DRAFT ECONOMIC AND/OR FINANCIAL ANALYSES (WORD AND EXCEL FILES, TO EXPLAIN METHODS AND ASSUMPTIONS) – (FINAL-V1.2)

Provision of Project Preparation Services to the South African National Biodiversity Institute (SANBI) through the GCF Project Preparation Facility (PPF)

1 April 2025

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LIST OF ABBREVIATIONS

Acronym	Definition
AAD	Average Annual Damage
AEP	Annual Exceedances Probability
BCR	Benefit Cost Ratio
CBA	Cost-Benefit Analysis
DM	District Municipality
DFFE	Department of Forestry, Fisheries and Environment
DFFE: EP	Department of Forestry, Fisheries and Environment: Environmental Programmes
EbA	Ecosystem-Based Adaptation
Eco-DRR	Ecosystem-Based Disaster Risk Reduction
EIRR	Economic Internal Rate of Return
ENPV	Economic Net Present Value
GCF	Green Climate Fund
GIS	Geographic Information System
IAP	Invasive Alien Plant
IRR	Internal Rate of Return
NPV	Net Present Value
SALC	South African Landcover
SANBI	South African National Biodiversity Institute
SDR	Social Discount Rate
SSP	Shared Socioeconomic Pathway
USD	United States Dollar
WRC	Water Research Commission
WUA	Water User Association
WWF	World Wide Fund for Nature

EXECUTIVE SUMMARY

In the feasibility study, a list of interventions were identified, across five District Municipalities. Of these, four sites were selected for further consideration for the final Funding Proposal, being Alfred Nzo, Ngaka Modiri Molema, Ehlanzeni and Sekhukhune. The interventions aim to address land degradation associated with floods and drought against three principles:

- Reducing the velocity of runoff water (and in so doing, reduced the energy to erode and carry soil)
- Increasing the infiltration rate of water into the soil
- Dissipating the kinetic energy of raindrops before they impact on the soil (Lotter, et al., 2009).

The subsequent component of the assessment involved evaluating the financial and economic feasibility of the proposed interventions, with the objective of demonstrating the economic viability of implementing the proposed EbA. The intervention areas have a combination of vulnerable built infrastructure assets, such as bridges and dams, and ecological infrastructure. ***This report provides a formal analysis of the economic costs, benefits, and the rates of return associated with the proposed interventions to demonstrate their potential for climate adaptation within the South African context , utilising a high-level cost-benefit analysis (CBA).***

The estimates of costs and benefits associated with the packages of interventions were profiled over a 20-year assessment period and then discounted using a social discount rate of 6% in the base case scenario. Interventions were assumed to be implemented over an 8 eight year period with capital cost outlays being incurred in seven-years , starting in 2025. Benefits streams start to accrue incrementally until 2032, at which point they accrue fully. Four return periods were assessed and aggregated, in line with the hydrological input data provided: 1:5; 1:10; 1:50; and 1:100. The benefits of the proposed interventions are estimated as the difference between the situation with climate change (two climate change scenarios are examined under SSP5 at the 50th and 90th percentile) with the proposed interventions, and the situation with climate change but no interventions.

The outcomes of the analysis are shown in the tables below, considering the 50th and 90th percentile climate change projections.

Table 0-1: Cost-benefit outcomes (base case) – 2024 values at the 50th and 90th Percentile projections

	Totals (50th Percentile)	Totals (90th Percentile)
Total costs of interventions (US$, million, undiscounted)	18.75	18.75
NPV (US$, million, discounted)	14.69	65.16
Benefit cost ratio	1.94	5.19
EIRR %	16.89%	49.65%

The net benefits of EbA interventions are strongly influenced by the substantial avoided damage costs and provisioning of raw materials. While costs related to gully rehabilitation and vegetation restoration initially reduce returns, these are offset by the long-term benefits and critical risk mitigation they provide. The overall project result is driven by sites which consist of higher hectarage of rehabilitated grasslands as well as more bridge and dam assets than other project sites. Benefit results for the sites use conservative estimates, as the ecosystem benefits are aligned to the hydrologic modelling which looked at the provisioning and exist and bequest ecosystem services of grasslands only. The results present a positive case for an adjustment to the sites in project implementation to include more built infrastructure assets and larger areas, and implement more detailed catchment modelling to understand and quantify the damage and opportunities, beyond dams and bridges, to grasslands.

Key outcomes of the economic evaluation of the interventions showed:

- **Modest return on investment:** At the 50^{th} percentile the project delivers a Net Present Value (NPV) of USD 14.69 million and a Benefit-Cost Ratio (BCR) of 1.94, demonstrating that every dollar invested yields 1.94times the return. An Internal Rate of Return (IRR) of 16.89% reflects a robust and economically efficient investment that modestly exceeds typical discount rates. At the 90^{th} percentile the project delivers a Net Present Value (NPV) of USD 65.16 million and a Benefit-Cost Ratio (BCR) of 5.19 , demonstrating that every dollar invested yields 5.19 times the return. An Internal Rate of Return (IRR) of 49.65% reflects a robust and economically efficient investment that modestly exceeds typical discount rates.
- **Mitigating Loss and Damage:** The interventions collectively avoid damage costs of between 44 million and 142 million USD (undiscounted). Major contributors to these savings include avoided damage to bridges and dams, reduced accessibility and travel time delays due to climate change, and a sediment yield reduction resulting in avoided costs due to sedimentation.
- **Provisioning ecosystem services** are the largest contributor to benefits amounting to 15 million USD (undiscounted), underscoring the value of sustainable management practices for long-term natural resource availability.
- **Key cost drivers:** Among the interventions, gully rehabilitation through gabions (USD 8.71 million) and restoring riparian vegetation (USD 2.37 million) represent the most significant investment costs, critical for stabilizing degraded landscapes and enhancing water retention.
- **Rangeland and grazing management interventions** (e.g., contour barriers, fencing, rotational resting) contribute most significantly, not only to avoided sedimentation costs but also to landscape restoration and resilience-building for communities reliant on these areas for livelihoods.
- **Alien invasive clearing interventions** generate indirect benefits through flood mitigation and reduced sedimentation, presented as avoided damage costs.
- Overall CBA results under climate scenarios at the 50^{th} and 90^{th} percentile are net beneficial, with higher benefits demonstrated in the 90^{th} percentile climate change event, therefore indicating that **interventions are appropriate for climate change adaptation at middle of the road and worst case climate projections.** Evidence of climate change in recent months indicate that climate projections at the upper quartile are likely to be most aligned with future climate scenarios, suggesting that results of the climate analysis at the 90^{th} percentile are particularly applicable to the SANBI project context.

The underlying calculations of cost and benefit estimates are detailed in a CBA model which is available as a separate Excel workbook. All assumptions and data sources are clearly noted in the model, together with a number of explanatory notes. This report sets out:

- The approach to, and scope of, the cost-benefit analysis (CBA)
- The nature and significance of anticipated benefits (primary and ancillary) resulting from the proposed interventions, including the methodologies used to quantify and value benefits where this was possible.

- The outcomes of the CBA, represented in terms of key decision metrics (NPV, Economic Internal Rate of Return and Benefit Cost Ratio), including an analysis of the sensitivity of the outcomes to changes in the underlying assumptions and important caveats and limitations to consider in the interpretation of the results.

It should be noted that, owing to data limitations, the cost and benefit estimates are necessarily high level and are intended to be indicative only of the net benefit derived from EbAs.

It is also important to note that the sites and interventions assessed in this report are for the sites selected during feasibility. Due to the results from this CBA, it was recommended that the sites be expanded and built infrastructure included. As such, the sites and interventions put forward in the funding proposal have been adjusted when compared to those in this report and site finalisation will need to be undertaken during the inception phase of the Eco-DRR project. More detailed analysis of costs and benefits will be undertaken during inception once the sites and interventions have been finalised.

1 Introduction

1.1 BACKGROUND

The impacts of climate change are already apparent across South Africa with the increasing frequency and severity of extreme events such as floods, droughts and wildfires. Climate projections show that this trend, including changes in intensity and unpredictability, will continue. These hazards are escalating the risks of significant impacts on South Africa's wider economy and both the urban and rural livelihoods and its most vulnerable populations. In line with climate projections, this aligns with between SSP5 at the 50^{th} and 90^{th} percentile climate trajectories.

In response, South Africa's National Biodiversity Institute (SANBI) is preparing a full application, with the associated supporting documents, to the Green Climate Fund (GCF) to fund a programme to scale up ecosystem-based approaches to managing climate intensified disaster risks in vulnerable regions of South Africa (the Eco-DRR project). Ecosystem-based approaches are broadly accepted as a cost-effective and sustainable means to promoting resilience in communities vulnerable to climate change intensified drought, flood and wildfire and this project will utilise ecosystem-based approaches to reduce the impacts of climate change to the benefit of 5 481 886 people. This will be achieved through the rehabilitation of vulnerable catchments, the integration of ecosystem-based approaches into settlement planning and disaster risk reduction (DRR), and the creation of an enabling environment that unlocks private sector finance and scales best practices across South Africa.

This report presents an analysis of the economic costs, benefits and rates of return associated with the proposed project interventions across four District Municipalities (DMs). This report is an input to the wider feasibility study and the full funding proposal.

1.2 STRUCTURE OF THE REPORT

The structure of the report is as follows:

- **1. Introduction:** includes a brief description of the project background to provide the context in which the economic analysis has been undertaken, and the purpose of the report.
- **2. Approach:** details the methodology used for the economic analysis including the process for identifying and prioritising the proposed interventions, the scope of the analysis, and methodology for costing and valuing the benefits of site-level interventions.
- **3. CBA Results:** presents the CBA results for the project as well as the overall conclusions from the economic analysis and the investment case for the project as a whole.

2 Approach

2.1 SITE SELECTION

The process for selecting the four sites for the funding proposal was a multi-phase effort spanning from 2022 to 2024, ensuring alignment with climate rationale and stakeholder inputs. Initially, seven district municipalities (DMs) were identified at the concept note stage. A multicriteria evaluation process and stakeholder engagements reduced the selection to five DMs (Alfred Nzo, Joe Gqabi, Ehlanzeni, Sekhukhune and Ngaka Modiri Molema), each with two priority Quaternary Catchments (QCs). Climate Risk and Vulnerability Assessments (CRVA), hydrological modelling for the 2 QCs, and site visits coupled with workshops were conducted in these five DMs to co-identify sites and potential interventions with local-level stakeholders. An initial cost-benefit analysis' (CBA) results supported the selected interventions. However, in 2024, stakeholder feedback led to the exclusion of Joe Gqabi DM and adjustments to sites in the remaining 4 DMs, ultimately focusing on four DMs, Alfred Nzo, Ngaka Modiri Molema, Ehlanzeni and Sekhukhune, for the final funding proposal. This phased and iterative approach ensured the final site selection was informed by strong scientific, technical, and economic justifications, as well as practical implementation considerations based on stakeholders' inputs. More details regarding site selection can be found in Annex 2: Feasibility Study.

2.2 IDENTIFICATION OF PROPOSED INTERVENTIONS

As part of the feasibility study, various hard and soft ecosystem-based adaptation (EbA) interventions were identified to address key issues of drought and flooding, for each case study site, with particular regard to their ability to:

- Reduce the velocity of runoff water (and in so doing, reduced the energy to erode and carry soil)
- Increase the infiltration rate of water into the soil
- Dissipate the kinetic energy of raindrops before they impact on the soil (Lotter, et al., 2009).

In practice, this involved:

1. Land cover mapping for 12 cover classes and configuration of hydrological models for each of the catchments across each case study site,
2. Interventions were mapped within each sub-catchment across the five districts involved. This was done by applying the land cover and degradation geographic information system (GIS) datasets to identify areas where rehabilitation and restoration interventions should be targeted. These were then refined through an iterative approach involving a visual assessment using Google Earth and comparing these against the GIS datasets.
3. Landcover mapping and hydrological models were then re-configured to model the impacts of proposed Eco-DRR interventions. The level of impact of the proposed interventions was evaluated through a comparison of the simulated timeseries of runoff depths from the respective hydrological response units, at each of the sites.

The costs of different interventions can be substantial; therefore a combination of interventions were identified for each district within the project considering the following:

- Cost of the different interventions (e.g. areas where high-cost interventions such as gabions and concrete weirs could be kept to a minimum).
- Focus on degraded areas higher up in each catchment where possible.
- Prioritise efforts towards areas where degradation and flood impacts can potentially impact on local built infrastructure (e.g. roads, houses) and people.
- Where possible distribute the interventions within different parts of the catchment to distribute the benefits associated with employment, learning and capacity building opportunities.

2.3 APPROACH TO THE CBA

The CBA was conducted across for District Municipalities (DMs); Ngaka Modiri Molema, Alfred Nzo, Ehlanzeni, and Sekhukhune DMs. The goal was to assess the economic feasibility of implementing EbA measures across areas and built infrastructure assets to mitigate the impacts of climate change.

This analysis evaluated the costs and benefits of a set of selected ecosystem adaptation interventions for each DM assessing their economic viability under varying climate change scenarios. The methodology sought to marry economic analysis with climate model information, considering different climate change scenarios to inform robust decision-making within climate change uncertainty.

This assessment aimed to determine whether the benefits of proposed interventions exceed the associated costs (including opportunity costs) over a 20 year assessment period, across the median (50^{th}) and 90^{th} percentiles of projected climate change events under Shared Socioeconomic Pathway (SSP) 5 – 8.5.

In each of the project areas, the following key steps were applied in undertaking the CBA:

a) **<u>Definition of an appropriate baseline or 'without intervention' scenario</u>** against which the impacts of the proposed project's interventions can be compared over their lifetime. The baseline recognises that the current situation will not remain static in the absence of the interventions given the influences of factors such as changes in climate, demography and socio-economic conditions. The baseline is also used to derive a measure of the opportunity costs associated with the proposed interventions, particularly insofar as these may relate to foregone agricultural production and ecosystem services.The baselines used for each of the case studies considers both the direct and indirect costs of climate change.

   Direct impacts of weather events are assumed to directly affect built infrastructure such as bridges and dams, crops private housing and commercial/industrial assets. Specifically considering flooding, the extent of the impact is determined by the replacement value of assets. These values have been based on reconstruction/ replacement costs observed in similar projects in South Africa.

   The **indirect impacts** of extreme weather events are the cumulative effect of weather events on downstream services produced by the respective assets. For example, bridge disruption due to flooding would result in travel route closures and or limited route accessibility for business and school travellers. This would result in diverted travel and transportation of goods to other modalities such as walking, increasing average travel time and forgone school trips.

b) Definition of climate change scenarios. For the purposes of this study, under a climate scenario within SSP5 – 8.5 hydrological uncertainty was assessed at the 50th and 90th percentile. Both scenarios are considered in the baseline direct and indirect impacts, and resultant avoided losses and benefits of adaptation interventions. Under the climate change scenario SSP5 – 8.5 the hydrological modelling considered the 50th percentile (middle of the road or median) impacts and the 90th percentile (more extreme case) impacts. The World Bank Climate Change Knowledge Portal was used to extract extreme precipitation anomaly data.

c) Estimation of the costs (including externality effects) associated with each of the types of interventions identified. The analysis considers the whole life costs (total cost of an intervention throughout its entire lifecycle) associated with each type of intervention including:

- The **capital costs** of providing the necessary built infrastructure, or acquiring equipment, technologies and expertise for the implementation of measures;
- Ongoing **operation and maintenance** costs; and
- Any projected **unintended environmental and social costs** (disbenefits) associated with the implementation of the proposed interventions, where these are foreseen and can be reliably quantified and valued. These include, for example, loss of productive land (e.g. where implementation of vegetated areas results in loss of agricultural output).

The approach to costing interventions involved a review of the literature and local knowledge specific to South Africa for ecological infrastructure interventions, drawing on the following:

- Meat Naturally / Conservation South Africa's Herding for Health Programme
- Department of Forestry, Fisheries and the Environment: Environmental Programmes' (DFFE: EP's) Norms and Standards, published papers (invasive alien plant (IAP) clearing, wetland rehabilitation) (SANBI, 2014)
- Tsitsa Project Documents
- Studies on the Breede Catchment for riparian restoration
- Monitoring data from Institute of Natural Resource's work in the uMkhomazi (grazing, rehabilitation, conservation agriculture)
- uMngeni Resilience Project (fire breaks and block burns)
- Land Degradation Assessment in Drylands Project Document (best practices for sustainable land management)
- Recent costings from the Water Research Commission's National Siltation Management Programme (unpublished)
- Personal communication with Michael Braack of DFFE: EP

The interventions which are considered, and their associated costs are listed in Table 2-1[1].

