SUSTAINABILITY THROUGH AGRICULTURE AND MICRO-ENTERPRISES

DAM CATCHMENT RESTORATION

EROSION PREVENTION AND RESPONSE

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SUSTAINABILITY THROUGH AGRICULTURE AND MICRO-ENTERPRISES

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ABSTRACT

Siandwazi Village, located in southern Zambia, is a community of smallholder farmers who rely on a community dam for dry season water supply and food production. Gully erosion is occurring on the dam spillway and in its watershed due to the dam's influence on stream gradient and agricultural land-conversion. A community-led, volunteer erosion control program was conducted throughout the 2019/20 rain season to protect the dam from erosion-derived failure and re-establish natural hydrological regimes. Erosion control efforts on the spillway reduced annual gully and rill erosion from 10.5 to 2m^3/yr through the placement of rock, sand-filled sacs, and vetiver grass (V*etiveria zizanioides)*. Erosion prevention and control efforts in the watershed were planned but never proceeded due to labour constraints and drought-derived socioeconomic challenges, therefore erosion increased from 12 to 14.5m^3/yr. Construction on a flood-mitigating check dam was initiated and a baseline run-off coefficient was established to allow for specific watershed objective-setting moving forwards into next rain season.

PROJECT CONTEXT

Zambia faces severe socioeconomic and environmental challenges. The majority of the population are rural subsistence farmers facing challenging socioeconomic and environmental challenges: 56.5% of Zambians live in rural settings (World Bank, 2018); 77% of these live below national poverty lines (CSO, 2018); and 54% lack access to basic drinking water services (CSO, 2014). A short and erratic rain season followed by 8 rainless months provokes food insecurity and water scarcity. A single, unreliable, rain-fed maize harvest is typically relied upon to feed and fund families for the entire year. Other means of survival include unregulated charcoal-production and free-grazing livestock rearing. These livelihoods drive Zambia's drastic land degradation and deforestation; each year, 250,000-300,000 ha of forest are cleared (Vinya et al., 2012). This has exasperating impacts of rural Zambians, as they rely closely on the land for construction materials, wood-fuel, food and medicine, and water supply and purification. Traditional leaders in Zimba District report that seasonal streams and perennial springs, the water source for the 46% of rural Zambians without access to basic water services, have been replaced with short-lived ephemeral floods (Chief Sipatunyana, personal communication).

The SAM Project, a Canadian-based NGO, strives to intercept the cycles of social and environmental decline in Zambia by increasing access to drought resistant and environmentally friendly sources of water, nutrition, and income. SAM does this by partnering with communities to connect them to the knowledge and resources needed to find locally maintainable solutions to community-identified priorities.

In 2015, SAM was approached by Siandwazi Village in Zimba District, Southern Province, to construct a small earth-fill dam to help address especially severe poverty and water scarcity (Fig. 1). When Siandwazi first engaged SAM in 2015, women and children were spending 8 hours round-trip to scoop for water beneath dried stream beds in neighbouring villages. After years of failed attempts to harness groundwater due to challenging hydrogeological conditions, SAM and Siandwazi agreed to construct a 140m long, 7m high earth-fill dam to harness flood run-off from an ephemeral stream in a 60,000m^3 reservoir. A gravity-fed irrigation scheme was attached to water 45 individually owned dry-season gardens in 2018. The dam proved its worth after the 2018/2019 drought and widespread crop failure across southern Zambia when the community used profits from vegetable sales to afford food, healthcare, school fees, and business capital without having to resort to environmentally destructive production of charcoal.

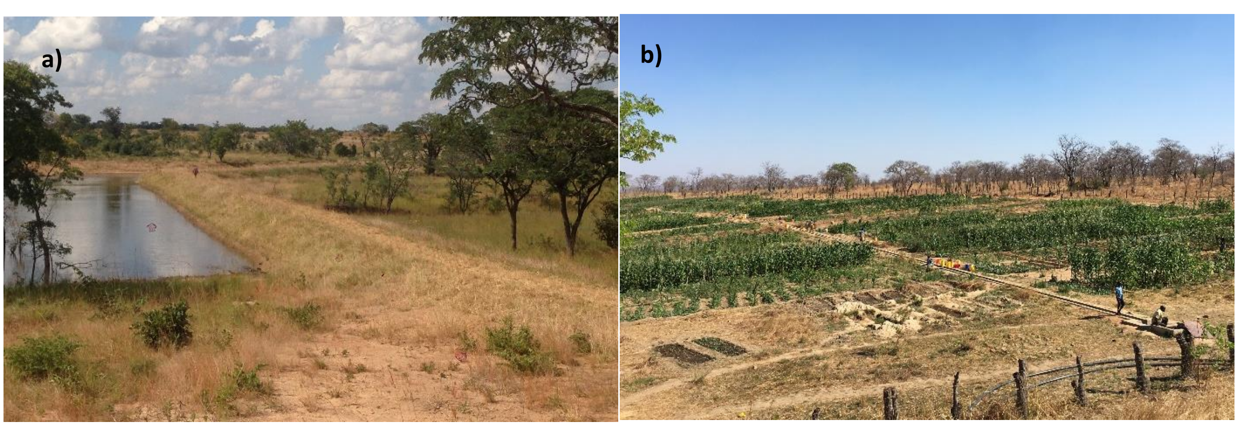

Figure 1: **a)** Siandwazi dam embankment, 140m long, 7m tall at the highest point, and roughly 3000m^3 in volume; **b)** Siandwazi irrigation scheme, supplied by a gravity-fed siphon system that pulls water over the embankment and runs it along canals to allow for dry season gardening

