished during this time. As both interventions are assumed in Scenario 4, the highest P concentration decrease is achieved. The P concentration remains constant after 2025 since interventions are finalized by then. Figure 2 also demonstrates that dredging alone is insufficient.

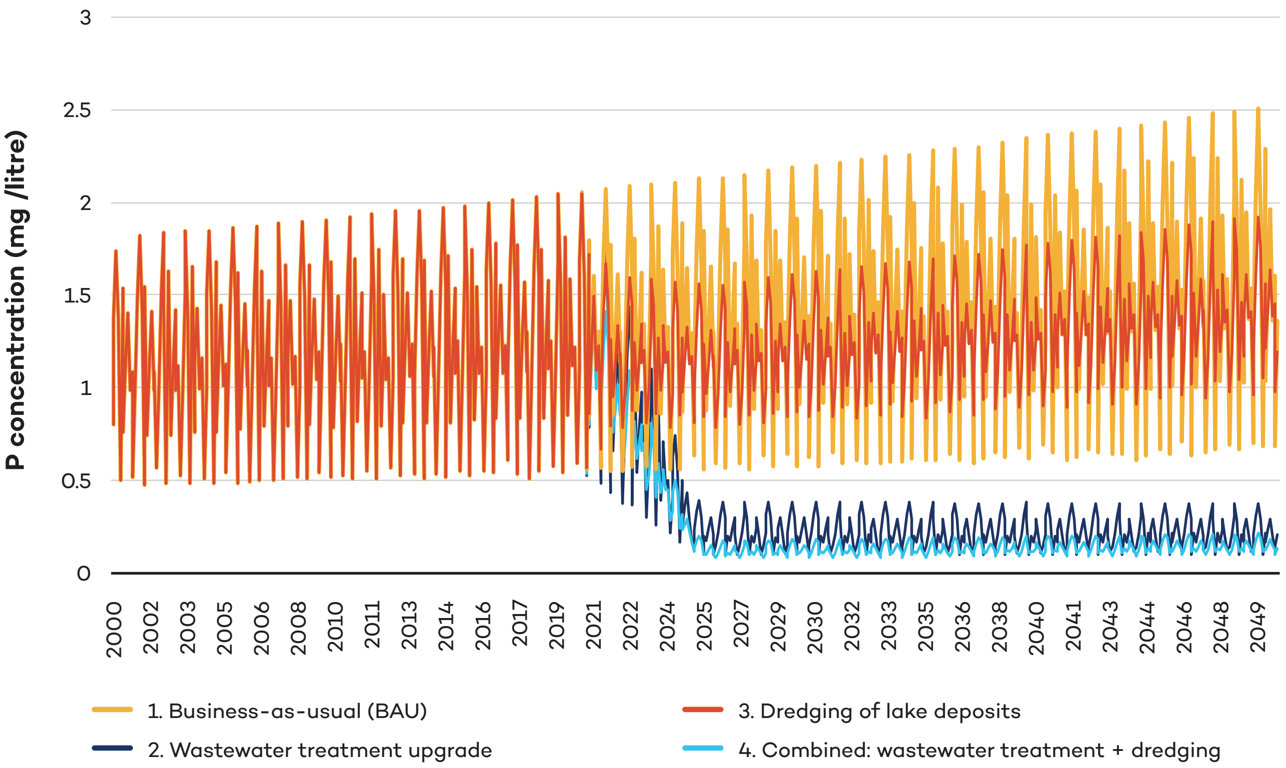

Figure 2. **P concentration in South-West Beira Lake over time (mg/l)**

CHLOROPHYLL-*A* CONCENTRATION AND WATER CLARITY

High nutrient concentration in the lake water provides a beneficial environment for algae and other aquatic plants to grow. For this SAVi assessment, the impact of P concentration on chlorophyll-*a* is calculated. Chlorophyll-*a* concentration is an indicator to measure the growth of aquatic plants. Water clarity tends to decrease, and the overall water quality worsens if chlorophyll-*a* concentration exceeds a certain threshold.

Table 6 displays the scenario results of the development of chlorophyll-a concentration and Secchi depth over time. The table compares values before (2017–2019) and after the implementation of a restoration intervention (2025–2027) for these two water-quality indicators. Annualized values for chlorophyll-*a* concentration are expressed in µg per litre of lake water. Secchi depth is a commonly used measure of water clarity: a “Secchi disk” is a white plastic disk used to determine the clarity of the water. The Secchi depth is the depth in metres at which the disk is still visible when held underwater.

Table 6. Chlorophyll-*a* concentration and water clarity of South-West Beira Lake before and after restoration interventions

	Chlorophyll-*a* concentration (µg/litre)			Water clarity = Secchi depth (metres)		
Scenarios	**2017–2019**	**2025–2027**	**% difference**	**2017–2019**	**2025–2027**	**% difference**
1. Business-as-usual (BAU)	19.09	19.74	3.4%	0.261	0.255	(2.3%)
2. Wastewater treatment upgrades	19.09	2.73	(85.7%)	0.261	0.725	177.8%
3. Dredging of lake deposits	19.09	18.82	(1.4%)	0.261	0.402	54.1%
4. Combined: Wastewater treatment + dredging	19.09	1.42	(92.5%)	0.261	1.712	556.0%

Results for chlorophyll-*a* and water clarity across scenarios are in line with results observed for nutrient loadings and nutrient concentration. Scenario 1 leads to a slightly higher chlorophyll-*a* concentration and worse water clarity. Hypereutrophic conditions in South-West Beira Lake remain. The other scenarios yield improvements for both water quality indicators to varying degrees. The most beneficial effects on chlorophyll-*a* and water clarity are observed in the combined Scenario 4 that includes wastewater treatment upgrades and dredging of lake deposits. The reduction in both external loadings (untreated wastewater) and internal loadings (resuspension of bottom layer P deposits) as well as the increase of water depth from 1.50 metres to 2.40 metres as a result of sediment dredging reduce chlorophyll-*a* concentration by more than 92 per cent. Likewise, the interventions improve water clarity by more than 145 cm, which equals an improvement of 556 per cent compared to conditions before wastewater treatment upgrades and dredging interventions.

Figure 3 shows the development of Secchi depth over time per scenario. Seasonal oscillations can be observed over time, which indicates that problems with lake pollution and algal blooms will still emerge despite interventions due to pressures from sewage overflows during heavy rainfall, low water flushing during the dry season and similar events. The figure also demonstrates how N and P loadings and concentration are linked to water clarity. Once interventions to mitigate external and internal nutrient loadings are implemented, water clarity improves. In particular, this can be observed once all interventions are implemented in Scenario 4 by year 2025. The water clarity decreases over time between 2027 and 2050 as some external nutrient loading continues to reach the lake, leading to sedimentation P loading. These external and internal nutrient loadings contribute to an increase of P and N concentration in the water, an increase in chlorophyll-a concentration and algae growth will result as long as no renewed sediment dredging takes place. The decrease of water clarity between 2027 and 2050 in Scenario 4 is stronger compared to the water clarity decrease over time in Scenario 2. This difference is caused by the higher nutrient-retention efficiency that can be observed in South-West Beira Lake when dredging takes place. Dredging increases the depths of the lake compartment and hence the water volume and inflow of nutrients while the water outflow does not change. Compared to Scenario 2 (in which no dredging takes place) a lower share of lake water is being exchanged. Consequently, nutrient concentration in the lake water and accumulation of nutrients in the lake sediment occur comparatively quicker in Scenario 4, leading to algae growth and a comparatively stronger decrease of water clarity over time.

