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Sustainable Asset Valuation of Nature-Based Flood Mitigation Infrastructure in Drakenstein, South Africa

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Sustainable Asset Valuation of Nature-Based Flood Mitigation Infrastructure in Drakenstein, South Africa

February 2025

Written by Henri Contor, Ronja Bechauf, and Marco Guzzetti.

Author contributions: Henri Contor developed the system map, the quantitative model, and the integrated cost-benefit analysis and led the writing of the report. Ronja Bechauf contributed to defining the scope of analysis and writing the report. Marco Guzzetti produced the various spatial maps and the InVEST analysis.

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This report is part of a wider collaboration between the C40 Cities Finance Facility (CFF) and IISD to support the project preparation phase of NBI projects in cities in Colombia and South Africa. C40 Cities Finance Facility and IISD are working together on integrated economic assessments of urban NBI projects to support implementation and showcase the value of nature for cities. C40 CFF is implemented by GIZ and C40.

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Executive Summary

The Western Cape region of South Africa, including the municipality of Drakenstein, is increasingly vulnerable to severe flooding. This vulnerability is driven by both climate change and human impacts, such as waste disposal and encroachment on floodplains, which have significantly degraded the natural ecosystems that once provided essential services like flood protection. The Berg River and its tributaries, crucial to the area's biodiversity and economy, have seen a sharp decline in their ecological integrity. This degradation exacerbates the flood risk as the river systems lose their capacity to manage excess water, putting communities, infrastructure, and local industries at significant risk. Drakenstein's recent floods have caused widespread damage, particularly to transportation and healthcare systems, underscoring the urgent need for improved flood resilience and water management solutions. Additionally, these floods have endangered the livelihoods tied to agriculture, industry, and tourism, further stressing the need for action.

Figure ES1. Flooding in Drakenstein

Source: Drakenstein Municipality (reprinted with permission).

In response to these escalating risks, Drakenstein is pursuing nature-based infrastructure (NBI) as a core strategy to restore the natural ecosystems and mitigate the impacts of flooding. Through the Hybrid Flood Alleviation project, the municipality is planning to implement several interventions to rehabilitate degraded rivers, wetlands, floodplains, and riparian zones. These plans span the catchments of Palmiet, Groenheuwel, and Mbekweni, which are located in Paarl.

Key proposed measures include reshaping streams, improving riverbank stability, installing erosion control systems like reno mattresses, and constructing wetlands with sedimentation basins to manage water flows, representing a total area of 214 hectares (ha). In flood-prone neighbourhoods, the creation of open spaces and infrastructure upgrades are prioritized to reduce vulnerabilities. These interventions aim to strengthen the region's natural flood defences while simultaneously providing social and economic benefits, such as improved water retention, reduced erosion, and enhanced public spaces. The NBI efforts align closely with broader municipal and provincial climate resilience strategies, integrating ecological restoration with sustainable urban development.

The explorative assessment of these interventions was carried out using the Sustainable Asset Valuation (SAVi) methodology. The SAVi approach provides a holistic evaluation by incorporating environmental, social, and economic factors that are often neglected in traditional assessments. This approach uses systems thinking to map the interconnected dynamics between natural ecosystems, infrastructure, and local communities. The analysis integrates climate projections, spatial analysis, and detailed cost-benefit calculations to assess the potential long-term impacts of the NBI interventions. By valuing externalities, such as flood prevention and ecosystem restoration, the SAVi methodology offers a comprehensive understanding of the financial and social benefits, ensuring that investment decisions support climate resilience and align with local development priorities. Some externalities were not quantified, given the lack of data. Such data gaps could be closed with further technical studies, informing further economic assessments beyond this exploratory SAVi report.

When looking at the results, the assessment of the NBI project in Drakenstein demonstrates a significant value proposition, especially under severe climate scenarios where flood risks are elevated. The integrated cost-benefit analysis (CBA) spans four distinct flood scenarios, each representing varying flood intensity and frequency, as illustrated in Table ES1. Flood intensity refers to the return period, representing the statistical probability of a flood event of a certain magnitude (e.g., a 1:10 or 1:50 event). In contrast, flood frequency captures how often such events actually occur within a given period. For example, in Climate Scenario 1, a flood with an intensity expected to occur once every 10 years (1:10) is modelled to occur every 2 years based on the adjusted frequency. Key metrics such as net benefits, benefit-to-cost ratio (BCR), and internal rate of return (IRR) were calculated to evaluate the viability of the NBI project. Note that this initial assessment is later supported by additional exploration of results across a broader range of possible flooding conditions.

The analysis estimates total project costs at ZAR 151 million (USD 5.7 million) over the course of 25 years (2025–2050 horizon) when discounted at 8%,[1] with benefits projected to range from ZAR 147.3 million to ZAR 748.3 million (USD 8.4 million to USD 42.8 million). Depending on the climate scenario, NBI has the potential to generate a net benefit of up to ZAR 597.3 million (USD 34.2 million). In one climate scenario, the NBI is projected to result in a net loss of ZAR 3.8 million (USD 0.2 million). The positive return on investment is further shown by a BCR ranging from 0.98 to 4.95, meaning that every ZAR invested in the NBI yields between ZAR 0.98 and ZAR 4.95 in return for society. The NBI also has a promising IRR between 7.5% and 53.6%.

The results detailed below emerge as critical:

- **Without investments in NBI, communities and economic activities face serious flood risks.** The potential consequences of inaction in flood risk management are significant, particularly for vulnerable communities and sectors. Depending on the flood scenario, formal settlements of 8.6 ha to 51.3 ha are at risk of flooding, while informal settlements in an area of 9.7 ha to 22.9 ha are threatened by floods. The industrial sector's exposure ranges from 27.5 ha to 140.6 ha, posing threats to production and employment. Agricultural land is at risk over an area of 6.4 ha to 23 ha, impacting local food security. Road networks are affected over distances from 19.4 km to 52.8 km, disrupting transportation. Economically, we estimate that in a no-action scenario, flood damage ranges from ZAR 175 million to ZAR 2,263 million in severe scenarios (USD 10.1 million to USD 129.5. million).
- **Implementing NBI in the water catchments effectively reduces flood risks.** The NBI mitigates flood damages, reducing costs significantly and yielding avoided costs that escalate from ZAR 47 million to ZAR 631 million as flood intensity rises (USD 2.7 million to USD 36.1 million). This emphasizes that the ZAR 151 million cost (USD 8.65 million) of the NBI project is minor compared to the potential damages of inaction, underscoring the need for investment.
- **NBI provides diverse societal benefits in addition to flood protection.** The NBI project generates a wide array of ecosystem services that extend beyond flood mitigation, including the creation of employment opportunities (valued at ZAR 30.3 million/USD 1.7 million), food provisioning (ZAR 2.6 million/USD 0.15 million), and recreational spaces (ZAR 47.8 million/USD 2.7 million). Additionally, it contributes to urban cooling, biodiversity conservation, and carbon sequestration and supports tourism activities, reflecting its comprehensive impact on socio-economic and environmental well-being in the region.

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[1] An analysis was conducted to assess the sensitivity of results to different discount rates (see details in main text). Lower-severity flooding scenarios showed a decline in net benefits as discount rates increased, while higher-severity scenarios maintained positive net benefits and a robust BCR.

- **Broader flood scenarios and breaking point.** Sensitivity analysis, as simplified in Table ES2, shows that as flood intensity and frequency increase, the performance of NBI interventions improves markedly. For example, at an 8% discount rate, lower-intensity and lower-frequency scenarios yield a BCR of 0.59, while higher-intensity and frequency combinations lead to a BCR of 13.81. A critical threshold is observed at a flood intensity of 1:10, with a frequency of just above one flood every 2 years, where the BCR reaches 1.40. As flood intensities rise to 1:15 and 1:20, the economic viability of NBI is achieved with less frequent events—one flood every 6 years for 1:15 intensity and one flood every 9 years for 1:20 intensity. These findings underscore the effectiveness of NBI, even in moderate flooding scenarios, highlighting the pressing need for proactive flood management.
- **Economic incentives for industries to support NBI.** Industrial areas in Drakenstein face significant flood risks, prompting a focused analysis on the avoided costs of flood damages to industries, excluding other project benefits. The findings reveal that floods with an intensity that statistically occur once in 10 years at most do not impact industries, resulting in no NBI benefits for industries. However, for floods with an intensity of 1:15, the BCR ranges from 0.11 to 1.22. A breaking point occurs when 1:15 floods happen annually, while 1:20 floods only require a frequency of one every 2 years to reach viability. Approximately half of the scenarios analyzed show a BCR above 1, demonstrating that the NBI is a viable climate adaptation strategy for the industrial sector. In other words, the analysis underscores the economic rationale for industrial stakeholders to contribute to NBI implementation, which effectively mitigates flood risks and reduces potential damages over time.

In conclusion, the municipality of Drakenstein is at a critical juncture, facing escalating flood risks exacerbated by climate change and human activities. The implementation of NBI emerges as a pivotal strategy to restore ecological integrity and bolster flood resilience while offering a wide array of socio-economic benefits. The comprehensive assessment of NBI projects demonstrates their potential to yield significant net benefits, particularly in high-risk scenarios, reinforcing the importance of proactive investment. By embracing a systems thinking approach, fostering private sector partnerships, and implementing targeted interventions, Drakenstein can effectively address the intertwined challenges of flood management, environmental sustainability, and community resilience. The commitment to NBI represents not just a response to immediate threats but a long-term vision for a more resilient and sustainable future for the region.

Table ES1. Integrated CBA across climate scenarios discounted at 8%

	Climate Scenario 1	Climate Scenario 2	Climate Scenario 3	Climate Scenario 4
Flood intensity/size (1 in X event type)	1:10	1:20	1:30	1:50
Flood frequency (flood of intensity X every Y year)	2	8	5	3
Direct costs (ZAR million)				
Implementation costs (CapEx)	99.9	99.9	99.9	99.9
Maintenance costs (OpEx)	51.2	51.2	51.2	51.2
Avoided costs/loss (ZAR million)				
Avoided cost of flood damages – formal settlement	0.9	1.4	4.2	12.1
Avoided cost of flood damages – informal settlement	20.4	7.7	16.7	36.1
Avoided cost of flood damages – industry	-	49.2	160.9	453.6
Avoided cost of flood damages – agriculture	1.6	5.8	14.9	34.1
Avoided cost of flood damages – roads	23.9	19.0	44.4	95.3
Avoided cost of flood damages – utilities	No data	No data	No data	No data
Avoided cost of flood damages – educational areas	No data	No data	No data	No data
Avoided cost of disaster relief	4.2	1.7	3.7	8.3
Avoided cost of mental health impact	12.4	4.9	10.9	24.4
Avoided cost of human death	No data	No data	No data	No data
Avoided cost of dredging	No data	No data	No data	No data
Avoided loss of agricultural production	0.0	0.1	0.3	0.6
Added benefits (ZAR million)				
Value of employment creation	30.3	30.3	30.3	30.3
Value of food provisioning	2.6	2.6	2.6	2.6
Value of recreational areas	47.8	47.8	47.8	47.8
Value of urban cooling	No data	No data	No data	No data
Value of nursery	No data	No data	No data	No data

	Climate Scenario 1	Climate Scenario 2	Climate Scenario 3	Climate Scenario 4
Value of biodiversity conservation	0.2	0.2	0.2	0.2
Value of carbon sequestration	1.0	1.0	1.0	1.0
Value of tourist activities	No data	No data	No data	No data
Value of tourism tax revenue	No data	No data	No data	No data
Value of property tax revenue	1.9	1.9	1.9	1.9
Key performance indicators				
TOTAL BENEFITS (ZAR million)	147.3	173.8	339.9	748.3
TOTAL COSTS (ZAR million)	151.1	151.1	151.1	151.1
NET BENEFITS (ZAR million)	-3.8	22.7	188.8	597.3
BENEFIT-TO-COST RATIO	0.98	1.15	2.25	4.95
INTERNAL RATE OF RETURN	7.5%	10.7%	26.8%	53.6%

Source: Authors.

Table ES2. BCR across flood scenarios discounted at 8%

	Flood intensity/size (1 in X event type)				
Flood frequency (flood of intensity X every Y year)	**10**	**20**	**30**	**40**	**50**
1	1.4	5.28	8.63	11.45	13.81
2	0.98	2.89	4.55	5.94	7.11
4	0.77	1.74	2.59	3.29	3.89
6	0.7	1.38	1.96	2.46	2.87
8	0.66	1.15	1.57	1.93	2.22
10	0.63	0.97	1.26	1.5	1.71

Source: Authors.

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Acronyms and Abbreviations

BCR	benefit-to-cost ratio
CapEx	capital expenditure
CBA	cost-benefit analysis
CLD	causal loop diagram
EIIF	Ecological Infrastructure Investment Framework
InVEST	Integrated Valuation of Environmental Services and Trade Offs
IRR	internal rate of return
LULC	land use/land cover
NBI	nature-based infrastructure
OpEx	operating expense
SAVi	Sustainable Asset Valuation
SPI	Standard Precipitation Index
SSP	Shared Socioeconomic Pathways

Glossary

Benefit-to-cost ratio: A ratio that measures the efficiency of an investment by comparing the economic benefits (including externalities) to the economic costs associated with a project or initiative over a specified period. It provides a holistic view of the investment's economic viability, considering broader impacts beyond direct financial returns.

Discounting: A financial technique used to adjust the value of future costs or benefits to their present value, reflecting the time value of money. It involves applying a discount rate to future cash flows to determine their current worth, facilitating comparisons and decision making across different time periods. Discounting allows analysts to account for the opportunity cost of capital and the preference for receiving benefits sooner rather than later.

Indicator: Parameter of interest to one or several stakeholders that provides 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: The discount rate that makes the net present value of the economic benefits (including externalities) of a project or initiative equal to zero. It indicates the rate of return at which the project's economic benefits balance its costs, encompassing all economic impacts.

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 a model's 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, as reported by the intervention scenario.

Net present value: The difference between the present value of the economic benefits (including externalities) and the present value of the economic costs associated with a project or initiative over its lifetime. It quantifies the net monetary impact of the economic aspects of the project, considering all relevant costs and benefits.

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).

1.0 Introduction

The Western Cape region of South Africa is facing severe threats from floods. River floods and extreme rainfall are increasingly impacting the health and safety of communities, especially in informal settlements located in flood-prone areas (see Figure 1). The rivers in the Western Cape are critically endangered, with 95% of them having less than 10% of their length remaining ecologically intact (Drakenstein Municipality, 2022). This ecological degradation of rivers and wetlands is mainly caused by climate change and human influences like waste disposal, water extraction, and the encroachment of floodplains. The reduced ability of rivers and wetlands to provide ecosystem services such as flood protection is a cause for concern for people in the Western Cape region. The natural systems are crucial for providing water for agricultural, domestic use, recreational, and industrial use, as well as natural resources such as fish and plants for human consumption. Furthermore, they are valuable resources for tourism and culture (Western Cape Government, 2018).

Figure 1. An informal settlement facing eroding riverbanks and flood risks

Source: Drakenstein Municipality (reprinted with permission).

In the municipality of Drakenstein, which is part of the Western Cape Province, floods from the Berg River and its tributaries have recently caused severe damage to transportation and health infrastructure (Leaner et al., 2012). The river is one of the Western Cape's critical biodiversity areas, as well as a major economic driver for agriculture, industry, and tourism (Turpie et al., 2021). Restoring a healthy ecosystem and safeguarding its functions for the local economy is therefore a priority for local planners and policy-makers (Drakenstein Municipality, 2022; Western Cape Government, 2023).

In response to these escalating risks, Drakenstein is pursuing nature-based infrastructure (NBI) as a core strategy to restore the natural ecosystems and mitigate the impacts of flooding (C40 Cities Finance Facility. 2024). Through the Hybrid Flood Alleviation project, the municipality is planning to implement several interventions to rehabilitate degraded rivers, wetlands, floodplains, and riparian zones. These plans span the catchments of Palmiet, Groenheuwel, and Mbekweni, which are located in Paarl.

This NBI project, representing a total of 214 ha and a potential 20,000 beneficiaries,[2] focuses on a range of targeted interventions designed to rehabilitate river systems, restore ecological balance, and enhance community resilience. Key measures include reshaping streams and channels into more natural forms, installing reno mattresses for erosion control, and placing litter traps at culverts to mitigate overbank flows. Constructed wetlands featuring sedimentation basins and vegetated swales will filter debris and improve water retention, while bio-retention ponds with native vegetation and gravel layers will manage runoff. The project also incorporates urban food gardens, riparian buffer restoration, and recreational spaces like pocket parks and pedestrian pathways, enhancing both ecological and social value. Additionally, floodplain restoration, including river channel reconfiguration, oxbow reconnection, and bioengineering techniques, aims to stabilize banks and improve hydrology. These interventions, alongside the construction of stormwater attenuation facilities and the installation of new culverts and upgraded bridges, will strengthen water management and infrastructure resilience in Drakenstein.

The project aligns with and supports several broader strategic frameworks and plans that guide sustainable development, climate resilience, and natural resource management in the region (Drakenstein Municipality, 2024a). As outlined in the Drakenstein Spatial Development Framework, managing and protecting natural assets, such as critical biodiversity areas and vulnerable freshwater ecosystems, is central to spatial planning efforts (Drakenstein Municipality, 2024b). By restoring river systems and rehabilitating wetlands, the NBI project contributes to the municipality's objective of integrating climate change adaptation measures into regular planning processes, supporting a low-carbon, climate-resilient trajectory for sustainable growth (Drakenstein Municipality, 2024c).

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[2] Estimated based on the total study area of 104 km^2 and a population density of 191 people/km^2.

The project also complements the goals of the Western Cape Sustainable Water Management Plan, particularly in maximizing water reuse, enhancing water retention, and restoring ecological functions in river catchments to address both drought and flooding risks (Western Cape Government, 2018). Furthermore, the project's ecosystem-based adaptation approach is consistent with the Western Cape Climate Change Response Strategy's vision for a climate-resilient province by 2050, which emphasizes restoring natural systems and mitigating climate risks through nature-based solutions (Western Cape Government, 2023). Overall, the NBI project not only addresses immediate environmental challenges but also aligns with the municipality's long-term objectives of building resilient human settlements and fostering sustainable urban development, as articulated in the Integrated Human Settlements Sector Plan (Drakenstein Municipality, 2019).

In line with the objectives of the Western Cape's Ecological Infrastructure Investment Framework (EIIF), the NBI project focuses on the benefits derived from restoring ecological infrastructure. By addressing key risks such as water security, flood management, and food supply, the project aims to protect vulnerable communities from the effects of climate change while promoting sustainable livelihoods and biodiversity (Audouin et al., 2021). The EIIF provides a foundation for guiding public and private sector investments, ensuring that these interventions not only mitigate environmental risks but also contribute to economic equity and social resilience. By prioritizing the restoration of natural capital, the NBI project advances the broader agenda of building climate resilience.

This strong alignment with the EIIF underscores the value of implementing NBI in Drakenstein. To support this project and create a better understanding of the value of implementing NBI in Drakenstein, this report presents a Sustainable Asset Valuation (SAVi) of the proposed interventions. The analysis combines system mapping, climate data analysis, spatial analysis, and Excel-based modelling to quantify and monetize the outcomes of investing in the NBI project. This process results in an integrated cost-benefit analysis (CBA), which highlights key metrics such as the benefit-to-cost ratio (BCR), net benefits, and internal rate of return (IRR).

This report aims to provide an explorative assessment of the potential benefits of the NBI project in Drakenstein. The C40 Cities Finance Facility is supporting the project through funding and by coordinating additional pre-feasibility studies, including socio-economic assessments, hydrological evaluations, climate change analyses, and ecosystem services assessments. However, these studies are still in progress and will be finalized at a later stage. The outcomes of the studies will enable a more refined approach, as well as assumptions and data inputs for future integrated CBAs. However, in their absence, this report offers an early-stage exploration of the potential environmental, social, and economic benefits that could arise from the implementation of NBI interventions.

This report is structured to provide a cohesive analysis of the potential benefits of NBI interventions in Drakenstein:

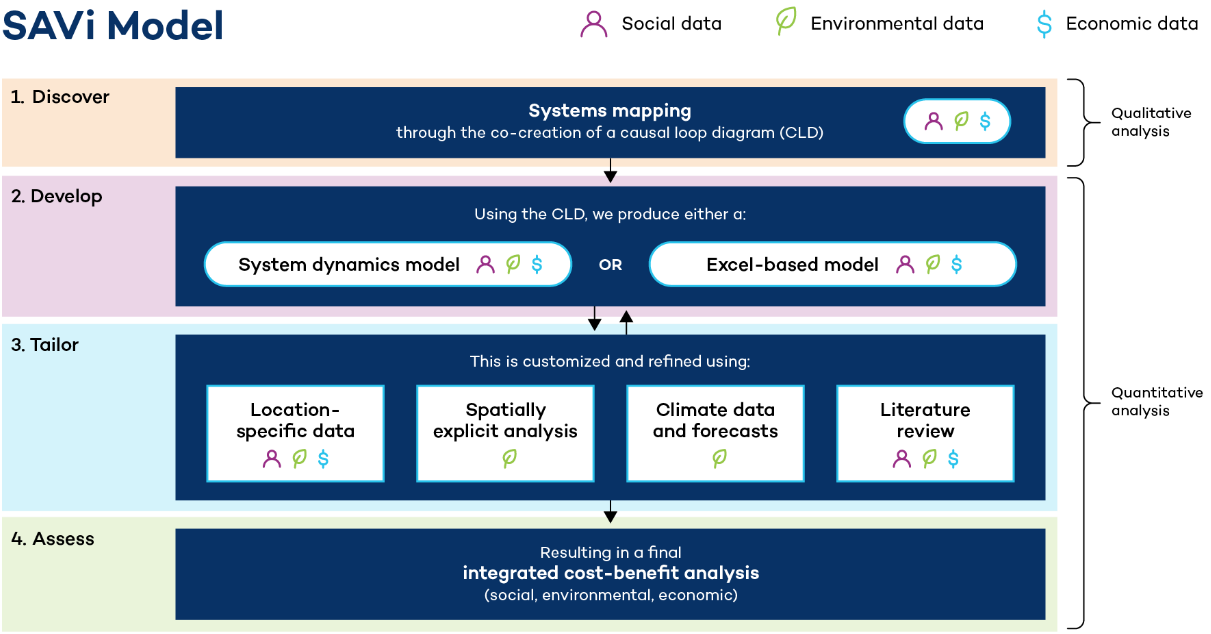
- It begins by introducing the SAVi methodology, which integrates social, economic, and environmental assessments to evaluate the outcomes of investing in sustainable infrastructure (Section 2). Building on this, the report emphasizes the importance of systems thinking, showing how this approach can be used to capture the interconnectedness of natural, social, and economic systems in Drakenstein (Section 2.1).
- To demonstrate this concept in practice, a system map, developed in collaboration with the municipality, highlights key relationships and feedback loops that influence flood resilience and ecosystem health (Section 2.2).
- This is followed by an analysis of local climate data, including patterns of extreme weather, temperature fluctuations, and precipitation trends, which sets the stage for understanding the region's climate risks (Section 2.3).
- Complementing this, spatial analysis using land cover and flood line maps identifies vulnerable flood-prone areas, helping to guide planning and intervention efforts (Section 2.4).
- The report then proceeds with an integrated CBA, detailing the methodology, scenarios, indicators, and results, providing a comprehensive assessment of the NBI interventions' impact (Section 2.5).
- In the conclusion, the key findings are summarized (Section 3), with additional detailed results and modelling assumptions provided in the Appendix. Together, these sections form a coherent narrative that builds from theoretical approaches to practical assessments of NBI's potential in Drakenstein.