[1] Costing includes implementer fees (local project manager / implementer); training of restoration teams; materials and equipment (including personal protective equipment; wages (pegged at the current minimum wage rate, not EPWP rates, which are below the legislated minimum wage); transport for restoration teams.
Costings do not provision for detailed surveys and associated professional fees, which will be required for site specific planning; stakeholder engagement and facilitation to co-create implementation plans and support to the proposed interventions.

Table 2-1: Cost estimates per area and assumptions for potential interventions applied in the Eco-DRR case study sites

Intervention focus area	Description	Unit	Cost per unit (ZAR)		Assumptions	Cost per ha (ZAR)	
			Low	High		Low	High
IAPs	Alien clearing	ha	38 000	38 000	Focussed only on riparian zones and infested areas. Includes seven follow ups. Wage cost is for private sector funding (i.e. paying legislated minimum wage, not Expanded Public Work Programme rates); 20-person days per ha for initial clearing; 11-person days per ha per follow up.	38 000	38 000
IAPs	Rehabilitation - bioturbation	ha	20 000	25 000	Cattle are kraaled overnight at a density of ~1LSU / 3 sqm	20 000	25 000
IAPs	Restore riparian vegetation	ha	30 000	30 000	Active restoration and management. Focus on erosion prone areas and areas where runoff is focussed. This includes convergence zones associated with roads and river crossings; culverts discharging road runoff where erosion can be initiated / exacerbated.	30 000	30 000
Gullies	Gully rehabilitation - Gabions (including earthworks)	m3	7 500	7 500	32 cubic metres per gabion site; gabions every 40m within a gulley; assume a gulley is 5 metres wide. Cost is per ha of gulley (i.e. 5m wide and 2 000 long to give 10 000m2 (1ha) of area)	12 300 000	12 300 000
Rangelands - all	Ecorangers - rotational resting Rangeland / Grazing management -	per 2 500 ha	130 000	150 000	management support for Ecorangers provided through separate budget. R30 000 per 2500ha	52	60
Rangelands - all	Fencing - Rangeland / Grazing management (Rotational Resting)	metres	150	200	Square camps (i.e. 400m perimeter per ha of land)	60 000	80 000
Rangelands - all	Firebreaks (Rotational Resting) Rangeland / Grazing management -	kilometre	2 700	3 000	Strategic fire break protects 200ha at a time (i.e. perimeter of 6000m); 20 of 200ha blocks require firebreaks	1 620	1 800
Rangelands - all	Planned burning (block burns) (Rotational Resting) Rangeland / Grazing management -	kilometre	2 700	3 000	Spring burn of 25% of protected blocks per annum (i.e. 5 blocks per annum from above)	405	450
Rangelands - degraded	Contour barriers - Brushpacks	metres	50	400	One brushpack every 3 horizontal metres across one hectare	350 000	500 000
Rangelands - degraded	Contour barriers - Vetiver hedgerows - gullies and eroded areas	metres	50	150	One vetiver hedgerow every 3 horizontal metres	150 000	300 000

Intervention focus area	Description	Unit	Cost per unit (ZAR)		Assumptions	Cost per ha (ZAR)	
			Low	High		Low	High
Rangelands - degraded	Revegetation / reseeding	hectares	30 000	44 000	Hand preparation (furrows) and hand broadcast at x kg of 'summer veld mix' (MacDonald's Seed) on degraded land and allow for follow up seeding where mortality occurs	30 000	44 000
Rangelands - degraded	Rainwater harvesting - Zai Pits (pitting)	ha	31 134	31 134	Rainwater harvesting ponds at 3m x 4m spacing, staggered across one hectare and seeded with native grass species	31 134	31 134
Wetlands	Wetland rehabilitation - soft	ha	5 000	10 000	Contour bunds and revegetation to 'push' wetland back towards a functioning system - bunds every 10-20m. Pole diversion barriers in pathways, revegetation, small gully and head cut rehabilitation	5 000	10 000
Wetlands	Wetland rehabilitation - hard (concrete weirs)	m3	9 000	12 000	Concrete weirs in eroded and degraded wetlands (gullies and head cuts) - one weir of 40m3 with 100m interval between weirs. Assume gully / head cut width is 5m. Cost is per ha of gully / head cut (i.e. 5m wide and 2 000 long to give 10 000m2 (1ha) of area)	7 320 000	7 320 000

It is important to note that the CBA serves to demonstrate the effectiveness and cost-efficiency of implementing Eco-DRR interventions to address key climate hazards, specifically across different areas and consisting of different built infrastructure asset quantities. Data availability from gauges etc. at respective sites is limited, requiring the hydrological modelling to draw on assumptions where necessary. The associated cost estimates for the rehabilitation interventions were determined under the following limitations:

- The assessment was carried out at a desktop level with limited infield verification having taken place (apart from confirming that the specific types of degradation do occur in the identified priority areas). Detailed planning (including infield assessments) is necessary in the implementation phase to locate and identify priority rehabilitation areas within the respective case study areas and to determine more refined cost estimates for the rehabilitation activities;
- The GIS datasets used were applied without field verification and in some cases, the differentiation between different types of degradation could vary in the field (e.g. areas classified as cultivated lands could actually be old fallow lands; or gully area could be larger than is indicated by the gully dataset)
- A standard rehabilitation approach was adopted for each category type of degradation, using a standard intervention type and spacing / volume;
- Dimensions such as slope and depth of gullies could not be derived from the GIS, and this may influence the estimated cost and approach to the rehabilitation.

d) <u>Estimation of the economic, social and environmental benefits of the proposed interventions</u>

The IPCC Fourth Assessment Report defines adaptation benefits as “the avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures”. While many of the benefits are simply the averted losses and damages identified and quantified in step (a) above, some of the adaptation interventions, if carefully designed, may also deliver important co-benefits such as habitat for biodiversity and existence and bequest ecosystem serviced. Unquantified, but noteworthy co-benefits include improved communal farming outcomes, and carbon mitigation etc. It should be noted that the nature and value of benefits from the same adaptation intervention may differ from one location to the next depending on, for example, existing vulnerability and the size of the beneficiary population and the physical and natural assets at risk.

Benefits have been quantified and valued in monetary terms as far as possible and where it is proportionate to do so, based on a combination of the hydraulic modelling outputs, analysis presented elsewhere in the Feasibility Study, and a review of the relevant literature, including statistical publications from the relevant provincial government departments. In cases where it has not been possible to quantify and value certain material benefits (e.g. where the detailed data necessary to derive estimates is not available), these benefits (and their likely significance) have been described in either quantitative (where possible) or qualitative terms.

The types of interventions being proposed are anticipated to give rise to a range of market and non-market benefits and co-benefits.

- **Market benefits** include, for example, avoided or reduced flood damage costs, avoided indirect damages (such as avoided travel time delays for work and school travellers resulting from accessibility of affected bridges), and water quality improvements associated with reduced sediment yields. Quantifiable market benefits have been valued using established market prices.
- **Non-market benefits** include impacts on ecosystem services such as provision of raw materials, and existence and bequest ecosystem services. These benefits are more challenging to value as they rely on scientific understanding and modelling of cause-effect relationships as well as an understanding of local preferences (demand) for the services and benefits in question. The non-market benefits have been described in qualitative terms and, where possible, valued with reference to values derived in other studies in similar contexts elsewhere, where available and relevant.

The benefits of the proposed interventions for each case study were selected based on three key elements:

1. Local context (for example, high reliance on subsistence livestock warrants an examination of proposed interventions impact on livestock farming and productivity).
2. The level of detail and suitability of hydrological modelling.
3. The availability of input data, including relevant market prices (or suitable economic proxy values).

Overall, the proposed interventions are expected to benefit vulnerable communities in the respective project areas through reduced flood risks (including associated improvements to accessibility), and increased provisioning ecosystem services of grasslands. Many of these benefits are underpinned by improved grassland management – broadly, practices that minimise the adverse effects of fire and drought and use improved grazing management techniques that maximise grassland quality.

The estimation of the ecosystem services is conservative as it only considers grasslands based on hydrological modelling. Wetland and IAP clearing ecosystem services have not been quantified due to modelling and data limitations, therefore higher co-benefits should be expected for EbA interventions than those presented in this report.

Further details of the methodology and valuation of direct and indirect benefits associated with each intervention are provided in Appendix A.

e) **Discounting and application of the appropriate decision rules**

The costs and benefits are estimated over a 50-year period, starting in 2025. Net benefits are calculated in terms of Economic Net Present Value (ENPV) and Economic Internal Rate of Return (EIRR) using a social discount rate (SDR) of 6%. While a range of discount rates are evident in available literature, the discount rate is based on Peacock et al (2023) who showed that the vast majority of ecological restoration projects in South Africa utilise a 6 percent SDR.

f) **Sensitivity analysis**

Sensitivity analysis is performed to test the sensitivity of the outcomes to changes in discount rate and climate scenario.

2.4 QUANTIFICATION OF BENEFITS METHODOLOGY

2.4.1 Avoided Damages

Valuation basis

The valuation of avoided damages is dictated by the coverage and suitability of available hydrological input data. In this regard, the economic valuation utilised the available hydrological input data in the following ways.

First, avoided direct flood damages are assessed for key built infrastructure (bridges, culverts and dams) only, since, according to the available flood hazard input data which was targeted towards understanding the magnitude of changes in high-flow (flood) hydrology dynamics in the catchment, agricultural, housing and industrial/commercial land covers appear to be unaffected by flooding (i.e., the flood lines do not reach irrigated land nor private housing, even under a 1:100 event).

Second, the hydrological input data dictated that damage be calculated by the number of assets exposed to the flood event rather than by the area inundated (ha). Available damage value estimates at the asset level are difficult to obtain. Average damage values are therefore based on relevant (re)construction costs observed in similar projects (in terms of size and location) in South Africa (**Error! Reference source not found.**). These damage values represent those observed under baseline conditions.

Table 2-2: Average flood damage values (construction costs, 2024 prices)

	Bridge, per asset	**Dam**, *per asset*
ZAR	19,933,028*	775,659,168†
USD	1,080,381	42,041,147

* Based on average construction costs of a typical 100m-long, 14m-wide bridge in South Africa. Values sourced from two separate studies (contained in Excel model).
† Based on a conservative cost estimate of a small-medium dam in South Africa.

Third, the hydrological modelling input data provided does not disaggregate flooding hazard or extent by flooding depth, nor by return period (magnitude of event)[2]. It is assumed that no damage occurs to built infrastructure under the 1:100 event return period as bridges and dams have been designed to withstand these events. Only the total number of assets affected by 1:100 return period flooding in the baseline (no intervention) are provided (**Error! Reference source not found.** above). Without depth-disaggregated information, this analysis assumes that under the without-intervention scenario, these vulnerable assets are damaged 40% of its total construction value ('full damage'); with intervention, damage is reduced to 'partial damage' (10% of total construction value for bridges, and 20% for dams). These damage factor assumptions are recommended upon hydrological modelling advice. They are intended to be updated with detailed hydrological modelling at a subsequent design phase.

Fourth, the hydraulic model estimated the extent of flooding discharge for the current baseline climate scenario (with and without interventions). Forecasted future flooding extent, however, was not available. In lieu of this information, simulated future climate change discharges were sought by equating the return periods for rainfall annual exceedances probabilities (AEPs) to flooding discharges. This yields an important characteristic for this economic assessment of the present value of avoided damages (typically assessed as depth- and return period-disaggregated AADs multiplied by AEPs): owing to the absence of depth- and return period-disaggregated AADs (a result of absent forecasted flooding extent information), the change in present value damages from current climate to future climate scenarios (both 50th and 90th percentiles) is embedded not in the AAD (which stays constant), but in the change in AEPs.

Overall, the reduced flooding benefits associated with the proposed interventions are calculated as the difference between the damage costs with and without the respective interventions under the two future climate change scenarios. These benefit estimates were then aggregated across return periods and annualised (to obtain an estimate of the equivalent annual damage costs) using the appropriate probability of occurrence (or AEP). Four return period are assessed: 1:5, 1:10, 1:50 and 1:100.

The tables below presents the total benefits of avoided direct damages to key infrastructural assets associated with the proposed interventions at the 50th and 90th percentiles. Implementation of interventions occurs over 7 years of the 8 year project period. Therefore, it is assumed that benefits increase incrementally and equally over the 7-year period until 2032 at which point benefits start to accrue fully. Note that total avoided damage costs disaggregated by individual intervention types are not presented since it requires implementation of all types concurrently to yield avoided damage benefits.

For a more detailed understanding of input parameters and calculations used, please see the accompanying Excel model.

Table 2-3: Total value of avoided direct damages, USD, 2024 prices, undiscounted – 50th Percentile climate change scenario

Avoided damage costs, USD (2024), undiscounted	**Ngaka Modiri Molema**	**Alfred Nzo**	**Ehlanzeni**	**Sekhukhune**	**Project level:** across all four project sites
Bridges	185 095	123 396	123 396	678 681	**1 110 568**
Dams	-	-	-	1 710 904	**1 710 904**

[2] Hydrological modelling focussed on assessing impacts associated with the top ten simulated discharge events only.

Table 2-4: Total value of avoided direct damages, USD, 2024 prices, undiscounted – 90th Percentile climate change scenario

Avoided damage costs, USD (2024), undiscounted	Ngaka Modiri Molema	Alfred Nzo	Ehlanzeni	Sekhukhune	**Project level:** across all four project sites
Bridges	1 110 568	740 379	740 379	4 072 084	**6 663 411**
Dams	-	-	-	10 265 423	**10 265 423**

2.4.2 Avoided Costs of Indirect Damages

Benefits of measures

The damage to key infrastructural assets (namely bridges) explored above also presents indirect damage to local communities in the form of lost or diminished accessibility for travellers using the bridge, which in turn incurs travel time delays and associated costs. The proposed project interventions are intended to reduce flooding hazard to the bridges, thereby enabling accessibility for its users to engage in key economic activities.

Valuation basis

Improved accessibility is examined for business and school-going travellers. While accessibility is relevant and important for those travelling to healthcare, funerals and other economic activities, values for these users could not be quantified with reasonable confidence owing to data limitations.

The table below presents estimates of the number of households indirectly impacted by a damaged/impassable bridge. Impact is defined as moderate (where alternative access routes are available but at a journey travel time delay – assumed to be a 50% increase in journey travel time) or high (where no alternative routes are available, preventing access and therefore business and school participation). Under the baseline scenario, bridges are fully damaged (occurring in line with the relevant AEP) are therefore inaccessible while being reconstructed over a 1 year period. Under the intervention scenario, on the other hand, damage is reduced to 'partial damage' where inaccessibility is limited to 2 week only – as recommended by the hydrological modelling team. The duration of inaccessibility determines the number of trips business and school travellers forego. Between baseline and intervention scenarios, the number of foregone business trips per business traveller reduces from 502 to 20, while the number of foregone school trips per learner reduces from 400 to 20, based on the average number of working and school days per year and return[3] journeys.

Table 2-5: Direct and indirect impacts associated with built infrastructure vulnerability within the DM's

DM	Directly Impacted Built Infrastructure			Indirect Impacts		
		Bridges		Household Affected by Accessibility		
	Dams	Number of Bridges	Road Class Associated with the Bridge	Moderate Impact (alternative access routes available)	High Impact (no alternative access routes)	Water Supply
Alfred Nzo	-	2	5	644	-	-
Ehlanzeni	-	2	2 and 5	435	-	-
Sekhukhune	1	11	2 and 5	4 475	-	Water supply to

[3] A return journey comprises two trips per day.

						the Jane Furse Area (5.54 Ml/day)
Ngaka Modiri Molema	-	3	5	-	82	

The economic value of travel time for business travellers is taken as the national minimum wage. For school travellers, average future earnings associated with schooling participation is used, based on a 2020 Organisation for Economic Co-operation and Development study that examined the impact of COVID-19 school closures on an individuals' lifetime income. The study showed that a 1.9% reduction in individual lifetime earnings – pooled across the United States of America, Greece and Singapore – is associated with a 25% (or 50 days) loss of a schooling year (Hanushek & Woessmann, 2020). This economic value of travel time for school travellers is combined with average years in paid work (23.55 average across males and females) and the nominal minimum wage.

Both economic proxies are used alongside average travel and number of trips per mode (only walking and taxi/car/bus modes were examined) to yield the annual value of avoided indirect impacts to accessibility and travel time. Present values are found by multiplying the average annual value by the relevant AEPs (since the occurrence of (avoided) damage is dependent on the probability of a flooding event).