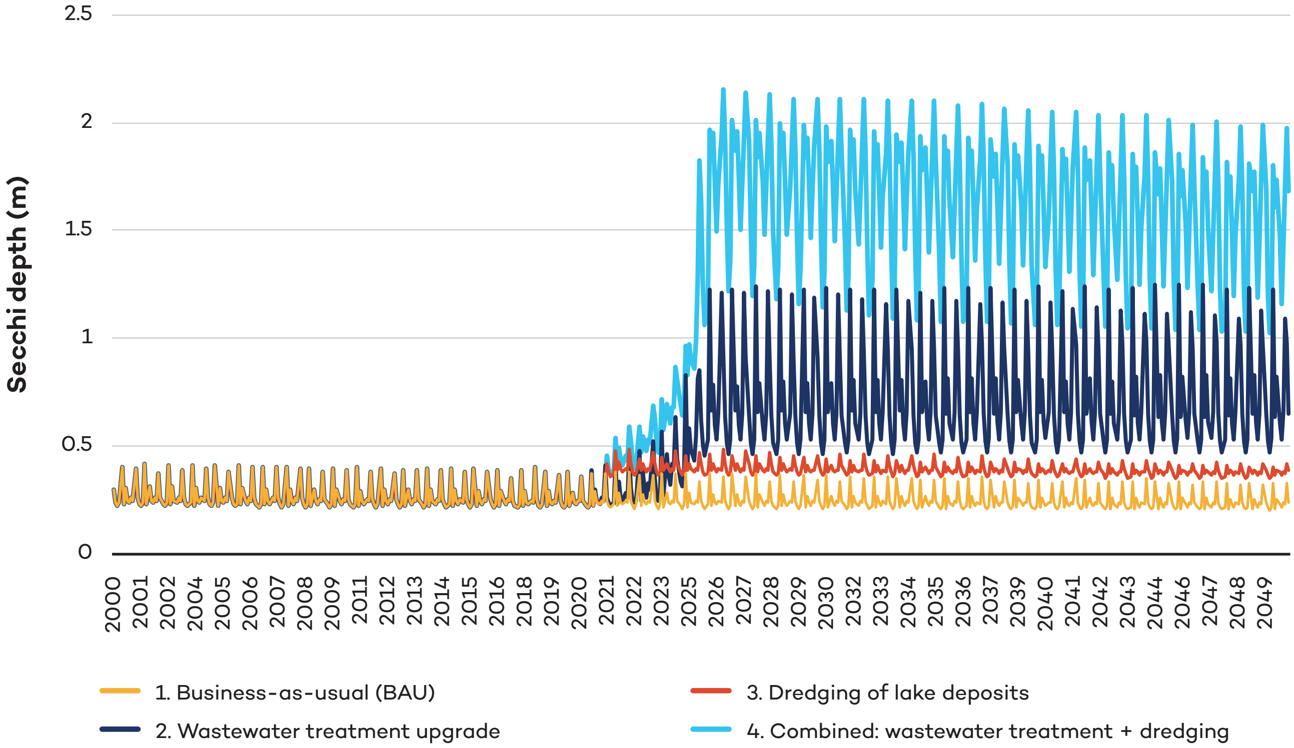

Figure 3. **Secchi depth (water clarity in metres) over time**

4.2 Valuation Results of a Restored South-West Beira Lake

PROPERTY VALUES SURROUNDING SOUTH-WEST BEIRA LAKE

Finally, the water clarity of South-West Beira Lake has implications for the economic value of properties surrounding this urban water body. A sustainably restored lake with improved water clarity has aesthetic value and enhances the quality of living in proximity to the lake. A clear lake provides a more pleasant view from apartments that face it. In addition, South-West Beira Lake's proximity to surrounding properties has greater value if it appears inviting to spend leisure time at the lakefront. The higher the water clarity of the lake, the more the property value of surrounding properties increases. This relationship was established based on three studies that provide estimates of the percent change in property value for waterfront properties resulting from changes in Secchi depth (Boyle, 1998; Gibbs et al., 2002; Walsh, Milon & Scrogin, 2010). Based on these studies and the maximum water depth of South-West Beira Lake, we estimate that a one-metre increase in water clarity (Secchi depth) results in a three per cent increase in property values of properties surrounding the lake. This assessment considers properties within 250 metres of the lakefront, while it is assumed that approximately 20 per cent of this area is roads and parks. To estimate the baseline property value of this area, a value of USD 3,375/m^2 of building ground was assumed in consultation with the client of this SAVi assessment. This square metre value yields a total property value of more than USD 1.3 billion. It needs to be noted that this value represents the value of the property (plot area) and its potential for vertical construction.

Table 7. Relation between water clarity improvements and changes in property values (undiscounted) around South-West Beira Lake (2020–2027)

	Scenario 1. Business-as-Usual			
	Change in water clarity compared to year 2019	Change of property value around South-West Beira Lake compared to 2019	Change in property value compared to 2019	Total property value around South-West Beira Lake per year
Unit	metre	USD/ year	%	USD million
2020	0.001	(52,032)	0.00	1,346.57
2021	0.000	(14,129)	0.00	1,346.61
2022	-0.003	(41,922)	0.00	1,346.58
2023	0.002	(109,537)	(0.01)	1,346.52
2024	-0.003	(74,341)	(0.01)	1,346.55
2025	0.001	(209,398)	(0.02)	1,346.42
2026	-0.001	(167,309)	(0.01)	1,346.46
2027	-0.001	(192,389)	(0.01)	1,346.43

	Scenario 2. Wastewater Treatment Upgrades			
	Change in water clarity compared to year 2019	Change of property value around South-West Beira Lake compared to 2019	Change in property value compared to 2019	Total property value around South-West Beira Lake per year
Unit	metre	USD/ year	%	USD million
2020	0.009	22,435	0.00	1,346.65
2021	0.030	636,238	0.05	1,347.26
2022	0.061	1,649,202	0.43	1,352.38
2023	0.123	3,309,869	0.25	1,349.93
2024	0.275	7,111,758	0.53	1,353.74
2025	0.464	14,712,884	1.09	1,361.34
2026	0.466	18,871,820	1.40	1,365.50
2027	0.468	18,894,059	1.40	1,365.52

	Scenario 3. Dredging of Lake Deposits			
	Change in water clarity compared to year 2019	Change of property value around South-West Beira Lake compared to 2019	Change in property value compared to 2019	Total property value around South-West Beira Lake per year
Unit	metre	USD/ year	%	USD million
2020	-0.003	(54,909)	0.00	1,346.57
2021	0.144	2,600,058	0.19	1,349.23
2022	0.141	5,750,473	0.43	1,352.38
2023	0.142	5,662,563	0.42	1,352.29
2024	0.143	5,743,893	0.43	1,352.37
2025	0.145	5,742,797	0.43	1,352.37
2026	0.143	5,797,143	0.43	1,352.42
2027	0.142	5,727,309	0.43	1,352.35