2.0 Sustainable Asset Valuation

This chapter presents the methodology and results of the SAVi (see Figure 2). First, we examine the broader picture in which the interventions are taking place by using system thinking and system mapping. Building on this qualitative storytelling, we then incorporate quantitative tools, including climate scenario projections and a detailed CBA, to assess the long-term implications of the proposed interventions. This combined approach enables a nuanced evaluation of both the immediate and future impacts of the NBI in Drakenstein.

SAVi is an assessment methodology that provides policy-makers and investors with a comprehensive life-cycle analysis of infrastructure projects. It considers social, environmental, and economic impacts that are often overlooked in conventional project assessments. Combining systems thinking and various quantitative modelling tools, SAVi captures the full costs, including environmental, social, economic, and governance risks. It calculates the monetary value of externalities, offering a nuanced evaluation. This holistic approach enables investment decisions to align with regional development priorities, climate change adaptation, and the United Nations Sustainable Development Goals, ensuring a financially sound and sustainable outcome.

Figure 2. SAVi methodology



Source: Authors.

2.1 Systems Thinking

Systems thinking offers a holistic framework for decision-makers by illuminating the interconnectedness of social, environmental, and economic factors (Meadows & Wright, 2011; Sanneh, 2018; Stroh, 2015). Rather than focusing on linear, short-term fixes, it encourages a deeper understanding of how elements interact over time, often revealing both synergies and trade-offs (Sterman, 2000). By emphasizing these interdependencies, systems thinking helps to identify the root causes of challenges and ensures that actions are designed within long-term visions (Jackson, 2019). It also brings clarity to the complex web of cause-and-effect relationships, allowing us to better perceive unintended consequences like temporary fixes and escalating problems (Moallemi et al., 2022). Through this approach, both qualitative insights and quantitative models provide the simplicity and precision needed for robust analysis (Probst & Bassi, 2014).

When applied to sustainability, a systems approach opens the door to a broader perspective that transcends immediate needs (Voulvoulis et al., 2022). Each decision becomes more than a momentary act—it is a seed from which a forest can prosper. This balance between the present and the future demands breaking silos, bridging the divides between sectors, disciplines, and time horizons. In reality, no challenge exists in isolation, and no solution can thrive without collaboration. Systems thinking fosters this interconnected view, allowing for the kind of cross-boundary cooperation needed to tackle today's complex issues (Senge, 2006).

In practice, systems thinking is both a compass and a safety net for decision-makers. It maps the relationships between causes and outcomes, revealing feedback loops and patterns that may otherwise remain hidden. This holistic view guards against short-sighted solutions that may do more harm than good in the long run, shifting the focus from isolated fixes to building resilience within the system (Chroust & Finlayson, 2016). Decisions are not just about solving today's problems but about creating frameworks that ensure sustainability, equity, and adaptability for the future. Ultimately, systems thinking reminds us that every action is part of something larger—a vast web of interactions that ripple across time and space. This perspective empowers decision-makers to develop strategies that not only address immediate challenges but also strengthen the system's ability to adapt and flourish over time.

Systems thinking can be a transformative approach for Drakenstein as the municipality faces interconnected challenges related to flood risks, ecological degradation, and the socio-economic impacts of climate change. Drakenstein's rivers and wetlands, which have been heavily impacted by human activities and climate shifts, play a critical role in flood management, agriculture, and overall community resilience. Systems thinking helps decision-makers in the municipality see these challenges not in isolation but as part of a larger network of cause and effect. When we restore a wetland or reinforce riverbanks, we are not only preventing floods but also creating ripples across other sectors—improving agriculture, securing water for domestic use, and even bolstering the tourism economy. By recognizing these interdependencies, systems thinking enables Drakenstein to design interventions that simultaneously address multiple objectives, from climate adaptation to economic growth.

Applying systems thinking in Drakenstein allows for a long-term vision where immediate solutions—like floodplain restoration—are seen as part of a broader strategy to restore ecological balance and ensure sustainable development. For instance, rehabilitating the Berg River is not just about reducing flood risks; it is also about creating resilient ecosystems that can continue providing essential services like water purification, biodiversity support, and even food security. A notable example of the importance of systems thinking is the issue of housing in Drakenstein, where rapid urbanization has led to the conversion of permeable land into impervious surfaces. This shift increases surface runoff during extreme weather events, exacerbating flood risks for communities, especially in informal settlements. By recognizing these unintended consequences, systems thinking emphasizes the need for holistic planning that addresses both housing and environmental sustainability. Through this lens, interventions are designed to enhance the resilience of the whole system—natural, social, and economic. By focusing on feedback loops and understanding how small changes in one area can affect the entire system, decision-makers in Drakenstein can better anticipate unintended consequences and avoid quick fixes that could lead to future problems. This approach is crucial in addressing the intricate challenges of the region, ensuring that each intervention strengthens the broader system, ultimately leading to a more resilient and sustainable future for the municipality.

2.2 Systems Mapping

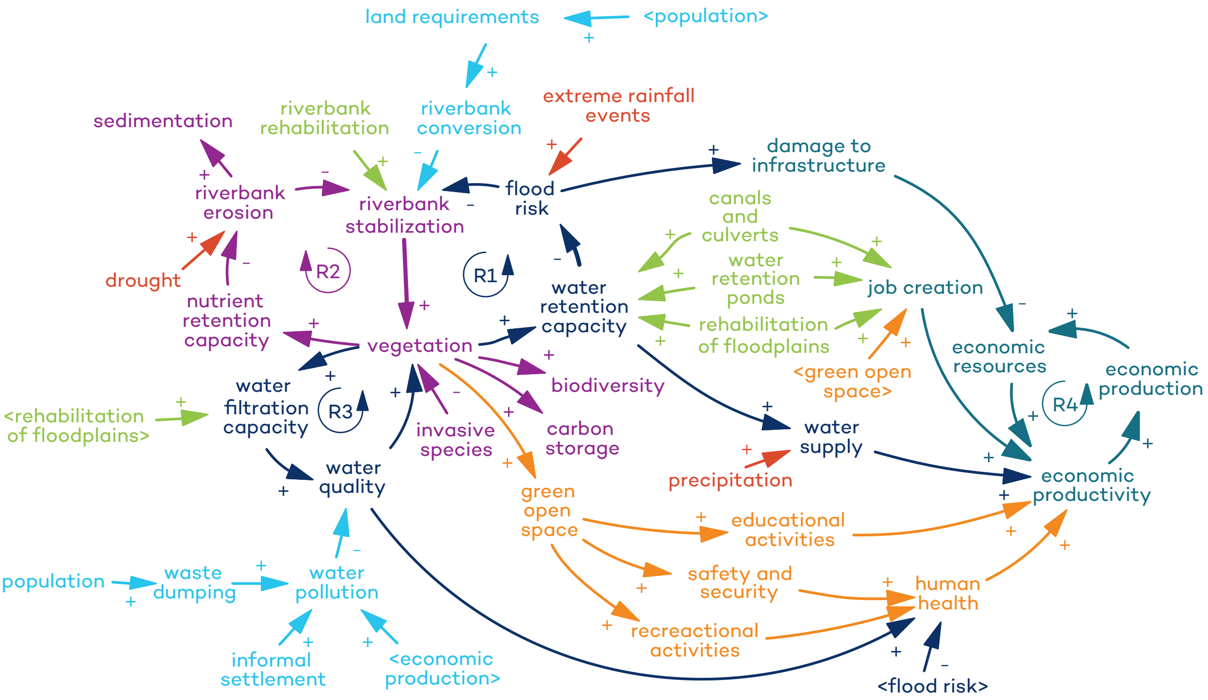
One effective way to apply systems thinking is by summarizing the different components and their interactions through a process known as systems mapping. Systems mapping is a collaborative and analytical method used to visualize and understand the elements and interconnections within a complex system. This approach serves various purposes, such as analyzing how a system functions and identifying potential interventions to improve its performance (Barbrook-Johnson & Penn, 2022).

For this SAVi assessment in Drakenstein, we created a systems map by examining the key variables within the system, their cause-and-effect relationships, and the feedback loops that drive its observed behaviour. This type of mapping is represented through causal loop diagrams (CLDs), illustrated in Figure 3. The CLD for this assessment was developed through an iterative co-creation process involving consultations with Drakenstein Municipality to capture the region-specific dynamics. As previously mentioned, the SAVi methodology aims to provide decision-makers with both qualitative and quantitative evidence. The knowledge described here serves as the foundation for the quantitative analysis that follows. In particular, the elements and relationships highlighted through the CLD are closely aligned with the indicators quantified in the integrated CBA. To enhance understanding of the CLD, we recommend referring to the colour coding in the diagram as you follow the narrative.

Box 1. Reading a CLD

A CLD is a tool that supports systems thinking. It shows relationships between the components of a system. Arrows indicate causality, and plus and minus signs are used to show the direction of causality. A plus sign means that two variables change in the same direction (a positive correlation), while a negative sign means that they change in opposite directions (a negative correlation). Feedback loops are labelled as either reinforcing (R) or balancing (B). A reinforcing loop indicates that a change in one variable will lead to further change in the same direction, whereas a balancing loop dampens change.

Figure 3. CLD of catchment issues



Legend:

■ Dynamics surrounding water
■ Dynamics surrounding climate
■ Dynamics surrounding economy
■ Dynamics surrounding human impact
■ Dynamics surrounding social dimensions
■ Dynamics surrounding nutrients
■ Dynamics surrounding interventions

Source: Authors.

Overall Dynamics. The Berg River catchment's health and resilience are shaped by complex and interconnected environmental, social, and economic dynamics. Climate events like floods and droughts destabilize riverbanks, leading to vegetation loss and infrastructure damage while also disrupting water and nutrient cycles. Human activities exacerbate these issues through water pollution from waste and riverbank conversion for housing and agriculture, further degrading water quality and soil structure. Water dynamics involve a reinforcing loop where vegetation loss reduces water retention, increasing flood risks, while improved vegetation enhances water filtration and quality. Nutrient dynamics follow a similar pattern, where erosion diminishes soil quality and vegetation, but maintaining vegetation can create a positive feedback loop for nutrient retention. Socially, vegetation improves water quality and community health, while green spaces offer recreational, educational, and research opportunities, contributing to well-being and economic activities like agriculture. Floods, however, can devastate infrastructure and human health, highlighting the need for effective river management. Economically, flood risks threaten infrastructure and productivity, but NBI investments like riverbank stabilization and vegetation growth can mitigate these risks and boost local economies. NBI projects enhance ecosystem services, provide job opportunities, and support sustainable development, linking environmental health to economic and social resilience.

Dynamics surrounding climate. Floods and droughts significantly impact the ecosystem that regulates the water cycle. Floods, caused by extreme rainfall events, destabilize riverbanks and reduce vegetation cover. This destabilization leads to damage to infrastructure, such as housing and economic assets. Droughts exacerbate riverbank erosion, also weakening the banks and leading to losses in soil and vegetation. This, in turn, disrupts the natural water and nutrient cycles.

Dynamics surrounding human impact. Human activities have two negative impacts on the ecosystem: water pollution and riverbank conversion. Indeed, on one hand, population growth and informal settlements add waste into the river, directly impacting water quality through solid and liquid pollution. On the other hand, an increase in population leads to an increase in land requirements (e.g., housing, agriculture). This demand for land is often met by converting riverbanks to artificial land, resulting in soil structure disruption.

Dynamics surrounding water. Water dynamics are crucial for the health of the catchment. The reinforcing loop R1 highlights how flood risk can destabilize riverbanks. If vegetation is reduced, we observe a loss in water retention capacity as a small quantity of water infiltrates the soil. This leads to higher surface runoff, which increases flood risk. Extreme rainfall events intensify this vicious cycle by increasing initial flood risks. Conversely, if vegetation increases—due to the implementation of NBI—then soil quality will increase and more water will be absorbed. This leads to a decrease in flood risk and associated damages. Besides the water retention capacities of vegetation, the reinforcing loop R3 shows how vegetation enhances water filtration, improving water quality. Better water quality supports further vegetation growth, creating a positive feedback loop. In contrast, human impacts degrade water quality, limiting vegetation growth and the services it provides. Effective waste management and stabilization efforts are essential to maintain these water dynamics and improve overall ecosystem health.

Dynamics surrounding nutrients. Like the dynamics surrounding water, the nutrient dynamic is influenced by a reinforcing loop (R2), where riverbank erosion reduces stabilization, decreasing soil quality and affecting vegetation growth. Vegetation is crucial for nutrient retention in the soil, which in turn helps stabilize riverbanks and reduce erosion. Droughts intensify riverbank erosion by weakening the soil structure and reducing vegetation cover, leading to poorer soil quality. This vicious cycle can be reversed into a virtuous cycle in which the maintenance of vegetation allows the retention of nutrients in the soil, which supports healthier ecosystems and reduces the rate of erosion over time.

Dynamics surrounding social dimensions. As described, vegetation impacts water quality, which directly affects human health. Improved water quality reduces waterborne diseases, enhancing community health. Moreover, green open spaces, supported by vegetation, provide recreational areas that contribute to physical and mental well-being. These spaces also offer opportunities for research and educational activities, enriching community knowledge and engagement. Increased water retention capacity ensures a stable water supply, benefiting economic activities, particularly downstream agriculture. Floods, however, can damage infrastructure such as housing and have devastating impacts on human health, including injuries and displacement. This dynamic highlights the importance of ensuring safe and stable living conditions through effective river management for community resilience.

Dynamics surrounding the economy. Economic dynamics are closely linked to environmental health and infrastructure stability. Flood risks lead to infrastructure damage, decreasing economic capital and productivity. However, investing in NBI, like riverbank stabilization and vegetation growth, can mitigate these risks. Improved water quality and retention capacity enhance human health and economic productivity, particularly in agriculture. Green open spaces and NBI projects can create job opportunities through construction and maintenance, contributing to local economies.

Dynamics surrounding interventions. The integration of NBI into riverine management strategies offers a promising avenue for enhancing resilience and sustainability within the Berg River catchment. Vegetation emerges as a central element of NBI, with its role extending from flood risk mitigation to water quality improvement and carbon sequestration. NBI interventions, such as riverbank rehabilitation and water retention ponds, enhance ecosystem services while promoting community well-being and economic development. Furthermore, NBI projects present opportunities for job creation and skills development, contributing to local empowerment and resilience-building efforts.

2.3 Climate Data Analysis

Nature is now recognized as essential for climate adaptation (Intergovernmental Panel on Climate Change, 2023; Key et al., 2022; Turner et al., 2022; United Nations, 2022), particularly for mitigating flood risks in urban areas (Kabisch et al., 2017; van Zanten et al., 2023). To ensure the effectiveness of these interventions, it is crucial to analyze climate data, which provides insights into future patterns of extreme events. With the systemic understanding depicted in the previous section and illustrated through the CLD, it becomes clear that climate can induce shocks (e.g., extreme rainfall events) and impact the ecosystem's bio-physical conditions in the long term (e.g., average precipitation). To effectively manage and adapt to these challenges, it is crucial to analyze how key climate indicators are expected to evolve over time.

In areas like Drakenstein, understanding the projected trends for extreme wet and dry periods, along with shifts in temperature and precipitation, allows for the strategic design and implementation of NBI projects. This data-driven approach ensures that NBI interventions are tailored to address the specific climate risks faced by communities, enhancing resilience against future climate impacts.

In this analysis, three Shared Socioeconomic Pathways (SSPs), as defined by the Intergovernmental Panel on Climate Change (Calvin et al., 2023; Hunter & O'Neill, 2014), are examined to explore potential climate futures:

- **SSP1 (Sustainability – Taking the Green Road):** This scenario represents a world that moves toward more sustainable development. It assumes significant investments in education, health, and green technologies, resulting in lower greenhouse gas emissions and more effective climate mitigation. SSP1 envisions a future where global cooperation leads to slower population growth, reduced inequality, and lower overall climate risks.
- **SSP3 (Regional Rivalry – A Rocky Road):** SSP3 depicts a fragmented world marked by regional competition, high population growth, and slow economic development. In this scenario, countries focus on self-sufficiency and national interests, leading to minimal cooperation on climate action. Fossil fuel dependency remains high, which drives up emissions and results in greater exposure to extreme climate events, including more frequent and intense droughts and floods.
- **SSP5 (Fossil-Fuelled Development – Taking the Highway):** This scenario envisions rapid economic growth driven by a reliance on fossil fuels and technological advances. Although it results in high economic development, the environmental costs are significant, with high emissions and increased global warming. SSP5 assumes a future where climate impacts are severe, with more frequent extreme weather events posing serious challenges for flood risk management and climate adaptation.

Each SSP presents a distinct trajectory that affects how climate risks, such as extreme wet and dry events, may unfold in Drakenstein, guiding the evaluation of future adaptation strategies. While these global scenarios offer valuable insights, it is crucial to recognize that regional impacts can vary significantly. Local factors, such as geography, socio-economic conditions, and environmental characteristics, can modify the way these broad trends are experienced. As a result, while the SSPs provide a useful framework for understanding possible futures, localized climate analysis is vital to capture the unique challenges and risks faced by Drakenstein. With this context in mind, the following sections explore four key climate indicators: extreme dry events, extreme wet events, average temperature, and average monthly precipitation. The data for these indicators comes from the European Union (EU) Copernicus database (EU, n.d.).[3]

Extreme Dry Events. As illustrated in Figure 4, by mid-century, the Standard Precipitation Index (SPI) increases in all three scenarios. The second half of the century sees its SSP 1 and SSP 5 projections decrease while SSP 3 experiences a higher occurrence of extreme dry events by the end of the century. This trend underscores the escalating threat of droughts in Drakenstein, which can destabilize riverbanks, leading to soil erosion and vegetation loss that disrupt essential water and nutrient cycles. Diminished vegetation cover reduces the land's water retention capacity, resulting in increased surface runoff and heightened flood risks. This echoes the vicious cycle described through the system map, where droughts intensify erosion and increase flooding risks, threatening community health and safety.

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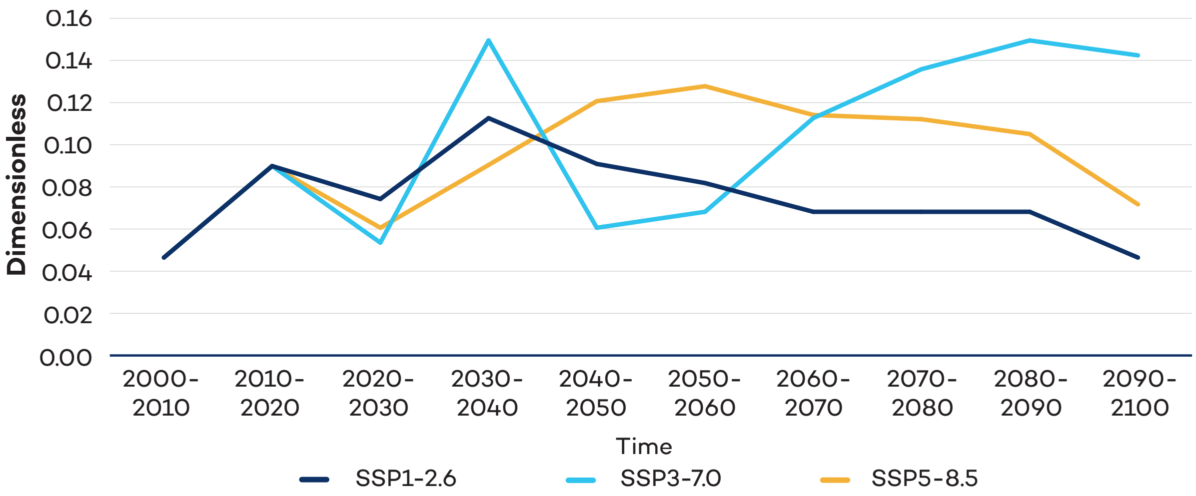
[3] Available at https://www.copernicus.eu/en

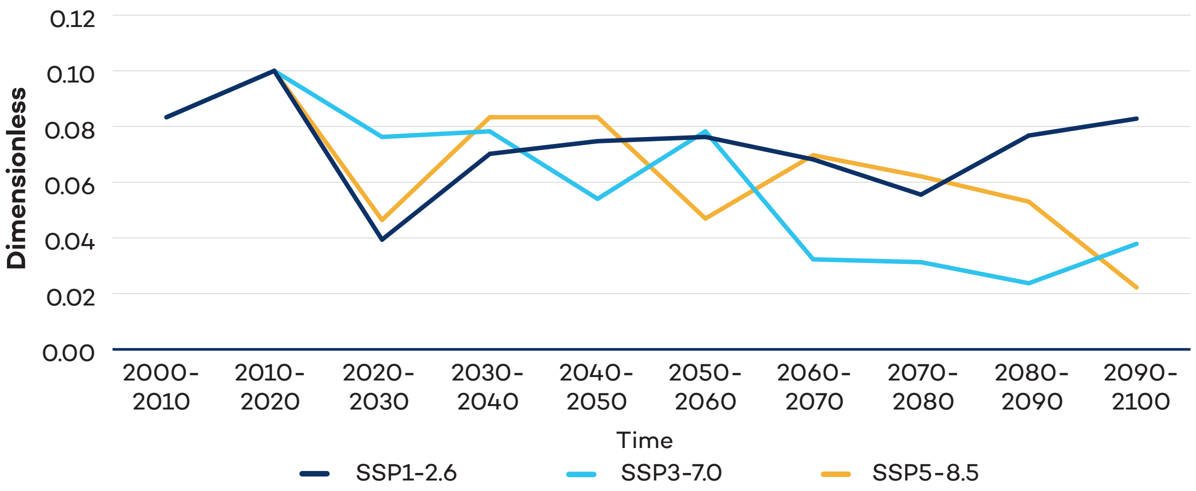
Figure 4. SPI: Extreme dry



Source: EU, n.d.