The tables below presents the total benefits of avoided indirect damages to accessibility and travel time associated with the proposed interventions at the 50th and 90th percentiles. Implementation of interventions occurs over 7 years of the 8 year project period. Therefore, it is assumed that benefits increase incrementally and equally over the 7-year period until 2032, at which point benefits start to accrue fully. For a more detailed understanding of input parameters and calculations used, please see the accompanying Excel model.

Table 2-6: Total value of avoided indirect impacts to accessibility and travel time, USD, 2024 prices undiscounted – 50th Percentile climate change scenario

	Ngaka Modiri Molema	**Alfred Nzo**	**Ehlanzeni**	**Sekhukhune**	**Project level:** across all four project sites
Avoided indirect impacts, USD (2024), undiscounted	1 319 388	5 838 914	3 770 139	28 692 225	**39 620 666**

Table 2-7: Total value of avoided indirect impacts to accessibility and travel time, USD, 2024 prices undiscounted – 90th Percentile climate change scenario

	Ngaka Modiri Molema	**Alfred Nzo**	**Ehlanzeni**	**Sekhukhune**	**Project level:** across all four project sites
Avoided indirect impacts, USD (2024), undiscounted	3 710 779	16 421 946	10 603 516	80 696 881	**111 433 123**

Note that the same limitations of present value damage calculations observed in avoided direct damages – linked to the absence of simulated flooding extent data – occur in the calculation of avoided indirect damage.

2.4.3 Improved Water Quality (Reduced Sedimentation)

Benefits of measures

As outlined in the Feasibility Study, soil erosion is a significant issue for the project sites. Increased sediment yields in surface runoff reduce overall water quality and diminish the total storage capacity of water bodies such as dams. The proposed sustainable land management interventions are envisioned to reduce this sediment yield, thereby presenting benefits measured in terms of avoided costs associated with water quality treatment, dredging or investment in additional storage capacity.

Assessing changes in sediment yield is important, despite the fact that only Sekhukhune DM has a large dam in its study area. Mander et al (2008) argue that reduced sediment yields are even more valuable in rivers without large dams, as large dams are usually over-engineered to take account of silt build-up that helps to regulate the sediment loads in lower reaches. Conversely, a system with no large dam is more reliant on additional baseflow during winter months since there is no engineered storage to capture the stormflow and to regulate the flow of the water from that point going forward.

Valuation basis

The economic valuation of reduced sediment yield utilises the hydrological input data from, most notably the simulated sediment loss scenario analysis results as well as the analysis of land cover distributions.

The economic value of reduced sediment yield is assessed in terms two different ways, depending on the project location. The first approach – used for Ngaka Modiri Molema, Alfred Nzo and Ehlanzeni DMs, owing to the absence of dams – views reduced sedimentation in terms of avoided dredging costs, based on the approach used in Mander et al (2008). Siltation affects the carrying capacity of water outlets, or indeed areas higher along the river course. Removing this siltation incurs an economic cost of R32 (or $1.8) per m^3 of siltation in 2024 prices (Mander, et al., 2008). This approach equates the quantity of sediment yield to siltation. The second approach – used for Sekhukhune DM only owing to its impacted dam – examines reduced sediment yield in terms of the replacement cost of lost dam storage capacity (e.g. through raising the dam wall, constructing a substitute dam at a new site to make up the reduction in capacity or constructing check dams). This was done by estimating the amount of storage that would have to be constructed to prevent a similar amount of sediment from reaching downstream aquatic environments, using an average capital replacement cost of R11.9 (or $0.6) per m^3 (Turpie, et al., 2021).

Notably, the difference in sediment yield between with and without interventions is provided for current climate scenario only. However, the positive relationship between rainfall and sedimentation suggests that forecasted sedimentation impact should rise under future climate change scenarios. To account for this, future sediment impact is multiplied by the % growth rate in rainfall exceedance probability compared to the current climate baseline. Sediment impact is not multiplied by AEP - as is the case under avoided direct and indirect flood damages - since sedimentation is not determined exclusively by flooding (it is rather a function of rainfall and land/topographical and soil characteristics). Additionally, using the probability of flooding events (AEP) implies using its inverse: the probability of flood event not occurring, which would not reflect the current reality where sedimentation occurs even without large flooding events. Therefore, the sediment yield benefit of proposed interventions is the difference between future climate change sedimentation damages with and without intervention, presented by the aggregation of return events.

The table below presents the total benefits of avoided direct sedimentation damages to key infrastructural assets associated with the proposed interventions at the 50th and 90th percentiles. Implementation of interventions occurs over 7 years of the 8 year project. Therefore, it is assumed that benefits increase incrementally and equally over the 7-year period until 2032 at which point benefits start to accrue fully. For a more detailed understanding of input parameters and calculations used, please see the accompanying Excel model.

Table 2-8: Total value of avoided costs from reduced sediment yields, USD, 2024 prices, undiscounted – 50th Percentile climate change scenario

Intervention type	Ngaka Modiri Molema	Alfred Nzo	Ehlanzeni	Sekhukhune	Project level: across all four project sites
IAP removal	0	7 650	104 325	427	112 402
Gully rehabilitation	3 806	3 621	4 538	3 515	15 480
Rangeland management	84 559	116 633	85 374	1 405 726	1 692 292
Wetland rehabilitation	0	0	0	0	0
All interventions	**88 365**	**127 904**	**194 237**	**3 942**	**1820174**

Table 2-9: Total value of avoided costs from reduced sediment yields, USD, 2024 prices, undiscounted – 90th Percentile climate change scenario

Intervention type	Ngaka Modiri Molema	Alfred Nzo	Ehlanzeni	Sekhukhune	Project level: across all four project sites
IAP removal	0	57 372	782 436	3 205	**3 310 758**
Gully rehabilitation	28 544	27 158	34 037	26 359	**8 706 667**
Rangeland management	634 195	874 749	640 309	10 542 948	**6 629 710**
Wetland rehabilitation	-	0	0	-	**106 233**
All interventions	**662739**	**959279**	**1456782**	**10572512**	**18647135**

2.4.4 Provisioning and Existence and Bequest Ecosystem Services

Benefits of measures

The proposed measures are expected to deliver a wide range of ecosystem services (benefits of functioning ecosystems to people) through revegetation and sustainable land management of grasslands. The benefits may include important sources for food, building materials and provide valuable regulating services such as water treatment. This section focuses on provisioning (specifically raw materials) and existence and bequest ecosystem services emanating from improved grassland management (assumed to have been transformed from degraded/unproductive to healthy, functioning states). These have been chosen based on their relevance to project and location-specific characteristics, and to avoid double counting with the other benefits estimated in this analysis. While improved wetlands may yield increased ecosystem services, data limitations regarding the extent to which interventions improve wetland condition and functioning suggest this ecosystem cannot be valued with reasonable confidence.

Valuation basis

The value of grassland ecosystem services specifically at the project sites could not be feasibly obtained from primary data collection. Therefore benefit transfer is used. In recent years several studies have attempted to derive estimates of the total economic value provided by grasslands**.** The Ecosystem Service Valuation Database is a globally recognised database that presents value estimates for a range of ecosystem services and biomes, with value estimates presented in monetary units/ha/year to allow easy retrieval for value transfer and meta-analysis. Monetary unit values (in $/ha/year) for the grassland biome were extracted for this assessment. Given the project and location-specific characteristics, provisioning (raw materials) specifically from grasslands were selected (De Groot, et al., 2012). These values are based on 32 studies, approximately 26% of which relate to Africa. Existence and bequest ecosystem services were based on Turpie (2003)

- Value of raw materials from grasslands (materials include woody products, thatched grass), inflated to 2024 (USD): $117.6/ha/year. A clearer understanding of the extent to which community members use these services specifically at the project sites will inform the accuracy/relevance of these proxy values. In lieu of this local context, the proxy values are deemed appropriate.
- Existence & Bequest from grasslands: $12.83/ha/year, inflated to 2024 value.
- These monetary values are then applied to the average area of rangeland that is rehabilitated from a degraded state to a healthy, functioning grassland ecosystem.
- Estimates of additionality from restoration activities such as improved grassland management practices in provisioning and habitat services are scarce. A 2006 study found that restoration of natural capital from existing subsistence activities in Bushbuck Ridge, Limpopo, could produce a 177% increase in total direct consumptive provisioning services (noting though that certain services are reduced) (Blignaut & Moolman, 2006). New rangeland (ha) was assessed as productive, healthy grassland, assuming it was transformed from a degraded/unproductive baseline state. Therefore, this assessment assumes a 100% additionality factor. With this source and the general data limitations in mind, this assessment assumes a 100% additionality factor, effectively showing that provisioning and habitat ecosystem services are created with new grasslands compared with completely denuded and unproductive grasslands in the base case.

The resulting annual values are shown in the table below. These emanate entirely from the rangeland management activities. Implementation of interventions occurs over 7 years of the 8-year project. Therefore, it is assumed that benefits increase incrementally and equally over the 7-year period until 2032 at which point benefits start to accrue fully. It is important to note that ecosystem functions, the flow of ecosystem services, and the economic value to society and the economy are site specific and depend on the ecological, social and economic systems and their interactions. For this reason the value ranges in Table 2-10 need to be considered as indicative.

For a more detailed understanding of input parameters and calculations used, please see the accompanying Excel model.

Table 2-10: Total value of grassland provisioning and existence and bequest ecosystem services, USD, 2024 prices, undiscounted

	Ngaka Modiri Molema	**Alfred Nzo**	**Ehlanzeni**	**Sekhukhune**	**Project level:** across all four project sites
Value of provisioning ecosystem services (raw materials)	1 038 668	780 517	746 895	5 924 726	8 490 806
Value of habitat protection ecosystem services (gene pool protection)	113 313	133 430	127 682	1 012 833	1 387 257

2.4.5 Income-Generating Opportunities (Livestock Production)

Benefits of measures

The proposed interventions are intended to rehabilitate and sustainably manage degraded land cover to a state of healthy and productive grasslands. Given the existing extent of degraded land at the project sites, healthy grasslands present an opportunity for local farmers to improve the conditions for enhanced livestock production – an important economic activity for many households at the project sites (30% of households in Joe Gqabi DM are involved in agriculture) (StatsSA, 2015). Improved grassland management broadly aims to employ practices that minimise the adverse effects of fire and drought and use improved grazing management techniques that maximise grassland quality.

Valuation basis

The economic analysis assumes that improved grasslands (transformed from a degraded to healthy, productive state) results in increased livestock production in two key ways: first, carrying capacity of the land increases under rehabilitated grasslands, supporting higher number of livestock; and second, improved grazing and land management practices (including grazing pressure distributed equally) improves the overall quality of livestock (measured in increased livestock weight and sales price) because livestock are better fed.

The following input variables and assumptions are used to calculate the economic value of higher income from improved livestock production.

- Under baseline conditions, carrying capacity is 0.096 LSU/ha (average between severely overgrazed / close to settlements and moderate condition /middle distance). Under the intervention scenario, improved grassland and livestock management practices increases average carrying capacity by 25% to 0.12 LSU/ha[4]. It is assumed that the increase in carrying capacity potential is realised by local farmers – that is, they can afford the costs of acquiring and managing additional livestock units.
- Carrying capacity is split 50%, 40% and 10% across cattle, sheep and goats respectively.
- Average weight of livestock under baseline conditions: 380kg/cow; 40kg/sheep; and 43kg/goat. Under the intervention scenario, improved livestock management and grazing leads to livestock weight gains of 70kg in cattle (De La Vida BORAN, 2023), 10kg in sheep (ProAgri, 2022) and 7kg in goats (Louw, 2025). Impact to birthing and weaning rates are not considered in this analysis.
- Average livestock price under baseline conditions: \$1.92/kg cattle; \$2.46/kg sheep; and \$1.93/kg goat. Assuming higher quality livestock receives higher market prices, under the intervention scenario the upper bound of livestock prices are expected to increase to: \$2.89/kg cattle; \$3.44/kg sheep; and \$2.89/kg goat (Selina Wamucii, 2025).

[4] Estimates provided by the engineering team (Jon McCosh).

- 2/3rds of the total grassland area is assumed to be rehabilitated from a degraded state (severe or moderate condition in the baseline) i.e., 1/3rd of grasslands are presumed to be in 'good' condition in the baseline, and while interventions will benefit this condition further, the change is expected to be marginal[5].

The table below presents the total benefits of increased livestock income from rehabilitated grasslands. Implementation of interventions occurs over a 7-year period. Therefore, it is assumed that benefits increase incrementally and equally over the 7-year period until 2032 at which point benefits start to accrue fully. For a more detailed understanding of input parameters and calculations used, please see the accompanying Excel model.

Table 2-11: Total value of income from increased livestock production, USD, undiscounted

Increased income from livestock production (USD)	Ngaka Modiri Molema	Alfred Nzo	Ehlanzeni	Sekhukhune	Programme level: across all four project sites
Existing planned grassland expansion scenario	427 680	503 609	481 915	3 822 779	**5 235 983**

2.4.6 Non-Quantifiable Benefits

In addition to the benefits that have been quantified and valued in the preceding sections, there are a number of other important benefits that are not amenable to monetary valuation. Some of the most significant of these benefits are described below.

Water security, drought

Infiltration potential is expected to increase as a result of the project's interventions. This will improve water security for local communities by improving the water table around the project sites that builds drought resilience and climate change adaptation capacity for dry seasons. This has particularly relevant for local farmers whose livestock rely on sufficient water supplies. However, the impact of interventions to groundwater and base flows were not assessed in the hydrological modelling, therefore they are excluded in the economic analysis.

Fire control

The proposed interventions include improved fire management activities. Understanding the economic impact of these activities is challenging, owing largely to the complex interactions of fires in grassland ecosystems. For example, wildfires and those that occur out of season or are unplanned can be destructive, damaging livestock and grassland fodder and releasing above-ground carbon stores. However, if planned and managed carefully (e.g., undertaken biennially in late winter or early spring) fires provide important stabilising services to grass bud banks and soil carbon stocks (Carbutt & Kirkman, 2022).

[5] The 2/3rds correction factor is applied to Joe Gqabi and Alfred Nzo DM sites only. These sites included a significant expansion to grassland area, with 1/3rd of this area assumed to be in 'severely degraded', 'moderately degraded' and 'good' conditions each. The relatively smaller grassland expansion areas in the remaining DM sites were assumed to be in a degraded baseline condition (not disaggregated by severe, moderate or good), and therefore the full area extent benefits from rehabilitation.

It is assumed that the proposed interventions such as fire breaks and improved livestock management will reduce the disbenefits and elevate the benefits of fire events. However, there is little available evidence of the extent to which benefits outweigh disbenefits i.e., the assessment is unable to distinguish between (beneficial) managed burning regimes and out-of-season, unplanned fires. This is complicated by the limited understanding of fire events at the project sites under baseline and intervention scenarios (for example, how many wildfires occur per year and at what duration).

A 2016 study in Zimbabwe estimated the willingness to pay of farming communities' for effective fire management that reduces direct damage to key provisioning services such as livestock numbers, woody resources, thatching grass and grazing fodder. While these benefits are relevant to this proposed project, conceptually they are already contained in the estimation of provisioning services and livestock production above (although the contribution from fire management specifically cannot be disaggregated) . Including these willingness to pay values would therefore result in double-counting.

Biodiversity

Healthy and productive grassland ecosystems play a pivotal role in supporting biodiversity, serving as habitats for diverse plant and animal species. Among their many ecological functions, grasslands contribute to pollination, a crucial process for plant reproduction and ecosystem stability. Pollinators such as bees, butterflies, and birds rely on the nectar and pollen provided by grassland plants for sustenance, in turn facilitating the fertilisation of flowering plants that ensures the production of seeds and fruits (Johnson, et al., 2009). The preservation and restoration of grassland ecosystems are therefore essential for maintaining pollinator populations and safeguarding the intricate web of life they support.

There is evidence to suggest that restoration of natural vegetation (primarily through removing alien invasive plants) leads to an increase in pollinators and their resulting pollinating services (Kaiser-Bunbury, et al., 2017). The degree of recovery may depend on the state of degradation prior to restoration intervention and the proximity to pollinator source populations in the surrounding landscape. The proposed intervention activities envisioned under this project will result in similar such pollination benefits, however there is limited understanding of baseline versus intervention conditions at the project sites to support the extent to which these benefits materialise. Most tellingly, there is limited evidence to show how changes in pollination services impact livestock production or provisioning services. Pollination and other biodiscovery benefits are therefore excluded from this assessment.