	Scenario 4. Combined: Wastewater Treatment + dredging			
	Change in water clarity compared to year 2019	Change of property value around South-West Beira Lake compared to 2019	Change in property value compared to 2019	Total property value around South-West Beira Lake per year
Unit	metre	USD/ year	%	USD million
2020	0.005	18,827	0.00	1,346.64
2021	0.188	3,434,621	0.26	1,350.06
2022	0.247	8,484,437	0.63	1,355.11
2023	0.373	11,965,337	0.89	1,358.59
2024	0.694	19,126,779	1.42	1,365.75
2025	1.405	41,826,511	3.11	1,388.45
2026	1.483	59,904,217	4.45	1,406.52
2027	1.470	60,239,436	4.47	1,406.86

Table 7 demonstrates the relationship between water clarity in South-West Beira Lake and the economic value of surrounding properties. The table displays changes in water clarity of each scenario compared to 2019, the respective changes in property value compared to 2019, percentage change in property value compared to the baseline year 2019 and the total property value in each particular year. All values in this table are undiscounted. Depending on the assessed scenario, the respective water clarity improvement yields varying degrees of change in economic values of properties surrounding South-West Beira Lake. Figure 4 illustrates the same relation graphically and highlights that the combined Scenario 4 leads to high increases in property value once interventions are being implemented, whereas Scenario 2 yields only slight increases and Scenario 3 yields even lower increases over time.

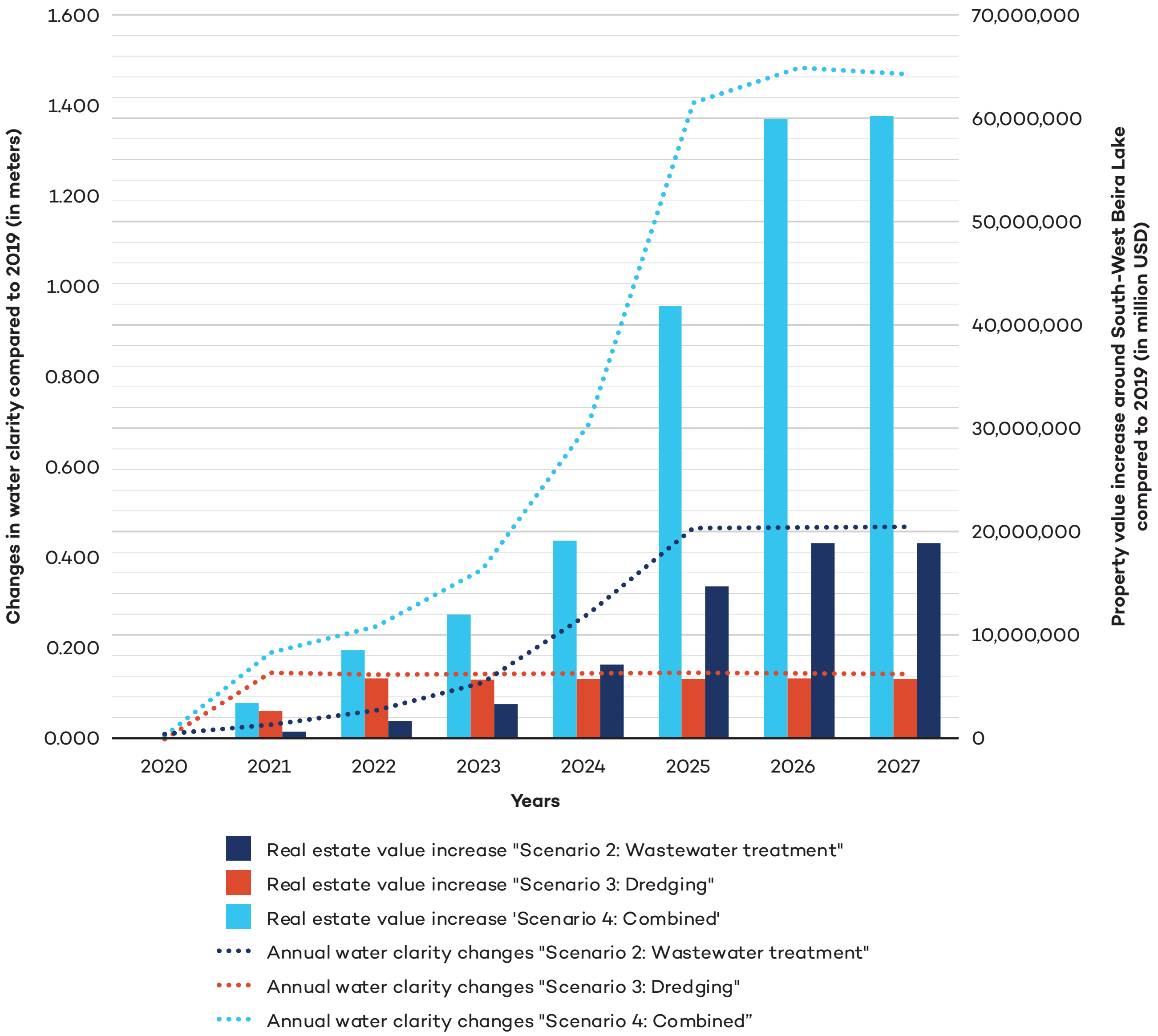

Figure 4. Changes in cumulative property values (undiscounted) around South-West Beira Lake in relation to water clarity improvements per scenario

Figure 5 displays the development of the undiscounted cumulative property value surrounding South-West Beira Lake under the different intervention scenarios. A more long-term view is illustrated up to 2050. As water clarity slightly decreases over time if no continuous cleaning of the lake and renewed dredging takes place, the cumulative property value in Scenario 4 will decrease over time. A similar tendency can be observed for the dredging Scenario 3, while the continuous improved wastewater treatment in Scenario 2 would yield a stable and increased property value over time. When comparing Scenario 4 and Scenario 2, the stronger decrease of water clarity and associated stronger decrease of the cumulative property value between 2027 and 2050 in Scenario 4 is caused by the higher nutrient-retention efficiency. Explanations for this observation are provided above in the discussion of Figure 3.