Extreme Wet Events. As illustrated in Figure 5, extreme wet events are projected to decline across SSPs, especially when looking at the end-of-century dynamics. However, during the first half of the century, this decline is less pronounced, suggesting that communities may still face significant wet weather events in the near term. This trend warrants careful interpretation, as the interplay between increasing extreme dry events and the reduction of wet events can exacerbate soil vulnerability. A weakened soil structure, resulting from prolonged drought conditions, may struggle to absorb heavy rainfall when it occurs, increasing the risk of surface runoff and flooding. Such dynamics echo the system map's depiction of interconnected vulnerabilities within the Berg River catchment, where the increased incidence of severe dry spells can ultimately heighten the risks associated with extreme wet events. Thus, while the frequency of these wet events may decline, the potential for severe consequences remains, underscoring the need for proactive river management strategies that enhance the resilience of both the soil and surrounding communities.

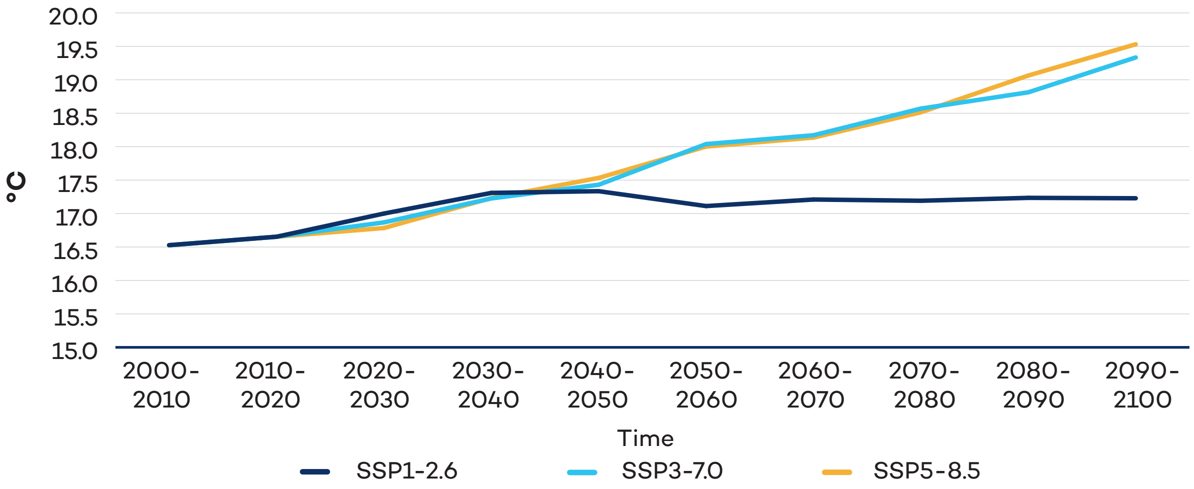
Figure 5. SPI: Extreme wet



Source: EU, n.d.

Average Temperature. As illustrated in Figure 6, average temperatures in Drakenstein are projected to rise across all SSPs, with a particularly pronounced increase observed in SSPs 3 and 5. Under these scenarios, projections suggest that Drakenstein could experience an alarming rise of up to 3°C by the end of the century compared to the beginning of the century. This increase in average temperature poses significant challenges for the region, as elevated temperatures can exacerbate water stress and diminish the resilience of local ecosystems. Higher temperatures can lead to increased evaporation rates, reducing water availability for both agricultural and domestic needs. Furthermore, as highlighted in the system map, warmer conditions may weaken vegetation cover, further destabilizing riverbanks and increasing vulnerability to both erosion and flooding. This interplay underscores the importance of enhancing soil moisture retention and promoting biodiversity.

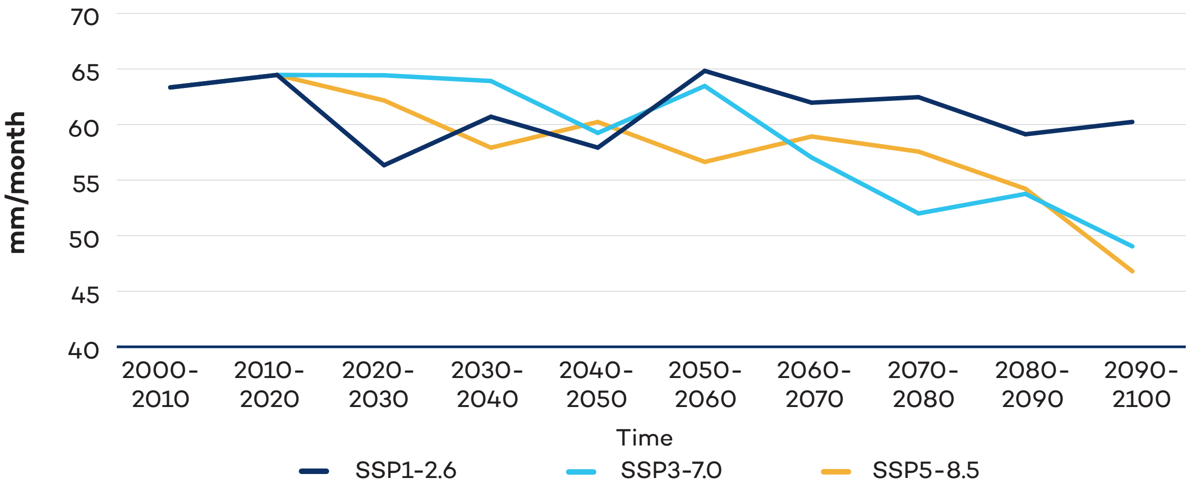
Figure 6. Average temperature



Source: EU, n.d.

Average Monthly Precipitation. As illustrated in Figure 7, average monthly precipitation is expected to decrease across SSPs, with SSPs 3 and 5 experiencing a notably more significant decline. Specifically, monthly precipitation is expected to drop from nearly 65 mm at the beginning of the century to below 50 mm by the century's end under these scenarios, while SSP 1 shows a more moderate decrease, tapering off to around 60 mm per month. This reduction in precipitation poses serious implications for water availability and ecosystem health in the region. Diminished rainfall can lead to increased water stress, adversely affecting agricultural productivity and community resilience. Furthermore, just like for average temperature, reduced precipitation exacerbates soil degradation and diminishes vegetation cover, which can destabilize riverbanks and disrupt essential water and nutrient cycles. Consequently, addressing these shifts in precipitation is critical for the sustainable management of water resources and the implementation of NBI strategies that can help buffer the effects of climate variability and enhance ecosystem resilience.

Figure 7. Average monthly precipitation



Source: EU, n.d.

To analyze potential flood damages in Drakenstein, we adopted a scenario-based approach in the integrated CBA that accounts for the inherent uncertainties surrounding the frequency and intensity of future flood events, as well as the vulnerability and exposure of the affected communities. Recognizing that climate projections indicate varying trends in extreme weather patterns, we developed a range of scenarios that combine high-frequency, low-intensity flood events with low-frequency, high-intensity occurrences. This dual approach, which can be understood as sensitivity analysis, allows us to capture the complexities of flood risk and its impacts on the region's infrastructure and ecosystems. By exploring how key metrics—such as BCR, net present value, and IRR—evolve under these different scenarios, we gain deeper insights into the potential economic implications of flood risks. This analysis not only highlights the importance of adaptive planning in the face of climate uncertainty but also informs decision-makers about the trade-offs and opportunities associated with various investment strategies in NBI and flood resilience measures. More of these aspects will be discussed in Section 2.5.

2.4 Spatial Analysis

The spatial analysis aims to assess how the NBI performs in the local context by leveraging geographic information system (GIS) data and spatially explicit models. These tools, such as the Integrated Valuation of Environmental Services and Tradeoffs (InVEST[4]) model, allow us to quantify, map, and value the ecosystem services provided by natural systems, which include regulating, provisioning, cultural, and supporting services. The spatial models help identify where these services are generated and how they would shift under various land-use scenarios. This spatial information is essential for determining the value of NBI interventions across different scales, from individual urban areas to entire landscapes, and provides critical input for the integrated CBA.

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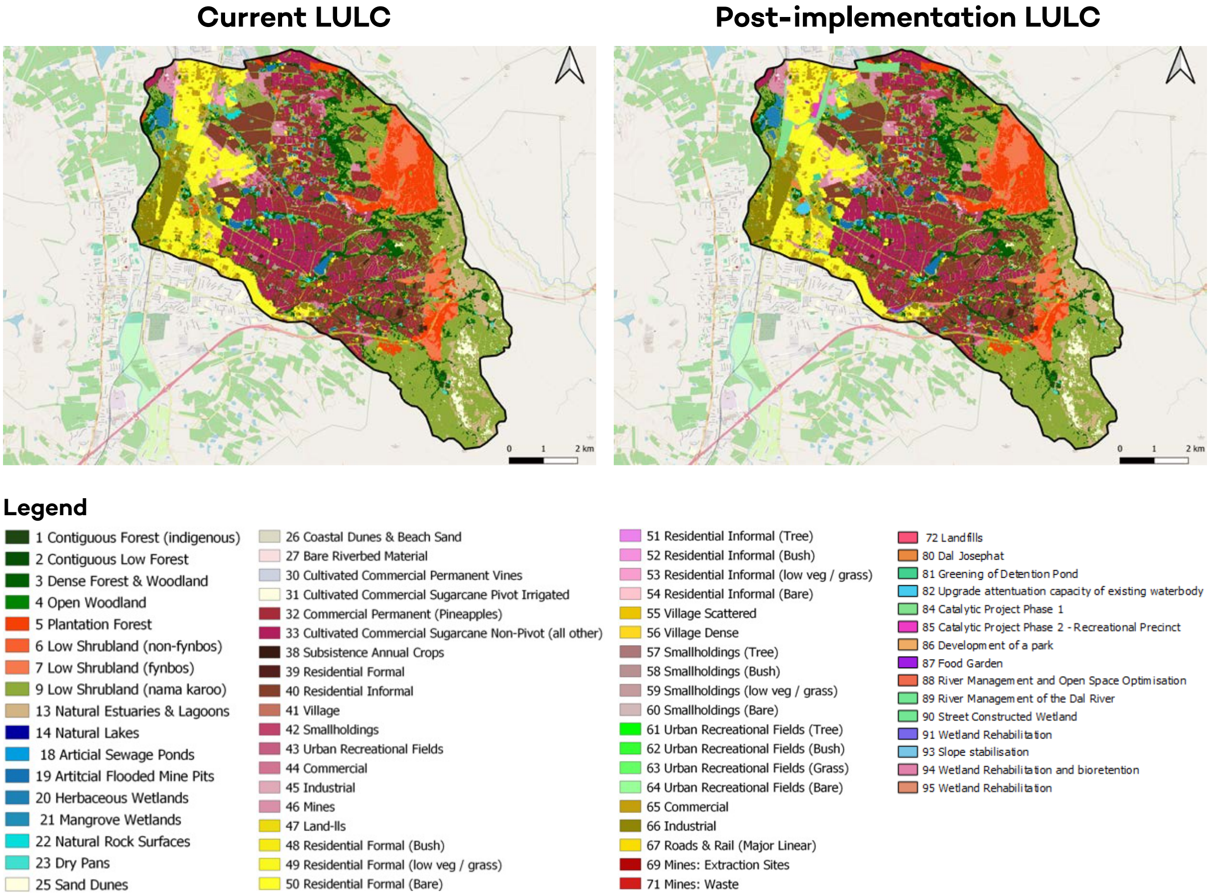
[4] Available at https://naturalcapitalproject.stanford.edu/software/invest.

For the spatial analysis of Drakenstein, we utilized two land-use/land-cover (LULC) maps provided by the municipality, representing the current LULC and the projected LULC post-implementation of the NBI, as illustrated in Figure 8. These maps, with a resolution of 25 metres (m), provide detailed classifications of the land within the catchment, including industrial, residential, wetland, and agricultural areas. Using this granular data, we applied Stanford University's InVEST model to assess how changes in land use will affect the ecosystem's ability to deliver key services. Specifically, we analyzed the impacts on water runoff, carbon storage, heat index, and habitat quality, providing a comprehensive understanding of how NBI interventions can influence ecosystem service provision across the landscape (see Appendix A for additional maps).

Figure 8. Spatial LULC maps

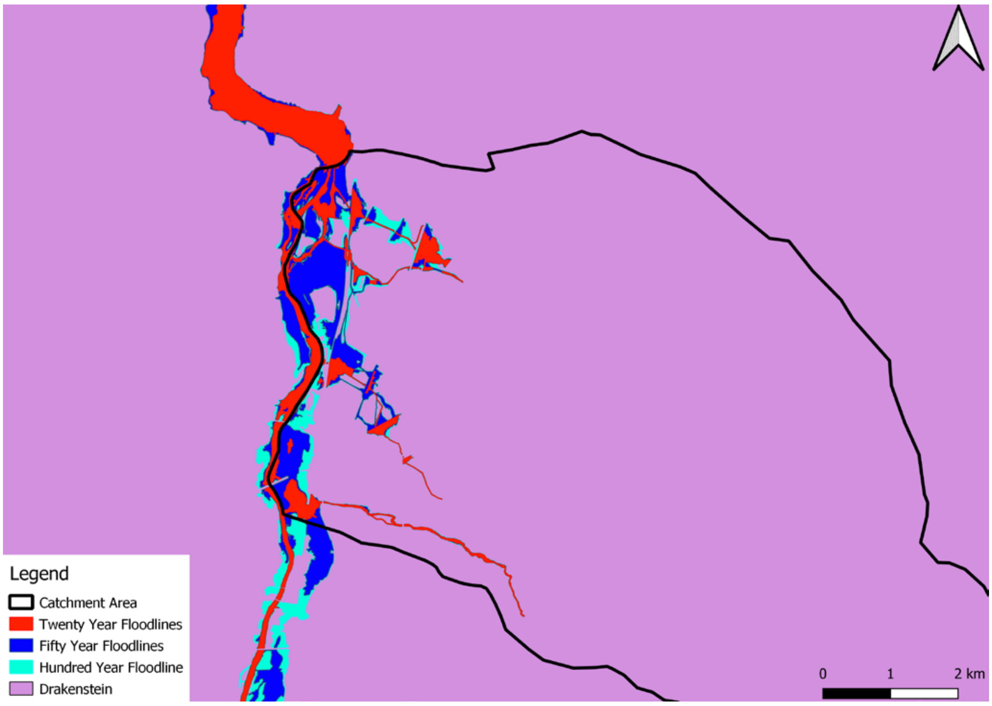

Current LULC

Post-implementation LULC

Source: Drakenstein Municipality (reprinted with permission).

The Drakenstein Municipality also provided flood lines estimating the areas affected by 1:20, 1:50, and 1:100 flood events, as shown in Figure 9. This map delineates the geographic extent of each flood scenario, enabling us to assess the specific locations and land areas at risk.

Figure 9. Spatial map of flood lines



Source: Authors.

By overlaying this flood line map with the LULC maps and road maps from Geofabrik,[5] we can estimate the types of infrastructure likely to be impacted by each flood event. This approach allows us to calculate the number of hectares affected within different land-use categories, such as industrial zones, residential areas, and agricultural lands, for each flood intensity. The results of this analysis are illustrated in Figure 10. The analysis reveals that as the severity of the flood event increases, the extent of impacted infrastructure and land grows substantially.

For example, formal settlements experience a dramatic increase in the area at risk of flooding, rising from 8.6 ha under the 20-year flood line to 51.3 ha under the 100-year flood line, posing significant risks to housing and community safety. Similarly, informal settlements face a growing threat, with 9.7 ha at risk under the 20-year flood line, increasing to 22.9 ha in a 100-year event, further exacerbating vulnerability in these already precarious communities. The industrial sector is particularly exposed, with the area impacted surging from 27.5 ha under the 20-year flood line to a significant 140.6 ha under the 100-year flood line. This not only highlights the economic risks posed by flooding but also underscores the potential for widespread disruption to production and employment. Agricultural areas show more moderate increases, from 6.4 ha under the 20-year flood line to 23 ha under the 100-year flood line, which may still lead to crop losses and impact local food security. Additionally, road networks face considerable exposure, with 19.4 km affected by a 20-year event and up to 52.8 km by a 100-year event, potentially disrupting transport and access across the region. In total, the area inundated grows from 135.8 ha in a 20-year event to 585.8 ha in a 100-year event, illustrating the scale of flooding risk across the area under study and the pressing need for effective flood management strategies. Note that Table A1 in Appendix 1 gives a complete disaggregation of the land-use area inundated.

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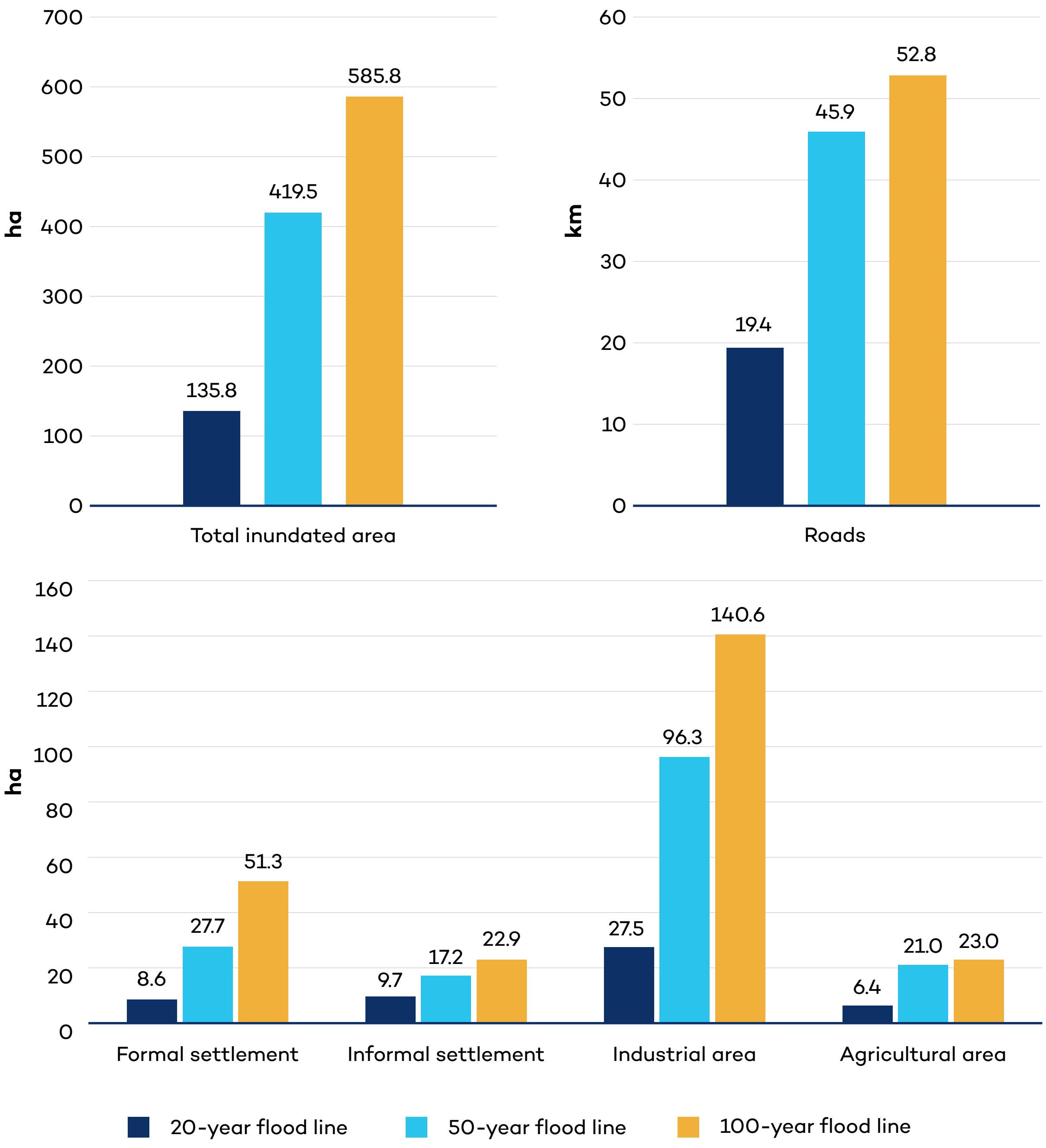
[5] Available at https://download.geofabrik.de/.

Figure 10. Area at risk of flooding across flood lines



Source: Authors.

Continuing from the flood risk analysis, the LULC maps also facilitated an assessment of ecosystem services generated by the proposed NBI interventions. By using spatially explicit models at the sub-catchment level, we were able to quantify the changes in four key services: carbon storage, water runoff retention, temperature regulation, and habitat quality, as illustrated in Table 1.

Table 1. Change in ecosystem services

LULC scenario	Units	Current LULC	Future LULC	Absolute net change	Relative net change
Carbon storage	tC	689,706	737,088	47,382	+6.87%
Water runoff retention	m^3	4,084,512	4,191,673	107,161	+2.62%
Temperature	°C	31.81	31.78	-0.04	-0.11%
Habitat quality	index	0.150	0.155	0.005	+3.40%

Source: Authors.