Global Climate Regulation (Carbon Storage and Sequestration)

The proposed measures prioritize restoring grasslands through improved rangeland management practices, including rotational resting, controlled burning, and the establishment of vegetative barriers. These interventions aim to rehabilitate degraded lands, promote healthier grassland ecosystems, and mitigate the adverse effects of fire, drought, and overgrazing.

In doing so, the project enhances the potential for carbon storage and sequestration in the landscape by fostering the recovery of vegetation and preventing soil erosion. Healthy grasslands serve as natural carbon sinks, capturing atmospheric carbon in their biomass and soil, which contributes to mitigating global climate change.

Additionally, the measures improve ecosystem resilience and long-term stability. For instance, by reducing soil carbon leakage and increasing above-ground vegetation, they help sustain ecological productivity and buffer against the escalating risks of land degradation. While the precise carbon storage potential depends on site-specific characteristics, the interventions reflect an ecologically sound approach to nature-based solutions for climate mitigation.

Given the inherent challenges in modelling carbon sequestration benefits at this scale, the full valuation of these ecosystem services remains outside the current economic assessment. However, their qualitative importance for achieving global climate targets and advancing sustainability goals is undeniable.

2.4.7 Determination of Direct and Indirect Beneficiaries for the CBA Exercise

An economic evaluation is inherently an assessment of benefits that accrue to society as a whole. The positive results demonstrated above indicate that South African society will benefit from the proposed interventions overall. Examining how certain benefits accrue to specific segments of society depends on how they were calculated. In this light, beneficiary numbers are presented per economic benefit below.

- *Avoided direct flood damage costs, avoided sedimentation damage*: the beneficiaries of avoided damage to these assets (bridges and dams) are those responsible for its operation and (re)construction – local and national government.
- *Avoided indirect impact to accessibility and travel time:* interventions that prevent the closure of key bridge crossings for work and school travellers will benefit a total of 30,104 people.
    - Ngaka Modiri Molema: 295 people
    - Alfred Nzo: 3,027 people
    - Ehlanzeni: 1,784 people
    - Sekhukhune: 17,453 people.
- *Provisioning and existence & bequest ecosystem services:* The beneficiaries of increased ecosystem services could not be quantified since these benefits are calculated as unit values based on unit values of rehabilitated grassland area (i.e., rather than number of people). However, conceptually ecosystem services will accrue to those households in the immediate vicinity of the respective study areas.

2.5 APPROACH TO IDENTIFYING AND COSTING ECO-DRR INTERVENTIONS IN THE SELECTED DISTRICTS

2.5.1 Mapping Land Covers in the Priority Sub-Catchment

A number of GIS data sources were used to identify land cover types and land conditions to inform the identification of potential interventions to be applied in the selected sub catchments.

2.5.2 The South African Landcover (SALC) Database

Landcover data was extracted from the SALC datasets. Thirty-two cover classes were extracted from the SALC and reclassified into 12 classes, as follows:

1. Active Cultivation

2. Bare and Rock Surfaces
3. Built-up (Commercial, Roads and Rails)
4. Eroded Lands
5. Fallow Lands and Old Fields
6. Forest and Woodland
7. Natural Grassland
8. Plantation
9. Residential
10. River and Water Bodies
11. Scattered Villages
12. Wetlands

Table 2-12 indicates how the broad land cover classes were derived.

Table 2-12: Reclassification of land cover classes from the National Landcover Dataset

Original Class	Description	Detail	New Class
Subsistence / small-scale annual crops	Cultivated	Temporary Crops	Active Cultivation
Natural rock surfaces	Barren Land	Consolidated	Bare and Rock Surfaces
Other bare	Barren Land	Unconsolidated	Bare and Rock Surfaces
Commercial	Built-up	Commercial	Built-up (Commercial and Roads and Rails)
Roads and rails (major linear)	Built-up	Transport	Built-up (Commercial and Roads and Rails)
Mines: extraction pits, quarries	Mines and Quarries	Extraction Sites	Built-up (Commercial and Roads and Rails)
Fallow land and old fields (wetlands)	Cultivated	Fallow Lands and Old Fields	Built-up (Commercial and Roads and Rails)
Eroded lands	Barren Land	Unconsolidated	Eroded Lands
Fallow land and old fields (trees)	Cultivated	Fallow Lands and Old Fields	Fallow Lands and Old Fields
Fallow land and old fields (bush)	Cultivated	Fallow Lands and Old Fields	Fallow Lands and Old Fields
Fallow land and old fields (grass)	Cultivated	Fallow Lands and Old Fields	Fallow Lands and Old Fields
Fallow land and old fields (bare)	Cultivated	Fallow Lands and Old Fields	Fallow Lands and Old Fields
Contiguous low forest and thicket	Forested land	Natural Wooded Land	Forest and Woodland
Dense forest and woodland	Forested land	Natural Wooded Land	Forest and Woodland
Open woodland	Forested land	Natural Wooded Land	Forest and Woodland
Natural grassland	Grassland	Natural Grassland	Natural Grassland
Contiguous and dense plantation forest	Forested land	Planted Forest	Plantation
Open and sparse plantation forest	Forested land	Planted Forest	Plantation
Temporary unplanted (clear-felled) plantation forest	Forested land	Planted Forest	Plantation
Residential formal (tree)	Built-up	Residential	Residential
Residential formal (bush)	Built-up	Residential	Residential
Residential formal (low veg / grass)	Built-up	Residential	Residential
Residential formal (bare)	Built-up	Residential	Residential
Residential informal (low veg / grass)	Built-up	Residential	Residential
Village dense (bare and low veg / grass combo)	Built-up	Village	Residential
Natural rivers	Waterbodies	Natural Waterbodies	River and Water Bodies

Original Class	Description	Detail	New Class
Artificial dams (including canals)	Waterbodies	Artificial Waterbodies	River and Water Bodies
Artificial flooded mine pits	Waterbodies	Artificial Waterbodies	River and Water Bodies
Bare riverbed material	Barren Land	Unconsolidated	River and Water Bodies
Village scattered (bare and low veg/ grass combo)	Built-up	Village	Scattered Villages
Herbaceous wetlands (currently mapped)	Wetlands	Herbaceous Wetlands	Wetlands
Herbaceous wetlands (previously mapped)	Wetlands	Herbaceous Wetlands	Wetlands

- **Degraded Land**

Degraded land was extracted from the national layer and clipped within the study area.

- **Wetlands**

National Wetland Map 5, (SANBI, 2018) was used to identify wetlands which were clipped from the national layer to the priority sub catchments.

- **Gullies**

Gullies (dongas) occurring within the priority sub catchments were derived from the national gully location map (Marakanye and Le Roux, 2012)

- **Gully Susceptibility**

Erosion (gully) susceptibility was derived from a modelling exercise that identified gully erosion susceptibility to inform avoided degradation planning (Le Roux and van der Wall, 2020)

- **Invasive Alien Wattle**

Without the availability of specific data on alien invasive infestation in the priority sub catchments, we drew on field observations conducted during site visits to identify areas infested with wattle near the riparian zone. Field observations indicated high levels of infestation by wattle, other woody species, or bush encroachment within riparian areas across the selected sub catchments. It was thus assumed that land cover classes classified as 'Plantation' or 'Forest and Woodland' within a 50 m buffer from the river were invasive woody alien species. The Buffer Analysis tool in ArcGIS was used to create a 50m buffer in the main rivers in the selected sub catchment. Within those buffers, smaller polygons were drawn around clusters of vegetation. Density within the polygons varied from sparse to very dense, with most being very dense.

2.6 DETAILED SITE METHODOLOGY AND COSTING OF SITE-LEVEL INTERVENTIONS

The cost estimates were compiled into a spreadsheet tool to calculate unit costs (e.g. per hectare, per metre) based on a number of underlying assumptions. These initial estimates, as well as the assumptions on which they were built, were reviewed and refined in consultation with a senior staff member of DFFE: EP. The final costing framework is provided in the table below. The costing model (available as a separate spreadsheet) links different interventions to different landcovers. For example, where gully erosion has been mapped, the gully erosion interventions are applied to the total area (i.e. 100%) to derive a maximum cost in the first instance. The size of the area covered by each intervention was then subsequently optimised against both budgetary constraints and the priorities for that particular sub-catchment.

3 Cost-Benefit Analysis

3.1 INTERVENTIONS – ALFRED NZO DM

The Luyengweni sub-catchment in Alfred Nzo District is 13 298 ha in extent. The catchment has in its headwaters the Ncome wetland system, some 193 ha in extent. The wetland is considered to be in moderate to good condition, with a high conservation prioritisation. Incipient infestations of wattle, and minor degradation have been observed in the system (Exigent, 2018). There is extensive degradation in the middle and lower sub-catchment, with numerous gullies, riparian and terrestrial wattle infestations, plantations and low basal cover in many areas. Further, there are more than four road river crossings that could be impacted by flooding and the clogging of bridges and culverts with wattle debris from riparian zones. Additionally, there are large areas of abandoned agricultural lands that are subject to sheet and gully erosion. Of built infrastructure assets, the area has two bridges. Given the extensive degradation, a limited set of interventions were identified which are shown in Figure 3-1 and characterised in Table 3-2 below.

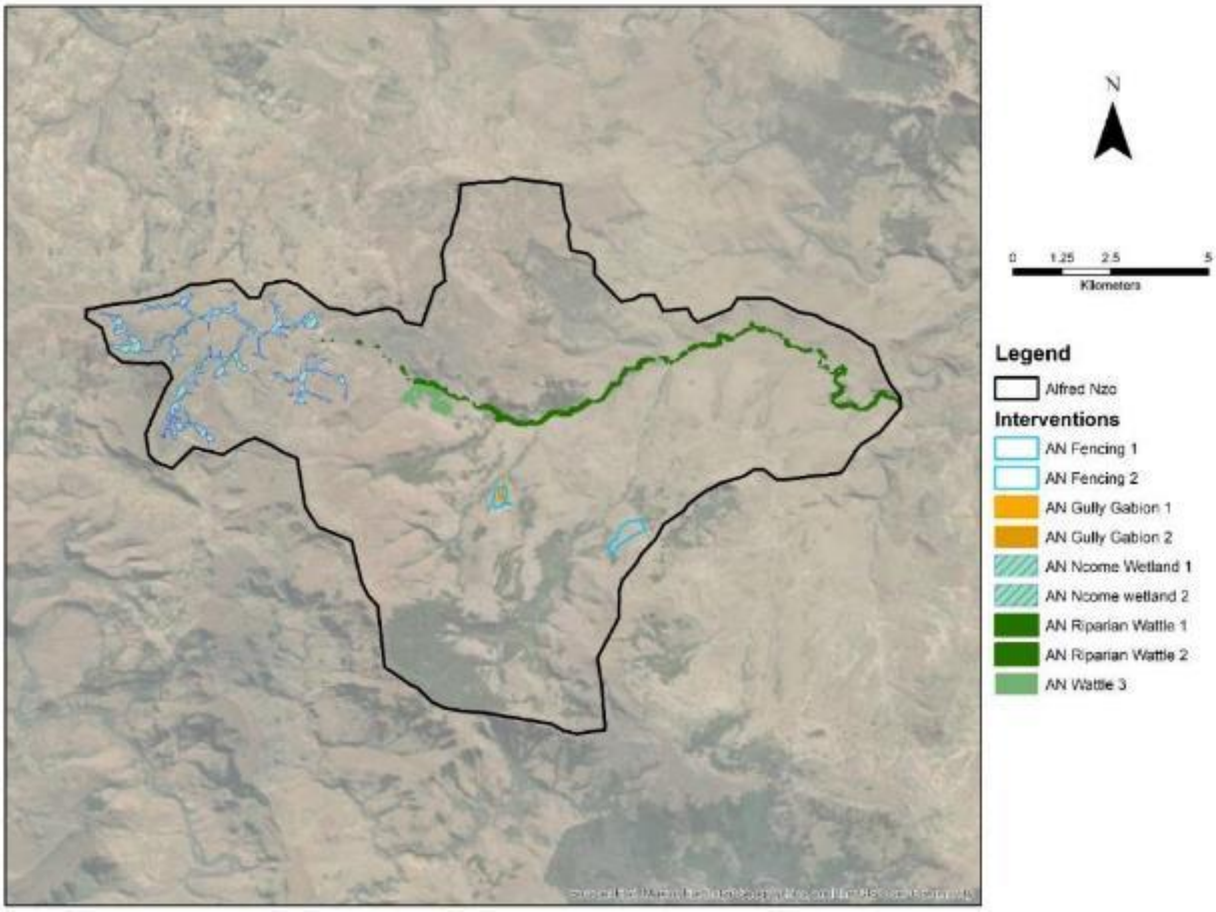

Figure 3-1: Map showing location of interventions in the Luyengweni area in Alfred Nzo DM

3.1.1 Impact of Flooding

Total direct and indirect damage costs across the20 year period for Alfred Nzo DM, are presented in Table 3-1. Given the rural nature of the area, bridges were the only physical assets identified as being exposed to flooding.

Table 3-1: Total damages without intervention (USD) for Alfred Nzo DM for 50th and 90th percentile climate event - Discounted

50th percentile	90th percentile
86 596	519 575

* Based on advice from the hydrological modelling team, average flood damage values (total asset construction value) is corrected by a factor of 40% in the without intervention scenario to illustrate average damage costs under baseline conditions. The intervention scenarios is expected to reduce this damage factor to 10% of total construction value. (see further detail below). Full cost value sources are contained in the Excel model.

3.1.2 Proposed Interventions

The EbA interventions proposed for the Alfred Nzo DM are set out in Table 3-2. These interventions cover invasive species management, erosion control, and wetland rehabilitation. The combined cost of these interventions is estimated to be around R87 585 933 (undiscounted).

Table 3-2: Proposed EbA Interventions for Alfred Nzo DM

Specific Action	Extent (ha)	Location	Additional Details
Invasive Plant Clearing			
Wattle clearing 1 (riparian)	14 ha	Riparian zone, lower catchment	Clearing invasive wattle from riparian zones. Field observations confirmed extensive wattle stands in riparian areas.
Wattle clearing 2 (riparian)	66 ha	Riparian zone, mid catchment	Removing wattle that obstructs riparian areas, preventing blockages in streams.
Wattle clearing 3 (terrestrial)	45 ha	Upper middle catchment below Ncome wetland	Clearing terrestrial wattle. Field observations noted woody debris blocking bridges and culverts.
Bioturbation and Revegetation			
Bioturbation with livestock	39 ha (25% of area)	Cleared wattle areas	Livestock used for bioturbation on shallow slopes outside riparian zones to minimize erosion risk.
Active revegetation	78 ha (50% of area)	Cleared wattle areas	Restoring vegetation on 50% of cleared land to accelerate ecosystem recovery.
Natural recovery	Remaining 25%	Cleared wattle areas	Lower-density wattle areas expected to recover naturally due to minimal infestation.
Rotational Resting			
Ecoranger herding model	13 313 ha	Entire catchment area	Rotational grazing to improve soil and vegetation health throughout the catchment area.
Erosion Control			
Gabion structure 1	0,84 ha	Near access road and homesteads	Installing gabions to control gully erosion near access roads and homesteads.
Gabion structure 2	2 ha	Adjacent to gabion structure 1	Additional gabion installation for erosion control near adjacent gully.
Post-gabion revegetation (Gabion 1)	0,84 ha	Around gabion 1	Replanting vegetation after gabion installation to reduce erosion.
Post-gabion revegetation (Gabion 2)	2 ha	Around gabion 2	Revegetation to support landscape stability post-gabion installation.
Fencing and Vegetation Recovery			

Specific Action	Extent (ha)	Location	Additional Details
Fencing area 1 (around gabions and upper catchment)	14 ha	Upper part of catchment	Fencing to protect gabion structures and upper catchment areas, allowing vegetation recovery and runoff reduction.
Contour-based brushpacks and vetiver planting (within fenced area)	14 ha	Within fenced area 1	Erosion control through brushpacks and vetiver planting to stabilize slopes.
Revegetation (within fenced area)	14 ha	Within fenced area 1	Restoring natural vegetation to enhance soil and water retention.
Fenced area 2 (rangeland)	31 ha	Degraded rangeland above roads and homesteads	Fencing degraded rangeland to control erosion and prevent further degradation.
Contour-based brushpacks and vetiver planting (within fenced area)	31 ha	Within fenced area 2	Erosion control through vetiver planting and brushpacks to stabilize slopes.
Revegetation (within fenced area)	31 ha	Within fenced area 2	Restoring vegetation cover in severely degraded rangeland.
Wetland Rehabilitation			
Ncome wetland 1	163 ha	Headwaters of the Ncome River (Ncome Springs)	Small-scale removal of invasive species and soft interventions to maintain wetland conditions at the river's source.
Ncome wetland 2	29 ha	Ncome River	Continued wetland restoration, focusing on removing invasive plants and promoting buffer zones to protect the ecosystem.