Although the Siandwazi dam provides an alternative to environmentally destructive livelihoods, it has had undeniable environmental impacts, notably erosion on its spillway. Direct environmental impacts of the dam include flooding of the 2.1 ha reservoir (Fig. 2a); clearing of 1.8 ha of land for gardens (Fig. 1b); alteration of local hydrology including downstream drying, erosion, and sediment restriction (Fig. 2c); and excavation of topsoil for construction material (Fig. 2d). It is also possible that the year-round release of seepage and irrigation water has negative impacts for downstream life cycles requiring temporarily dry conditions, such as seeds and eggs reliant on desiccation or re-wetting (Philip et al., 2017). Indirect environmental impacts include erosion from concentrated livestock traffic and possible up-scaling of farming activities due to increased ability to purchase inputs. Restoration of some of these impacts is unfeasible, unnecessary, and/or not the priority of the community. For example, portions of the excavated topsoil are already re-colonized by root-suckers of the dominant tree species, *Brachystegia speciformis,* and are on an unassisted trajectory back to woodland. Also, the total area flooded, cleared, and excavated in the name of community-wide food and water supply is less than the area cleared by most families for individual household food production. Contrarily, erosion occurring on the dam's spillway is severe, addressable, and of a high priority to the community. The re-directing of the natural watercourse is leading to significant gully erosion on the dam's spillway and jeopardizes the structural integrity of the dam. Neighbouring dams provide an example for the threat posed to the dam and landscape if left unchecked – 5m deep gullies that can spread up-watershed 100m in single flood events (Fig. 2d). For these reasons, erosion impacts were prioritized for restoration.

Figure 2: **a)** A portion of the 2.1 ha flooded by the dam reservoir; **b)** rill erosion occurring on the dam spillway; **c)** excavated top-soil for embankment construction; **d)** unchecked gully erosion at nearby dam which cued need for expensive dam rehabilitation

Figure 3: Gully erosion occurring at the outlet of the eroding micro-catchment

Investigations into the dam's erosion impacts revealed similarly severe erosional degradation occurring in its watershed. Surprisingly, when comparing upstream and downstream stream-bank erosion, it was found that the *upstream* was experiencing much more severe erosion, notably at the outlet of one rapidly eroding micro-catchment. The vegetation cover in this eroding micro-catchment was sampled and compared to another similar stable micro-catchment. The prevalence of cleared fields and tilling practices upon them were found to be the primary sources of erosion (Josephy, 2019a). Subsequent study of deforestation rates in the watershed using satellite imagery revealed a drastic increase in the extent of fields from 21% to 36% in only 11 years (Josephy, 2019b). This rapid land conversion poses severe threats to local biodiversity and socioeconomic wellbeing. To promote watershed management values and protect the dam against flood and siltation risks, The SAM Project decided to group the eroding micro-catchment into discussions of dam restoration.

This document summarizes the initial phase of restoration efforts to control erosion on the Siandwazi dam and its watershed. The first section provides an overview of the project, including details of the project's site, stakeholders, objectives, indicators, and benefits. The second section describes the restoration methods used and activities performed. The third and fourth sections respectively summarize and discuss restoration results. In the final section, conclusions are made along with recommendations for moving forward.

PROJECT OVERVIEW

SITE DESCRIPTION

Siandwazi is located in Zimba District, Southern Province, Zambia. In traditional jurisdictions, it falls within the Sipatunyana Chiefdom. The dam is located at 17° 29' 43.51" S, 26° 17' 53.99" E and has a 259ha catchment (Fig. 4).

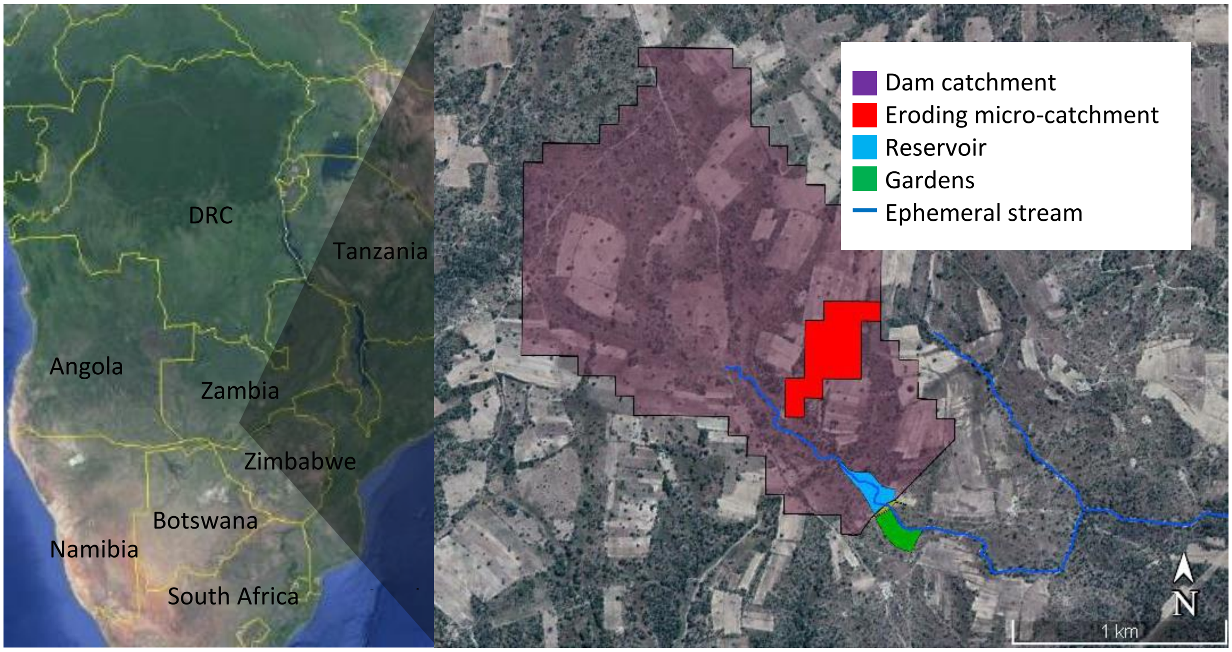

Figure 4: Siandwazi dam site and watershed, produced using Google Earth Pro

The erosion on the dam spillway is due to the geomorphological disequilibrium introduced by re-routing the ephemeral stream around the dam – a sudden, steep gradient has been introduced to the watercourse and the stream is attempting to readjust itself. This has led to one large ~1m deep, 80m long gully stemming from the intersection with the natural stream (Fig. 5b, 5c). Although this is to be expected, it must be stabilized before the re-adjusted gradient intersects the reservoir, which would result in catastrophic collapse. This gully was plugged with rock prior to the 2018/19 season but grew slightly as the gully head jumped above the rock. The 2018/19 rain season also led to a new ~2m wide, 40m long rill erosion closer to the dam (Fig. 5b).

