Land Degradation & Development Group

Monitoring soil water interactions of South African succulent thicket restoration cost effectively on field scale

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Monitoring soil water interactions of South African succulent thicket restoration cost effectively on field scale

By

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PRESENCE (Participatory Restoration of Ecosystem SErvices and Natural Capital (in the Eastern Cape))

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1 Introduction and objective

1.1 Introduction

In the Baviaanskloof, Eastern cape, South Africa, ecosystem restoration is facilitated by Presence/Livinglands. One of their objectives is to restore South African succulent thicket (SAST). SAST is an important biome in the Baviaanskloof, covering 26% of the watershed (Euston-Brown, 2006 in Draaijer, 2010). 'It is a unique vegetation type located in the semi-arid valleys of the Eastern Cape. It is dense, perennial, semi-succulent and thorny, ca. 2–3m high, with a wide range of growth forms and a high diversity of plant species' (Everard, 1987; Cowling, 1983 in Lechmere-Oertel et al., 2005a). SAST vegetation nowadays only covers 52% (Draaijer, 2010) of its original biome in the Baviaanskloof, being decimated to its current extent by overgrazing with domestic herbivory. Spekboom (*lat. portucularia afra*) is a main succulent in SAST. During the degradation process of SAST, approximately 3/4 of the dry biomass is lost of which the bulk consists of *p. afra* (Stuart-Hill & Aucamp, 1993; Aucamp, 1976 in Lechmere-Oertel 2005a). Lechmere-Oertel (2005b) found high levels of soil organic matter in intact SAST, being more similar to temperate deciduous forests. This was attributed to high levels of leaf litter fall and decomposition by its dominant species; *p. afra*.

High levels of soil and above ground biomass accumulation by *p. afra* have put this plant into the spotlight for restoration. It's carbon fixing properties have well been studied, but it is hypothesized that SAST restoration has a positive effect on soil and water conservation (SWC) as well. However, a lot of uncertainties in quantification currently persist in the relation of restoration to soil-water interactions (SWI).

Currently, degraded SAST suffers from high runoff and erosion during high intensity rainfall events. It is hypothesized that the moisture holding capacity in the degraded area is lower than in pristine SAST. High runoff and erosion lead to high peak flows in the Baviaanskloof river that flows into the Kouga Dam reservoir downstream. This dam supplies water to the Nelson Mandela Bay Metro (NMBM) which currently suffers from water scarcity. During high quantity rainfall events water resources are lost for consumption because the Kouga dam then overflows. Massive scale SAST restoration should increase the storage effect of soil and water in the SAST which results in steadier surface and groundwater flow to the river, resulting in a higher baseflow throughout the year and thus a more optimal use of the storage capacity of the Kouga Dam. So far, however, field measurements on the effect of the restoration on SWI lack to underpin this hypothesis. Additionally, a steadier baseflow (and lower peakflows) should result in a lower sediment load, reducing siltation in the Kouga reservoir, which should assist in maintaining its capacity. In most old reservoirs, sediment is simply permitted to accumulate because the costs of reservoir storage lost to sedimentation has not been incorporated into decision-making and planning for reservoirs. Furthermore, mechanical removal is prohibitively expensive (Kondolf, 1997).

1.2 Objective

1.2.1 Main objective

The objective of this research come up with cost-effective ways to monitor the effect of SWI in the restoration process of SAST by identifying key parameters which can give an estimate of change in SWC properties of restored SAST.

1.2.2 Sub objectives

1. Identify a representative location and scale for the monitoring program
2. Identify active soil-water parameters at the proposed monitoring plot
3. Identify which soil-water parameters can/should be monitored
4. Identify how these parameters can be monitored cost effectively
5. Give suggestions for data management

2 Research method

2.1 Monitoring

Monitoring is the gathering of feedback information that will be essential for evaluating the effectiveness and efficiency of practices and management in general. Monitoring programs should be designed to collect only the information needed by users for their particular evaluation purposes. Collecting, processing and storing data and then processing it to generate useful information is expensive. Only the data actually needed should be collected at a time and in a form that meets the needs (Gregersen et al., 2007). The purpose of monitoring biophysical parameters is to determine whether the (proposed) activities will be/have the effects as anticipated. This is best achieved to compare two sites with and without the proposed interventions at the start of the intervention, and at a time (or multiple times) in the future. When sufficient information is gathered, evaluation is required to analyze if the activities had the anticipated effect. (figure 1, Olsen et al., 1981).