3.1.3 Benefits

In addition to reducing the damage costs associated with flood events, the proposed interventions also deliver a suite of valuable co-benefits (see Figure 3-3 and Figure 3-3). These include avoided impact to accessibility and provisioning ecosystem services associated primarily with the rangeland management interventions. Given the limited exposure of physical assets, agriculture and people to flooding in the Alfred Nzo case study area, the benefits from avoided flood damages are relatively small when compared to the wider co-benefits. However, these co-benefits can themselves make an important contribution to both climate change mitigation and strengthening the resilience of local communities to climate change. The benefits for this site would be wider when considering the damage of a flood event to the grassland and vegetated areas. As the assessment of this was out of scope, it is recommended that the project considers more detailed flood impact analysis. It is thus assumed that the benefits from avoided costs for this site are understated and can be expected to be higher.

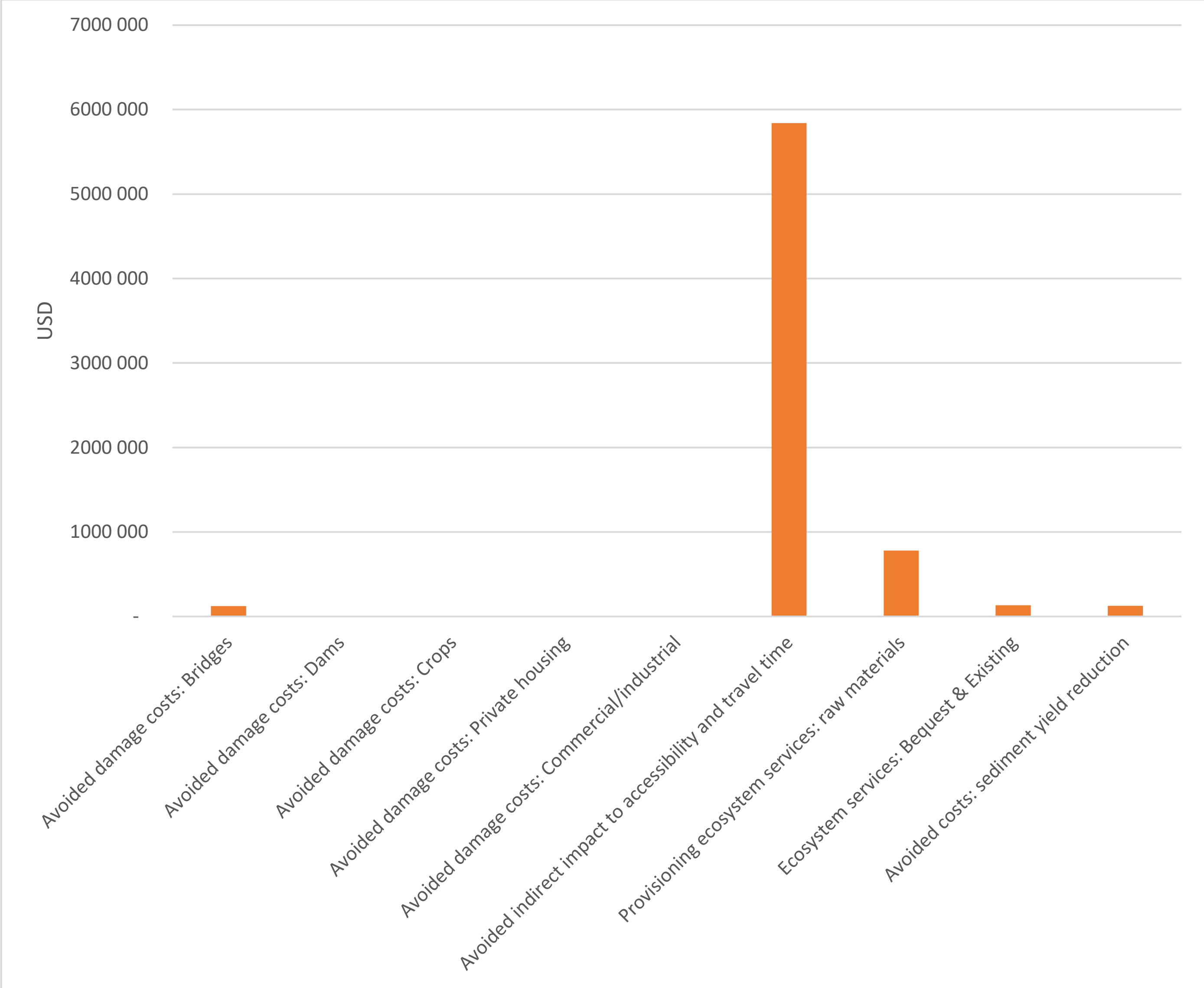

Figure 3-2: Distribution of Benefits for Alfred Nzo DM with Interventions at 50th Percentile Climate Scenario

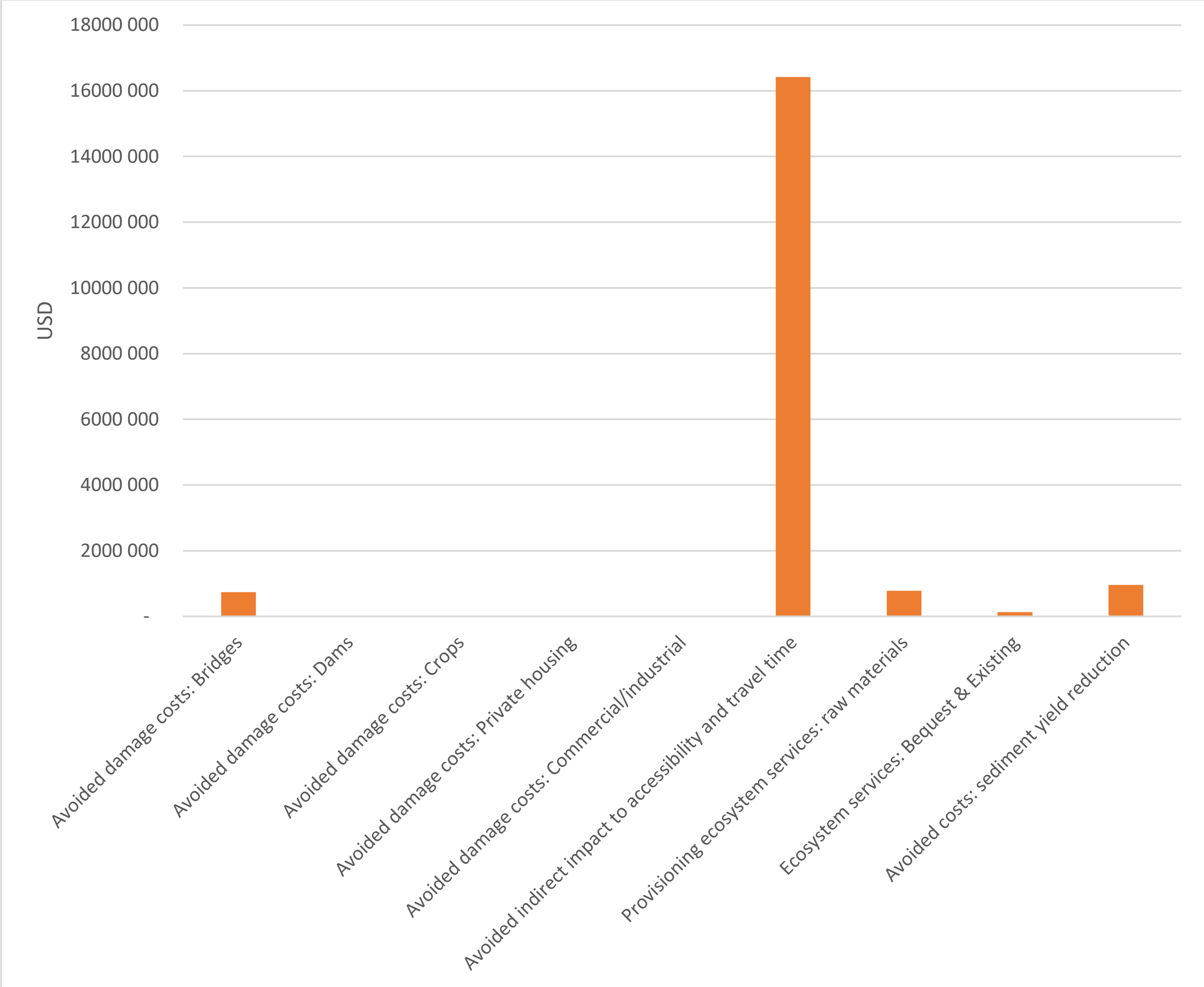

Figure 3-3: Distribution of Benefits for Alfred Nzo DM with Interventions at 90th Percentile Climate Scenario

3.2 INTERVENTIONS – EHLANZENI DM

The Upper Sand River sub-catchment in Ehlanzeni DM is 7 721 ha in extent. A large proportion of the upper catchment is commercial timber plantations that have not been included for interventions as part of this analysis as there are limited opportunities for Eco-DRR interventions in this area. The focal area for interventions is thus in the lower part of the sub-catchment, covering an area of 3 342 ha as shown in Figure 3-4. This catchment is the headwaters of the Sand River Catchment, which joins the Sabie River and flows through Kruger National Park and into Mozambique. It is considered an important catchment to sustain environmental flows into the Park. The southern parts of this catchment show signs of degradation and western and northern areas are characterised by deep densely vegetated valleys. Of built infrastructure assets, the area has two bridges. The proposed EbA interventions are discussed in Table 3-4.

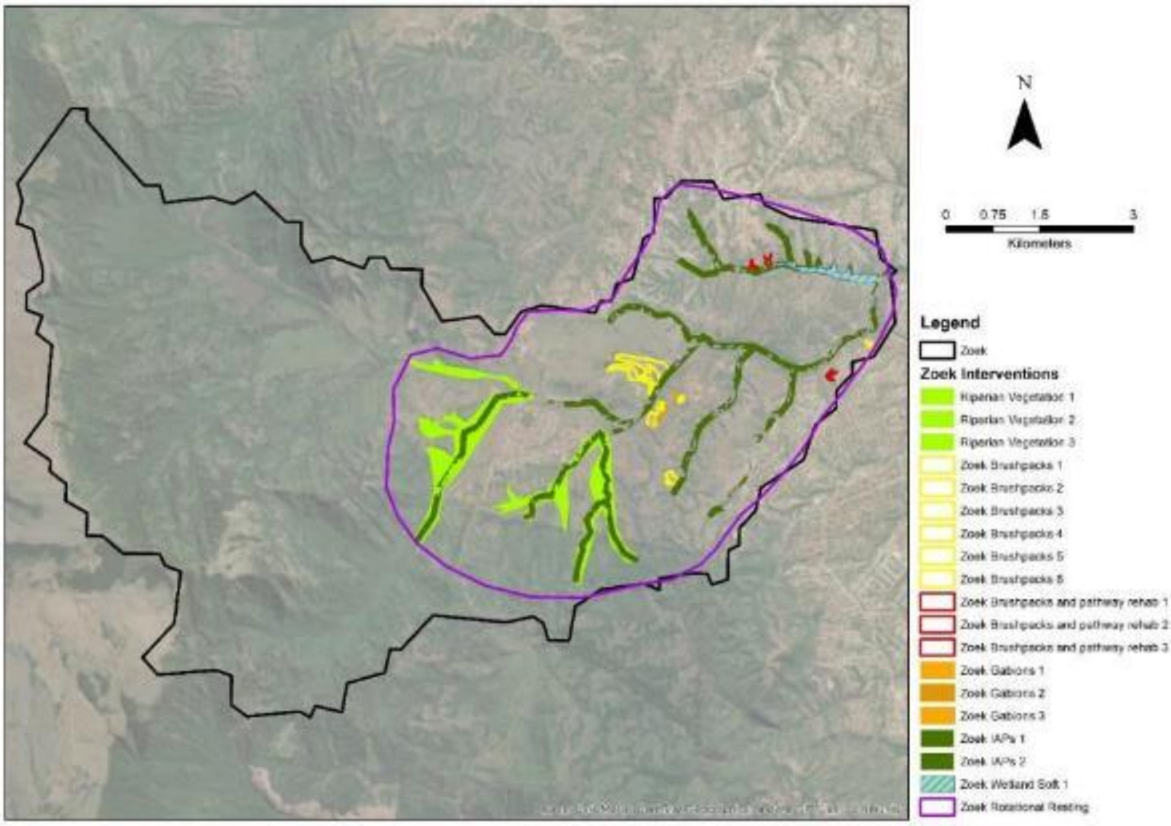

Figure 3-4: Map showing location of interventions in the Upper Sand River Catchment in Ehlanzeni DM

3.2.1 Impact of Flooding

The total direct and indirect damage costs for Ehlanzeni DM, across different flood return periods over a 20-year period, range between $86 596 and $519 575 (discounted). Given the area's susceptibility to flooding, bridges (two in Ehlanzeni DM) are identified as the primary physical assets at risk.

Table 3-3: Total damages without intervention (USD) for Ehlanzeni DM for 50th and 90th percentile climate event - Discounted

50th percentile	90th percentile
86 596	519 575

* Based on advice from the hydrological modelling team, average flood damage values (total asset construction value) is corrected by a factor of 40% in the without intervention scenario to illustrate average damage costs under baseline conditions. The intervention scenarios is expected to reduce this damage factor to 10% of total construction value. Full cost value sources are contained in the Excel model.

3.2.2 Proposed Interventions

Proposed EbA interventions for Ehlanzeni DM are provided in Table 3-4. These interventions focus on invasive species management, erosion control, and rangeland and wetland rehabilitation to restore degraded ecosystems, reduce flood risks, and enhance landscape resilience in the Ehlanzeni DM. The total cost of interventions costs is estimated to be around R72 million over a 7 year capital investment period.

Table 3-4: Proposed EbA Interventions for Ehlanzeni DM

Specific Action	Extent (ha)	Location	Additional Details
Invasive Plant Clearing			
Clearing of IAPs 1	146 ha	Drainage lines and riparian areas	Clearing of various IAPs to restore ecosystem health.
Clearing of IAPs 2	73 ha	Drainage lines and riparian areas	Clearing of various IAPs to restore ecosystem health.
Erosion Control			
Gabions 1	0.35 ha	Near gully	Installing gabion structures to control erosion.
Gabions 2	0.96 ha	Near gully	Installing gabion structures to control erosion.
Gabions 3	0.51 ha	Near gully	Installing gabion structures to control erosion.
Brushpacks 1	4 ha	Below Gabions 1 and 2	Brushpacks, vetiver planting, and revegetation to control erosion below gabions.
Brushpacks 2	16 ha	Around local dam site	Brushpacks, vetiver planting, and revegetation around dam site to control erosion.
Brushpacks 3	2 ha	Downstream of Brushpack 2	Brushpacks, vetiver planting, and revegetation in degraded lands.
Brushpacks 4	1 ha	Areas with pathways and gully erosion	Brushpacks, vetiver planting, and revegetation to control gully erosion.
Brushpacks 5	1 ha	Denuded area above gully system	Brushpacks, vetiver planting, and revegetation to reduce runoff.
Brushpacks 6	1 ha	Below Brushpack 5	Brushpacks, vetiver planting, and revegetation to control gully erosion.
Brushpacks and pathway rehabilitation 1	0.62 ha	Steep eroded pathway to Sand River	Rehabilitation of steep eroded pathway leading to Sand River.
Brushpacks and pathway rehabilitation 2	0.72 ha	Steep eroded pathway to Sand River	Rehabilitation of steep eroded pathway leading to Sand River.
Brushpacks and pathway rehabilitation 3	0.81 ha	Southern catchment pathways	Rehabilitation of eroded pathways in southern catchment.
Riparian revegetation 1	101 ha	Riparian area	Riparian revegetation with vetiver planting in 33% of area to control erosion.
Riparian revegetation 2	119 ha	Riparian area	Riparian revegetation with vetiver planting in 33% of area to control erosion.
Riparian revegetation 3	20 ha	Riparian area	Riparian revegetation with vetiver planting in 33% of area to control erosion.
Bioturbation and Revegetation			
Revegetation post gabions 1	0.35 ha	Around Gabion 1	Revegetation to reduce erosion post gabion installation.
Revegetation post gabions 2	0.96 ha	Around Gabion 2	Revegetation to reduce erosion post gabion installation.
Revegetation post gabions 3	0.51 ha	Around Gabion 3	Revegetation to reduce erosion post gabion installation.
Rotational Resting			
Rotational resting	3 342 ha	Old cropping fields	Rotational resting to improve flood reduction, soil water, and livestock production.
Wetland Rehabilitation			
Wetland rehabilitation	4 ha	Unchanneled valley bottom wetland	Soft interventions to restore small wetland.