The benefits of these services are not evenly distributed across the landscape. For instance, while carbon storage shows a modest overall increase of 6.87%, this change is spread across the entire catchment, with some areas benefiting more than others, depending on land-use changes and vegetation types. Water runoff retention, critical for flood mitigation, displays a 2.62% improvement overall, but when we focus on flood-prone areas, the impact is more pronounced. By concentrating on these high-risk zones, where the interventions have been strategically placed, we estimate a 35% reduction in potential flood damage. Temperature regulation through urban cooling exhibits a small overall change of -0.11%, but, again, this effect is concentrated in densely populated areas, where even slight reductions in temperature can provide significant relief from heat stress. Similarly, habitat quality improvements are distributed unevenly, with localized interventions boosting the index by 3.4%, but the most substantial benefits are seen in targeted areas where ecological restoration efforts have been prioritized. This spatial analysis highlights how ecosystem services vary across the sub-catchment, demonstrating that the success of NBI interventions depends heavily on where they are implemented and how they address localized challenges, as illustrated in Figure A1 to Figure A6 in Appendix A.

2.5 Integrated CBA

The following section presents an integrated CBA aimed at evaluating the economic viability of different interventions within the sub-catchments under various flood scenarios. This analysis is divided into three key subsections.

- First, the methodology subsection outlines the approach and key assumptions used to assess the costs and benefits, providing a clear understanding of how the results were derived.
- Second, the indicator subsection goes through the definition of all indicators present in the CBA. This allows the reader to better grasp the true meaning of the elements quantified.
- Finally, the CBA results subsection presents the monetized outcomes, comparing the costs and benefits across the different flood projections. Through this analysis, we aim to provide insights into the long-term economic implications of adopting NBI strategies versus maintaining the status quo.

2.5.1 Methodology

The integrated CBA was developed using an Excel-based model and was structured as an input-output framework. This model is driven by static input parameters that define the time development of each indicator over the analysis period. For each scenario (Baseline and NBI), the model computes absolute values for individual indicators. For example, it calculates the cost of flood damage under both scenarios. Following this, the model measures the difference between the two scenarios, quantifying the net change caused by interventions. This approach allows for capturing the direct benefits of interventions, such as the avoided costs of flood damages. The outputs of this process include aggregated indicators like total costs, total benefits, net benefits, BCR, and IRR. All results are discounted to their present value, enabling a clear comparison of future costs and benefits.

The time horizon for the analysis extends from 2025 to 2050. A discount rate of 8% was selected to ensure consistency with other economic assessments in the region. To account for uncertainties in future economic conditions, a sensitivity analysis was conducted by testing the discount rate across a range from 6% to 10%. This sensitivity analysis helps to gauge how robust the CBA results are to changes in economic assumptions and informs decision making on the viability of the proposed interventions.

Given the absence of location-specific studies, the analysis relies on secondary data sourced from a literature review and carefully reasoned assumptions. The data gathered from existing studies, which may be global or regional in scope, is adjusted to fit the context of the Drakenstein catchment. Where relevant data gaps exist, assumptions are made based on similar ecosystems or regions, allowing for a more tailored analysis of the local context. All data sources, assumptions, and adjustments used in the analysis are documented in Appendix B, ensuring full transparency and allowing for potential recalibration as more location-specific information becomes available in future studies. This approach balances the limitations of available data with the need for a robust and credible assessment of the benefits and costs associated with NBI interventions.

While climate data from the SSPs has already been discussed in Section 2.3, it is important to note that this data was not integrated into the CBA model. In place, we decided to evaluate the range of potential flood-related impacts by analyzing a range of different possible futures. Given the inherent uncertainty in predicting extreme weather events, this approach allows for a clear understanding of the range of possible infrastructure damage, disaster relief costs, and productivity losses. This helps to capture the possible outcomes of extreme events, ensuring that the results are reflective of frequent but low-intensity events and the potential for unexpected shocks of high-intensity events.

2.5.2 Indicators

To evaluate the costs and benefits of the Baseline and NBI scenarios, a range of indicators were identified through the system mapping process to capture the direct and indirect impacts of the interventions. These indicators provide a comprehensive picture of the economic, social, and environmental implications of the scenarios. Each indicator measures a specific aspect of the catchment's ecosystem and infrastructure performance, allowing for a nuanced understanding of the interventions' effects. Below is a brief definition of each indicator used in the CBA.

Table 2. List and definitions of CBA indicators

Direct costs	
Implementation costs (capital expenditures [CapEx])	The initial costs associated with carrying out the NBI interventions, including construction, labour, materials, and other one-time expenditures.
Maintenance costs (operating expenses [OpEx])	Ongoing costs required to keep the NBI interventions functional over time, such as upkeep of rehabilitated wetlands, litter traps, and other infrastructure. For the baseline, this indicator includes the current maintenance costs.
Avoided costs/loss	
Avoided cost of flood damages – formal settlement	Savings resulting from reduced damages to residential buildings and infrastructure in formal settlements due to flood mitigation measures provided by NBI interventions.
Avoided cost of flood damages – informal settlement	The reduction in losses incurred by informal settlements, where housing and infrastructure may be more vulnerable to flooding, due to flood risk reduction from NBI interventions.
Avoided cost of flood damages – industry	Savings associated with the reduction in repair costs for industrial infrastructure and capital assets, preventing expensive reconstruction or refurbishment efforts after flood events.
Avoided cost of flood damages – agriculture	Benefits from reducing the repair and restoration costs of agricultural land damaged by flooding, ensuring the land remains viable for future cultivation without incurring heavy rehabilitation expenses.
Avoided cost of flood damages – roads	Savings associated with the prevention of damage to road infrastructure, reducing repair costs, and maintaining transportation networks critical for economic and social activity.
Avoided cost of flood damages – utilities	The reduction in costs associated with repairing or replacing damaged utilities, such as water, electricity, and communication infrastructure, due to flood mitigation efforts.
Avoided cost of flood damages – educational areas	Savings from preventing damages to educational facilities and resources, ensuring minimal disruption to education services during flood events.
Avoided cost of disaster relief	Savings generated by reducing the need for emergency services and post-disaster recovery efforts through proactive flood risk management.
Avoided cost of mental health impacts	The reduction in health care costs associated with mental health conditions that may arise from disasters such as floods, given the stabilizing effect of NBI on reducing extreme events.
Avoided cost of human death	The value assigned to avoiding fatalities caused by flooding or other extreme events. This indicator was ultimately excluded from the monetary valuation.

Avoided cost of dredging	Savings from reduced sediment buildup in waterways, as the NBI interventions limit sedimentation through ecological restoration efforts.
Avoided loss of agricultural production	The value preserved by reducing flood-related disruptions to agricultural operations, ensuring sustained crop production and limiting losses in farm outputs and income.
Added benefits	
Value of employment creation	The economic value of new jobs generated through the implementation, maintenance, and long-term management of NBI projects. This latter is computed based on discretionary spending from labour benefits.
Value of food provisioning	Benefits generated from food gardens established in communities, which enhance food security and provide local agricultural value.
Value of recreational area	The value of creating new public access to parks, pathways, and other recreational spaces, which contributes to community well-being and physical health.
Value of urban cooling	The reduction in energy costs and improvement in public health resulting from lower urban temperatures, achieved through increased green spaces and tree planting. Due to data gaps, we did not include this indicator in the CBA.
Value of fish nurseries	Benefits from preserving fish nurseries and biodiversity within the catchments, as healthy ecosystems contribute to the sustainability of downstream fisheries.
Value of biodiversity conservation	The value of maintaining ecosystem diversity, which is integral to sustaining long-term ecological resilience and ecosystem services.
Value of carbon sequestration	The social cost value assigned to carbon dioxide captured and stored by restored ecosystems, contributing to climate change mitigation.
Value of tourist activities	The benefits of increasing tourism activity through the creation of green open spaces and recreational areas.
Value of tourism tax revenue	The retained government revenue from tourism-related taxes, which might increase through a higher frequency of tourists, given the newly created spaces.
Value of property premium tax revenue	The municipal revenue from property taxes, specifically property premiums associated with open space proximity, which are created and generate aesthetic value.

Source: Authors.

2.5.3 Results

This sub-section presents the results of the integrated CBA by first assessing all indicators across four flood scenarios, each representing varying levels of flood intensity and frequency. After this initial detailed analysis, we will examine the distribution of benefits to highlight which categories contribute the most to the overall value. Following this, the focus shifts to flood damage specifically, comparing outcomes from both the Baseline and NBI perspectives. The next part of the analysis explores how key metrics fluctuate across different flood scenarios in a sensitivity analysis using colour-coded tables that resemble heat maps. This will help identify when a breaking point occurs between costs and benefits. All results are presented as cumulative values over the 2025–2050 time horizon, with monetary values discounted at 8%, as outlined in the Methodology section. Finally, the sub-section concludes by analyzing the potential gains for the industrial sector, focusing solely on the flood attenuation benefits relevant to them, offering insights into the potential for industry participation in financing the NBI project.

2.5.3.1 FULL CBA RESULTS ACROSS FOUR SCENARIOS

The integrated CBA of the NBI project, illustrated in Table 3, provides a detailed comparison of the project's economic and societal impacts under varying climate scenarios. The analysis considers four distinct climate scenarios:

- Climate Scenario 1: Represents frequent but less severe flooding, with a flood intensity of 1:10, meaning that such floods have a 10% chance of occurring in any given year. In this case, flooding occurs once every 2 years, making it a scenario that simulates frequent, low-intensity flood events.
- Climate Scenario 2: Flood intensity is more severe at 1:20, meaning there is a 5% chance of this flood occurring each year. The floods are less frequent, with one flood event expected every 8 years, but they are strong enough to cause moderate impacts.
- Climate Scenario 3: Involves a 1:30 intensity flood, with a 3.33% annual probability. Such events happen every 5 years and bring higher floodwater, posing a more substantial threat to assets and ecosystems compared to previous scenarios, although less frequent.
- Climate Scenario 4: With a 1:50 flood intensity, it represents relatively frequent and extremely damaging events, occurring approximately once every 3 years. Floods of this magnitude can cause widespread damage to infrastructure, agriculture, and communities.

The primary costs of the project are divided into two categories: CapEx and OpEx. The implementation costs (CapEx) remain constant across all scenarios at ZAR 99.9 million, reflecting the upfront investment needed for the construction and establishment of nature-based infrastructure. Likewise, the maintenance costs (OpEx) are fixed at ZAR 51.2 million across all scenarios, representing the ongoing expenses required to ensure the infrastructure remains functional over time.

The key benefits of the NBI project stem from its ability to avoid significant flood-related costs and deliver additional ecosystem services. These benefits increase as the frequency and intensity of floods rise, making the project more valuable under severe climate conditions. The avoided costs, which represent savings from reduced flood damage, are distributed across multiple sectors, including formal and informal settlements, industry, agriculture, roads, and utilities. For example, the avoided cost of damage to roads alone ranges from ZAR 23.9 million in a mild scenario to ZAR 95.3 million in the most extreme scenario. Similarly, avoiding disaster relief costs and mental health impacts also becomes more pronounced in severe flooding conditions, with the avoided costs of mental health impacts rising from ZAR 12.4 million to ZAR 24.4 million. These figures underline the critical role of NBI in reducing the socio-economic impacts of floods across the municipality.

Beyond avoided costs, the NBI project generates additional benefits related to ecosystem services and benefits for local communities. These include the creation of employment opportunities (valued at ZAR 30.3 million), food provisioning (ZAR 2.6 million), and recreational areas (ZAR 47.8 million). Furthermore, the project delivers significant long-term value through urban cooling, biodiversity conservation, carbon sequestration, and support for tourism activities. Though some of these values are not quantified, they represent important socio-economic and environmental contributions that bolster the project's overall impact.

Key metrics, such as the net benefits, demonstrate the economic viability of the NBI project. The net benefits, which measure the difference between the total benefits and costs over the project's lifespan, vary significantly across the climate scenarios. In less severe scenarios, the net benefits are negative (-ZAR 3.8 million), suggesting that the project may not deliver sufficient returns under milder flood conditions. However, as flood risks increase, the net benefits rise sharply to ZAR 597.3 million in the most extreme scenario, highlighting the substantial long-term gains.

The project's benefits outweigh its costs, especially in scenarios with severe floods. The BCR increases from 0.98 in the mildest scenario to 4.95 in the most severe flood scenario. A BCR above 1 indicates that the benefits outweigh the costs, making the project economically justifiable. Under higher flood frequencies, the BCR reflects the project's growing value in reducing flood risks and generating additional benefits. The IRR, which indicates the project's expected rate of return, also rises dramatically from 7.5% to 53.6% as flood intensity increases. This high IRR under severe conditions makes the NBI project a particularly attractive investment in areas facing high climate risk.

Overall, this first set of results shows that the NBI project in Drakenstein offers significant value, especially under more extreme climate scenarios where flood risks are higher. While the initial and ongoing costs remain fixed across all scenarios, the avoided flood-related damages and added ecosystem benefits grow substantially with increasing flood frequency and intensity. Financial metrics such as net benefits, BCR, and IRR indicate that the project becomes more economically viable and socially beneficial as climate risks escalate, making a strong case for investing in NBI to mitigate flood risks and support long-term sustainability in the region.

Table 3. Integrated CBA across climate scenarios discounted at 8%

	Climate Scenario 1	Climate Scenario 2	Climate Scenario 3	Climate Scenario 4
Flood intensity/size (1 in X event type)	1:10	1:20	1:30	1:50
Flood frequency (flood of intensity X every Y year)	2	8	5	3
Direct costs (ZAR million)				
Implementation costs (CapEx)	99.9	99.9	99.9	99.9
Maintenance costs (OpEx)	51.2	51.2	51.2	51.2
Avoided costs/loss (ZAR million)				
Avoided cost of flood damages – formal settlement	0.9	1.4	4.2	12.1
Avoided cost of flood damages – informal settlement	20.4	7.7	16.7	36.1
Avoided cost of flood damages – industry	-	49.2	160.9	453.6
Avoided cost of flood damages – agriculture	1.6	5.8	14.9	34.1
Avoided cost of flood damages – roads	23.9	19.0	44.4	95.3
Avoided cost of disaster relief	4.2	1.7	3.7	8.3
Avoided cost of mental health impact	12.4	4.9	10.9	24.4
Avoided loss of agricultural production	0.0	0.1	0.3	0.6
Added benefits (ZAR million)				
Value of employment creation	30.3	30.3	30.3	30.3
Value of food provisioning	2.6	2.6	2.6	2.6
Value of recreational areas	47.8	47.8	47.8	47.8
Value of biodiversity conservation	0.2	0.2	0.2	0.2
Value of carbon sequestration	1.0	1.0	1.0	1.0
Value of property tax revenue	1.9	1.9	1.9	1.9

	Climate Scenario 1	Climate Scenario 2	Climate Scenario 3	Climate Scenario 4
Key performance indicators				
TOTAL BENEFITS (ZAR million)	147.3	173.8	339.9	748.3
TOTAL COSTS (ZAR million)	151.1	151.1	151.1	151.1
NET BENEFITS	-3.8	22.7	188.8	597.3
BENEFIT-TO-COST RATIO	0.98	1.15	2.25	4.95
INTERNAL RATE OF RETURN	7.5%	10.7%	26.8%	53.6%

Source: Authors.

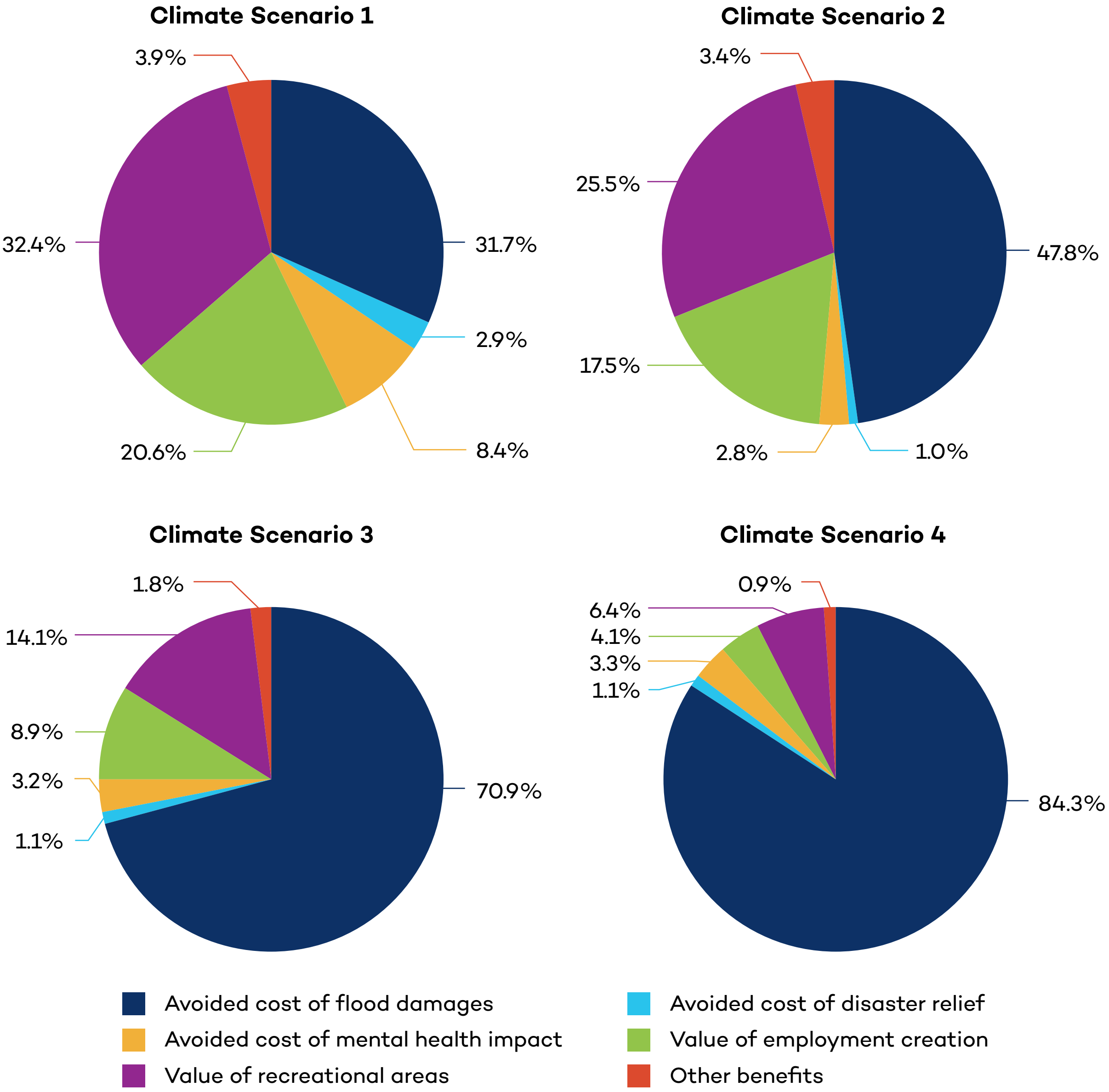
2.5.3.2 DISTRIBUTION OF BENEFITS ACROSS FOUR SCENARIOS

The distribution of benefits across the four climate scenarios highlights the role of NBI interventions in mitigating flood risks and enhancing other ecosystem services, as shown in Figure 11. In Climate Scenario 1, which represents frequent, low-intensity floods, the largest share of benefits (32.4%) comes from the value of recreational areas, meaning the benefits of creating new public access to parks, pathways, and other recreational spaces, which contributes to community well-being and physical health. The second-largest benefit in this scenario is the avoided cost of flood damages, at 31.7%. Employment creation also plays a significant role, providing 20.6% of the benefits, while mental health impacts and disaster relief avoidance contribute smaller shares at 8.4% and 2.9%, respectively. Other benefits make up 3.9% of the total. As we move to Climate Scenario 2, where floods are less frequent but more intense, the avoided cost of flood damages rises dramatically to 47.8%, overtaking recreational and employment benefits, which decline to 27.5% and 17.5%, respectively. The avoided costs of mental health and disaster relief are relatively small but still noteworthy, at 2.8% and 1%, with other benefits contributing 3.4%.

In Climate Scenario 3, where flood intensity increases further and frequency is moderately high, the distribution shifts even more significantly toward flood damage mitigation. The avoided cost of flood damages constitutes 70.9% of the total benefits, highlighting the growing importance of this metric as flood intensity increases. Other benefits, including employment creation (8.9%) and recreational areas (14.1%), become less prominent, while mental health and disaster relief avoidance remain low at 3.2% and 1.1%, respectively. Finally, in Climate Scenario 4, which simulates rare but highly destructive floods, the avoided cost of flood damages reaches its peak, comprising 84.3% of the benefits. This underscores the critical role NBI interventions play in preventing extensive damage under extreme flood conditions. Other benefits, such as recreational areas (6.1%) and employment creation (4.1%), become marginal, and the avoided costs of mental health and disaster relief are minimal at 3.3% and 1.1%, respectively, with other benefits contributing just 0.9%.

This analysis reveals a clear trend: as flood intensity increases across scenarios, the avoided cost of flood damages becomes the dominant benefit, growing from 31.7% in Scenario 1 to 84.3% in Scenario 4. This shift underscores the growing importance of flood risk mitigation as the primary driver of NBI value under more severe flooding conditions. Conversely, the contributions of recreational areas and employment creation diminish significantly in higher-intensity scenarios, indicating that these ecosystem services, while important in lower-risk contexts, become secondary as flood risks escalate. This dynamic highlights the need for tailored interventions that balance flood protection with broader ecological and social benefits, depending on the level of flood risk.