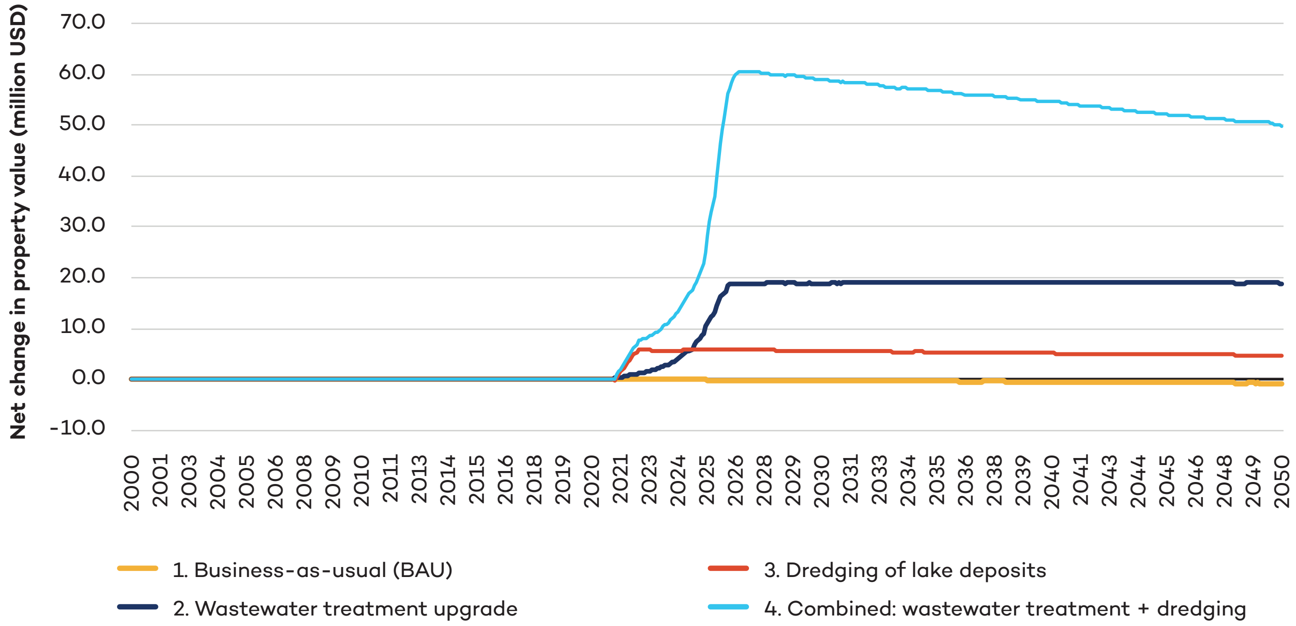

Figure 5. Net change in property values compared to 2019 (undiscounted) around South-West Beira Lake over time

RECREATIONAL VALUE OF SOUTH-WEST BEIRA LAKE

Many waterbodies, including urban lakes, are known to have a recreational value for people living near them. Beira Lake has been a landmark of Colombo for centuries and is appreciated by the local population and tourists alike as a location for gatherings, walking, boating, relaxing and other leisure activities. The lake is a key natural element in the urban built environment of Colombo and hence has strong potential to contribute to the well-being of the urban population. However, the poor water quality of the lake tends to make it less attractive to visitors and diminishes its recreational value.

This issue is recognized by local authorities, which is why the Sri Lankan Ministry of Megapolis and Western Development Colombo launched the Beira Lake Intervention Area Development Plan in 2017 with the objective of transforming Beira Lake into a scenic asset of the city. Among other aspects, the plan suggests improving the water quality of Beira Lake to enhance opportunities for recreational activities (Urban Development Authority, 2017). Likewise, citizens are increasingly voicing their concerns about the ecological health of Beira Lake and the heavy pollution loads that the lake is facing, as highlighted by the “No Kunu” (no waste) citizen campaign and their initiated cleanup program (Daily News, 2018; Daily FT, 2018). This provides strong evidence for the desire to achieve better water quality of Beira Lake.

A range of context-specific studies in other regions of the world provide evidence that citizens attribute a use value to waterbodies and are willing to pay for improved water quality (Crase & Gillespie, 2008; Mishra, 2017; Othman & Jafari 2019), or more specifically for better water clarity

(Keeler et al., 2015). Moreover, studies provide evidence that waterbodies with better water quality attract more visitors and elicit overall greater visitor spending on recreational activities and associated consumption for food and similar expenses. Both of these factors point to the recreational value of clean waterbodies.

The SAVi assessment accounts for this crucial recreational benefit of Beira Lake, one that could be enhanced by lake restoration interventions. However, to calculate the added recreational value of a cleaner lake, extensive local data would need to be collected and analyzed. The studies cited above base their valuation on local surveys and highly contextual information to calculate revealed and stated preferences, travel costs and other expenditures, and people's overall willingness to pay. Due to the lack of sufficient data about the current lake visitation behaviour of citizens and tourists in Colombo (and the lack of quantitative information about the value these target populations would ascribe to a cleaner Beira Lake), we proceeded with rough estimations and made several assumptions. These were informed by cited studies, especially Othman & Jafari (2019).

To arrive at approximate monetary estimates of the recreational value of South-West Beira Lake, we assessed expected consumer spending from additional visitors in case of improved water clarity. It is assumed that additional visits by people living near South-West Beira Lake and additional visits by tourists will take place if the water clarity (Secchi depth) threshold of 0.4 m is reached. According to our assumptions, reaching this water clarity threshold would imply that 50 per cent of the 13,964 people living near South-West Beira Lake will visit that part of the lake two additional times per month compared to the baseline and would spend USD 2 during each additional visit for food or a local recreational activity such as boat riding.

Table 8 displays the cumulative additional spending by locals for different time periods between 2017 and 2027, whereas the average annual value between 2025 and 2027 indicates the additional spending after all restoration interventions have been implemented. An average annual value for these three years is presented to account for potential annual variations in water clarity. The results are structured in accordance with the assessed scenarios. By far the most additional spending associated with recreation between 2020 and 2025 is achieved by the combined Scenario 4, amounting to more than USD 1.5 million. Only treating wastewater achieves roughly 55 per cent of this added spending volume, and the dredging scenario leads only to 34 per cent of this spending volume. These differences are caused by the varying effectiveness of assessed interventions in terms of achieving long-term water clarity improvements.

Table 8. Added recreational spending from the local population under different scenarios

	Added recreational spending from local population			
Intervention scenarios	**2017–2019 (USD/Year)**	**2025–2027 (USD/Year)**	**Cumulative undiscounted in USD (2020–2025)**	**Cumulative discounted in USD (2020–2025)**
1. Business-as-usual (BAU)	0	0	0	0
2. Wastewater treatment upgrades	0	343,750	848,824	656,674
3. Dredging of lake deposits	0	123,800	533,851	433,114
4. Combined: Wastewater treatment and dredging	0	343,750	1,548,195	1,240,463

Likewise, we assume that roughly 50 per cent of the tourists visiting Sri Lanka annually will also spend time in Colombo and will visit South-West Beira Lake one additional time when the water clarity exceeds 0.4 m. Indeed, it is more likely that tourists would visit the part of Beira Lake that is comparatively cleaner and clearer. The number of additional visits would amount to approximately 1 million tourists given that annual tourist numbers in recent years exceeded 2 million (Sri Lanka Tourism Development Authority, 2017). We assume that tourists would spend more per lake visit than the local population and likely also spend more for transportation reaching South-West Beira Lake. Per additional visit, a tourist is assumed to spend USD 5—informed by statistics on the average costs for meals and drinks in Colombo, Sri Lanka (NUMBEO, 2019).

Table 9 indicates the cumulative additional spending for recreation from tourists visiting South-West Beira Lake when the water clarity level of 0.4m is exceeded. In line with the above explanations on additional spending by the local population, Scenario 4 also yields by far the highest amount of cumulative additional spending by tourists between 2020 and 2025, while Scenario 2 yields the second highest results, and Scenario 3 leads to only one third of the highest amount. Investing into both wastewater treatment upgrades and dredging of lake deposits ensures significant and long-term water clarity improvements and hence attracts more tourists compared to investing into only one.