3.2.3 Benefits

The proposed interventions demonstrated direct flood damage reduction benefit to bridges as well as sediment reduction. The proposed interventions also deliver a variety of valuable co-benefits (see Figure 3-5 and Figure 3-6) in the form of avoided travel time costs and provisioning ecosystem services. Given the relatively small area covered by the interventions, there is limited exposure of physical assets, grasslands and people to flooding in the area. This also has in impact on the relative contribution of ecosystem services to total benefits when compared to the other sites. The benefits for this site would be broader when taking into account the damage of a flood event to the grassland and vegetated areas. Since the assessment of this was beyond the scope, it is recommended that the project includes a more detailed flood impact analysis. Consequently, it is assumed that the benefits from avoided costs for this site are understated and can be expected to be higher.

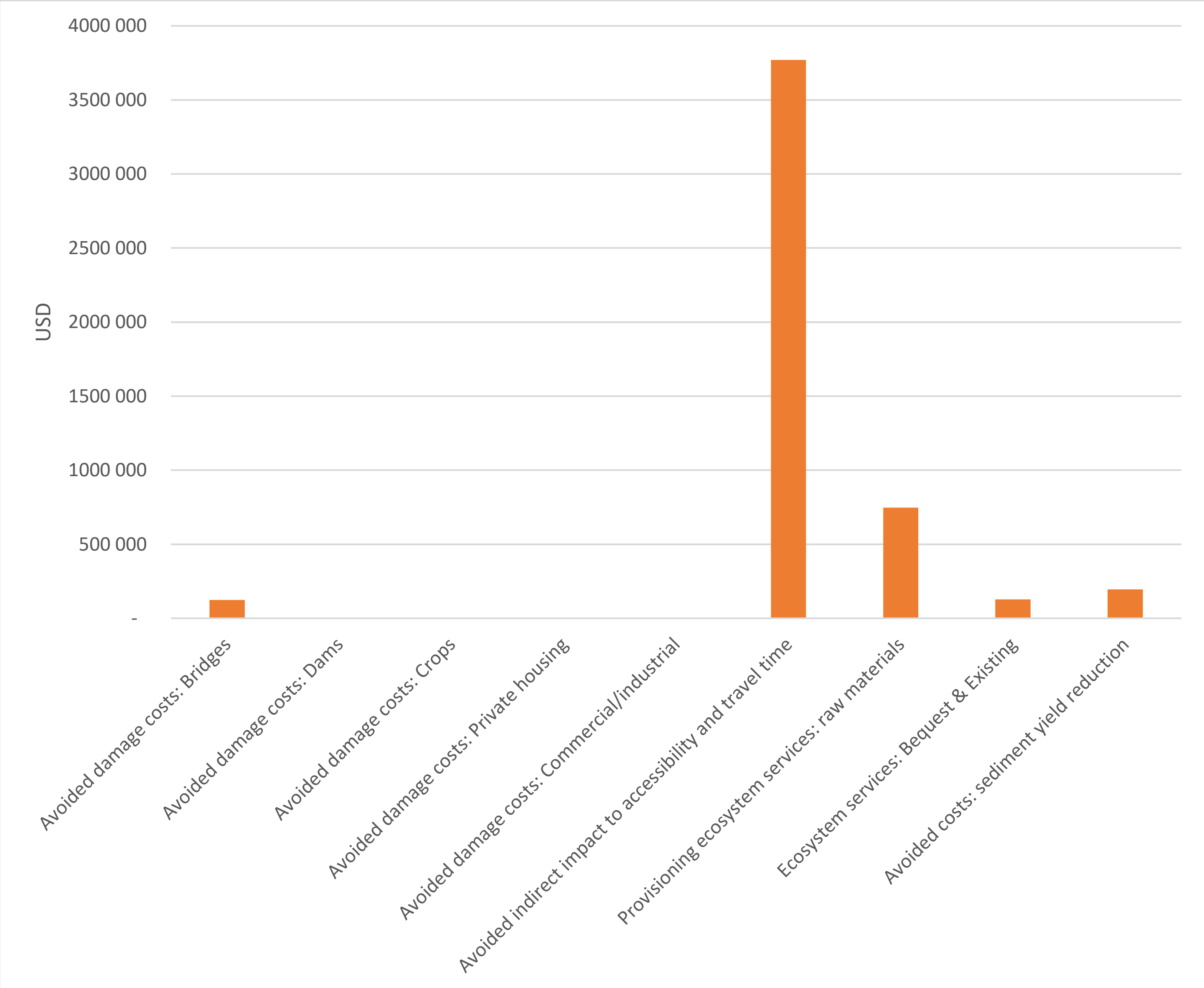

Figure 3-5: Distribution of benefits for Ehlanzeni DM with Interventions at 50th percentile Climate Scenario

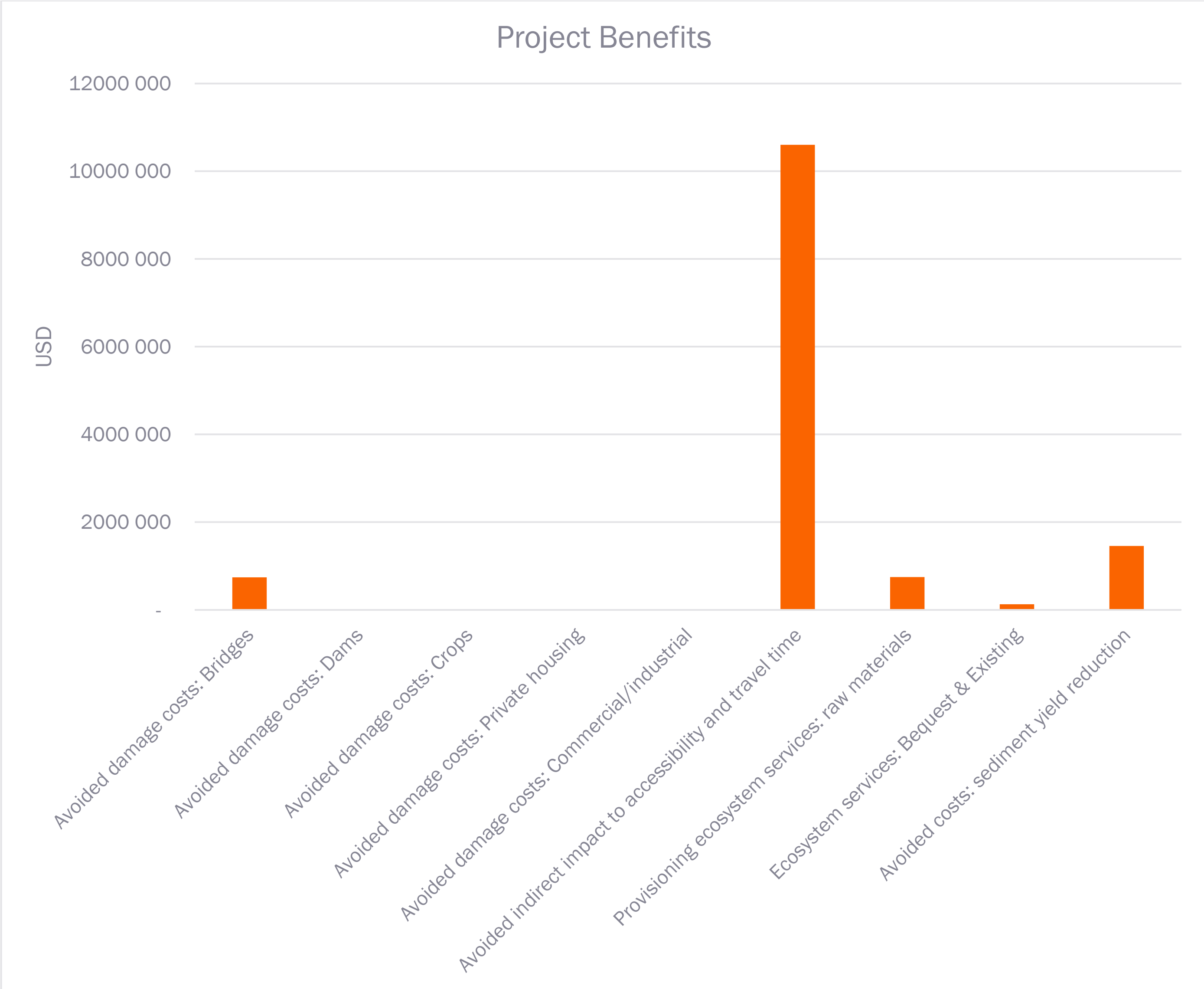

Figure 3-6: Distribution of benefits for Ehlanzeni DM with Interventions at 90th percentile Climate Scenario

3.3 INTERVENTIONS – NGAKA MODIRI MOLEMA DM

The Mokgola Catchment is bounded on the northeast by fairly dense settlements in the village of Mokgola. To the northwest, west of the R49 road that traverses the catchment is largely woody vegetation, that did not appear to have large stands of IAP species when rapid field observations were conducted. The central and southern parts of the catchment are characterised by highly degraded and eroded drainage lines, which is where the Eco-DRR interventions are to be focused (Figure 3-7). Of built infrastructure assets, the area has three bridges within the DM.

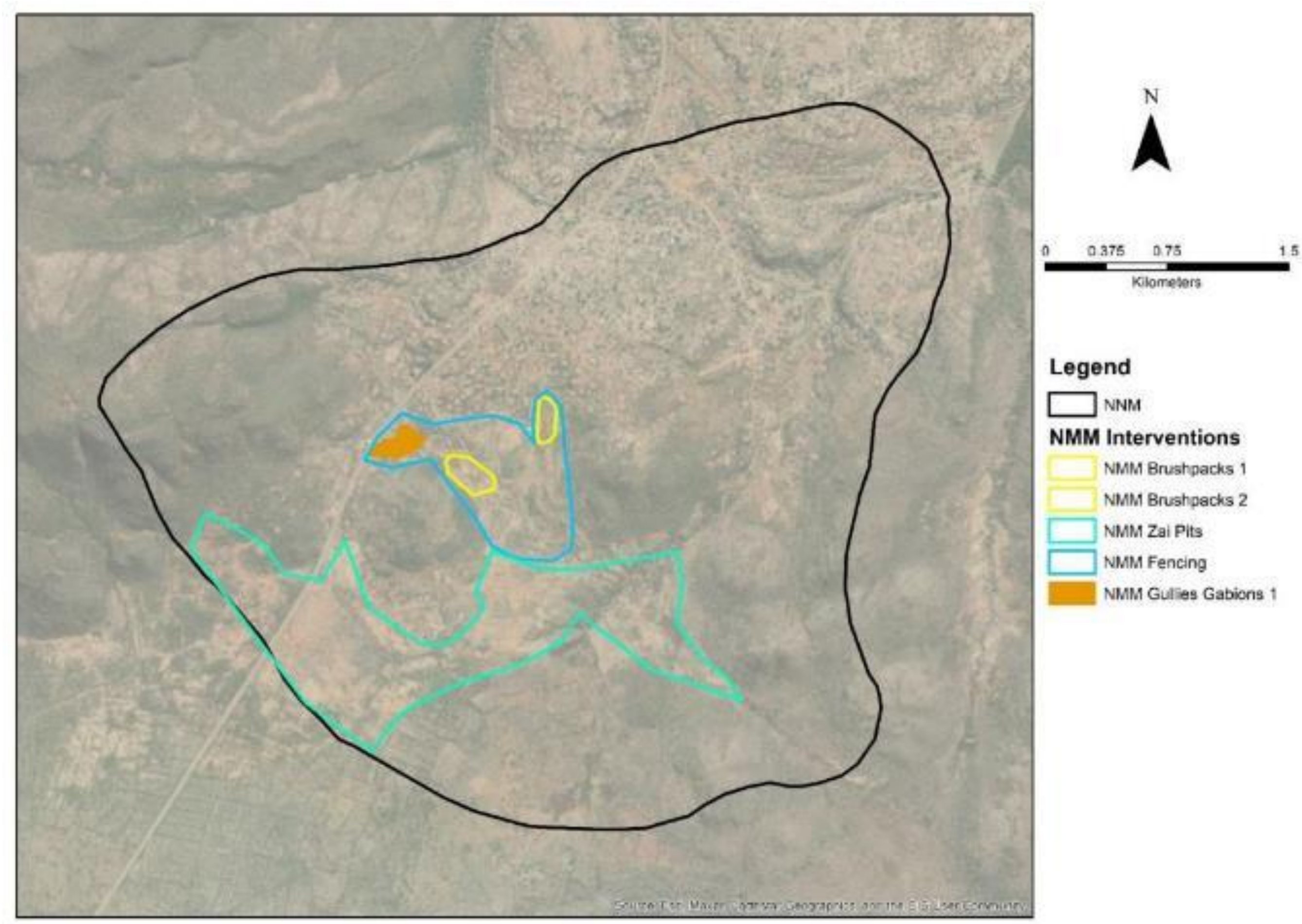

Figure 3-7: Map showing interventions and locations within Mokgola Catchment, Ngaka Modiri Molema DM

3.3.1 Impact of Flooding

The total direct and indirect damage costs for Ngaka Modiri Molema DM, across various flood return periods and over a 20 year period, are outlined in Table 3-3. Due to the area's vulnerability to flooding, the primary assets at risk are three bridges located within the district.

Table 3-5: Total damages without intervention (USD) for Ngaka Modiri Molema DM for 50th and 90th percentile climate event - Discounted

50th percentile	90th percentile
129 894	779 362

* Based on advice from the hydrological modelling team, average flood damage values (total asset construction value) is corrected by a factor of 40% in the without intervention scenario to illustrate average damage costs under baseline conditions. The intervention scenarios is expected to reduce this damage factor to 10% of total construction value. Full cost value sources are contained in the Excel model.

3.3.2 Proposed Interventions

Proposed EbA interventions for Ngaka Modiri Molema DM are estimated to costs R64 133 400 over 7 years. The application of these interventions are summarised as follows:

- Rotational resting systems applied within the whole catchment (93 480ha)
- Fencing off the most severely degraded area, requiring 70 ha to be fenced to prevent further degradation and possible future impacts on the adjacent R49. This will allow for the protection of the following additional interventions to be applied within the fenced area:
  - Gabions in the most severe gullies covering an area of 3.74 ha.
  - Contour brushpacks and vetiver grass lines applied in the small gullies covering a total area of 14 ha.
  - Revegetation of the entire fenced area using indigenous grass and tree species (70 ha)
- Given the dry nature of this area, and additional 180 ha of degraded land in the southeast will be rehabilitated using Zai Pits as a rainwater harvesting tool, with indigenous grass species to be established in each of the pits. This will be applied in conjunction with grazing management where Ecorangers will actively exclude livestock as this area will not be fenced.

3.3.3 Benefits

The proposed interventions demonstrated a distinct direct flood damage reduction benefit to bridges. This suggests that where there is more vulnerable built infrastructure, avoided costs from flood adaptation measures are larger. Additionally, the interventions deliver sediment yield reduction and a variety of valuable co-benefits (see Figure 3-9) such as raw materials and avoided travel time costs. The reduction in flood damages and indirect costs are supported by alien invasive clearing activities. Considering potential flood damage to the grassland and vegetated areas (not quantified in this assessment), a more detailed flood impact analysis is recommended. The benefits from avoided costs for this site are likely understated and expected to be higher.