Figure 11. Distribution of benefits across scenarios discounted at 8%



Climate Scenario 1

Climate Scenario 2

Climate Scenario 3

Climate Scenario 4

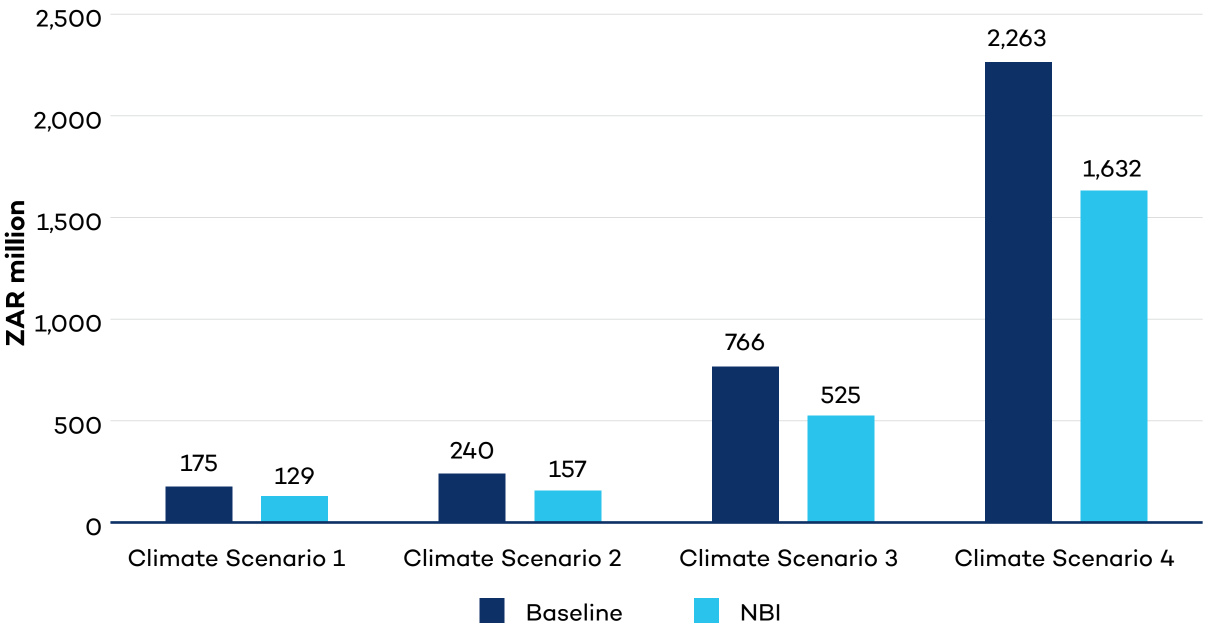
Source: Authors.

2.5.3.3 FLOOD DAMAGE ACROSS FOUR SCENARIOS

The analysis of avoided flood damages under both the Baseline and NBI scenarios, illustrated in Figure 12, reveals a substantial reduction in costs across all four climate scenarios. In Climate Scenario 1, the NBI reduces flood damages from ZAR 175 million to ZAR 129 million, resulting in an avoided cost of ZAR 47 million. As the flood intensity increases in Climate Scenario 2, the NBI's impact grows, cutting flood damage from ZAR 240 million to ZAR 157 million, yielding an avoided cost of ZAR 83 million. In more severe flood conditions, represented by Climate Scenario 3, the NBI demonstrates even greater effectiveness, with damages reduced from ZAR 766 million to ZAR 525 million, resulting in an avoided cost of ZAR 241 million. Finally, in Climate Scenario 4, the NBI reduces damages from ZAR 2,263 million under the Baseline to ZAR 1,632 million, leading to an avoided cost of ZAR 631 million.

These results highlight the increasing value of NBI interventions as flood risk intensifies, with avoided costs rising dramatically from ZAR 47 million in Scenario 1 to ZAR 631 million in Scenario 4. The results also illustrate the significant cost of inaction, as reflected by the baseline flood damage estimates, which range from ZAR 175 million to ZAR 2,263 million across the scenarios. The comparison shows that the ZAR 151 million cost of implementing NBI is a small price to pay when set against the potentially much higher cost of damages that inaction would incur.

Figure 12. Total cost of flood damage across scenarios discounted at 8%



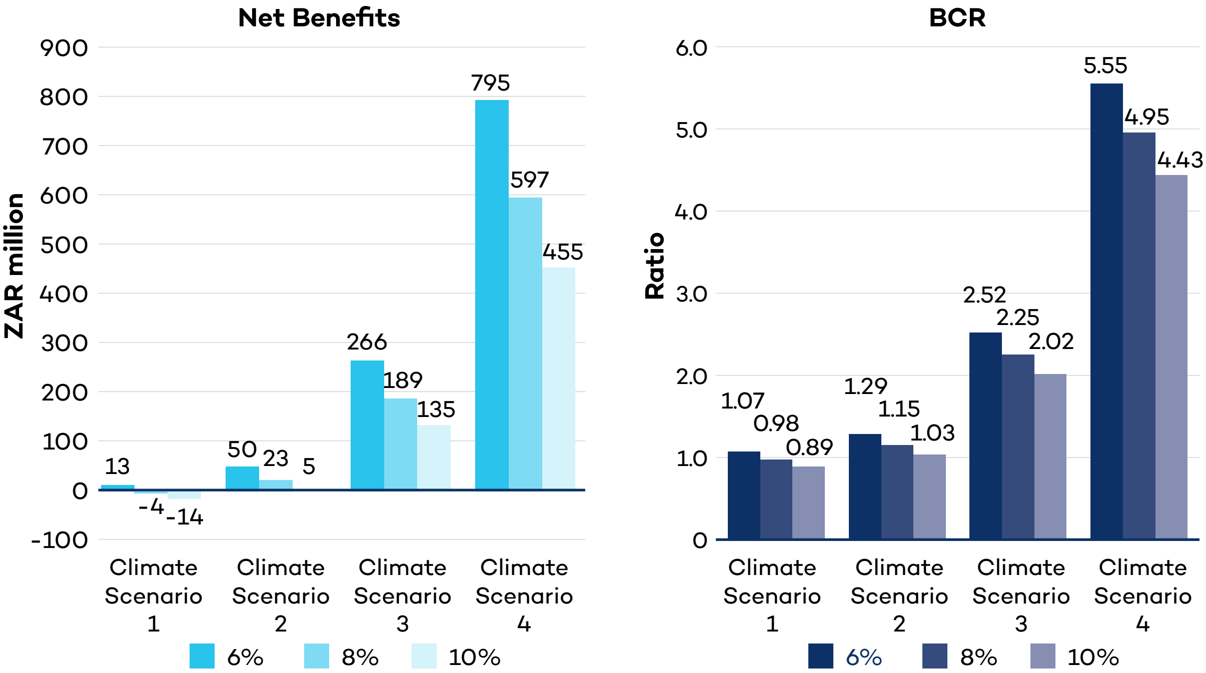
Source: Authors.

2.5.3.4 SENSITIVITY OF KEY METRICS TO DISCOUNT RATE ACROSS FOUR SCENARIOS

Figure 13 presents net benefits and the BCR under different discount rates (6%, 8%, and 10%) and climate scenarios (1 to 4). For Climate Scenario 1 (frequent, low-intensity flooding), the net benefits decrease significantly as the discount rate increases. At a 6% discount rate, net benefits are positive (ZAR 12.57 million), but they turn negative at higher discount rates (e.g., -ZAR 14.47 million at 10%). This suggests that under frequent, low-severity floods, future benefits diminish quickly with higher discount rates, making the project less viable over time. For more severe climate scenarios like Scenario 4 (frequent, high-intensity flooding), the net benefits remain high even at elevated discount rates. For instance, the net benefits decrease from ZAR 795.13 million (at 6%) to ZAR 455.07 million (at 10%), but they remain positive. This implies that under high-risk flooding conditions, the infrastructure project is more robust to changes in discount rates, retaining its value even when future benefits are discounted more heavily.

For all climate scenarios, the BCR decreases as the discount rate rises, indicating that the project's efficiency in delivering benefits relative to costs is sensitive to discount rate changes. For Scenario 1, the BCR drops from 1.07 (6% rate) to below 1 (0.98 at 10%), implying that under frequent, less severe flooding, the project becomes less cost-effective as the discount rate increases. In contrast, for Scenario 4, the BCR remains above 1 across all discount rates, dropping from 5.55 (at 6%) to 4.95 (at 10%), still indicating strong economic justification for the project under severe flood conditions. In summary, both net benefits and BCR are highly sensitive to the discount rate, especially in lower-severity climate scenarios. However, under more extreme flooding scenarios, the project's value and cost-effectiveness remain resilient to changes in discount rates.

Figure 13. Key metrics across discount rates and scenarios



Source: Authors.

2.5.3.5 KEY METRICS ACROSS BROADER FLOOD SCENARIOS

In this sub-section, we conduct a sensitivity analysis to assess how key performance indicators—BCR, IRR, and net benefits—respond to variations in flood intensity and frequency. By using heat maps to visualize these dynamics, we can better understand how flood conditions affect the overall performance of the NBI interventions. This analysis helps identify the conditions under which the benefits of the NBI exceed the costs or, alternatively, when the balance tilts unfavourably. To assist the reader in interpreting these visualizations, Box 2 provides guidance on how to read and understand the heat maps included here and in the Appendices.

Box 2. Reading and interpreting heat maps

The heat maps visualize how flood intensity (horizontal axis) and flood frequency (vertical axis) affect key indicators: BCR, IRR, and net benefits. Each cell shows the value for a specific combination of intensity and frequency, with colour indicating the result:

- For BCR, red represents the lowest values, light yellow indicates values around 1 (where costs equal benefits), and green highlights values around or above 2, where benefits significantly outweigh costs.
- For IRR, red marks the lowest returns, light yellow signals values near 6%, and green shows returns around or above 15%, reflecting highly favourable project performance.
- For net benefits, red corresponds to the lowest financial gains, light yellow indicates values near ZAR 50 million, and green represents values around or above ZAR 100 million, signalling strong net positive impacts.

By interpreting the colour transitions, readers can easily identify the most favourable or critical scenarios for each indicator.

Examining the results discounted at 8%, as shown in Table 4 and Table 5, reinforces earlier findings that indicate a clear correlation between flood frequency and intensity and NBI's performance. Specifically, the data reveals that lower frequency and intensity scenarios, situated in the bottom left of the tables, correspond to a lower BCR of 0.59 for decadal 1:5 floods, alongside negative net benefits amounting to -ZAR 62.4 million. Conversely, as we shift toward the top right of the tables, where high-frequency and high-intensity conditions prevail, both the BCR and net benefits significantly increase, reaching a BCR of 13.81 and net benefits of ZAR 1,935.5 million under yearly 1:50 floods.

Moreover, the analysis uncovers various scenarios where the benefits of the NBI surpass its costs, which are identified as breaking points. For instance, in situations involving lower-intensity events below 1:10, the NBI does not achieve a net positive benefit, regardless of the frequency of flooding. However, under a 1:10 flood intensity, a critical turning point emerges where, with a frequency just above one flood every 2 years, the NBI achieves a break-even point, resulting in positive net benefits of ZAR 61 million. If we increase the flood intensity to 1:15, the analysis reveals that the breaking point is reached sooner, with a lower frequency—specifically, just above 7 (or approximately one flood every 7 years). This indicates that even a modest increase in flood intensity can enhance the performance of the NBI, allowing it to generate net benefits with relatively infrequent flooding. This shift underscores the sensitivity of the NBI's effectiveness in addressing changes in flood conditions. Furthermore, by increasing the flood intensity to 1:20, we see that all frequencies below 10 yield positive outcomes as BCR ranges between 1.01 (when considering one flood every 9 years) and 5.28 (when considering one flood every year), while the net benefits range between ZAR 1.3 million and ZAR 647.1 million. After the 1:20 flood intensity mark, and regardless of the frequency, all scenarios give way to positive outcomes—BCR above 1 and positive net benefits, illustrating the range of scenarios in which the NBI's economic viability is completely justified. Note that results considering scenarios above the flood intensity of 1:50 are illustrated in Table A8 and Table A9.

When looking at the IRR across flood scenarios, as illustrated in Table 6, the overall narrative is similar: the higher the frequency or intensity of flood events, the higher the IRR. In particular, for a flood intensity of 1:5, the analysis reveals that if the flood frequency is below 2 (or approximately one flood every 2 years), the IRR remains negative, illustrating the insufficient returns in these scenarios. However, as the frequency increases, the IRR improves, reaching 6.2% for a yearly flood of this intensity. In the case of a flood intensity of 1:10, the IRR remains negative if the frequency is below 6 (or one flood every 6 years). Notably, the IRR increases from 1.5% with a frequency of one flood every 5 years to 7.5% with a frequency of one flood every 2 years. This scenario showcases how relatively frequent flooding can enhance economic returns, culminating in a robust IRR of 15.4% for a yearly flood of intensity 1:10. For a flood intensity of 1:15, positive IRR values are observed across all frequencies, but the threshold of 8% is only surpassed when the frequency exceeds one flood every 7 years. This indicates that while benefits start to materialize sooner, more frequent flooding is necessary to achieve higher returns. Lastly, for flood intensities at or above 1:20, the IRR consistently exceeds 7.3%, signalling a strong financial incentive for implementing NBI in these scenarios.

The evidence clearly shows that the NBI performs particularly well under high flood frequency and intensity, transforming flood risks into significant economic benefits. Even modest increases in flood intensity greatly enhance NBI performance, with scenarios exceeding 1:20 consistently yielding positive returns. The analysis identifies critical breaking points where benefits exceed costs, highlighting the need to implement NBI strategies in flood-prone areas to maximize resilience against climate impacts.

Table 4. BCR across flood scenarios discounted at 8%

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	0.92	1.4	3.36	5.28	7.03	8.63	10.1	11.45	12.68	13.81
2	0.73	0.98	1.94	2.89	3.76	4.55	5.28	5.94	6.56	7.11
3	0.68	0.84	1.48	2.12	2.7	3.23	3.72	4.17	4.58	4.95
4	0.65	0.77	1.26	1.74	2.18	2.59	2.96	3.29	3.61	3.89
5	0.63	0.73	1.14	1.55	1.91	2.25	2.56	2.84	3.1	3.34
6	0.62	0.7	1.04	1.38	1.69	1.96	2.22	2.46	2.67	2.87
7	0.61	0.67	0.95	1.22	1.47	1.69	1.9	2.09	2.26	2.42
8	0.6	0.66	0.91	1.15	1.37	1.57	1.76	1.93	2.08	2.22
9	0.59	0.64	0.82	1.01	1.18	1.33	1.47	1.6	1.72	1.83
10	0.59	0.63	0.8	0.97	1.12	1.26	1.38	1.5	1.61	1.71

Note: If any readers would prefer a non-colour shaded version of the table, please contact publishing@iisd.ca.
Source: Authors.

Table 5. Net benefits in ZAR million across flood scenarios discounted at 8%

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	-12.5	61	356.1	647.1	910.8	1,152.20	1,374.10	1,578.00	1,764.90	1,935.50
2	-40.1	-3.8	142.2	286.1	416.6	536	645.8	746.6	839.1	923.5
3	-49	-24.6	73.3	169.8	257.3	337.4	411	478.6	540.7	597.3
4	-53.4	-34.9	39.3	112.5	178.8	239.5	295.3	346.6	393.6	436.6
5	-55.7	-40.3	21.7	82.8	138.2	188.8	235.4	278.2	317.5	353.3
6	-57.6	-44.8	6.7	57.5	103.6	145.7	184.5	220.1	252.7	282.5
7	-59.5	-49.2	-7.7	33.2	70.3	104.2	135.4	164.1	190.4	214.3
8	-60.3	-51	-13.9	22.7	55.9	86.3	114.2	139.8	163.4	184.8
9	-61.9	-54.9	-26.6	1.3	26.6	49.8	71.1	90.6	108.6	124.9
10	-62.4	-56	-30.4	-5.1	17.8	38.7	58	75.7	92	106.8

Note: If any readers would prefer a non-colour shaded version of the table, please contact publishing@iisd.ca.
Source: Authors.

Table 6. IRR across flood scenarios

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	6.2%	15.4%	40.1%	58.2%	72.2%	83.8%	93.8%	102.5%	110.1%	116.9%
2	1.2%	7.5%	23.5%	35.1%	44.0%	51.4%	57.6%	62.9%	67.6%	71.6%
3	-0.7%	4.2%	16.6%	25.5%	32.4%	38.0%	42.8%	46.9%	50.5%	53.6%
4	-1.7%	2.4%	12.9%	20.4%	26.3%	31.1%	35.2%	38.7%	41.7%	44.4%
5	-2.2%	1.5%	10.8%	17.4%	22.5%	26.8%	30.3%	33.4%	36.0%	38.3%
6	-2.8%	0.5%	8.9%	14.8%	19.2%	22.9%	25.9%	28.4%	30.6%	32.5%
7	-3.7%	-0.8%	6.9%	12.2%	16.1%	19.2%	21.8%	23.9%	25.8%	27.3%
8	-3.5%	-0.7%	6.1%	10.7%	13.9%	16.5%	18.7%	20.5%	22.0%	23.3%
9	-4.5%	-2.4%	3.8%	8.2%	11.3%	13.7%	15.6%	17.2%	18.6%	19.8%
10	-4.4%	-2.3%	3.5%	7.3%	10.1%	12.1%	13.8%	15.2%	16.4%	17.4%

Note: If any readers would prefer a non-colour shaded version of the table, please contact publishing@iisd.ca.
Source: Authors.

2.5.3.6 FOCUS ON THE INDUSTRY PERSPECTIVE

As first highlighted by the spatial analysis, industrial areas in Drakenstein are at a high risk of flooding. To address this observation, the present analysis focused on the avoided cost of flood damages affecting industries while considering all of the project's costs (CapEx and OpEx). In other words, the key metrics exclude all other benefits. This way, it offers insights concerning the potential gains of the industrial sector in financing or contributing to the NBI project.

The first observation when looking at the industry's BCR across flood scenarios, as illustrated in Table 7, is that floods with an intensity below 1:10 do not have a direct impact on industrial areas, leading to no benefits from the NBI. However, any flood event with a slightly higher intensity leads to damage to industries. When considering flood events of 1:15, the BCR ranges from 0.11 to 1.22, exemplifying once more that the higher the frequency, the higher the benefits of the NBI. Moreover, we already have a breaking point—where industry's benefits outweigh the cost of project implementation and maintenance—when 1:15 floods are yearly events. Similarly to previous heat maps analyzed, increasing the flood intensity makes this breaking point more reachable, as we only need one flood every 2 years for 1:20 floods or every 5 years for 1:30 floods. Overall, about half of the scenarios considered in Table 7 have a BCR above 1, showing that under a variety of flood intensities and frequencies, the NBI project presents a viable climate adaptation option for the industrial sector. This highlights that in the face of moderate to severe flooding, industries stand to gain significantly by investing in NBI. In particular, higher-intensity floods consistently show a favourable return on investment for industries even at lower flood frequencies. These results underline the economic rationale for industrial stakeholders to consider financial contributions toward NBI implementation, as it effectively mitigates flood risks and prevents potentially costly damages in the long term.

Table 7. BCR across flood scenarios discounted at 8% – industry

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	-	1.22	2.59	3.87	5.07	6.19	7.23	8.18	9.05	9.84
2	-	0.6	1.28	1.91	2.51	3.06	3.57	4.05	4.48	4.87
3	-	0.41	0.86	1.28	1.68	2.05	2.4	2.71	3	3.26
4	-	0.31	0.65	0.97	1.28	1.56	1.82	2.06	2.28	2.47
5	-	0.26	0.54	0.81	1.06	1.3	1.52	1.72	1.9	2.07
6	-	0.21	0.45	0.68	0.89	1.08	1.26	1.43	1.58	1.72
7	-	0.17	0.36	0.54	0.71	0.87	1.02	1.15	1.27	1.38
8	-	0.15	0.33	0.49	0.64	0.78	0.91	1.03	1.14	1.24
9	-	0.12	0.25	0.37	0.49	0.59	0.69	0.78	0.87	0.94
10	-	0.11	0.22	0.34	0.44	0.54	0.63	0.71	0.79	

Note: If any readers would prefer a non-colour shaded version of the table, please contact publishing@iisd.ca.
Source: Authors.

3.0 Conclusions

Implementing NBI interventions in Drakenstein presents a compelling case for substantial long-term value. The integrated CBA estimates total project costs at ZAR 151 million, with benefits projected to range from ZAR 147.3 million to ZAR 748.3 million. The positive return on investment is further evidenced by a BCR ranging from 0.98 to 4.95, indicating that every ZAR invested in NBI yields a return of between ZAR 0.98 and ZAR 4.95 for society. Additionally, the IRR is estimated to range between 7.5% and 53.6%. The calculations of these values can be further improved over time as more data becomes available when specific areas for NBI have been identified and further technical feasibility studies are carried out.

These metrics underscore the significant societal advantages of the NBI interventions, reinforcing their value as a robust investment in sustainable urban development. The analysis reveals a clear contrast between action and inaction; without NBI, flood damages could escalate to between ZAR 175 million and ZAR 2.26 billion, while the avoided costs of flooding with NBI significantly enhance its attractiveness as a flood management strategy. Notably, sensitivity analysis identifies critical breaking points: at a flood intensity of 1:10 occurring just above once every 2 years, NBI yields positive net benefits of ZAR 61 million. As intensity increases to 1:15 and 1:20, the performance improves significantly, as the frequency can be lower to achieve economic viability—one flood every 6 years for 1:15, and one flood every 9 years for 1:20. This highlights that NBI thrives even under non-extreme flooding conditions, underscoring the urgent need for proactive flood management strategies.

Moreover, the additional co-benefits of the NBI interventions give them an advantage over traditional built/grey infrastructure (even if not all quantified). Indeed, the analysis estimates the benefits of recreational areas and employment creation to a total of ZAR 80 million combined. These recreational areas not only provide green spaces for local communities, improving quality of life and promoting physical and mental well-being, but they also foster social cohesion by creating spaces for community interaction. Additionally, the jobs created through the maintenance of the NBI, such as wetland restoration, vegetation management, and waterway upkeep, provide stable employment opportunities, contributing to skill development and long-term livelihood security. Together, these benefits amplify the social value of NBI, making it a more sustainable and inclusive solution for urban resilience.

The findings from this assessment offer valuable insights for a range of stakeholders involved in the management and development of Drakenstein's urban ecological systems.

- **Municipalities:** The positive value proposition of the NBI projects underscores the urgency for proactive investment in flood management solutions. By integrating the comprehensive benefits of NBI, which extend beyond flood mitigation to encompass economic growth, employment opportunities, and ecosystem restoration, the municipality can justify prioritizing these initiatives in its budget.