Table 9. Added recreational spending from tourists under different scenarios

	Added recreational spending from tourists			
Intervention scenarios	**2017–2019 (USD/Year)**	**2025–2027 (USD/Year)**	**Cumulative undiscounted in USD (2020–2025)**	**Cumulative discounted in USD (2020–2025)**
1. Business-as-usual (BAU)	0	0	0	0
2. Wastewater treatment upgrades	0	5,000,000	12,499,990	9,676,134
3. Dredging of lake deposits	0	1,800,000	7,916,664	6,427,039
4. Combined: Wastewater treatment and dredging	0	5,000,000	22,916,640	18,373,396

4.3 Results of the Integrated Cost–Benefit Analysis

The integrated cost–benefit analysis (CBA) compares the costs and benefits of the different intervention scenarios with the BAU scenario. Table 10 summarizes the cumulative costs and benefits of each assessed scenario between 2020 and the end of 2025. Results are indicated as relative numbers to express the required additional investments and resulting benefits of the intervention scenarios (Scenarios 2, 3 and 4) compared to the BAU scenario. Considered cost factors are capital expenditures and, if applicable, operation and maintenance costs for the different intervention scenarios. Detailed cost figures for the wastewater treatment upgrades are provided in Annex I.

Table 10. Cumulative costs and benefits per intervention scenario (2020 to 2025) relative to BAU, in USD and discounted

Costs and benefits (in USD, discounted)	Scenarios			
	1. Business-as-usual (BAU)	**2. Wastewater treatment upgrades**	**3. Dredging of lake deposits**	**4. Combined: wastewater treatment and dredging**
Costs				
Costs for wastewater treatment upgrades				
Nitrogen removal technology	\	479,314	\	479,314
Phosphorus removal technology	\	140,718	\	140,718
Cost of sediment removal	\	\	5,712,616	5,712,616
Total cost (2020 to 2025)	****	**620,032**	**5,712,616**	**6,332,648**
Benefits				
Property value net change by end of 2025*	(172,770)	14,266,034	5,098,886	43,221,392
Additional spending for recreation by local population	\	656,674	433,114	1,240,463
Additional spending for recreation by tourists	\	9,676,134	6,427,039	18,373,396
Total benefits (by end of 2025)	**(172,770)**	**24,598,842**	**11,959,039**	**62,835,251**
Net results	**(172,770)**	**23,978,810**	**6,246,424**	**56,502,603**
Benefit to cost ratio	**N/A**	**39.67**	**2.09**	**9.92**

**The calculated property value net changes do not account for the market-driven, organic appreciation of property values around South-West Beira Lake over time. For example, the negative value in the BAU scenario indicates solely the negative impact of deteriorated water clarity on property values.*

The assessed benefits of the interventions are the induced economic value changes of properties surrounding South-West Beira Lake as well as the additional spending for recreation by local population and tourists. These benefits are achieved by changing levels of water clarity of South-West Beira Lake as described above in detail.

The most important insights of the CBA for each for each scenario are explained in the following. These explanations refer to the discounted results of the integrated CBA as indicated in Table 10. A discount factor of 5 per cent was assumed. Explanations apply proportionally to the undiscounted results as shown in Annex III.

Scenario 1 (BAU), assumes no additional investments for restoring South-West Beira Lake. This will lead to a further deterioration of water quality. This assessment does not consider the market-driven appreciation of property values around the South-West Beira Lake over time. As a consequence, Scenario 1 yields a net decrease of property values amounting to slightly more than USD 170,000. No additional recreational visits to South-West Beira Lake by locals or tourists will occur due to the poor water quality. Consequently, the recreational value of the lake will not be enhanced under the BAU scenario.

Scenario 2 requires investments into the incremental upgrade of Colombo's wastewater treatment network to treat the wastewater of the entire population in the drainage area of South-West Beira Lake and to enhance the effectiveness of the treatment process. Investments are necessary for technologies that remove both N and P from the wastewater and amount to approximately USD 620,000. Improvements in water clarity lead to a net increase in property values by end of 2025 of almost USD 14.3 million. The improved water clarity attracts local people and tourists to visit South-West Beira Lake more often, which will result in additional recreation spending of more than USD 10 million between 2020 and 2025. Due to the relatively low investments for wastewater treatment upgrades, a highly positive benefit to cost ratio of 39.76 is achieved in Scenario 2.

Scenario 3 requires significant investment for the dredging of lake deposits. To dredge an area of 180,000 m^3 (and subsequently treat the dredged deposits) would cost approximately USD 5.7 million. Since Scenario 3 does not assume any interventions to reduce the external nutrient loadings, overall water-quality improvements are not very significant. However, the slight improvements in water clarity lead to a net increase in property values of more than USD 5 million by the end of 2025. Spending for recreation by locals and tourists increases and amount to approximately USD 6.8 million between 2020 and 2025. However, due to the high costs of dredging, the benefit to cost ratio for Scenario 3 amounts to only 2.09.

Scenario 4 combines the wastewater treatment upgrades with dredging of lake sediment, implying overall costs of approximately USD 6.3 million. The combined interventions achieve lasting improvements in water quality. The higher water clarity—of more than one-metre—leads to a net change of values of property surrounding South-West Beira Lake of more than USD 43 million by the end of 2025. In addition, the long-lasting water-clarity improvements attract a large amount of local people and tourists to this part of the lake more often. The additional spending for recreation by these two visitor groups add up to more than USD 19.5 million between 2020 and 2025. Given the comparatively high costs for this intervention scenario, the benefit to cost ratio is not as high as in Scenario 2 but still amounts to 9.92 and hence is significantly higher than the benefit to cost ratio of Scenario 3.

5.0 Final Remarks

5.1 Conclusions of the SAVi Assessment: The value of a restored South-West Beira Lake

The SAVi assessment provides a range of key insights about the value of different restoration intervention options for Beira Lake.

Reducing the inflow of nutrients from sewage drains is paramount to solving the eutrophication and algae bloom problems, as reflected by the results of the wastewater treatment scenario (Scenario 2). The reductions in P and N loadings improve water clarity in the long run and significantly increase the value of properties surrounding South-West Beira Lake by more than USD 14 million at the end of 2025. Likewise, recreational spending increases because the improved water clarity attracts locals and tourists to visit that part of Beira Lake more often. The added recreational value between 2020 and 2025 amounts to more than USD 10 million. The benefit to cost ratio of wastewater treatment upgrades is by far the highest among all assessed scenarios at 39.67.

Dredging of the lake sediment (Scenario 3) yields a very slight increase in water clarity but the problem of a high P concentration and resulting algae blooms persists due to continuous inflow of nutrients from untreated wastewater that reaches the lake. Property values do not increase much in comparison—the increase at the end of 2025 is close to USD 5.1 million. Also, more visitors will come to the lake once dredging took place, but visitor rates are characterized by seasonal shifts associated with persisting algae blooms. The added recreational value from dredging between 2020 and 2025 adds up to almost USD 7 million. The benefit to cost ratio of this scenario is slightly higher than 2. While this indicates that the expenditures are worthwhile since the value of benefits is twice as high, investing only into the dredging of lake sediment is considered insufficient for restoring the ecosystem integrity of the lake and achieving positive impacts for properties and recreation in the long run.

Reducing nutrient inflows by improved wastewater treatment and dredging the lake sediment at the same time (Scenario 4) achieves significant improvements in water clarity and provides for the highest increase in property values and recreational spending. The estimated value increase of properties surrounding South-West Beira Lake amounts to more than USD 43 million by the end of 2025 compared to the status quo before any restoration interventions. The strong increase of local visitors and tourists thanks to the strong improvement in water clarity yields recreational spending between 2020 and 2025 of more than USD 19.5 million. Despite these significant benefits, the benefit to cost ratio for Scenario 4 is only 9.92 and thus significantly lower as compared to conducting only wastewater treatment in isolation (Scenario 2). This is due to the high costs of dredging lake sediment. If an investment prioritization has to be made and capital expenditure for restoring the lake has to be kept relatively low due to insufficient financing sources, it is recommended to invest into the upgrade of the wastewater treatment system in the drainage area of South-West Beira Lake: this promises significant increases in water quality with comparatively little investment as shown by Scenario 2.