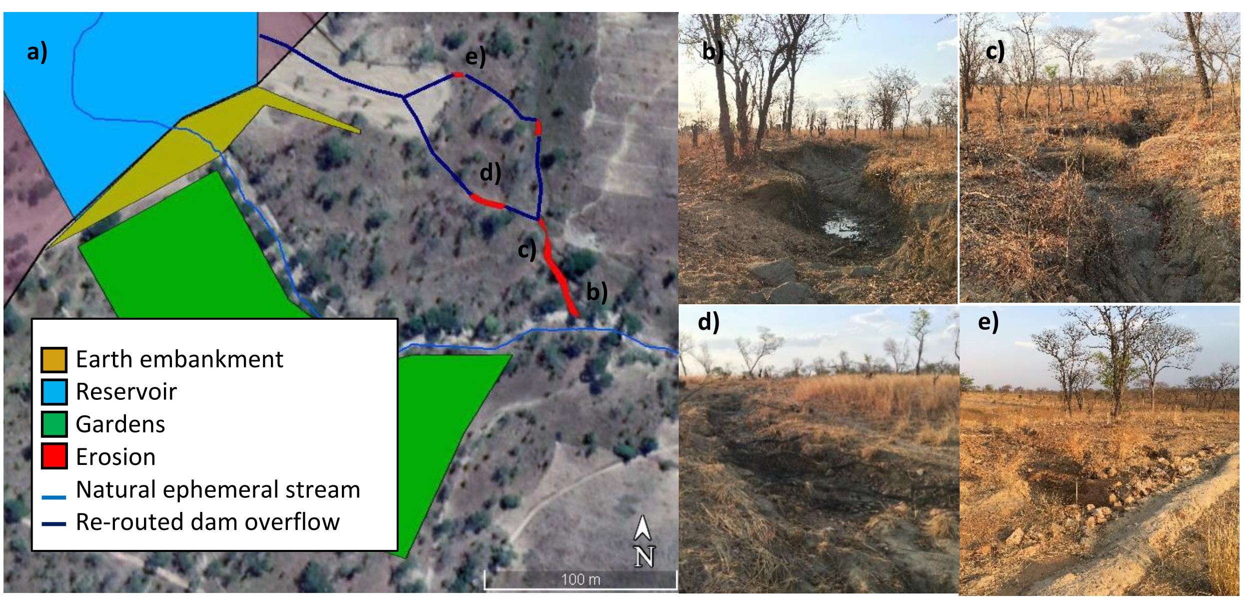

Figure 5: a) Schematic of dam spillway, water flow routes, and status of erosion at the start of the project; **b)** gully erosion at the intersection of the re-routed and natural stream; **c)** mid-way point along the gully erosion shown in 5b; **d)** rill erosion occurring closer to the excavated spillway; **e)** narrow gully erosion at the edge of the excavated spillway

The eroding micro-catchment is experiencing gully erosion both at the start and end of its watershed (Fig. 6). The erosion is a recent occurrence originating from a change in agricultural practices at the top of the watershed. In 2015, down-slope tilling and misplaced water-conservation bunds concentrated water on easily erodible soils, leading to gullying along bare land (6d, 6e). Seasonal wetland (dambo) withstand the concentrated flow throughout the middle of the micro-catchment, but active gullying at the outlet is advancing into the dambo (Fig. 6b, 6c).

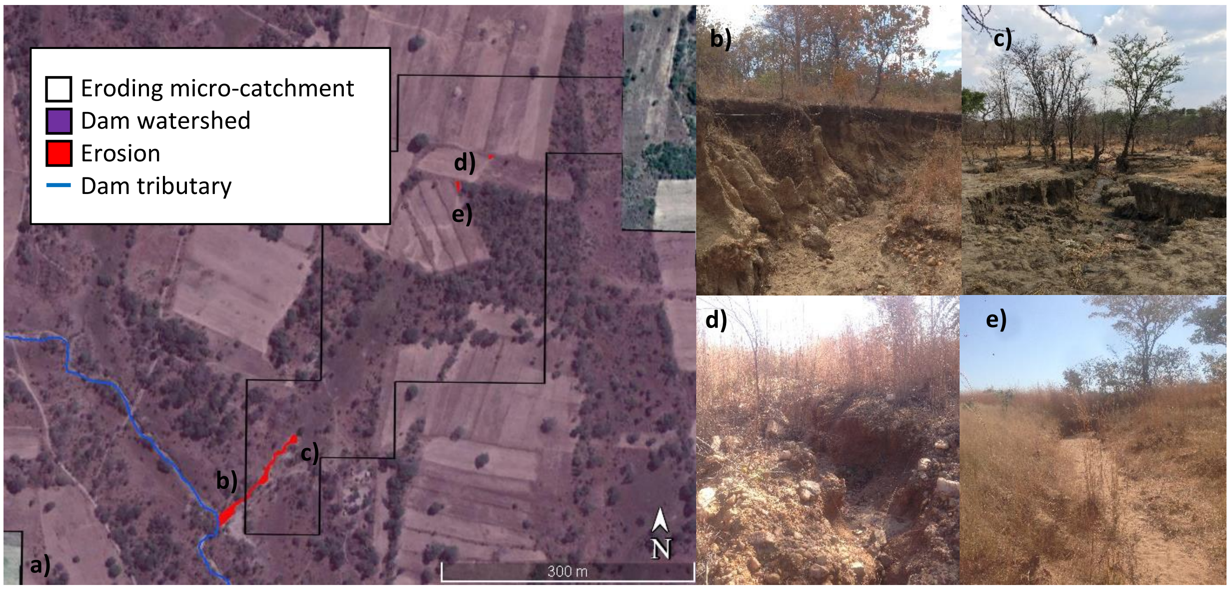

Figure 6: a) Schematic of eroding micro-catchment; **b)** gully erosion at the micro-catchment's outlet; **c)** gully head; **d)** narrow gully erosion at base of field with down-slope tilling; **e)** out-flow from narrow gully cross-cutting fields