- **Private Sector and Financing Institutions:** Financiers and the private sector can leverage these findings to assess the viability of funding NBI projects. The demonstrated IRR ranging from 7.5% to 53.6% makes NBI an attractive investment, especially given the increasing flood risks. By fostering partnerships with the industrial sector, financial contributions for NBI projects can be secured, highlighting the economic benefits of mitigating flood risks. Moreover, structuring funding mechanisms, such as public–private partnerships, ensures ongoing maintenance and shared responsibility, enhancing the long-term sustainability and resilience of NBI initiatives.
- **Communities:** The results highlight the essential role that NBI can play in enhancing local livelihoods and reducing flood risks. Community members can advocate for the implementation of tailored NBI projects that directly address their vulnerabilities, particularly in flood-prone areas. Furthermore, the comprehensive nature of NBI initiatives encourages community participation in maintenance efforts, fostering a sense of ownership and responsibility.
- **Environmental Agencies:** Environmental agencies can utilize these findings to bolster their advocacy for sustainable practices and policies for infrastructure decision making. Agencies can use this evidence to promote the integration of NBI into urban planning and development strategies.

In summary, the evaluation of NBI interventions in Drakenstein underscores their vital role in enhancing urban resilience, environmental sustainability, and socio-economic well-being. The compelling evidence of positive net benefits and strong return on investment highlights the urgency for municipalities to prioritize NBI projects as proactive flood management solutions. By embracing a systems thinking approach, decision-makers can better understand the interdependencies among ecosystems, infrastructure, and community resilience.

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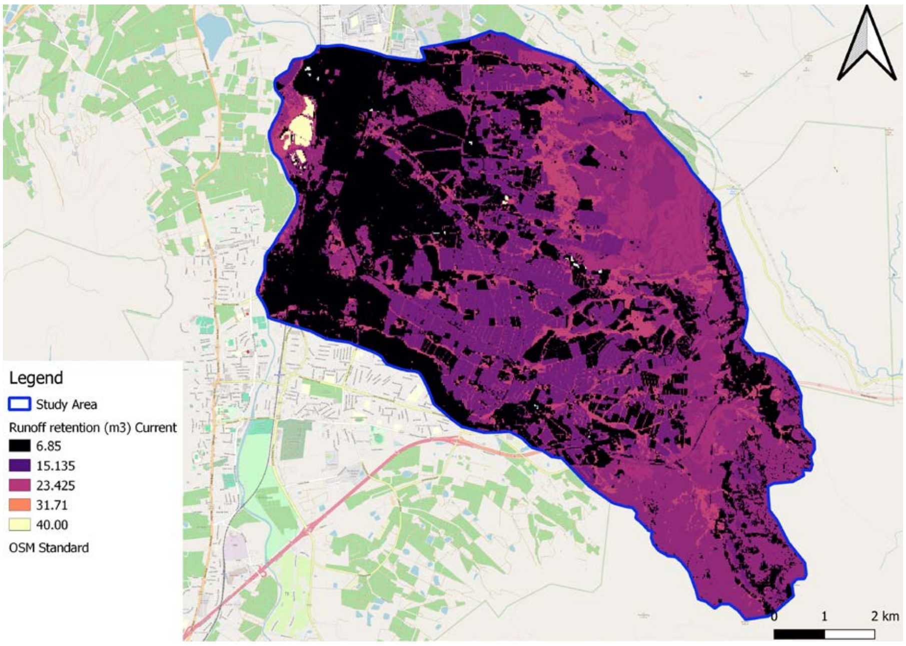
Appendix A. Further Results

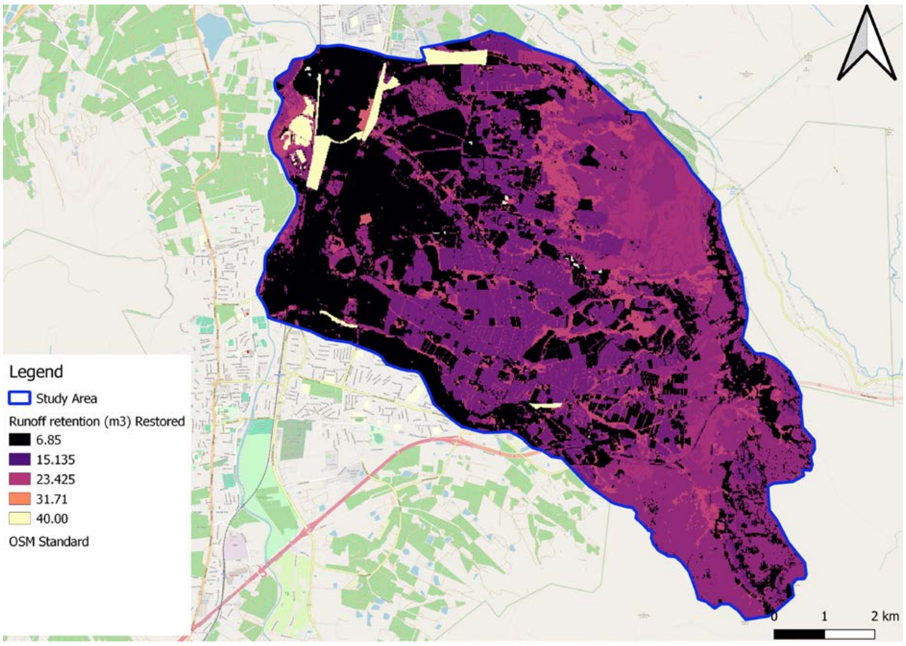
Spatial Analysis

Figure A1. Spatial map of water runoff – current land use/land cover (LULC)



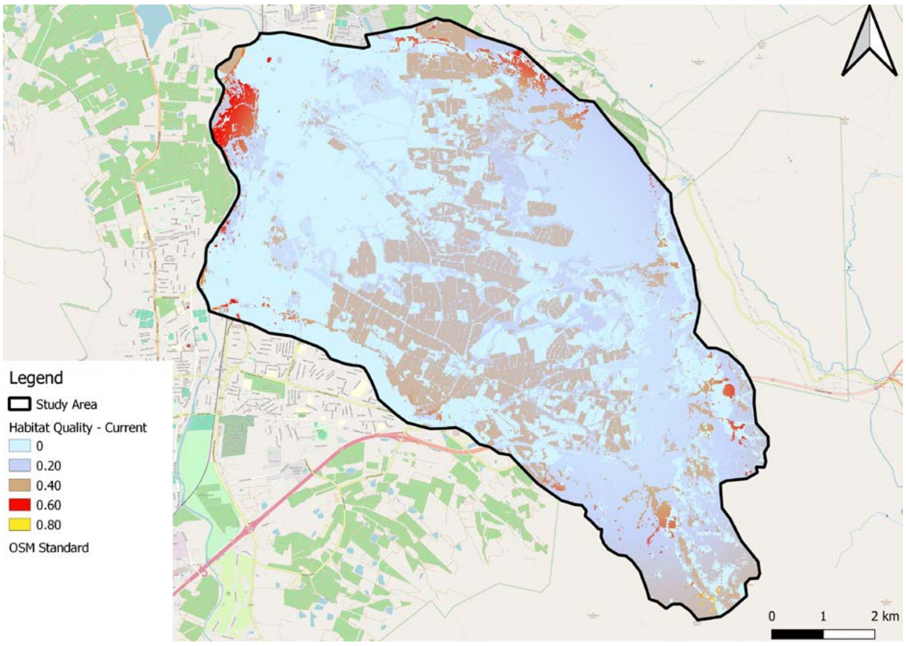
Source: Authors.

Figure A2. Spatial map of water runoff – post-implementation LULC



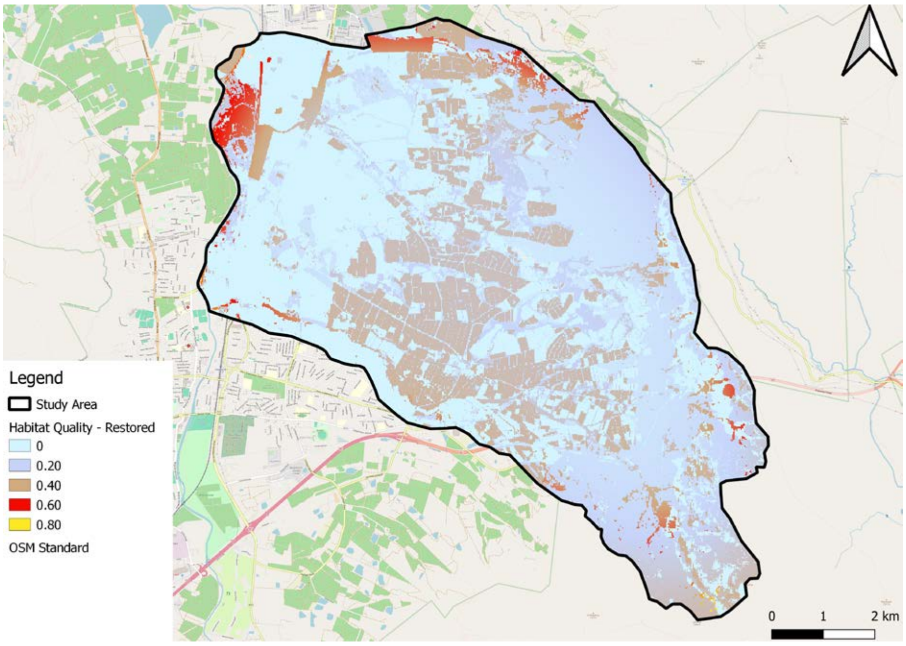
Source: Authors.

Figure A3. Spatial map of habitat quality – current LULC



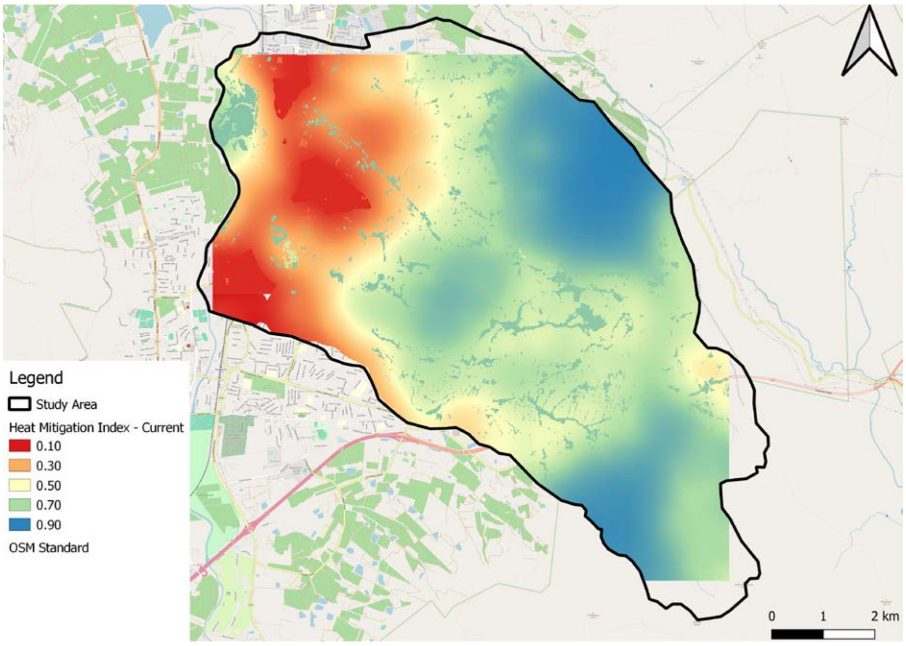
Source: Authors.

Figure A4. Spatial map of habitat quality – post-implementation LULC



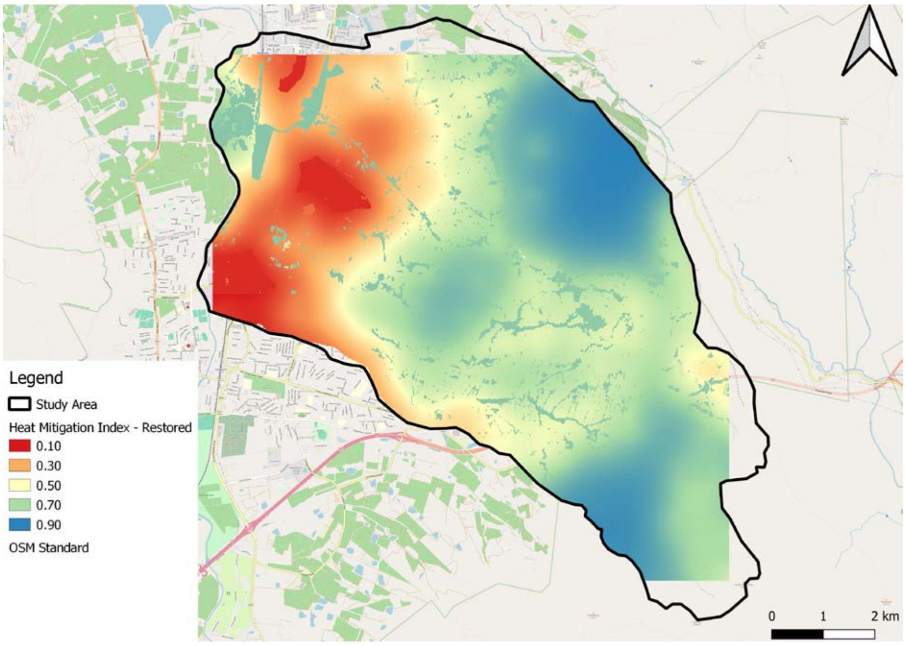
Source: Authors.

Figure A5. Spatial map of heat index – current LULC



Source: Authors.

Figure A6. Spatial map of heat index – post-implementation



Source: Authors.

Table A1. LULC areas inundated

			Total area inundated (m²)		
	Label	**Total area (m²)**	**20-year flood line**	**50-year flood line**	**100-year flood line**
1	Contiguous forest (indigenous)	157,211	-	-	-
2	Contiguous low forest	3,096,609	86,406	267,218	331,822
3	Dense forest & woodland	6,089,211	174,412	420,428	512,935
4	Open woodland	368,425	4,000	7,601	11,001
5	Plantation forest	5,987,204	46,403	74,405	85,306
6	Low shrubland (non-fynbos)	25,602	1,200	1,200	1,700
7	Low shrubland (fynbos)	4,063,874	-	-	-
9	Low shrubland (nama karoo)	27,263,841	313,221	879,259	1,405,795
13	Natural estuaries & lagoons	4,273,089	25,202	83,606	140,209
18	Artificial sewage ponds	64,404	-	-	-
19	Artificially flooded mine pits	1,091,674	6,800	6,800	7,200
20	Herbaceous wetlands	505,234	400	360,424	426,729
21	Mangrove wetlands	16,801	-	-	-
22	Natural rock surfaces	318,021	10,801	30,402	33,802
23	Dry pans	470,832	26,002	68,005	99,107
25	Sand dunes	705,648	-	-	-
26	Coastal dunes & beach sand	40,803	-	-	15,201
30	Cultivated commercial permanent vines	800	-	-	-
31	Cultivated commercial sugarcane pivot irrigated	786,853	1,600	6,800	11,501
32	Commercial permanent (pineapples)	8,209,755	-	-	-
33	Cultivated commercial sugarcane non-pivot (all other)	9,098,215	30,002	156,011	165,811
39	Subsistence annual crops	463,231	-	-	-
40	Residential informal	10,194,689	11,601	35,202	44,103
42	Smallholdings	838,857	32,802	46,403	51,303
43	Urban recreational fields	34,802	-	-	-

			Total area inundated (m^2)		
	Label	**Total area (m^2)**	**20-year flood line**	**50-year flood line**	**100-year flood line**
44	Commercial	179,212	4,000	10,801	14,101
45	Industrial	53,204	3,200	3,600	7,000
46	Mines	1,987,334	100,007	321,622	350,724
47	Land-fills	290,820	40,403	52,004	58,704
48	Residential formal (bush)	16,401	-	400	1,200
49	Residential formal (low veg/grass)	5,900,799	63,604	198,413	349,224
50	Residential formal (bare)	3,347,826	20,801	76,805	160,911
51	Residential informal (tree)	10,401	2,800	4,000	5,800
52	Residential informal (bush)	400	400	400	400
53	Residential informal (low veg/grass)	355,224	34,002	51,203	62,704
54	Residential informal (bare)	220,415	36,002	49,203	58,604
55	Village scattered	958,465	12,401	32,402	57,404
56	Village dense	137,209	1,200	1,200	1,200
57	Smallholdings (tree)	414,428	-	400	1,000
58	Smallholdings (bush)	11,201	-	-	-
59	Smallholdings (low veg/grass)	706,848	-	-	-
60	Smallholdings (bare)	12,001	-	-	-
61	Urban recreational fields (tree)	1,200	-	-	-
63	Urban recreational fields (grass)	11,601	-	-	-
65	Commercial	2,066,940	6,000	72,805	176,412
66	Industrial	3,236,219	262,018	875,659	1,208,582
67	Roads & rail (major linear)	118,808	-	-	-
69	Mines – extraction sites	40,803	-	-	-
	TOTAL (m^2)	**104,243,441**	**1,357,692**	**4,194,683**	**5,858,096**
	TOTAL (ha)	**10,424**	**136**	**419**	**586**

Source: Authors.

Cost-Benefit Analysis

Table A2. Benefit-to-cost ratio (BCR) across flood scenarios discounted at 6%

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	1.01	1.56	3.75	5.92	7.88	9.68	11.33	12.85	14.24	15.51
2	0.8	1.07	2.16	3.23	4.19	5.08	5.9	6.65	7.33	7.96
3	0.74	0.92	1.65	2.37	3.02	3.62	4.16	4.67	5.13	5.55
4	0.7	0.84	1.4	1.94	2.44	2.89	3.31	3.69	4.04	4.36
5	0.69	0.8	1.27	1.73	2.14	2.52	2.87	3.19	3.49	3.76
6	0.67	0.77	1.15	1.54	1.88	2.2	2.49	2.75	3	3.22
7	0.66	0.73	1.04	1.35	1.62	1.88	2.11	2.32	2.52	2.69
8	0.65	0.72	1.01	1.29	1.54	1.77	1.98	2.18	2.36	2.52
9	0.64	0.69	0.9	1.11	1.3	1.47	1.63	1.78	1.91	2.03
10	0.64	0.69	0.88	1.07	1.25	1.41	1.56	1.69	1.82	1.93

Note: If any readers would prefer a non-colour shaded version of the table, please contact publishing@iisd.ca.
Source: Authors.

Table A3. Net benefits across flood scenarios discounted at 6%

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	1.4	97.0	480.7	859.1	1202.0	1515.9	1804.5	2069.6	2312.6	2534.5
2	-34.6	12.6	201.9	388.7	557.9	712.9	855.3	986.1	1106.1	1215.6
3	-46.1	-14.3	113.1	238.7	352.6	456.9	552.7	640.7	721.4	795.1
4	-51.8	-27.7	69.1	164.6	251.1	330.3	403.1	470.0	531.3	587.3
5	-54.7	-34.4	46.8	126.9	199.5	265.9	327.0	383.1	434.6	481.6
6	-57.2	-40.4	27.0	93.5	153.8	209.0	259.7	306.3	349.0	388.1
7	-59.7	-46.3	7.6	60.7	108.8	152.9	193.4	230.7	264.8	295.9
8	-60.6	-48.2	1.2	49.9	94.1	134.5	171.7	205.8	237.1	265.7
9	-62.9	-53.7	-16.8	19.6	52.6	82.8	110.5	136.0	159.4	180.7
10	-63.4	-54.9	-20.7	13.0	43.5	71.5	97.2	120.8	142.4	162.2

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Source: Authors.

Table A4. BCR across flood scenarios discounted at 10%

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	0.84	1.27	3.01	4.73	6.29	7.72	9.03	10.23	11.33	12.34
2	0.68	0.89	1.75	2.61	3.38	4.08	4.73	5.33	5.88	6.38
3	0.62	0.77	1.34	1.91	2.43	2.9	3.34	3.74	4.1	4.43
4	0.6	0.71	1.14	1.57	1.96	2.32	2.65	2.95	3.23	3.48
5	0.58	0.67	1.04	1.4	1.72	2.02	2.29	2.54	2.77	2.98
6	0.57	0.65	0.95	1.25	1.52	1.77	1.99	2.2	2.39	2.57
7	0.56	0.62	0.87	1.11	1.33	1.53	1.71	1.88	2.03	2.18
8	0.56	0.61	0.82	1.03	1.23	1.4	1.56	1.71	1.85	1.97
9	0.55	0.59	0.75	0.92	1.06	1.2	1.32	1.44	1.54	1.64
10	0.54	0.58	0.73	0.87	1	1.12	1.23	1.34	1.43	1.51

Note: If any readers would prefer a non-colour shaded version of the table, please contact publishing@iisd.ca.
Source: Authors.

Table A5. Net benefits across flood scenarios discounted at 10%

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	-21.4	36.1	266.9	494.6	700.9	889.8	1063.3	1222.8	1369.0	1502.5
2	-43.0	-14.5	99.9	212.7	314.9	408.5	494.5	573.6	646.0	712.2
3	-50.0	-30.9	45.6	121.0	189.4	252.0	309.5	362.4	410.8	455.1
4	-53.4	-39.0	18.9	76.0	127.8	175.2	218.7	258.7	295.4	328.9
5	-55.2	-43.2	4.9	52.4	95.5	134.9	171.1	204.4	234.9	262.7
6	-56.7	-46.8	-6.7	32.8	68.6	101.4	131.5	159.2	184.6	207.8
7	-58.2	-50.1	-17.7	14.3	43.2	69.7	94.1	116.5	137.0	155.7
8	-58.9	-51.8	-23.5	4.5	29.9	53.1	74.5	94.1	112.1	128.5
9	-60.1	-54.6	-32.7	-11.0	8.6	26.5	43.1	58.2	72.1	84.8
10	-60.6	-55.7	-36.2	-17.0	0.4	16.3	30.9	44.4	56.7	68.0

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Source: Authors.