5.2 Insights for Financing the Restoration of South-West Beira Lake: Opportunities for blended finance

The economic valuations provided in this report make a strong case for the restoration of the South-West Beira Lake given its property value and recreational benefits. The question that then arises is *Who pays for the restoration interventions?* The polluters or the beneficiaries of a cleaner lake? Or both?

Given the socioeconomic context of Colombo, it is extremely difficult to identify historic and present-day polluters and establish direct liability. The beneficiaries, on the other hand, may be easier to pinpoint. They are the citizens of Colombo, along with tourists and the property developers, owners and investors around the lake.

In such a context a blended financing solution to fund the continued cleanup of the lake may be the most appropriate. Perhaps the first step in this direction may need to be the recognition of the dependency of the city and citizens of Colombo on the lake for recreation, property valuation and much more. The valuations in this report can contribute toward considering the Beira Lake a tangible capital asset. It can then be recorded as such in public sector capital asset inventories.

Global best practice on public asset management suggests that cities and municipalities compile inventories of tangible public assets and determine their condition and value. From there the preparation and implementation of asset-management plans to maintain and refurbish aging assets can be envisaged. The Beira Lake is certainly a tangible asset—the valuations in this report demonstrate it. In addition, with the availability or collection of more data, a more customized valuation of the recreational value of Beira Lake can be conducted as well as a valuation of its stormwater retention service.

Investors around Beira Lake have been proposing to co-fund (or even fund entirely) the cleanup of the lake should public investments be made to prevent continued pollution thereafter. The Municipality of Colombo and the Urban Development Authority would be well served to dialogue with investors, especially in light of the *No Kunu* ("No Waste") citizen campaign to improve municipal waste management in Sri Lanka.

Recognition of the lake as a tangible capital asset will also help all stakeholders design innovative solutions to finance the restoration and long-term conservation.

Potential solutions include:

1. **A dedicated Beira Lake maintenance charge:** Designed in the form of a municipal charge, this can be levied on the direct beneficiaries of a cleaner lake to raise capital to build and maintain wastewater treatment plants and carry out one-off dredging. The Municipality of Colombo and the Urban Development Authority would need to carefully ringfence the revenues from these charges into a dedicated budget line and use it expressly to meet the capital and operating costs of wastewater treatment/dredging. The downside of this option is that it will take a number of years to raise enough capital to sufficiently upgrade the wastewater treatment facilities and to conduct a large-scale dredging intervention. It is also uncertain if the Municipality of Colombo and the Urban Development Authority would have the necessary skills to administer such a program.
2. **Public–private partnership for wastewater treatment facilities:** The public tender for the wastewater treatment upgrades could also be designed as a public–private partnership, under which the private counterparty raises the necessary capital, implements and operates the

wastewater treatment and is reimbursed on their performance on an "availability payment." This availability payment can be raised through contributions from the Municipality of Colombo, Urban Development Authority and a fund established by investors around the lake.

3. **Capital fund:** Beneficiaries of a cleaner lake contribute toward a fund that meets the capital costs for upgrading the wastewater treatment plants. The operating costs could be met by the Municipality of Colombo and the Urban Development Authority. A non-government organization could be mandated to monitor or even operate the treatment plants and moreover, work with the local communities to implement measures to reduce pollution loads for Beira Lake.

Many other innovative solutions can also be envisaged.

As this study closes in August 2019, Indocean Developers (Pvt) Ltd., the project developer of the Altair real estate development project in Colombo, who requested this assessment, plan to use it to consult widely on the next steps for financing the restoration of Beira Lake. We look forward to further engagement with stakeholders in Colombo in the months to come.

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Annex I. Cost of Wastewater Treatment

Table A1.1. Cost of wastewater treatment

Extended aeration	**99% P removal efficiency (USD)**		**Objective F (USD)**	**Average (USD)**
Plant capacity →	**1 million gallons per day (MGD)**	**10 MGD**	**100 MGD**	
Capital cost per gallon per day (GPD)	8.44	3.92	3.25	**5.20**
incremental O&M per GPD	0.61	0.26	0.18	**0.35**
Cost per lb of total inorganic nitrogen (TIN) removed	16.61	5.27	3.34	**8.41**
Cost per kg	36.62	11.62	7.36	**18.53**
Cost per lb of P removed	43.20	26.86	22.46	**30.84**
Cost per kg	95.24	59.22	49.52	**67.99**

Activated sludge	**100% P removal efficiency (USD)**		**Objective F (USD)**	**Average (USD)**
Plant capacity →	**1 MGD**	**10 MGD**	**150 MGD**	
Capital cost per GPD	11.00	6.45	4.16	**7.20**
incremental O&M per GPD	0.59	0.33	0.24	**0.39**
Cost per lb of TIN removed	19.53	11.88	7.38	**12.93**
Cost per kg	43.06	26.19	16.27	**28.51**
Cost per lb of P removed	44.17	23.14	18.08	**28.46**
Cost per kg	97.38	51.01	39.86	**62.75**

Sequencing batch reactor	**87% P removal efficiency (USD)**		**Objective F (USD)**	**Average (USD)**
Plant capacity →	**0.5 MGD**	**2 MGD**	**10 MGD**	
Capital cost per GPD	4.85	2.97	1.80	**3.21**
incremental O&M per GPD	0.86	0.39	0.19	**0.48**
Cost per lb of TIN removed	172.21	71.54	29.76	**91.17**
Cost per kg	379.66	157.72	65.61	**201.00**

Sequencing batch reactor	**87% P removal efficiency (USD)**		**Objective F (USD)**	**Average (USD)**
Plant capacity →	**0.5 MGD**	**2 MGD**	**10 MGD**	
Cost per lb of P removed	76.08	49.41	33.77	**53.09**
Cost per kg	167.73	108.93	74.45	**117.04**

Trickling filter	**P removal efficiency not available (USD)**		**Objective F (USD)**	**Average (USD)**
Plant capacity →	**1 MGD**	**10 MGD**	**150 MGD**	
Capital cost per GPD	12.44	7.62	4.53	**8.20**
incremental O&M per GPD	0.65	0.36	0.24	**0.42**
Cost per lb of TIN removed	23.82	14.70	8.34	**15.62**
Cost per kg	52.51	32.41	18.39	**34.44**
Cost per lb of P removed	42.81	22.13	17.27	**27.40**
Cost per kg	94.38	48.79	38.07	**60.41**

Membrane bioreactor	**100% P removal efficiency (USD)**		**Objective F (USD)**	**Average (USD)**
Plant capacity →	**1 MGD**	**10 MGD**	**100 MGD**	
Capital cost per GPD	1.35	0.35	0.28	**0.66**
incremental O&M per GPD	0.20	0.12	0.10	**0.14**
Cost per lb of TIN removed	2.11	1.90	1.89	**1.97**
Cost per kg	4.65	4.19	4.17	**4.34**
Cost per lb of P removed	24.78	11.75	9.32	**15.28**
Cost per kg	54.63	25.90	20.55	**33.69**

Average across all technologies for 1 mgd	
TIN per kg	USD 57.36
Phosphorus per kg	USD 68.38

Source: numbers based on Tetra Tech (2011)

Annex II. Methodology of the SAVi Analysis

Methodological Assumptions for Biophysical Parameters

POPULATION IN THE LAKE'S DRAINAGE AREA

The estimated population in the drainage area of South-West Beira Lake was 13,500 in 2017. This population increases to 17,000 by 2050. The amount of wastewater treated differs between the scenarios. For the BAU scenario, the amount of wastewater treated is kept constant at 80 per cent at any point in time. Since the population in the drainage area increases over time while the percentage of treated wastewater of the total population is kept constant, there will be an increase of untreated wastewater volume over time. Translating this in population figures suggests that the wastewater of 2,700 people will enter the lake untreated in 2017 while this amount increases to 3,400 people in 2050.