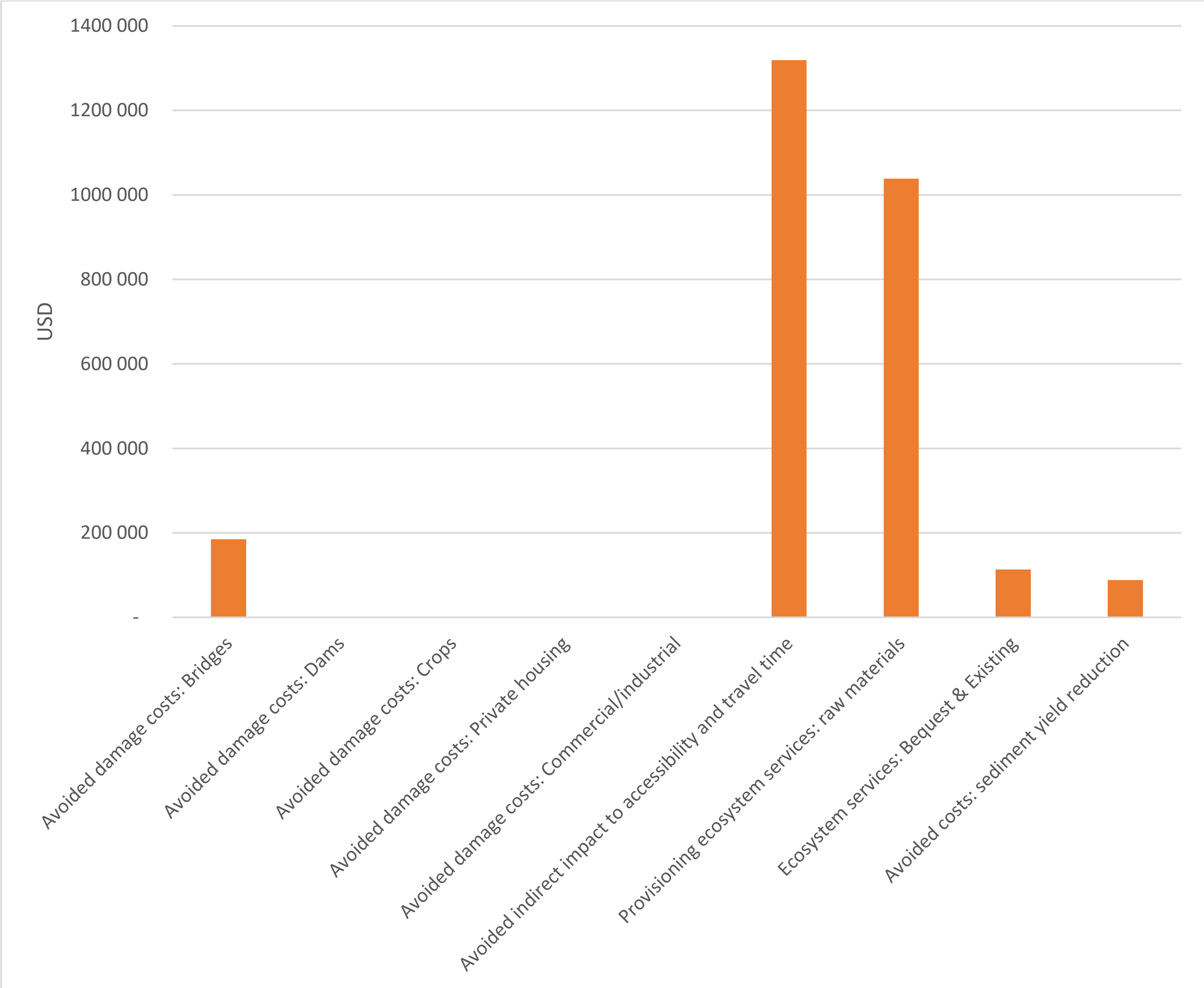

Figure 3-8: Distribution of benefits for Ngaka Modiri Molema DM with Interventions at 50th percentile climate scenario

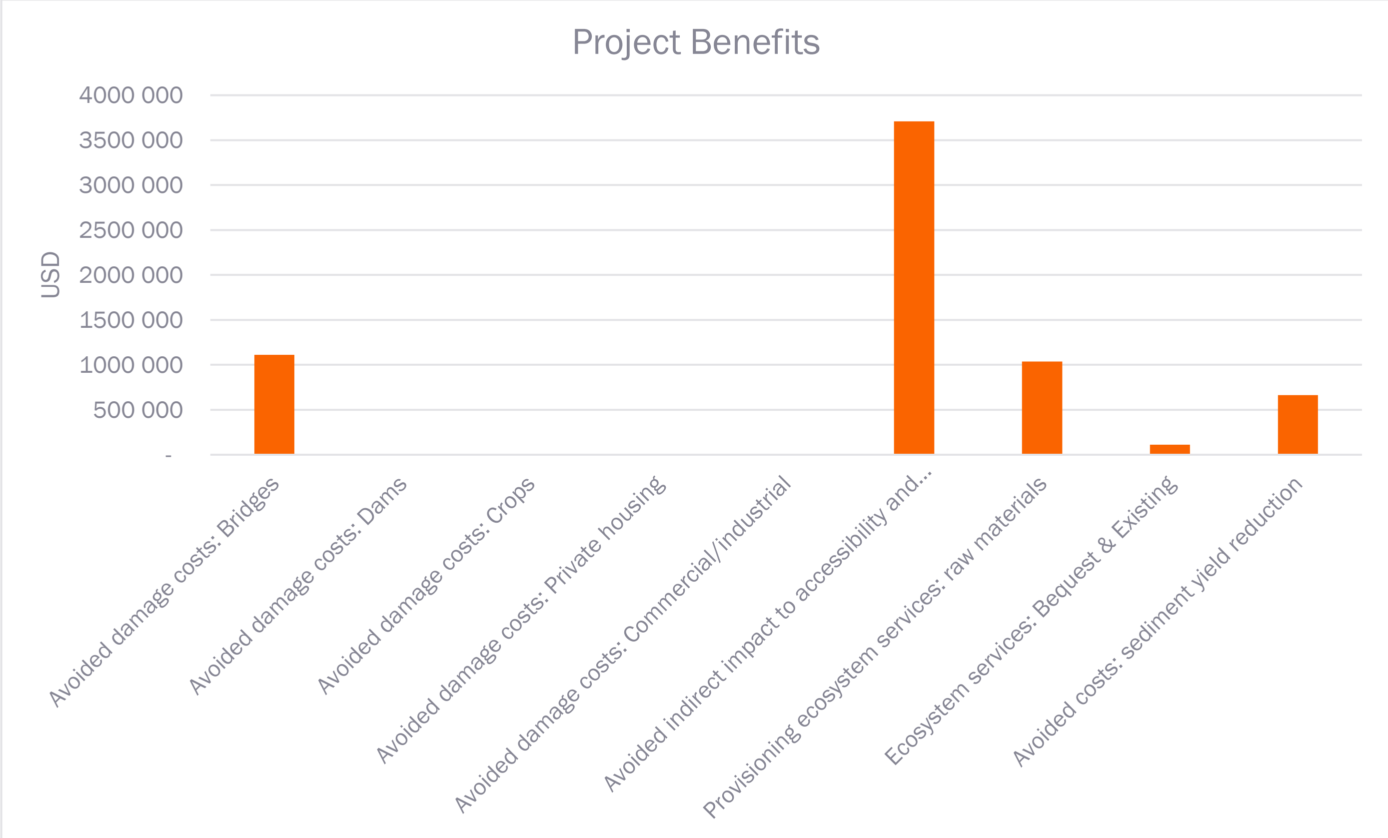

Figure 3-9: Distribution of benefits for Ngaka Modiri Molema DM with Interventions at 90th percentile climate scenario

3.4 INTERVENTIONS – SEKHUKUNE DM

The Vergelegen Dam sub-catchment in Sekhukhune District is 25 120 ha in extent. Large areas of the lower and middle catchment are built-up and semi-dense residential areas. There are extensive areas in the middle and upper catchment that are classified as cropping fields (13 000 ha), however a historical time series analysis using the Google Earth history function revealed that few of the fields have been cultivated as far back as 2011. Consequently, these are considered old abandoned agricultural lands for the purposes of the assessment. Reports from field visits indicated concerns regarding the sedimentation of the Vergelegen Dam and access to water as local challenges that were considered important. Inherently low rainfall was reported have resulted in limited field crop production or livestock keeping. Table 3-7 and Figure 3-10 illustrate proposed interventions which are estimated to cost R122 206 281 across a seven year period.

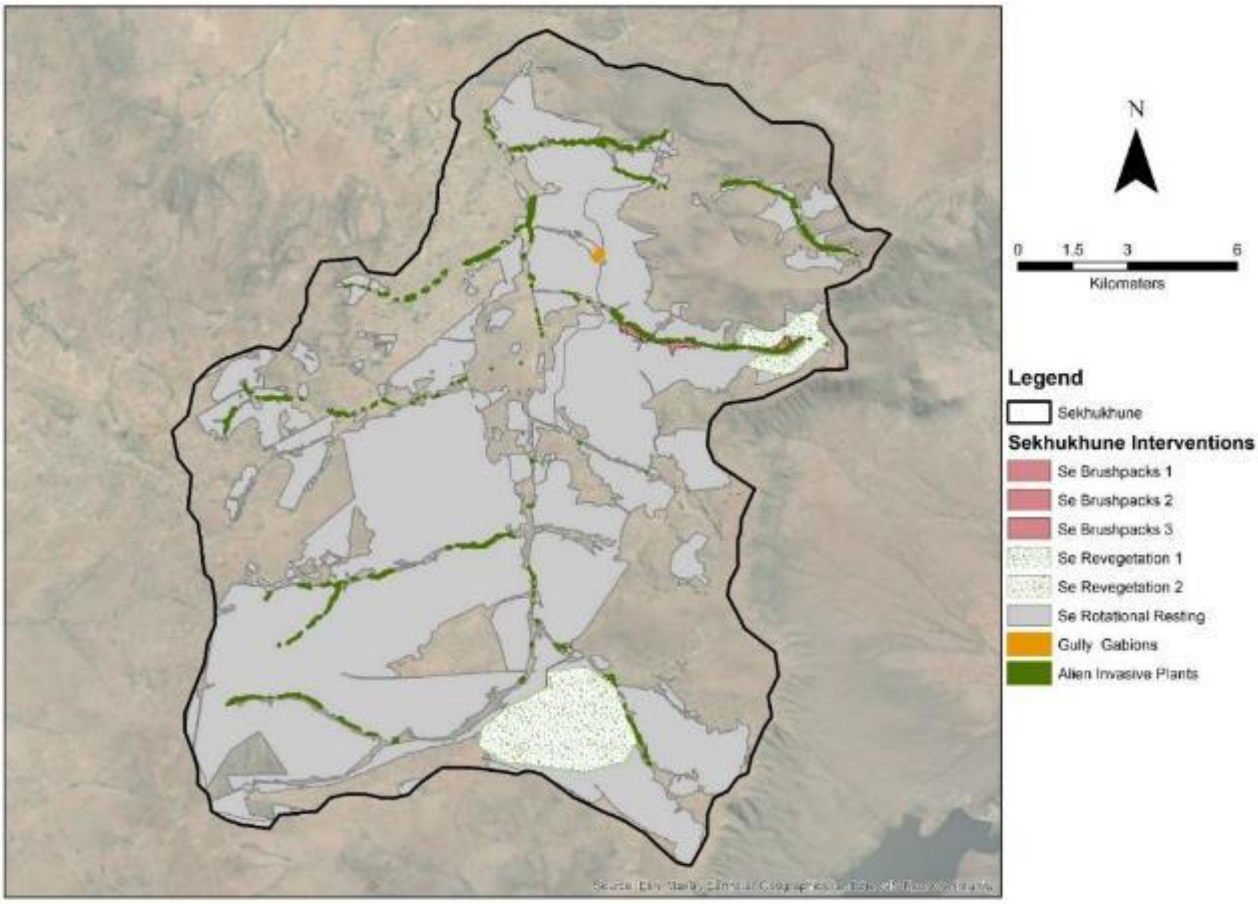

Figure 3-10: Map showing location of interventions in the Vergelegen Dam Sub Catchment in Sekhukhune DM

3.4.1 Impact of Flooding

Total direct and indirect damage costs across the 20 year period for Sekhukhune DM as shown in Table 3-6 below. This area contains one dam and eleven (11) bridges, which, at least in part, explains the higher total damage costs across the 20 year period due to flooding compared to other sites.

Table 3-6: Total damages without intervention (USD) for Sekhukhune DM for 50th and 90th percentile climate event - Discounted

50th percentile	90th percentile
2 113 538	12 681 226

* Based on advice from the hydrological modelling team, average flood damage values (total asset construction value) is corrected by a factor of 40% in the without intervention scenario to illustrate average damage costs under baseline conditions. The intervention scenarios is expected to reduce this damage factor to 10% of total bridge construction value and 20% of total Dam construction value. Full cost value sources are contained in the Excel model.

3.4.2 Proposed Interventions

The proposed interventions for the Sekhukhune DM focus on IAP clearing, erosion control, and rangeland rehabilitation. These interventions aim to restore ecosystem functionality, reduce erosion, and improve water retention in key areas of the catchment. The combined cost of these interventions is estimated to be around R122 206 281 (undiscounted).

Table 3-7 Proposed EbA Interventions for Sekhukhune DM

Specific Action	Extent (ha)	Location	Additional Details
Invasive Plant Clearing			
IAP clearing	111 ha	Drainage lines and riparian areas	Clearing of invasive woody alien plants, primarily wattle.

Specific Action	Extent (ha)	Location	Additional Details
Bioturbation and Revegetation			
Revegetation associated with the gully	4.8 ha	Associated with the gully	Revegetation of the area associated with the gully for erosion control.
Revegetation (Brushpacks 1)	15 ha	Rehabilitating degraded area near Brushpacks 1	Rehabilitating degraded area using revegetation methods.
Revegetation (Brushpacks 2)	15 ha	Rehabilitating degraded area near Brushpacks 2	Rehabilitating degraded area using revegetation methods.
Revegetation (Brushpacks 3)	14 ha	Rehabilitating degraded area near Brushpacks 3	Rehabilitating degraded area using revegetation methods.
Revegetation 1	179 ha	Old abandoned cropping fields surrounding Brushpacks 3	Revegetation of abandoned fields using farming machinery and indigenous grass species.
Revegetation 2	756 ha	Upper sub-catchment in the south	Revegetation to reduce runoff and improve grazing availability.
Rotational Resting			
Rotational resting (Ecoranger herding model)	13 313 ha	Entire catchment area	Applying rotational resting with Ecoranger model across the catchment.
Rotational resting	12 928 ha	Old cropping fields and remaining natural grasslands	Rotational resting focusing on improving livestock production and flood reduction.
Erosion Control			
Gabion structures installation	4.8 ha	Head cut area of gully	Installation of gabions to prevent erosion and reduce sediment runoff into Vergelegen Dam.
Brushpacks 1	15 ha	Near small wetland draining into non-perennial watercourse	Establishing brushpacks to control erosion near small wetland.
Vetiver hedgerows (Brushpacks 1)	15 ha	Supporting Brushpacks 1	Vetiver planting to support erosion control at Brushpacks 1.
Brushpacks 2	15 ha	Adjacent to non-perennial watercourse	Establishing brushpacks to control erosion adjacent to non-perennial watercourse.
Vetiver hedgerows (Brushpacks 2)	15 ha	Supporting Brushpacks 2	Vetiver planting to support erosion control at Brushpacks 2.
Brushpacks 3	14 ha	Headwaters of small local tributary	Brushpacks applied in degraded site at headwaters of tributary.
Vetiver hedgerows (Brushpacks 3)	14 ha	Supporting Brushpacks 3	Vetiver planting to support erosion control at Brushpacks 3.

3.4.3 Benefits

The proposed interventions provide the most significant benefits for avoided flood damage of both dams and bridges compared to the other sites, as well as avoided indirect impacts which are supported by interventions such as alien invasive clearing. In addition, these proposed interventions deliver a range of co-benefits (see Figure 3-11 and Figure 3-12), most notably provisioning ecosystem services.