Table A6. Net benefits across flood scenarios discounted at 8% – industry

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	-151.1	33.3	239.7	433.6	615.1	784.1	940.6	1084.6	1216.1	1335.2
2	-151.1	-59.8	42.3	138.2	227.9	311.5	388.9	460.2	525.3	584.2
3	-151.1	-89.9	-21.4	42.9	103.1	159.2	211.1	258.9	302.5	342.1
4	-151.1	-104.7	-52.8	-4.0	41.7	84.2	123.5	159.7	192.8	222.8
5	-151.1	-112.3	-69.0	-28.3	9.8	45.3	78.1	108.4	136.0	161.0
6	-151.1	-118.9	-82.8	-49.0	-17.3	12.2	39.5	64.7	87.7	108.4
7	-151.1	-125.1	-96.1	-68.9	-43.4	-19.6	2.4	22.6	41.1	57.9
8	-151.1	-127.8	-101.9	-77.5	-54.6	-33.4	-13.7	4.4	21.0	36.0
9	-151.1	-133.4	-113.6	-95.0	-77.6	-61.4	-46.3	-32.5	-19.9	-8.5
10	-151.1	-135.0	-117.1	-100.3	-84.5	-69.8	-56.2	-43.7	-32.3	-22.0

Note: If any readers would prefer a non-colour shaded version of the table, please contact publishing@iisd.ca.
Source: Authors.

Table A7. Internal rate of return (IRR) across flood scenarios discounted at 8% – industry

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	N/A	11.5%	28.1%	40.2%	50.1%	58.5%	65.7%	72.0%	77.5%	82.3%
2	N/A	-0.8%	12.5%	20.8%	27.3%	32.8%	37.5%	41.6%	45.1%	48.2%
3	N/A	-8.9%	5.4%	12.4%	17.7%	22.0%	25.7%	28.9%	31.7%	34.1%
4	N/A	N/A	1.0%	7.6%	12.3%	16.1%	19.3%	22.0%	24.4%	26.5%
5	N/A	N/A	-1.3%	4.7%	9.0%	12.5%	15.4%	17.8%	20.0%	21.8%
6	N/A	N/A	-4.7%	1.8%	6.0%	9.3%	11.9%	14.2%	16.1%	17.7%
7	N/A	N/A	N/A	-3.3%	2.1%	5.6%	8.3%	10.4%	12.2%	13.7%
8	N/A	N/A	-8.6%	-2.1%	1.7%	4.5%	6.6%	8.4%	9.9%	11.1%
9	N/A	N/A	N/A	N/A	N/A	-1.9%	1.5%	3.9%	5.6%	7.0%
10	N/A	N/A	N/A	N/A	-5.3%	-1.3%	1.2%	3.1%	4.6%	5.8%

Note: If any readers would prefer a non-colour shaded version of the table, please contact publishing@iisd.ca.
Source: Authors.

Table A8. BCR across broader flood scenarios discounted at 8%

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	1.4	5.28	8.63	11.45	13.81	15.76	17.31	18.47	19.25	19.64
2	0.98	2.89	4.55	5.94	7.11	8.08	8.84	9.42	9.8	10
3	0.84	2.12	3.23	4.17	4.95	5.6	6.11	6.5	6.76	6.89
4	0.77	1.74	2.59	3.29	3.89	4.38	4.77	5.06	5.26	5.36
5	0.73	1.55	2.25	2.84	3.34	3.75	4.07	4.32	4.48	4.56
6	0.7	1.38	1.96	2.46	2.87	3.21	3.48	3.68	3.82	3.89
7	0.67	1.22	1.69	2.09	2.42	2.69	2.91	3.07	3.18	3.24
8	0.66	1.15	1.57	1.93	2.22	2.47	2.66	2.81	2.91	2.96
9	0.64	1.01	1.33	1.6	1.83	2.01	2.16	2.27	2.35	2.39
10	0.63	0.97	1.26	1.5	1.71	1.88	2.01	2.11	2.18	2.21

Note: If any readers would prefer a non-colour shaded version of the table, please contact publishing@iisd.ca.
Source: Authors.

Table A9. Net benefits in ZAR million across broader flood scenarios discounted at 8%

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	61.0	647.1	1152.2	1578.0	1935.5	2230.0	2463.9	2639.0	2756.2	2816.2
2	-3.8	286.1	536.0	746.6	923.5	1069.2	1184.9	1271.5	1329.5	1359.2
3	-24.6	169.8	337.4	478.6	597.3	695.0	772.6	830.7	869.5	889.5
4	-34.9	112.5	239.5	346.6	436.6	510.6	569.5	613.5	643.0	658.1
5	-40.3	82.8	188.8	278.2	353.3	415.1	464.2	501.0	525.6	538.2
6	-44.8	57.5	145.7	220.1	282.5	333.9	374.7	405.3	425.8	436.3
7	-49.2	33.2	104.2	164.1	214.3	255.7	288.6	313.2	329.7	338.1
8	-51.0	22.7	86.3	139.8	184.8	221.9	251.3	273.3	288.1	295.7
9	-54.9	1.3	49.8	90.6	124.9	153.2	175.6	192.4	203.6	209.4
10	-56.0	-5.1	38.7	75.7	106.8	132.4	152.7	167.9	178.1	183.3

Note: If any readers would prefer a non-colour shaded version of the table, please contact publishing@iisd.ca.
Source: Authors.

Table A10. IRR across broader flood scenarios

Flood frequency (flood of intensity X every Y year)	Flood intensity/size (1 in X event type)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	15.4%	58.2%	83.8%	102.5%	116.9%	128.2%	136.9%	143.3%	147.5%	149.7%
2	7.5%	35.1%	51.4%	62.9%	71.6%	78.3%	83.3%	87.0%	89.3%	90.5%
3	4.2%	25.5%	38.0%	46.9%	53.6%	58.7%	62.5%	65.2%	67.0%	67.9%
4	2.4%	20.4%	31.1%	38.7%	44.4%	48.7%	52.0%	54.3%	55.8%	56.6%
5	1.5%	17.4%	26.8%	33.4%	38.3%	42.0%	44.8%	46.8%	48.0%	48.7%
6	0.5%	14.8%	22.9%	28.4%	32.5%	35.6%	37.8%	39.4%	40.5%	41.0%
7	-0.8%	12.2%	19.2%	23.9%	27.3%	29.9%	31.7%	33.0%	33.9%	34.3%
8	-0.7%	10.7%	16.5%	20.5%	23.3%	25.4%	26.9%	28.0%	28.7%	29.0%
9	-2.4%	8.2%	13.7%	17.2%	19.8%	21.6%	22.9%	23.9%	24.5%	24.8%
10	-2.3%	7.3%	12.1%	15.2%	17.4%	19.0%	20.1%	20.9%	21.4%	21.7%

Note: If any readers would prefer a non-colour shaded version of the table, please contact publishing@iisd.ca.
Source: Authors.

Table A11. Integrated CBA in USD[6] across climate scenarios

	Climate Scenario 1	**Climate Scenario 2**	**Climate Scenario 3**	**Climate Scenario 4**
Flood intensity/size (1 in X event type)	1:10	1:20	1:30	1:50
Flood frequency (flood of intensity X every Y year)	2	8	5	3
Direct costs (USD million)				
Implementation costs (CapEx)	5.72	5.72	5.72	5.72
Maintenance costs (OpEx)	2.93	2.93	2.93	2.93
Avoided costs/loss (USD million)				
Avoided cost of flood damages – formal settlement	0.05	0.08	0.24	0.69
Avoided cost of flood damages – informal settlement	1.17	0.44	0.95	2.07
Avoided cost of flood damages – industry	-	2.81	9.21	25.96
Avoided cost of flood damages – agriculture	0.09	0.33	0.86	1.95
Avoided cost of flood damages – roads	1.37	1.09	2.54	5.45
Avoided cost of flood damages – utilities	No data	No data	No data	No data

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[6] The USD value is a simple conversion from ZAR, using the following exchange rate: 1 USD = 17.4775 ZAR

	Climate Scenario 1	**Climate Scenario 2**	**Climate Scenario 3**	**Climate Scenario 4**
Avoided cost of flood damages – educational areas	No data	No data	No data	No data
Avoided cost of disaster relief	0.24	0.10	0.21	0.48
Avoided cost of mental health impact	0.71	0.28	0.63	1.39
Avoided cost of human death	No data	No data	No data	No data
Avoided cost of dredging	No data	No data	No data	No data
Avoided loss of agricultural production	0.00	0.01	0.02	0.04
Added benefits (USD million)				
Value of employment creation	1.74	1.74	1.74	1.74
Value of food provisioning	0.15	0.15	0.15	0.15
Value of recreational areas	2.73	2.73	2.73	2.73
Value of urban cooling	No data	No data	No data	No data
Value of nursery	No data	No data	No data	No data
Value of biodiversity conservation	0.01	0.01	0.01	0.01
Value of carbon sequestration	0.06	0.06	0.06	0.06
Value of tourist activities	No data	No data	No data	No data
Value of tourism tax revenue	No data	No data	No data	No data
Value of property tax revenue	0.11	0.11	0.11	0.11
Key performance indicators				
TOTAL BENEFITS (USD million)	8.43	9.94	19.45	42.83
TOTAL COSTS (USD million)	8.65	8.65	8.65	8.65
NET BENEFITS (USD million)	-0.21	1.30	10.81	34.18
BENEFIT-TO-COST RATIO	0.98	1.15	2.25	4.95
INTERNAL RATE OF RETURN	7.5%	10.7%	26.8%	53.6%

Source: Authors.

Appendix B. Modelling Assumptions

INDICATOR: IMPLEMENTATION COSTS (CAPEX)

Implementation costs (capital expenditures [CAPEX]) are the initial costs associated with carrying out the NBI interventions, including construction, labour, materials, detailed design, and other one-time expenditures. For the Baseline, these costs are defined as zero. On the other hand, for the NBI scenario, these costs occur from year 1 till year 8, each year representing a different component of the project.

The costs are estimated by the Drakenstein Municipality at ZAR 28.1 million in year 1, ZAR 20.5 million in year 2, ZAR 18.8 million in year 3, ZAR 23 million in year 4, ZAR 14.8 million in year 5, ZAR 9.4 million in year 6, ZAR 16.7 million in year 7, and ZAR 12.4 million in year 8.

INDICATOR: MAINTENANCE COSTS

The maintenance costs (operational expenses [OpEx]) include all activities necessary to upkeep the various interventions (e.g., recreational areas). We assumed that the maintenance costs represent 5% of the implementation costs and start materializing the year after implementation.

INDICATOR: COST OF FLOOD DAMAGES – FORMAL SETTLEMENT

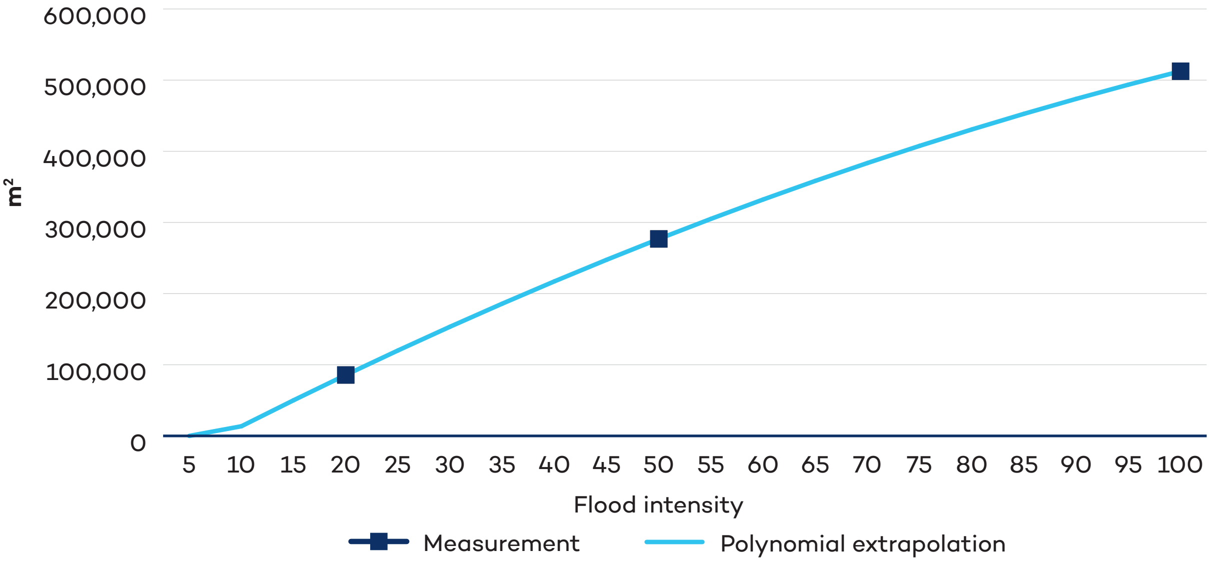
Under the Baseline scenario, the cost of flood damages to formal settlements occurs only when floods occur. This latter is defined based on the chosen flood frequency. Based on the flood frequency, we assume a homogenous distribution of flood occurrence across the 2025–2050 time horizon. In other words, if we assume a flood frequency of one flood every Y years then the flood occurrence marker would jump to 1 every Y years throughout. Note that the flood frequency parameter is chosen for each simulation.

Moreover, when a flood occurs, the flood intensity parameter is used to compute the area of formal settlement affected. Indeed, through land-use/land-cover (LULC) maps and flood lines, the spatial analysis estimated the area of formal settlement affected (LULC codes 39, 41, 48, 49, 50, 56) for three flood lines (1:20, 1:50, 1:100). With these three data points we extrapolated a function between the flood intensity and the area impacted. For a formal settlement, this function is a polynomial defined as follows:

$$f_1(x) = -518.58\,x^2 + 39{,}129\,x - 62{,}612$$

Where $f_1(x)$ is the area of formal settlement affected when a flood occurs, measured in square metres (m^2) and x is the flood intensity. Graphically, this function looks as follows:

Figure B1. Formal settlements



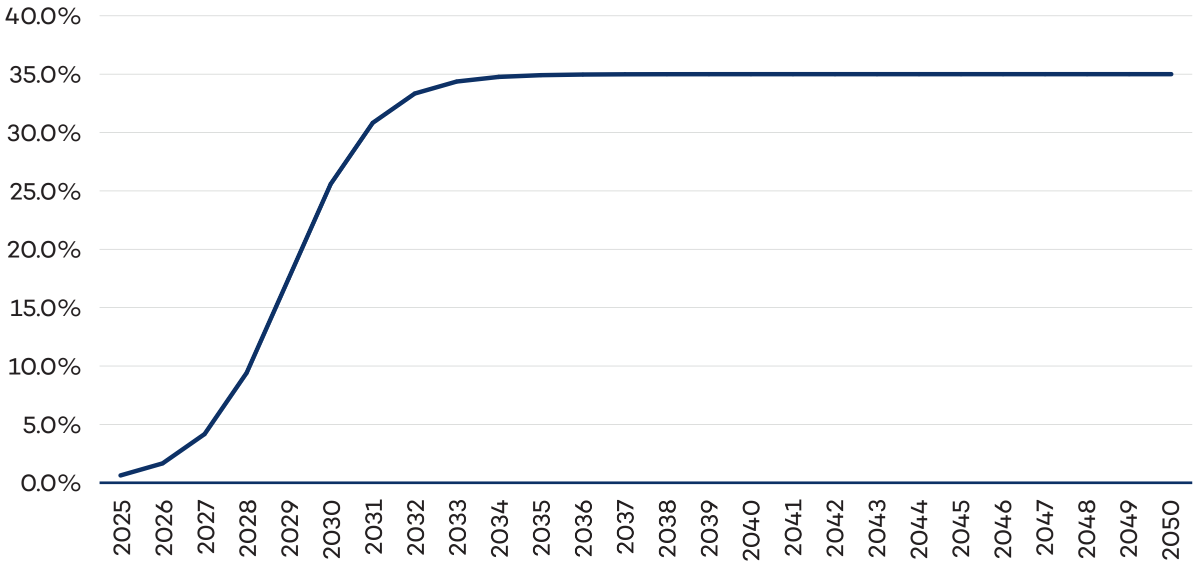
Source: Authors.

Based on the area of formal settlement land affected, we estimated the number of formal settlements affected by measuring the number of buildings per square metre of land. This latter measurement was done through satellite imagery and resulted in about 12 buildings per 5,000 m^2. Furthermore, based on satellite imagery, we estimated the average size of the formal settlement to be 100 m^2. Finally, based on the property valuation of Drakenstein Municipality, we assumed a value of ZAR 1,500/m^2 of buildings, for which we assumed damage to be 15%. In other words, we used the following equation:

$$\begin{aligned}
&\text{Formal settlement costs when flood occurs}\\
&\quad = \text{Area of formal settlement affected when flood occurs}\\
&\quad \times \text{Number of formal settlements per unit of land}\\
&\quad \times \text{Average size of formal settlements}\\
&\quad \times \text{Unit value of formal settlements}\\
&\quad \times \text{Percentage of formal settlement damage considered}\\
&\quad = f_1(x)\times 0.0025\times 100\times 1{,}500\times 15\%
\end{aligned}$$

Under the NBI scenario, the spatial analysis revealed that we could expect a 35% decrease in flood damages due to interventions. We then assumed it would take 8 years to achieve this 35% decrease, given the implementation timeline. In other words, we assumed the following materialization over time (see Figure B2):

Figure B2. Percentage decrease in flood damages



Source: Authors.

INDICATOR: COST OF FLOOD DAMAGES – INFORMAL SETTLEMENT

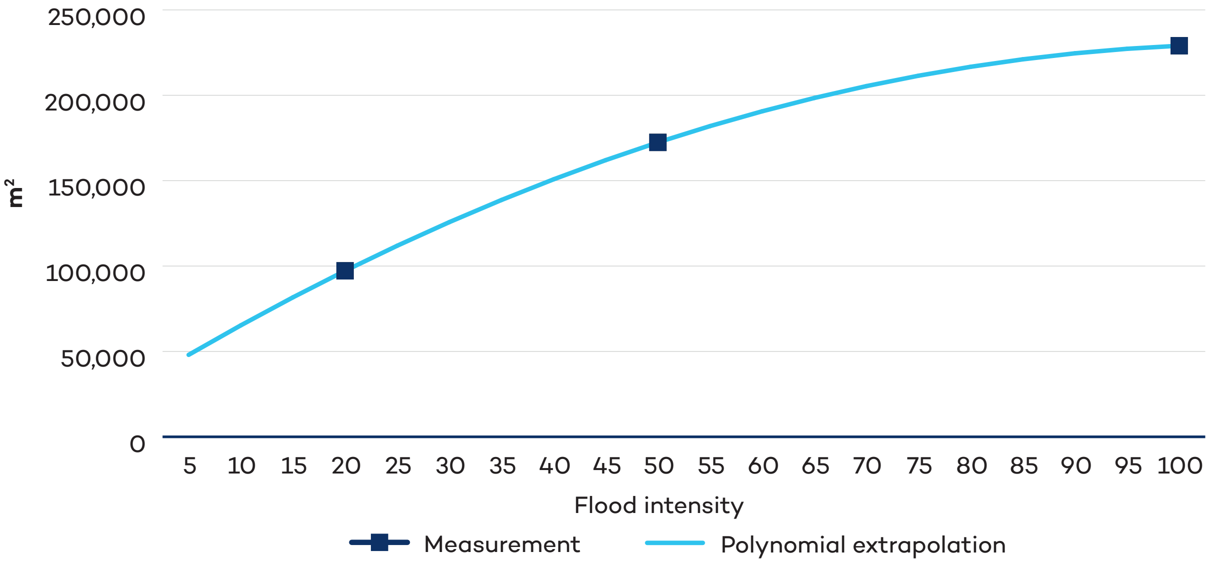
Under the Baseline scenario, the cost of flood damages to informal settlement occurs only when floods occur (see "cost of flood damages – formal settlement" for details about flood occurrence).

Moreover, when a flood occurs, the flood intensity parameter is used to compute the area of informal settlement affected. Indeed, through LULC maps and flood lines, the spatial analysis estimated the area of informal settlement affected (LULC codes 40, 51, 52, 53, 54, 55) for three flood lines (1:20, 1:50, 1:100). With these three data points, we extrapolated a function between the flood intensity and the area impacted. For informal settlements, this function is a polynomial defined as follows:

$$f_2(x) = -429.61x^2+18{,}549x+29{,}885$$

Where $f_2(x)$ is the area of informal settlement affected when a flood occurs, measured in square metres, and x is the flood intensity. This function is expressed graphically in Figure B3.

Figure B3. Informal settlements



Source: Authors.

Based on the area of informal settlement land affected, we estimated the number of informal settlements affected by measuring the number of buildings per square metre of land. This latter measurement was done through satellite imagery and resulted in about 30 buildings per 1,500 m^2. Furthermore, based on satellite imagery, we estimated the average size of formal settlement land to be 25 m^2. Finally, we assumed a value of ZAR 300/m^2 of buildings for which we assumed damage at 90%. In other words, we used the following equation:

$$\begin{aligned}&\text{Informal settlement costs when flood occurs}\\ &\quad= \text{Area of informal settlements affected when flood occurs}\\ &\quad\times \text{Number of informal settlements per unit of land}\\ &\quad\times \text{Average size of informal settlements}\\ &\quad\times \text{Unit value of informal settlements}\\ &\quad\times \text{Percentage of informal settlement damage considered}\\ &\quad= f_2(x)\times 0.023\times 25\times 300\times 90\%\end{aligned}$$

Under the NBI scenario, the spatial analysis revealed that we could expect a 35% decrease in flood damages due to interventions. We then assumed it would take 8 years to achieve this 35% decrease, given the implementation timeline. In other words, we assumed the materialization depicted in "cost of flood damages – formal settlement."