Both sites fall within the extensive eco-zone of Miombo woodland which spreads across 42% of Zambia and 8.9% of Africa (Vinya et al., 2012; Millington et al, 1994). Miombo woodland is endemic to Africa, containing over 4500 species found nowhere else in the world (Rodgers et al., 1996). Frost (1996) describes Miombo woodland as being dominated by a canopy of *Brachystegia* ("Miombo"), *Julbernardia* and *Isoberlinia* trees 380-1400 stands/ha. This diverse canopy is underlain by a low-biomass understory of grasses, sedges, and saplings. Variable soil conditions result in a high diversity of plant species. Miombo woodland is unique in its extremely high biomass of termites (which results in low soil organic matter) and its long history of frequent fire disturbance. Production is extremely seasonal, following intensive rainfall concentrated into short rain seasons. The spillway and eroding catchment outlet would both be classified as "Mopane" woodland, a sub-class of Miombo, due to a dominance of *Colophospermum mopane.* The correlation between Mopane trees erosion is not coincidental, as it prefers dispersive and easily erodible sodic soils (Stephens, 2010). The extremely high salt content of the soil is also evident be observed cows *eating* the soil in the eroding micro-catchment. Both sites are underlain by thinly distributed, unidentified native grasses. Although soil sodic, sieve, and proctor tests were performed in nearby soil test pits during dam construction, the results are irrelevant due to the heterogeneity of local soils.

PROJECT STAKEHOLDERS

The project stakeholders are shown in Table 1, along with their project roles and home institutions.

Table 1: Siandwazi dam restoration stakeholders

Institution/Group	Stakeholder	Role
Ministry of Agriculture (MOA)	Maambo Lilando	Surveying, erosion control, and agricultural expertise; author of monthly reports
Department of Water Resource Dev. (DWRD)	Henry Lungu	Surveyor, designer, and construction supervisor of check dam
Community	Headman, Dam Committee, Dam Users, Landowners	Recipients and participants of restoration; final decision-makers; community mobilizers
The SAM Project	Taylor Josephy	Funder; hydrological data collection; community data collection; author of final report

PROJECT OBJECTIVES

The over-arching goal of the Siandwazi dam restoration project is to protect the dam against erosion and, in the process, regulate disturbances to hydrology due to the dam's construction and land-use in the watershed. During an initial concept planning meeting with the community, it was agreed that three primary objectives should be completed, including:

1) *Cease gully and rill erosion on the dam spillway by March 2020;*
2) *Cease gully and rill erosion in the eroding micro-catchment by March 2020; and*
3) *Increase baseflow to dam (long-term) and establish baseline measurements to allow for specific objective-setting in the future by March 2020 (short-term).*

These objectives were chosen on the basis of the benefit they brought the community, the primary stakeholder in the project. The community's priorities were held in especially high regard because the restoration would occur on their land, would rely on their labour, and would directly impact families living in vulnerable socioeconomic conditions. Objective two was suggested by The SAM Project to the community, and they agreed after learning of the siltation and flood risks erosion in the catchment posed to the dam.

Objective 3 was a result of discussions between SAM and the community, and it warrants elaboration. At the time of the objective-setting meeting, families in neighbouring villages were skipping meals and livestock were dying from thirst due to the 2018/19 rain season drought. While other dams in the area dried completely, the Siandwazi dam maintained some water and mid-dry season garden production afforded general food security. However, low dam levels in peak dry season meant that the gravity-fed irrigation system stopped functioning, leading to a loss in profits. Community members first proposed that the dam be expanded, however SAM explained that dam expansion would be impossible due to extreme costs, that it would exacerbate erosion issues on the spillway by increasing the gradient, and that it is would be possible to raise water levels next dry-season by practicing water conservation and water-shed management. The community was enthusiastic about restoring the watershed's ability to retain its water, and since the same actions that encourage infiltration and baseflow mitigate run-off and erosion, the objective was grouped into this restoration project.

EVALUATION: INDICATORS, BASELINES, AND TARGETS

The Society for Ecological Restoration (SER) states that all restoration project should be assessed against clear goals and objectives using measurable indicators (Gann et al., 2019). Rather than quantifying complex erosivity and erodibility measures, Objective 1 and 2 were evaluated simply on the presence of new gully and rill erosion and estimates of soil loss volume over the rain season. Sheet erosion was not addressed due to the scale of response required and the complexity of measure. Dominant gully heads were marked the previous year, allowing for estimates of expanded gully area and volume to take place. Most rill erosion occurred in 2019, allowing for direct volume measurements using area and average depth of rills. Estimates show that $10.5m^3$ was lost on the spillway and $12.0m^3$ was lost in the eroding micro-catchment during the 2018/19 rain season. A complete halt of gullies and rills, or $0m^3$ soil loss volume, was the objective for both the spillway and the eroding micro-catchment.

Setting measurable indicators is problematic in the case of Objective 3 due to the lack of baseline data and the difficulty of establishing quantitative measures. In order to establish a simple pseudo-indicator for future years, the project would collect hydrological information throughout the rain season to establish a run-off coefficient for the catchment. Methods used for coefficient calculation are explained in detail in the restoration methods for Objective 3 (p. 12).

SER also states that natural ecosystems should always be used for reference targets when performing restoration. The stable micro-catchment provides a relatively undisturbed reference for the eroding micro-catchment. Rehabilitating the gully with silt-catching check dams could eventually return the space to the seasonal wetland it once was. However, mitigating the concentration of water at the top of the watershed and ceasing the active advance of gullies at the bottom of the watershed was prioritized for this project, with dambo restoration remaining a possibility the following rain season.