The share of population whose wastewater is not treated will decrease accordingly in Scenario 2 and Scenario 4. Both scenarios assume an incremental increase of the share of population that is served with wastewater treatment capacity.

NITROGEN AND PHOSPHORUS CONCENTRATION

The assessment currently only assumes a resuspension of bottom layer P back into the water and no resuspension of N deposits. This assumption is due to the lacking information on a reference value for the magnitude of the N flow from lake sediment into the water. Overall, our research suggests that the N flow would likely only have a minor impact on waterbody N concentration.

CHLOROPHYLL-A

The function for determining the chlorophyll-a concentration in South-West Beira Lake was developed using a regression analysis based on phosphate and chlorophyll-a concentration data reported by Idroos and Manage (2014). While phosphate values reported in this study were by factor 10 smaller than those reported for Beira Lake in the study of MMWD et al. (2017), the regression coefficient was divided by 10 to adjust for the difference. The regression model is based on data for one year and has an R^2 value of 0.3681.[2] The regression equation obtained from the regression model is:

*Chl-a concentration = 11.44 + 7.31653 * P concentration*

SECCHI DEPTH

The function for estimating the Secchi depth in the lake based on chlorophyll-a is informed by a *nutrient loading – lake response relationship* reported by Rast and Lee (1978). The function was customized for the Beira Lake as the maximum Secchi depth in the data reported by Rast and Lee (1978) was nine metres, while the average depth of the South-West Beira Lake is estimated at 1.5 metres. The function for estimating Secchi depth based on chlorophyll-*a* is presented in Figure A2.1.

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[2] The lack of long-term historical data and the weak R2 value suggest that multiple other factors than phosphate influence the concentration of chlorophyll-a. Further research is recommended to assess the key determinants for the growth of algae in Beira Lake.

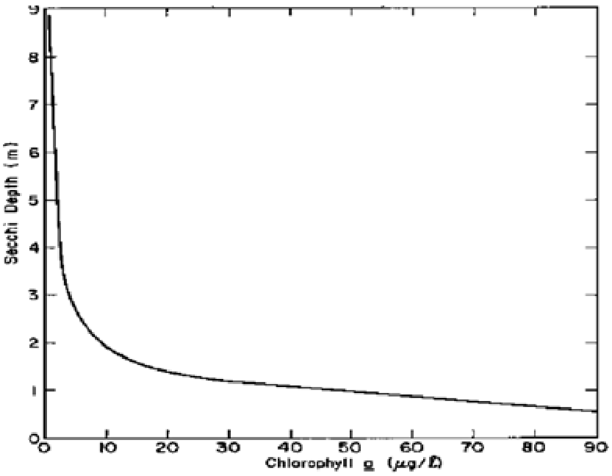

Figure A2.1. Nutrient loading – lake response relationship curve

Source: Rast & Lee, 1978.

Values along the curve presented in Figure 6 were extracted using the WebPlotDigitizer software. Chlorophyll-a values (X-axis) are assumed to be the same, while water clarity values (Y-axis) were normalized (8.84m = 1) and then applied to the maximum depth of 1.5 meters. Table A2.1 provides information about the initial relationship, and the transformation that was conducted to estimate water clarity in the South-West Beira Lake for the baseline and water treatment scenario (average water depth = 1.5m) and the dredging scenario (average water depth = 2.4m).

Table A2.1. Normalization of Secchi depth based on nutrient loading – lake response data reported by Rast & Lee (1978)

Original data reported by Rast & Lee (1978)		**Normalization of Secchi depth to the South-West Beira Lake for the BAU and the Dredging scenario respectively**		
Chlorophyll-*a* conc. (Mg/l)	**Secchi depth** (metres)	**Relative Secchi depth**	**Secchi depth (Business-as-usual)** Max water depth = 1.5 m	**Secchi depth (Dredging)** Max water depth = 2.4 m
0.592105	8.84	1.000	1.50	2.40
2.171053	4.00	0.452	0.68	1.09
3.355263	3.21	0.364	0.55	0.87
5.328947	2.63	0.297	0.45	0.71
9.078947	2.00	0.226	0.34	0.54
14.802632	1.59	0.179	0.27	0.43
27.039474	1.23	0.139	0.21	0.33
48.157895	0.99	0.112	0.17	0.27

Original data reported by Rast & Lee (1978)		**Normalization of Secchi depth to the South-West Beira Lake for the BAU and the Dredging scenario respectively**		
Chlorophyll-*a* conc. (Mg/l)	**Secchi depth** (metres)	**Relative Secchi depth**	**Secchi depth (Business-as-usual)** Max water depth = 1.5 m	**Secchi depth (Dredging)** Max water depth = 2.4 m
76.184211	0.69	0.078	0.12	0.19
89.605263	0.55	0.062	0.09	0.15

The Need for a System-based Approach

Assessing the value of an infrastructure asset—be it natural or built—is complex. In particular, natural infrastructure often provides ecosystem services that may enable economic activity, strengthen social empowerment and well-being, and further support ecological integrity. As a result, any analysis of natural infrastructure has to assess impacts across (i) dimensions of development (i.e., social, economic and environmental), (ii) economic sectors, (iii) economic actors (e.g., households, public and private sector), (iv) over time and (v) in space.

Specifically, the analysis performed with SAVi on South-West Beira Lake builds on the following main pillars:

1. Assess and determine the costs of different intervention options to improve the water quality of the lake
2. Assess and quantify the economic benefit (property value impacts and recreational spending) from a restored lake

The SAVi model is developed using the System Dynamics methodology (Sterman, 2000). Its core pillars are feedback loops, delays and non-linearity. These are explicitly represented in the model using stocks and flows, which are solved with differential equations. The SAVi model has been developed based on global literature, customized with local stakeholder input and parametrized with local, accessible data. The model simulates from 2000 to 2050. There are two main reasons for using this specific timeframe: (i) being causal-descriptive SAVi needs to be validated against historical data (hence the simulation of the model from 2000 onwards), (ii) being focused on infrastructure and long-term interventions (and their costs and outcomes) SAVi needs to forecast the impacts of interventions after they have been implemented and are fully operational—hence the simulation of the model between 2019 and 2050, assuming an incremental increase of wastewater treatment capacity between 2020 and 2025. The focus of this assessment is to highlight the short-term effects of water-quality improvements in South-West Beira Lake on the real estate value of Altair. Therefore, most outcomes are only displayed until 2027. This report outlines the model, scenarios and simulation outputs, and the results of the analysis. The model was run based on available and local reports/data to show how SAVi can be applied in a customized manner to the valuation of an urban waterbody, in this case South-West Beira Lake.