INDICATOR: COST OF FLOOD DAMAGES – INDUSTRIAL AREA

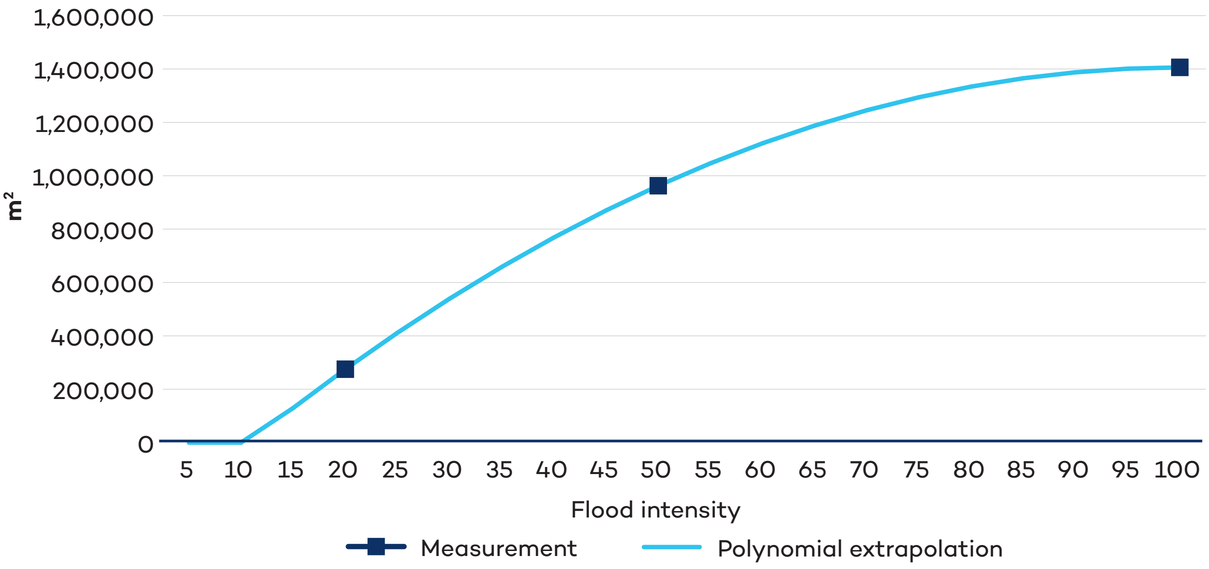
Under Baseline, the cost of flood damages to industrial areas occurs only when floods occur (see "cost of flood damages – formal settlement" for details about flood occurrence).

Moreover, when a flood occurs, the flood intensity parameter is used to compute the industrial area affected. Indeed, through LULC maps and flood lines, the spatial analysis estimated the industrial area affected (LULC codes 44, 45, 65, 66) for three flood lines (1:20, 1:50, 1:100). With these three data points, we extrapolated a function between the flood intensity and the area impacted. For the industrial area, this function is a polynomial defined as follows:

$$f_3(x) = -4392.8\ x^2 + 176{,}107\ x - 358924$$

Where $f_3(x)$ is the industrial area affected when a flood occurs, measured in square metres, and x is the flood intensity. This function is expressed graphically in Figure B4.

Figure B4. Industrial area



Source: Authors.

Based on the industrial area affected, we assumed a unit value of 6,075 ZAR per square metre (AECOM, 2023), for which we assumed damage of 10%. In other words, we used the following equation:

Industrial costs when flood occurs
= Industrial area affected when floods occur
× Unit value of industrial area
× Percentage of industrial damage considered
= $f_3(x) \times 6{,}075 \times 10\%$

Under the NBI scenario, the spatial analysis revealed that we could expect a 35% decrease in flood damages due to interventions. We then assumed it would take 8 years to achieve this 35% decrease, given the timeline of implementation. In other words, we assumed the materialization depicted in "cost of flood damages – formal settlement."

INDICATOR: COST OF FLOOD DAMAGES – AGRICULTURAL AREA

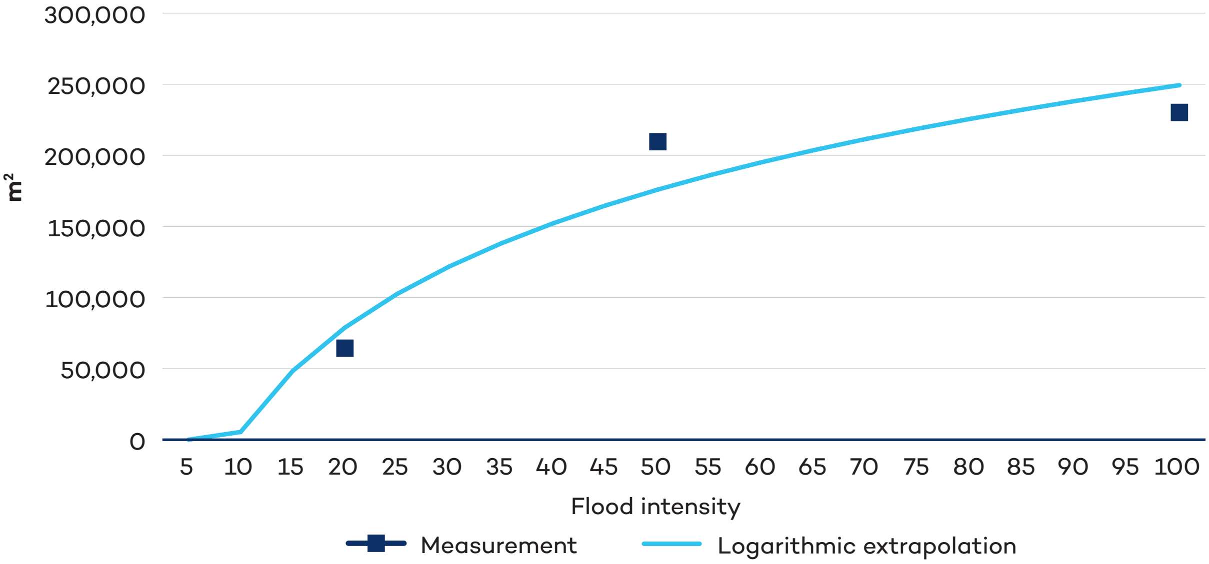
Under the Baseline scenario, the cost of flood damages to agricultural areas occurs only when floods occur (see "cost of flood damages – formal settlement" for details about flood occurrence).

Moreover, when a flood occurs, the flood intensity parameter is used to compute the agricultural area affected. Indeed, through LULC maps and flood lines, the spatial analysis estimated the agricultural area affected (LULC codes 30, 32, 32, 33, 38, 42, 57, 58, 59, 60) for three flood lines (1:20, 1:50, 1:100). With these three data points, we extrapolated a function between the flood intensity and the area impacted. For the agricultural area, this function is a logarithm defined as follows:

$$f_4(x) = 105{,}925 \ln x\text{-}67{,}942$$

Where $f_4(x)$ is the agricultural area affected when a flood occurs – measured in square metres, and x is the flood intensity. This function is expressed graphically in Figure B5.

Figure B5. Agriculture area



Source: Authors.

Based on the agricultural areas affected, we assumed a unit value of ZAR 500,000/ha, for which we assumed damage of 5% (e.g., the ratio between the cost of repair and the value of the land). In other words, we used the following equation:

$$\begin{aligned}&\text{Agricultural land costs when flood occurs}\\&\quad= \frac{\text{Area of agricultural land affected when flood occurs}}{\text{Number of square metres per hectare}}\\&\quad\times \text{Unit value of agricultural land}\\&\quad\times \text{Percentage of agricultural land damage considered} = \frac{f_4(x)}{10{,}000} \times 500{,}000 \times 5\%\end{aligned}$$

Under the NBI scenario, the spatial analysis revealed that we could expect a 35% decrease in flood damages due to interventions. We then assumed it would take 8 years to achieve this 35% decrease, given the implementation timeline. In other words, we assumed the materialization depicted in "cost of flood damages – formal settlement."

INDICATOR: COST OF FLOOD DAMAGES – ROADS

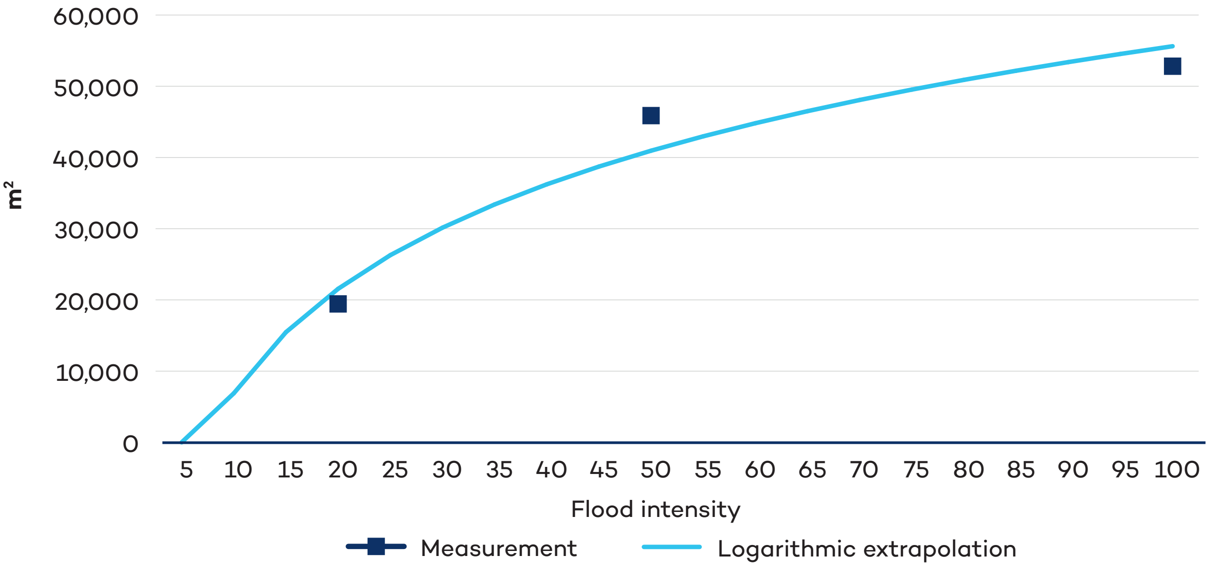
Under the Baseline scenario, the cost of flood damages to roads occurs only when floods occur (see "cost of flood damages – formal settlement" for details about flood occurrence).

Moreover, when a flood occurs, the flood intensity parameter is used to compute the roads affected. Indeed, through road maps and flood lines, the spatial analysis estimated the roads affected for three flood lines (1:20, 1:50, 1:100). With these three data points, we extrapolated a function between the flood intensity and the length of roads impacted. For roads, this function is a logarithm defined as follows:

$$f_5(x) = 21{,}164 \ln x - 7779.4$$

Where $f_5(x)$ is the length of road affected when a flood occurs, measured in metres, and x is the flood intensity. This function is expressed graphically in Figure B6.

Figure B6. Roads



Source: Authors.

Based on the length of road affected, we assumed a unit cost of strengthening of ZAR 3,000,000 per kilometre (Breytenbach & Fourie, 2021). In other words, we used the following equation:

$$\begin{aligned}&\text{Roads costs when flood occurs}\\ &\quad = \frac{\text{Meters of road affected when flood occurs}}{\text{Number of metres per kilometre}}\\ &\quad \text{x Cost of strengthening road per kilometre} = \frac{f_5(x)}{1{,}000} \times 3{,}000{,}000\end{aligned}$$

Under the NBI scenario, the spatial analysis revealed that we could expect a 35% decrease in flood damages due to interventions. We then assumed it would take 8 years to achieve this 35% decrease, given the implementation timeline. In other words, we assumed the materialization depicted in "cost of flood damages – formal settlement."

INDICATOR: COST OF DISASTER RELIEF

Under the Baseline scenario, the cost of disaster relief occurs only when floods occur (see "cost of flood damages – formal settlement" for details about flood occurrence).

Moreover, when a flood occurs, the flood intensity parameter is used to compute the number of people impacted. Indeed, we estimate the disaster relief cost based on the number of people impacted. This latter is estimated based on the number of formal and informal settlements affected when a flood occurs (see "cost of flood damages – formal settlement" and "cost of flood damages – informal settlement" for details about the number of settlements affected). Based on the number of settlements affected, we assumed that 3.6 people live in a formal settlement and five people live in an informal settlement, allowing us to compute the total number of people impacted when a flood occurs. From this latter result, we assumed that 50% would need disaster relief assistance. Finally, we used the Red Cross's estimation of disaster relief cost per person assisted, standing at ZAR 960 per person (International Federation of Red Cross & Red Crescent Societies, 2022). In other words, we used the following equation:

$$\begin{aligned}&\text{Disaster relief cost when flood occurs}\\&\quad= [\ (\text{Number of formal settlements damaged when a flood occurs}\\&\quad\times \text{Number of people per formal settlement})\\&\quad+ (\text{Number of informal settlements damaged when a flood occurs}\\&\quad\times \text{Number of people per informal settlement})\ ]\\&\quad\times \text{Percentage of people impacted needing assistance}\\&\quad\times \text{Disaster relief cost per person assisted}\end{aligned}$$

Under the NBI scenario, the spatial analysis revealed that we could expect a 35% decrease in flood damages due to interventions. We then assumed it would take 8 years to achieve this 35% decrease, given the implementation timeline. In other words, we assumed the materialization depicted in "cost of flood damages – formal settlement."

INDICATOR: COST OF MENTAL HEALTH IMPACTS

Under the Baseline scenario, the cost of mental health impacts occurs only when a flood occurs (see "cost of flood damages – formal settlement" for details about flood occurrence).

Moreover, when a flood occurs, the flood intensity parameter is used to compute the number of people impacted (see "cost of disaster relief" for details about number of people impacted). Based on the total number of people impacted when a flood occurs, we assume that 10% will be mentally affected. Finally, we used the UK Government's estimate of the mental health costs of flooding of GBP 3,014 per person by adjusting it to the South African context (e.g., using an exchange rate of ZAR 23/GBP and a cost-of-living converter of 80%). In other words, we used the following equation:

$$\begin{aligned}&\text{Cost of mental health impacts}\\ &\qquad = \text{Total number of people impacted when a flood occurs}\\ &\qquad \times \text{ Percentage of people impacted mentally affected} \times \text{Average cost of mental health}\\ &\qquad \times \text{ Exchange rate} \times (1 - \text{Cost of living converter})\end{aligned}$$

Under the NBI scenario, the spatial analysis revealed that we could expect a 35% decrease in flood damages due to interventions. We then assumed it would take 8 years to achieve this 35% decrease, given the implementation timeline o. In other words, we assumed the materialization depicted in "cost of flood damages – formal settlement."

INDICATOR: LOSS OF AGRICULTURAL LAND PRODUCTION

Under the Baseline scenario, we follow the same logic as "cost of flood damage – agricultural land" to estimate the area of agricultural land affected when a flood occurs. With this latter, we assume using FAOSTAT data—an average yield of 70 tonnes/ha (Food and Agriculture Organization of the United Nations, 2023) and an average price of ZAR 650/tonne (Food and Agriculture Organization of the United Nations, 2024)—given the high proportion of sugar cane plantations affected. In other words, we used the following equation:

$$\begin{aligned}&\text{Loss of agricultural land production}\\ &\qquad = \text{Area of agricultural land affected when a flood occurs}\\ &\qquad \times \text{ Average yield of agricultural land} \times \text{Average price of agricultural production}\end{aligned}$$

Under the NBI scenario, the spatial analysis revealed that we could expect a 35% decrease in flood damages due to interventions. We then assumed it would take 8 years to achieve this 35% decrease, given the implementation timeline. In other words, we assumed the materialization depicted in "cost of flood damages – formal settlement."

INDICATOR: VALUE OF EMPLOYMENT CREATION

Under the Baseline scenario, the value of employment creation is 0, since we only consider the value generated by interventions. Under the NBI scenario, the value of employment creation is estimated based on the implementation and maintenance expenditure. We use the cost figures (see "implementation costs [CapEx]" and "maintenance costs [OpEx])" and assume that a certain percentage goes to labour. For implementation costs, we assume that 50% goes to labour, and for maintenance costs, we assume that 100% goes to labour. This gives us the total paid wages. From this number, we assume that labour's discretionary spending is 30% of its wage. The remaining value is what we consider as the value of employment creation.

INDICATOR: VALUE OF FOOD PROVISIONING

Under the Baseline scenario, the value of food provisioning is 0 since we only consider the value generated by the interventions. Under the NBI scenario, the value of food provisioning is computed based on the total food garden area (equal to 11,201 m^2). We then assumed an average yield of 5 kg/m^2 per year and a unit value of production of ZAR 10/kg. Finally, we assumed that this benefit would only materialize after 8 years. In other words, we used the following equation:

$$\begin{aligned}&\text{Value of food provisioning}\\ &\qquad = \text{Total food garden area} \times \text{Average yield of food gardens}\\ &\qquad \times \text{ Average price of food garden production} = 11{,}201 \times 5 \times 10\end{aligned}$$

INDICATOR: VALUE OF A RECREATIONAL AREA

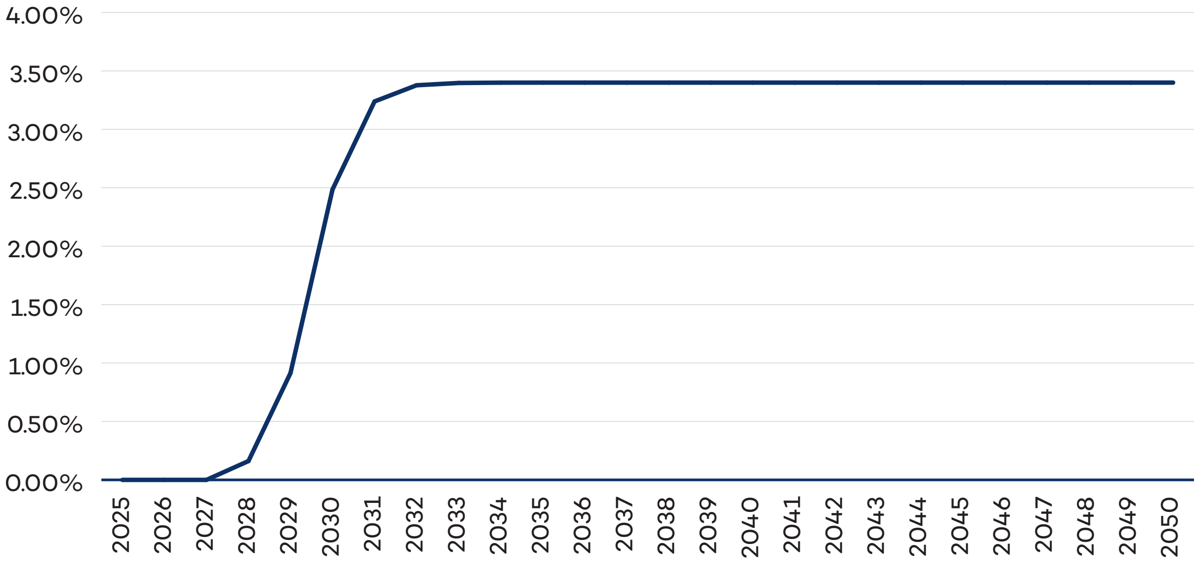
Under the Baseline scenario, the value of a recreational area is 0 since we only consider the value generated by the interventions. Under the NBI scenario, the value of a recreational area is computed based on the number of people benefiting from open green spaces. This latter is obtained by measuring the formal and informal settlement area within 500 m of the newly created green spaces. Following the same logic as for "cost of flood damages – formal settlement" and "cost of flood damage – informal settlement," we estimated the number of people that would benefit from the green space's proximity. With this result, we assumed that given the newly accessible park, people would not have to cover the annual cost of non-communicable diseases and mental health—equal to ZAR 75 per year per person (Charman et al., 2024). Finally, we assumed that it takes 3 years for green spaces to be implemented.

INDICATOR: VALUE OF BIODIVERSITY CONSERVATION

Under the Baseline scenario, the value of biodiversity is computed based on the existence value of biodiversity in South Africa (Turpie, 2003) and adjusted to 2024 prices. Indeed, the total study area represents 10,425 ha and is classified as a fynbos biome. Turpie's 2003 study suggests that the willingness to pay for such a biome corresponded to a value of USD 2.85/ha/year in 2003, which was adjusted to 2024 and applied an exchange rate of ZAR 85/ha/year.

Under the NBI scenario, the baseline value of biodiversity is estimated to increase based on the increase in habitat quality. Indeed, this latter is estimated to increase by 3.4% (see spatial analysis). Finally, Figure B7 represents how we assume this increase would materialize.

Figure B7. Net change in biodiversity value



Source: Authors.

INDICATOR: VALUE OF CARBON SEQUESTRATION

Under the Baseline scenario, the value of carbon sequestration is 0, since we only consider the value generated by interventions. Under the NBI scenario, the value of carbon sequestration is based on the social cost of carbon and the wetland areas created. In other words, we used the following equation:

$$\begin{aligned}&\text{Value of carbon sequestration}\\&\quad= \frac{\text{Number of square metres of wetland implemented}}{\text{Square metre to hectare conversion}}\\&\quad\times \text{Average carbon sequestration rate of wetlands} \times \text{Carbon to } CO_2 \text{ multiplier}\\&\quad\times \text{Unit value of } CO_2 \text{ in USD} \times \text{Exchange rate from ZAR to USD}\\&\quad= \frac{1{,}684{,}914}{10{,}000} \times 0.77 \times 3.7 \times 15.6 \times 18.5\end{aligned}$$

Note that the value average carbon sequestration rate of 0.77 tonnes of carbon/ha/year (Cheng et al., 2020) and a social cost of carbon of USD 15.6 USD per tonne of CO_2 (Ricke et al., 2018) both represent averages. Finally, the materialization of this latter benefit only takes place after 3 years.

INDICATOR: TAX REVENUE FROM PROPERTY PREMIUM

Under the Baseline scenario, the tax revenue from a property premium considered comes from the areas slated for transformation into open green spaces. Indeed, we estimated the area composed of formal settlements that are within a buffer zone of 500 m. Based on this total land area of 1,394,094 m^2, we estimated the number of buildings and their associated value (see “cost of flood damages – formal settlement” for more details). Finally, we applied the municipal rate of 0.77% to this value. In other words, we used the following equation:

$$\begin{aligned}&\text{Tax revenue from property premium}\\&\quad= \text{Formal settlement area within 500m}\\&\quad\times \text{Number of formal settlements per unit of land}\\&\quad\times \text{Average size of formal settlements} \times \text{Unit value of formal settlements}\\&\quad\times \text{Municipal rate on residential properties}\\&\quad= 1{,}394{,}094 \times 0.0025 \times 100 \times 1{,}500 \times 0.77\%\end{aligned}$$

Under the NBI scenario, we assumed that the Baseline property value would increase by 10% after 8 years (final year of project implementation).

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