For the dam spillway, it could be possible to compare the land with additional dam overflow to the adjacent land without and strive to restore similar vegetation cover, however this would likely be futile due to natural limits on flood mitigation and the inherent erodibility of the land. It must be asked whether we are restoring the land or restoring the stream, which now has a new path due to disturbance. This does not change the objective of achieving a stable geomorphological equilibrium, however it does have implications for restoration approaches (ex. placing rock vs. propagating native vegetation). With this in mind, the eventual target for the spillway would be a watercourse imitating a natural stream.

RESTORATION METHODS

This section describes the restoration methods and activities used to execute each of the objectives. In the same community meeting which established the project's objectives, strategies on how to execute them were discussed and selected. Methods suggested by the community which utilized locally available materials were prioritized.

Starting in December, work plans would be established and reviewed on a monthly basis. It was agreed that the objectives should be completed chronologically (Objective 1, then 2, then 3) in order to protect the dam from the possibility of early flash floods. After the completion of rain season, it was agreed that progress re-assessed and objectives for the following year would be set.

OBJECTIVE 1 METHODS: CEASE GULLY AND RILL EROSION ON DAM SPILLWAY

Three approaches were used to establish an alternative, erosion-stable water course around the dam that mimics a natural stream's ability to disseminate energy: 1) the placement of stones and sand-filled sacs on gullies and rills to stop their advance; 2) the placement of a flood-spreading sill to reduce water concentration on an erosion-prone location; and 3) the planting of vetiver grass (V*etiveria zizanioides)* to stabilize areas around the main watercourse.

Following the guidance of the Ministry of Agriculture representative, sacs and rocks were placed to disseminate energy, similar to how the bedrock, boulders, and large woody debris function within a natural stream. Figure 7 shows the community working to place stones and sacs. Due to a limited budget and difficult site access, the work was performed solely using volunteer manual labour. The sacs were placed primarily as a space-filler underneath a "stream-bed" of rock.

Figure 7: a) Dam committee vice-chairperson standing next to rock collected by the community; **b)** sand-filled sacs to be placed in rill erosion; **c)** placed sand-filled sacs; **d)** Maambo (MOA) assessing rock placement atop sand-filled sacs

Figure 8: a) Flood-spreading sill trench; **b)** levelling top of sill; **c)** constructed sill above gradient drop; **d)** finished sill after rock placement

The sill was constructed to spread the flow of water prior to an erosion-prone, steep section along the watercourse where the rill erosion started (Fig. 8). A 50cmx15cmx10m trench was dug to prevent under-cutting of the rill (Fig. 8a). A concrete sill was constructed and levelled using an ocular builder's level, with a low point placed in the middle to avoid water flowing around the sill (Fig. 8a-c).

Figure 9: a) Women digging trenches for vetiver grass planting; **b)** planting vetiver grass along bank of sill; **c, d)** soaked vetiver being planted in contour trench

Vetiver grass (V*etiveria zizanioides)* was planted adjacent to and upstream of the watercourse (Fig. 9). Vetiver was chosen because of its hardiness, quick ability to root, ability to withstand heavy flows, and proven non-invasive behaviour at neighbouring sites. 300 bundles were sourced from a private farm in the region. The bundles were planted closely along contour trenches following directions from the Ministry of Agriculture. Planting occurred in mid-January after the first rains to benefit from wet-soil and the longest possible duration for rooting prior to the dam spilling.

OBJECTIVE 2 METHODS: CEASE GULLY AND RILL EROSION IN MICRO-CATCHMENT

Figure 10: a) Maambo (Ministry of Agriculture) next to an adapted A-frame which uses a level to establish two points of equal elevation to build a contour; **b)** contour for farmers to follow while tilling

To cease erosion in the eroding micro-catchment, it was agreed that floods would be managed from their source, a field with down-slope, open-tilling. A meeting between the dam committee and the landowner took place to sensitize on the impacts of the land-use and establish how the landowner could be assisted to manage floods. The erosion was a priority concern for the landowner, and it was revealed that the tilling direction and water-concentrating bund at the edge of the field were attempts to mitigate erosion occurring in another catchment which endured the field's run-off when tilling occurred along the other slope. Discussing potential solutions with the landowner, the Ministry of Agriculture, and the dam committee, it was agreed that the Ministry of Agriculture would help the farmer perform "contour farming" to ensure tilling occurs perpendicular to slope to catch water and split the run-off between the two catchments as would have occurred prior to the field. This was chosen over alternative conservation farming methods being promoted due to economic and labour trade-offs experienced by farmers in the region. A simple "A-frame" was constructed to establish contours in a time-effective manner and contours were pegged across the field (Fig. 10). Despite enthusiasm from the landowner, the field remained uncultivated throughout the rain season due to economic challenges derived from an early drought, thus water continued along the down-slope furrows from the year before.

It was agreed that the gullies formed at the top of the watershed (Fig. 6d) would be addressed using a method used by the landowner to rehabilitate gullies in the neighbouring catchment: placing logs within the gully, allowing sediment to back-fill, and waiting for captured natural grass seed grasses to germinate for stabilization. The larger, wider gullies at the base of the micro-catchment would be plugged with sacs and rock, like those on the spillway (Fig. 11). However, the large labour demands of Objective 1 and community-wide economic issues from early drought prevented the community from addressing the gullies in the micro-catchment in time, leaving them unprotected against the floods.

Figure 11: Plugged gully on dam spillway

OBJECTIVE 3 METHODS: IMPROVE BASEFLOW TO THE DAM / ESTABLISH RUN-OFF BASELINE

To establish both event-based and seasonal run-off coefficients for the watershed, precipitation and dam water levels were monitored throughout the rain-season. A rain-gauge was set up at the home closest to the dam embankment and the homeowners were trained in how to measure and record daily precipitation (Fig. 12). Water levels were recorded by placing pegs in 25cm vertical intervals along an exposed reservoir bank when water was at its lowest. These levels were referenced against known benchmarks established during the dam's construction. Water volume was calculated using the polynomial equation from the volume-depth curve for the dam's reservoir, developed from contours during dam surveying (Fig. 13). Event-based run-off coefficients were calculated by dividing the increase in dam water volume by the total volume to fall on the catchment (precipitation depth x catchment area). The seasonal run-off coefficient was established using the same method but with the sum of precipitation prior to the dam reaching its full supply level.