Method: Systems Thinking

The key variables and main drivers for the assessment of nature-based and built infrastructure were analyzed and summarized in a causal loop diagram (CLD). The CLD includes the main indicators analyzed; their interconnections with relevant components related to the use of infrastructure, such as total area and ecosystem/infrastructure services provided; and the feedback loops they form. The capturing of feedback allows us to see the asset as part the socioeconomic and environmental subsystems that it is part of and allows for inferring direct and indirect impacts. The CLD, as displayed in Figure A2.2, was developed and customized to the local context in collaboration with local stakeholders, which also provided the necessary information for the assessment. The CLD is the starting point for the development of the mathematical stock and flow model. The model results are presented in Part IV.

Designing a CLD for a project helps to combine and integrate a team's knowledge, ideas and concepts. Moreover, an interactive CLD design and verification process with key stakeholders of a project ensures that these stakeholders have a common understanding of the analysis being undertaken, both in terms of its overarching scope and its underlying factors. This will then enable these stakeholders to later appreciate and make use of analysis results (TEEB, 2018; Pittock et. al. 2016). In this regard, CLDs highlight the root causes of a problem, as well as the variables of a system that could, with the appropriate technical or policy interventions, be targeted to develop solutions (UNECA, 2018).

To design solution-oriented and effective interventions, CLDs need to capture causal relations of a system correctly. Therefore, CLDs establish causal links between variables by linking them with arrows and attributing a sign to the arrow (either + or –) that indicates whether a change in one variable generates a positive or negative change in the other. (See Table A2.2 below, not to be confused with Figure A2.2).

As noted by Bassi et. al.:

- A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction.
- A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction" (Bassi et al. 2016).

Table A2.2. Causal relations and polarity

Variable A	Variable B	Sign
↑	↑	+
↓	↓	+
↑	↓	-
↓	↑	-

Moreover, these causal interactions can form what is known as a positive or negative "feedback loop,". (Forrester, 1961). In other words, an intervention made in that system can either support the tendency towards an equilibrium within the overarching system, in which case this negative feedback loop is called a balancing loop. Alternatively, an intervention can reinforce the intervention's impact and hence create a positive feedback loop, which is called a reinforcing loop. (Bassi, 2009, Forrester, 1961) What makes CLDs especially useful for decision-makers and other stakeholders is this feedback component, showing how the different elements within a system interact with each other and either exacerbate or ameliorate a given situation. (TEEB, 2018) These mapped relationships may not necessarily indicate linear behaviour, and potential impacts may occur following a delay, which is why a CLD that captures the extent and complexity of this system is important. The interaction of "feedback loops" may also be where the source of a given policy problem lies, and therefore where decision-makers will need to direct their efforts for finding a solution – along with being aware of how this solution will affect the rest of the system. (WWF, 2014).

Model: SAVi for South-West Beira Lake

We have applied the SAVi model to South-West Beira Lake. The following CLD presents the underlying causal links between the different environmental, social and economic systems that interact with South-West Beira Lake. The elements in orange font colour in Figure A2.2 indicate different restoration interventions that aim to improve the water quality of the lake. The biophysical dynamics of the lake and water-quality changes caused by assessed interventions are explained in Chapter IV.

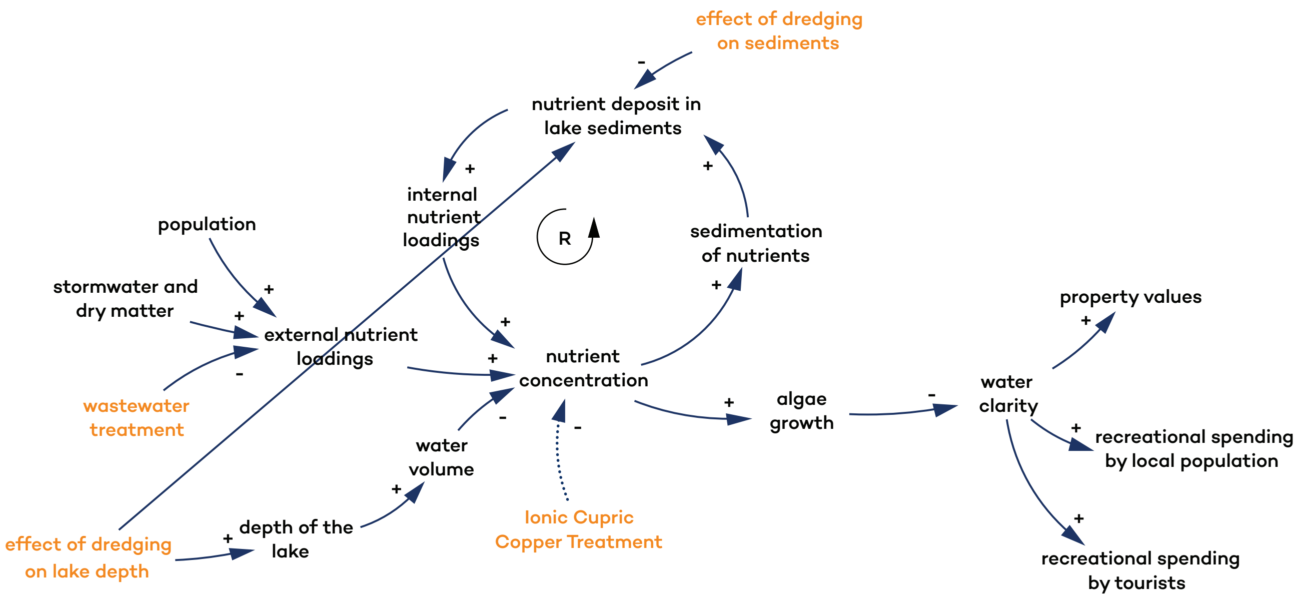

Figure A2.2. **Causal loop diagram of South-West Beira Lake and intervention options for lake restoration**

Annex III. Cost–Benefit Analysis, Undiscounted Values

Table A3.1. Cumulative costs and benefits relative to BAU from 2020 to 2025, in USD and undiscounted

Costs and benefits (in USD, discounted)	**Scenarios**			
	1. Business-as-usual (BAU)	**2. Wastewater treatment upgrades**	**3. Dredging of lake deposits**	**4. Combined: wastewater treatment and dredging**
Costs				
Costs for wastewater treatment upgrades				
Nitrogen removal technology	\	600,543	\	600,543
Phosphorus removal technology	\	179,730	\	179,730
Cost of sediment removal	\	\	6,296,921	6,296,921
Total cost (2020 to 2025)	****	**780,273**	**6,296,921**	**7,077,194**
Benefits				
Cumulative property value net change by end of 2025*	(215,269)	18,580,692	5,762,403	56,160,932
Additional spending for recreation by local population	\	848,824	533,851	1,548,195
Additional spending for recreation by tourists	\	12,499,990	7,916,664	22,916,640
Total benefits	**(215,269)**	**31,929,506**	**14,212,918**	**80,625,767**
Net results	**(215,269)**	**31,149,232**	**7,915,997**	**73,548,573**
Benefit to cost ratio	**N/A**	**40.92**	**2.26**	**11.39**

**The calculated property value net changes do not account for the market-driven, organic appreciation of property values around South-West Beira Lake over time. For example, the negative value in the BAU scenario indicates solely the negative impact of deteriorated water clarity on property values.*

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