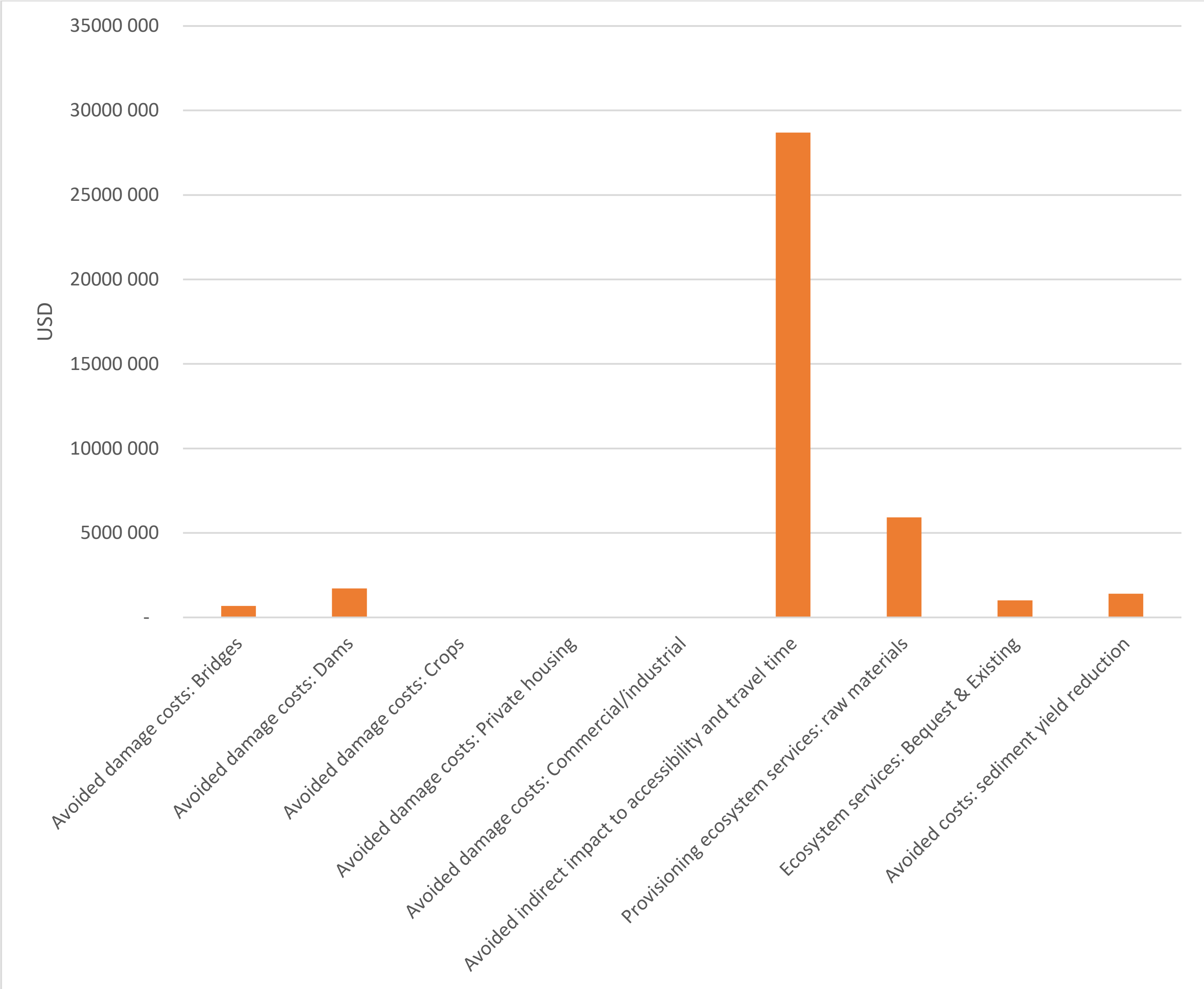

Figure 3-11: Distribution of benefits for Sekhukhune DM with Interventions at 50th percentile climate scenario

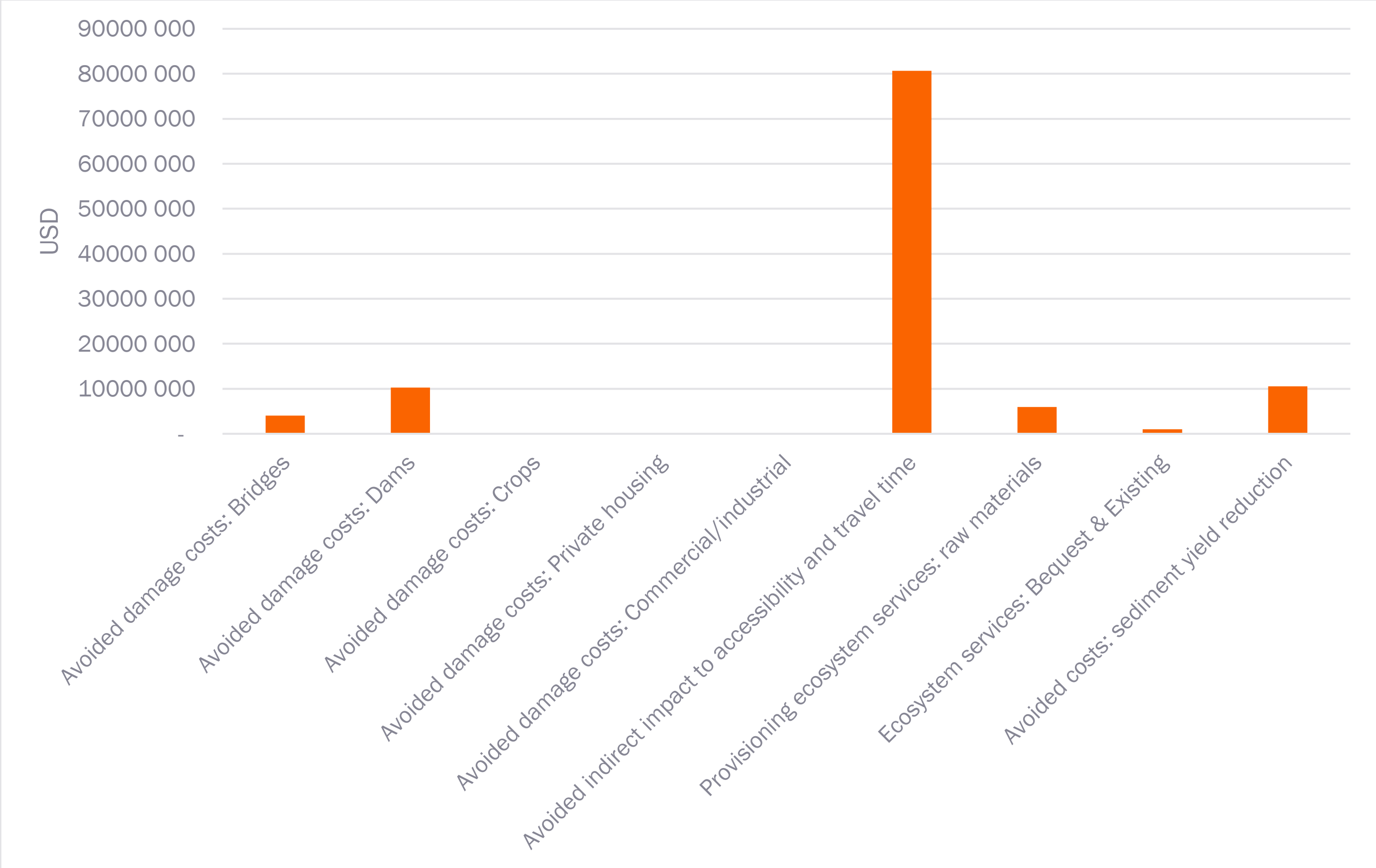

Figure 3-12: Distribution of benefits for Sekhukhune DM with Interventions at 90th percentile climate scenario

3.5 CBA RESULTS

Across both the 50th and 90th percentile projections, and under the assumptions used to generate estimates of the cost and benefit flows, the proposed interventions are shown to generate a positive economic outcome across climate scenarios as demonstrated in Table 3-8, with higher benefits generated under worst-case climate projections.

The economic evaluation of the interventions indicates a modest to positive return on investment across the 50th percentile and 90th percentile climate scenarios. Under extreme climate change, the project delivers a Net Present Value (NPV) of USD 65.16 million and a Benefit-Cost Ratio (BCR) of 5.19, illustrating that every dollar invested generates 5 times the return. Additionally, an Internal Rate of Return (IRR) of 49.7% highlights the economic efficiency of the investment, exceeding typical discount rates. These metrics confirm the feasibility and viability of the proposed interventions. As stated up front, the severity of climate change currently experienced in South Africa is most aligned with the SSP5 90th percentile climate projections. Therefore it is likely that the results of climate change would be between those modelled at the 50th and 90th percentile.

When assessed individually, most sites in the economic appraisal have a BCR close to, or higher than, 1 at the 50th percentile and a BCR of over 2 at the 90th percentile. Considering that damages to grasslands were not included in this analysis due to limitations (leading to understated avoided damage costs) in combination with the anticipated climate to sit between the 50th and 90th percentile projections, investment into these adaptations is likely to produce a higher ratio of benefits to costs presented in this analysis in real life, even at the site level.

Table 3-8: Economic evaluation of interventions across all sites (the Project)

Climate Scenario	NPV Base Case (million USD)	BCR Base Case	IRR Base Case (%)	NPV Worst Case (million USD)	NPV Best Case (million USD)
SSP5 -8.5 90th Percentile	65.16	5.19	49.7%	41.3	86.46
SSP5 -8.5 50th Percentile	14.69	1.94	16.9%	6.65	22.1

The net benefits of Ecosystem-based Adaptation (EbA) interventions are strongly influenced by the substantial avoided damage costs and the provisioning of raw materials. While the initial costs associated with gully rehabilitation and vegetation restoration may reduce early returns, these are offset by the long-term benefits and critical risk mitigation provided by these interventions. The overall project results are primarily driven by the Sekhukhune site, which has a larger hectarage of rehabilitated grasslands and more bridge and dam assets compared to other project sites. The benefit results at the sites have been derived using conservative estimates, as ecosystem benefits are aligned only to hydrologic modelling that specifically focused on grasslands. Nonetheless, the results present a strong case for expanding the sites to include additional built infrastructure assets and larger intervention areas.

The interventions significantly mitigate loss and damage, collectively generating benefits of between 30.2 million and 80.7 million (discounted). Among these, 2.8 million to 16.9 million (undiscounted) is attributed to avoided damage to bridges and dams. Furthermore, interventions reduce accessibility and travel time delays resulting from climate-related impacts, generating savings of between 40 million and 111.4 million USD. The reduction in sediment yield through these measures avoids additional costs of up to 13.6 million. With interventions livelihoods will be supported by livestock farming, resulting in 5.2 million USD in income opportunities for smallholder farmers.

With built infrastructure at risk from flooding, such as in the Sekhukhune and Alfred Nzo DMs, generates higher NPVs and BCRs due to avoided built infrastructure damage. In contrast, municipalities with fewer vulnerable grey infrastructure assets derive most of their benefits from co-benefits rather than direct damage reduction. This underscores the value of integrating EbAs with built infrastructure protection to maximise economic gains, and supports the expansion of proposed areas to include more built infrastructure assets. The current assessment of avoided damages is conservative, as it does not include an assessment of flood event damage to grassland and vegetated areas. Since this assessment was out of scope, it is recommended that the project considers a more thorough flood impact analysis. Therefore, it is assumed that the benefits from avoided costs for this site are understated and may be higher.

Provisioning ecosystem services emerge as the largest contributor to the benefits, valued at USD 8.5 million (undiscounted). These figures underscore the importance of sustainable management practices in ensuring the long-term availability of natural resources. Key cost drivers of the project include gully rehabilitation through gabions (USD 8.71 million) and the restoration of riparian vegetation (USD 2.37 million). These investments are pivotal for stabilizing degraded landscapes and improving water retention, which are essential to the success of the project.

Rangeland and grazing management interventions, such as contour barriers, fencing, and rotational resting, significantly contribute to the restoration of landscapes and the building of resilience for local communities that rely on these areas for their livelihoods. These interventions also play a key role in avoiding sedimentation costs. Alien invasive species clearing provides indirect benefits, such as flood mitigation and reduced sedimentation, which are reflected as avoided damage costs.

The scale of intervention areas plays a crucial role in the overall economic outcomes. Larger areas of intervention, such as in Alfred Nzo DM, and potentially the larger Ehlanzeni DM, show greater potential for positive economic returns. There is clearly a balance to be found between the scale of the interventions and the relative density of the built infrastructure that can integrated with ecological infrastructure to derive an improved level of cost benefit.

The economic and climate projections further strengthen the case for these interventions. Under both the 50th and 90th percentile climate scenarios, the interventions demonstrate net positive benefits. Higher benefits are observed in the 90th percentile climate change event, underscoring the appropriateness of these measures in addressing climate adaptation needs under moderate to worst-case climate projections.

The sensitivity of the results to changes in discount rates show that the proposed interventions would deliver a positive NPV even under a worst case scenario. Discount rates in the sensitivity analysis are 10% and 3.66% under worst and best case scenarios respectively.

The longer-term viability of the benefits for these projects far exceeds the 20 year assessment period, with potential positive economic returns extending into the 50 year period.

During the stakeholder engagement process the consequences of disasters for rural and vulnerable communities were often described as being cut-off, being unable to access schools, medical facilities or places of work. It was not possible to assess these impacts and the Eco-DRR will need to undertake processes to measure these knock-on or indirect costs and benefits. Citizen science can play a key and supportive role in generating the data needed to undertake these analyses. Plus, noting that the project design is grounded in social learning and active stakeholder engagement, it will be important to determine the Social Return on Investment (SROI) to determine what matters to people the most when effected by climate hazards and the interventions that the Eco-DRR project will undertake. These aspects surface though community engagements and active discourse. SROI recognises that economic, environmental and social outcomes are all critical factors in well-being as well as sustainable and resilient lives.

3.6 BENEFIT CAVEATS AND LIMITATIONS

The CBA method applied across the case studies is necessarily high-level and is therefore subject to a number of caveats and limitations, as follows:

- Hydrological modelling-linked benefits (namely avoided direct flood damages) are based on an original site scoping at the five sites. All remaining benefits are linked to an expanded sizing of site areas. Hydrological modelling could not be undertaken for the expanded area owing to data constraints. The difference in project area extent between hydrological modelling-linked benefits and others presents an inconsistency. However, given hydrological modelling-linked benefits are significantly smaller than the remaining benefits, this inconsistency does not have significant bearing on the economic results. If hydrological modelling of expanded grassland area is done, this can be incorporated into an updated economic evaluation (and will certainly increase, albeit marginally, overall benefits).
- A number of important benefits are omitted from the quantitative analysis either because the data necessary to reliably quantify and value the benefits was not available, or because the effort required to derive estimates was considered disproportionate to the scale of benefits at stake. The analysis considers the impacts of changes in flood extent as a primary benefit, but the interventions are also likely to make a significant positive contribution to groundwater recharge which will, in turn, enhance agricultural productivity and household water security. Additionally, the estimates to do not include the value of reduced mortalities and morbidity, fire hazards, impacts to biodiversity (e.g., pollination services), and changes in methane and nitrogen oxide emissions. These exclusions suggest that current modelled results , specifically benefits, are underestimated.
- The benefits of some interventions (e.g. revegetation) may take several years to be fully realised but may then continue into perpetuity if interventions are properly managed and maintained. A multi-year assessment period would be required to capture the full benefits of the EbA measures.
- Hydrological input data that underpins most of the key benefits contain limitations that necessitated corrective assumptions for the economic analysis. These limitations include the fact that hydrological input data provided does not disaggregate flooding hazard or extent by flooding depth. Rather, only the total number of assets affected by flooding in the baseline (no intervention) are provided. Without depth-disaggregated information, this analysis assumes that under the without-intervention scenario vulnerable assets are totally damaged ('full damage'); with intervention, damage is reduced by 50% to 'partial damage'. Most fundamentally, the hydraulic model estimated the extent of flooding discharge for the current baseline climate scenario (with and without interventions) only – forecasted future flooding extent was not available. In lieu of this information, simulated future climate change

discharges were sought by equating the return periods for rainfall annual exceedances probabilities (AEPs) to flooding discharges. This yields an important characteristic for this economic assessment of the present value of avoided direct and indirect damages (typically assessed as depth- and return period-disaggregated average annual damages (AADs) multiplied by AEPs): owing to the absence of depth- and return period-disaggregated AADs, these remain constant regardless of the return period. This implies that present value of damage is only determined by AEP. Therefore, damages for lower return period floods (e.g., 1:5) are larger than for higher return period floods (e.g., 1:100) purely because they occur more often. This doesn't take into account the fact that these lower return period floods might not cause major damage to built infrastructure. The converse is true for a 1:100 flood. Therefore, benefits are likely to be overestimated for lower return periods (1:5, 1:10) and potentially underestimated for higher return periods. This is a limitation of the economic analysis.

It should be noted that, owing to data limitations, the cost and benefit estimates are necessarily high level and are intended to be indicative only of the net benefit derived from EbAs. It is also important to note that the sites and interventions assessed in this report are for the sites selected during feasibility. Due to the results from this CBA, it was recommended that the sites be expanded and built infrastructure included. As such, the sites and interventions put forward in the funding proposal have been adjusted when compared to those in this report and site finalisation will need to be undertaken during the inception phase of the Eco-DRR project. More detailed analysis of costs and benefits will be undertaken during inception once the sites and interventions have been finalised

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