Figure 12: Rain-gauge set up near Siandwazi dam

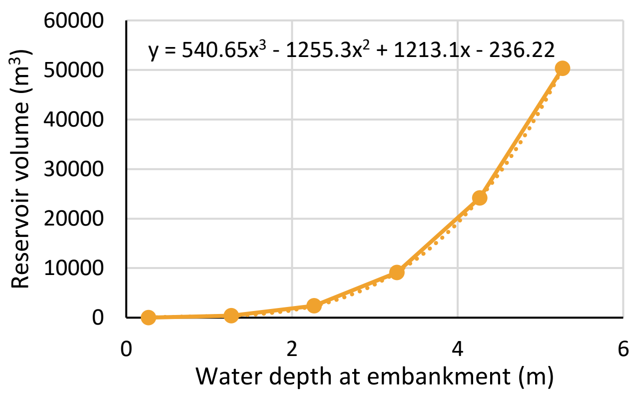

Figure 13: Siandwazi dam volume-depth curve created from pre-construction topographic surveys of the reservoir

After the delayed completion of Objective 1, it was agreed that once work on Objective 3 proceed rather than Objective 2. Construction of a small gabion check dam would be initiated to mitigate flood intensity, recharge local water tables, capture silt, and increase dry season baseflow. Work on the earth dam spillway finished in early March, so work started on the check dam by mid-March with the knowledge that it may or may not be installed in time for the last floods of the rain season. A stream-gradient survey was conducted to identify the most favorable location (narrow banks; solid, shallow bedrock; shallow upstream gradient; steep downstream gradient). This was found to be 40m upstream of the maximum throwback of the reservoir. A profile of the stream banks was performed using a builder's level and a design was made by the local Water Engineer for the Department of Water Resources Development (Fig. 14a, 14b). Pre-made gabion baskets made of durable and corrosion-resistant material were sourced for the construction. Initial excavations and rock collection were conducted by the community (Fig. 14c). As of the writing of this report, the structure is awaiting environmental approval before proceeding.

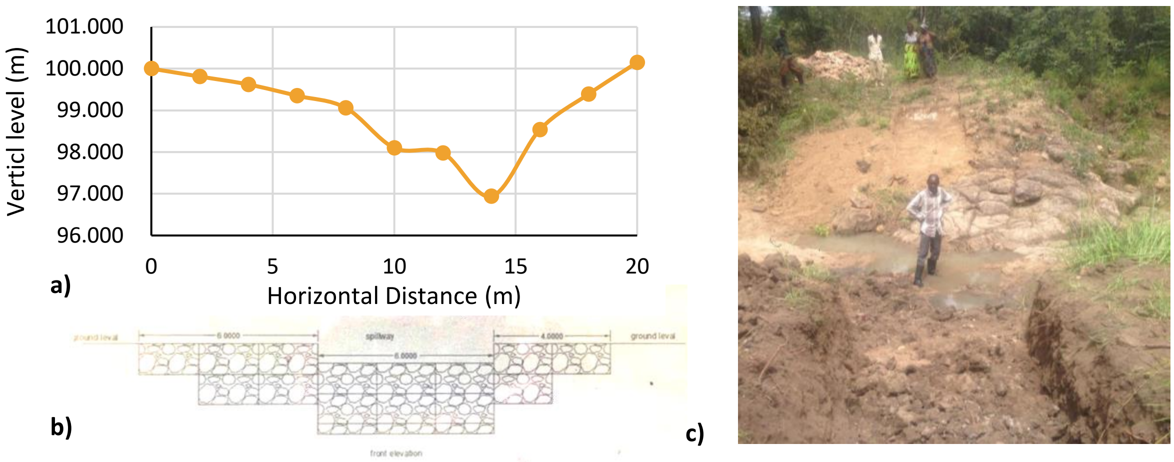

Figure 14: a) Stream-bank profile of the check dam site; **b)** profile-view of check dam design; **c)** Siandwazi headman standing on the stream-bed of the check dam site

RESTORATION RESULTS

A summary of the restoration results is shown in Table 2. Objective 1 was nearly met; Objective 2 went unaddressed due to reasons discussed below; and Objective 3 is still in progress, though the run-off baseline indicator was established.

Table 2: Summary of restoration objectives, indicators, baselines, targets, and results

Objective	Indicator	Baseline	Target	Actual	Outputs
1. Cease erosion on the dam spillway	Volume of soil lost to gully and rill erosion per rain season	10.5m^3/yr	0	2.0m^3/yr	• Flood spreading rill • Planted vetiver grass • Plugged gullies
2. Cease erosion in the eroding micro-catchment	Volume of soil lost due to gully and rill erosion per rain season	12.0m^3/yr	0	14.5m^3/yr	• A-frame contour tool
3. Improve baseflow to dam / establish baseline indicators	Run-off coefficient Reservoir levels throughout dry season	4% 1.8m at start of rain season	n/a n/a	TBD TBD	• Baseline indicator established • Check dam construction initiated • A-frame contour tool

OBJECTIVE 1 RESULTS: CEASE EROSION ON THE SPILLWAY

The rills and gullies which were protected remained stable throughout the largest floods of the 2018/19 season (Fig. 15a), but an additional estimated 2.1m^3 was eroded from unprotected sections. Most of this erosion occurred in a flat section of the spillway which was expected to have lower water velocities and be less erosion prone (Fig. 15b). Another example is near the bottom-most gully, where excess water was pushed to fall on an unprotected gully head (Fig. 15c). Surprisingly, this resulted in little soil loss as the bank remained stable until the community could respond with more rock. The sill performed generally well, and the erosion-prone area immediately downstream did not experience any new erosion (Fig. 15d). However, its wings were not extended long or high enough, so water could bypass the structure, threatening erosion. Most of the vetiver grass planted upstream of the main drainage was washed away due to the strength of the floods and limited rooting time, however the grass planted adjacent to the drainage rooted well.

Figure 15: a) Plugged gully at outlet of dam spillway; **b)** flat area of new erosion on unprotected land; **c)** overflow re-routing flowing over unprotected gully head; **d)** flood-spreading sill

OBJECTIVE 2 RESULTS: CEASE EROSION IN THE ERODING MICRO-CATCHMENT

Since none of the planned activities in the eroding micro-catchment went forward, gullies and rills were exposed to floods and grew significantly. It is estimated that this soil loss is around 14.5m^3. On the field responsible for the previous year's erosion, water followed the same concentrated pathway as the contours were not tilled and the previous down-slope furrows remained. The resultant soil loss manifested primarily as gully slumping at the bottom of the micro-catchment (Fig. 16a,b), however narrow gullies at the top of the watershed also deepened (Fig. 16c,d).

Figure 16: a, b) Advancing gullies at the bottom of the eroding micro-catchment; **c,d)** deepening gullies at the top of the eroding micro-catchment

OBJECTIVE 3: INCREASE BASEFLOW TO DAM / ESTABLISH BASELINE INDICATOR

The precipitation and dam water level data are shown in Figure 17. Overall, 583mm of precipitation was recorded over 25 rainfall days. The dam filled and spilled during the season's largest rainfall event of 120mm on February 24th. The season's run-off coefficient was calculated to be 3.9%, while event-based coefficients were, in chronological order, 0.7%, 2.2%, 6.4%, 1.4%, 3.6%, 4.4%, 9.7%, and 5% (averaging to 4.2%).

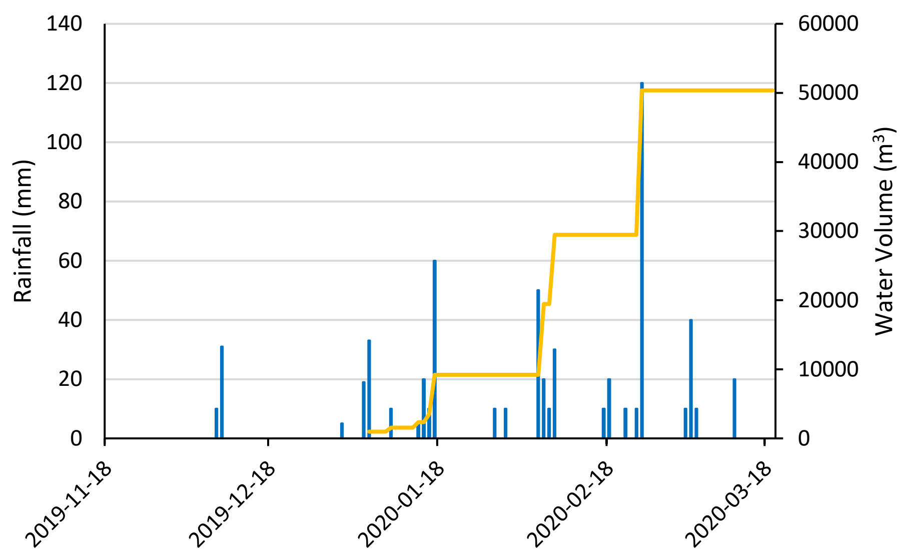

Figure 17: Siandwazi precipitation depth (blue) and reservoir volume (orange) throughout the 2019/20 rain season

Since the contour farming in the eroding micro-catchment did not go forward and the check dam construction is still underway, there were no activities that could have contributed to increased baseflow during this rain season captured in the present data. Even if there are late rains, since the dam is full, the effect of the check dam on watershed-scale run-off will not be measurable.

DISCUSSION

LIMITATIONS AND CHALLENGES

The project was inherently limited by a small budget, high labour demands, and the challenging socioeconomic conditions of the local community. Plugging the gullies and rills with rock entailed extremely large labour demands and the volunteers' time came at an especially high opportunity cost. Considering this, it is important to appreciate the work performed – volunteers were choosing to pile rock day after day in the name of community benefit instead of spending their time searching for much needed food and income. Despite their ambitious efforts, the labours of the objectives outweighed the supply, resulting in exposed gullies in the eroding micro-catchment. From a biocentric perspective, the challenging socioeconomic conditions and the need to prioritize protecting the dam's food and water supply also limited the project's ability to prioritize more ecological objectives.

The study is also limited by the absence of a restoration supervisor experienced in ephemeral stream restoration and the absence of baseline ecological data. Literature on ephemeral stream restoration is scarce, and many recommendations made (ex. fencing the stream to prevent livestock access) are unfeasible due to the socioeconomic setting, limited resources available, and absence of reference species data. The remaining knowledge gap regarding what is realistically achievable in this restoration environment and how to achieve it resulted in the formation of basic objectives and informal indicators while ecological considerations (ex. dry season stream bed habitat) were neglected.

Drought throughout the 2018/19 rain season and early 2019/20 rain season introduced additional challenges. By February, the community had gone 22 months without their primary source of food and income due to the previous crop-failure. Those with gardens were coping and able to re-invest in their fields, but early drought in November and December led many to lose their invested inputs, hence the lack of cultivation in the eroding micro-catchment. Moral for restoration is difficult to foster while families are wondering how they will survive through the next year. When the rains finally did come, moral was boosted, however project participation understandably lowered as farmers focused on working their fields and securing their livelihood.

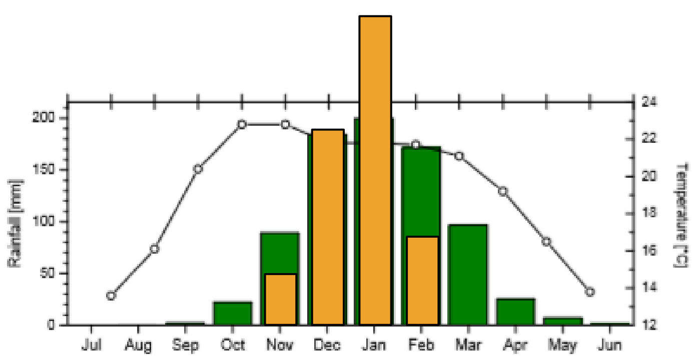

Figure 18: 50-year monthly average precipitation (green) and temperature (grey line) from meteorological station in Choma (Baumle et al, 2007) and Siandwazi 2019/20 precipitation (orange)

Contrarily, intensified rainfall late in the rain season increases the difficulty of controlling erosion. Figure 18 shows a comparison between Siandwazi's 2019/20 rainfall data (orange) and a nearby meteorological station's 50-year average. Although it is only one year, Siandwazi's distribution aligns with climate change observations and predictions of a shortened, intensified rain season (GRZ, 2017). The 120mm rainfall event is an example of this trend and a testament to the relative success of this project - the nearest dam to Siandwazi underwent an expensive rehabilitation with multiple cement drop-down structures on its spillway and even these were damaged in the same flood event. Without the restoration on the spillway, it is possible that the Siandwazi dam could have failed.

INTERPRETATIONS

It was difficult to predict the erosion on the spillway because it occurred in areas that had been stable throughout the previous two rain seasons. The intensity of the February 24th rainfall undeniably contributed, but it is also possible that the rock and sacs pushed water to the side of the desired watercourse in some areas. No levels were taken to ensure the rock was not creating high points. Ideally, a banked watercourse would be constructed to ensure that water only flows over the neo-stream bed, however the scale of this work makes it unfeasible.

Although the spillway is approaching erosional stability, it is important to be skeptical of its ecological function. Erosion is not the only property relevant to a stream's function, yet it was the only one inspected. Other important properties include flow permanence, species composition, meandering and gradient, water chemistry, sediment distribution, habitat, and shade. If all of these properties were measured against a historic reference, it is likely that the that re-routed watercourse would closer resemble rip-rap engineering protection. That said, the restored spillway closer resembles a natural stream than the destructive gullies would have if no action was taken.

The increase in erosion in the eroding micro-catchment is expected as there was more rainfall this year than last and no preventative or protective measures were taken. Although the land was not cultivated, it still maintained little vegetation cover due to an absence of productive root network from years of tilling. Cultivation could have increased the amount of infiltration by providing some vegetation cover and breaking up a compacted clay crust.

Striving to address both the eroding micro-catchment and the dam spillway erosion in one year proved to be over ambitious. Still, the project could benefit the micro-catchment moving forward as it has shown that stabilization of erosion is possible, even with large flows. Moving forward, focus will shift from the dam to its watershed, and the flooding of the micro-catchment will be the first issue to be addressed.

The run-off coefficients observed were less than anticipated. A coefficient of 10% was used by in the dam design, and this was thought to be an under-estimate from personal observations of flash-flooding behaviour. The low value could be the result of below-average rainfall and undersaturation of the watershed. The wide range of values (0.7-9.7%) is expected due to the numerous factors that contribute to run-off, especially soil saturation and rainfall intensity. The early rains tend to be gentle and fall on dry, thirsty soil, hence the low run-off at the start of the rain season.

Varying groundwater gradients throughout the rain season and the duration between precipitation and water level measurements could have skewed run-off estimates. If water levels were recorded long after precipitation, discharge into banks early in the rain season could have resulted in under-estimates of run-off volume. Vice versa, if water levels were recorded long after precipitation when water tables were recharged in late rain season, baseflow into the dam could have led to over-estimates. The rough methods of measurement (25cm height intervals) also likely introduced error, therefore the coefficients should be only be used as a rough inference.

CONCLUSIONS AND RECOMMENDATIONS

Efforts to cease 10.5m^3/yr erosion on the spillway were largely successful. Although roughly 2.0m^3 of soil was lost from unprotected areas, primary erosion-prone areas were stabilized using rock and sand-filled sacs. These protective measures withstood large flood events which damaged infrastructure across Southern Province, including a cement-engineered spillway on a neighbouring dam. The flood-spreading sill performed well, though measures must be taken to prevent water from circumnavigating the structure next rain season. Cuttings of vetiver helped stabilize the areas adjacent to the primary watercourse, however some cuttings were washed away in early floods. Planting next year should commence before the rains using hand watering to establish solid root systems prior early on.

Efforts to prevent and protect against erosion in the eroding micro-catchment did not go forward due to the labour demands of protecting the spillway and drought-derived economic struggles. In combination with exposed gully heads and higher intensity rainfall compared to last rain season, the continued concentration of floods resulted in an increase in erosion from 12.0m^3/yr to 14.5m^3/yr. The same measures intended for this year should be prioritized prior to next rain season to prevent further advance of gullies into valuable season wetland. If appropriate and necessary, the farmer could be supported further to perform contour farming or another flood-management approach.

A baseline seasonal run-off coefficient of 4.2% was established through precipitation and dam volume measurements, but no baseflow-inducing outputs were produced prior to this report. The low run-off coefficient places limitations on what is possible for improvements to infiltration, and this will have to be considered when establishing objectives for next year. However, reducing run-off from late-season floods may be possible and should be attempted with water-infiltrating approaches next rain season. A more feasible target for watershed conservation may be mitigating flood-intensity and lengthening flow-prevalence, however further hydrological monitoring and investigations into reference watersheds would be required to establish baseline measures.

The study was limited by its budget, the labour demands of the necessary restoration, drought-stressed socioeconomic conditions of the local community, a lack of historic or reference ecological data, and the limited experience of the project implementers. Despite these challenges, the community displayed an impressive cooperation and work ethic, ultimately successfully protecting a crucial source of livelihood.

Moving forward, a subsequent community meeting will be hosted after harvest (May) to review progress on the objectives, discuss challenges, and establish the community’s priorities for the following rain season.

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