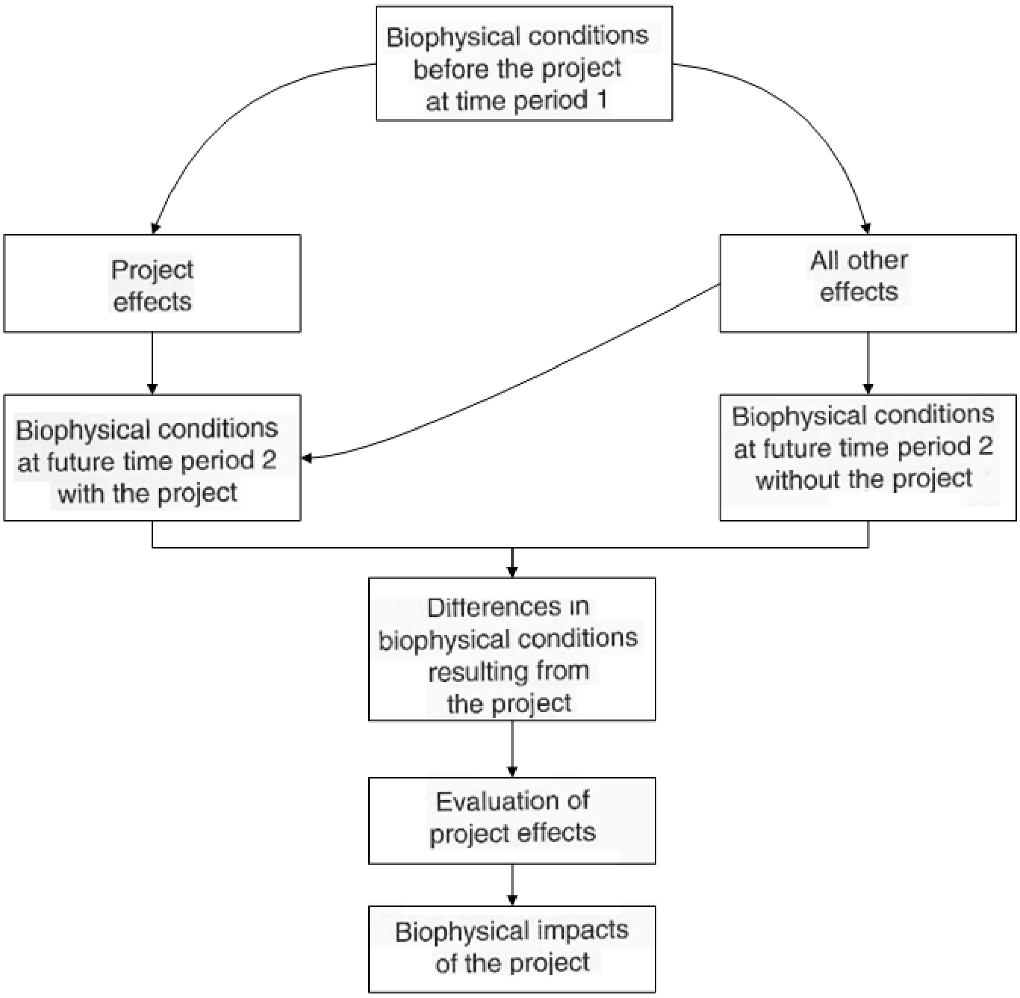

figure 1: Comparing the impacts of a watershed management practice on biophysical conditions. (Adapted from Olsen et al., 1981)

In the Baviaanksloof watershed, several interventions are proposed to conserve water retention capacity, vegetation restoration being one of them. To quantify the effects of these interventions data is required, which monitoring should be able to provide.

This research focuses on water-related biophysical properties of SAST restoration in the Baviaanskloof watershed (aside from other beneficial properties (ecological, economic and aesthetic benefits) attributed to vegetation restoration) and will identify key biophysical parameters within the SWI area which are likely to change due to SAST restoration. Monitoring these parameters should give an estimate of change in SWC properties of restored SAST, but has to be practically feasible. The main objective is to come up with cost-effective ways to monitor the effect of SWI in the restoration process of SAST.

The location for a monitoring site has to be found within the SAST biome in this watershed, preferably with an intact and degraded component to compare results. The term 'soil and water interactions (SWI)' was chosen because it deals better with the objective than terms like; 'erosion' 'moisture storage' or 'infiltration.' This research will try to identify which and how such processes should be monitored. Furthermore, the methods have to be budgetary and practically feasible, implying reasonable good accessibility and measurement methods with little labor and revisiting times, which shouldn't be expensive either. Additionally, the scale of monitoring has to be chosen since several scales exists in which monitoring can be conducted (point, plot, hillslope, field and watershed; Stroosnijder, 2005). Finally, monitoring water-related properties should be linked to rainfall events, so inquiry is required to study how this 'event' component is integrated best into the monitoring plan, because most important data is to be expected during and after precipitation.

2.2 Baviaanskloof watershed

Monitoring will be conducted within the Baviaanskloof watershed, a 75 km long valley located in the Eastern Cape province of South Africa. The valley is locked between the Baviaans mountains to the north and the Kouga mountains in the south. The area of the valley is 1234 km^2. Its most eastern point is situated just 100 km west-north-west of Port Elizabeth, which is the nearest major city in the region. Approximate coordinates that stretch the valley are from 23°35'E to 24°25'E and 33°30'S to 33°45'S

Landuse consist mainly of grazing land and wildlife reserve, both covered by natural vegetation. The vegetation in the Baviaanskloof is dominated (95%, Draaijer 2010) by fynbos, renosterveld and South African subtropical thicket (SAST). The appearance of fynbos and renosterveld landscapes can be described as heathlands. Fynbos and renosterveld are fire driven, which results that these landcape tend to be patch-works of stands in various stages of post-fire recovery (Hope et al., 2009). "SAST is characterized by dense, low growing vegetation, including small trees (3-5 m), succulent shrubs, lianas forbs and geophytes" (Kerley et al., 1999a). The dominating specie in the area, which is used for vegetation restoration as well, is the spekboom (*Portulacaria afra*, or *Elephant's Food*). In general, a sharp distinction can be made between vegetation supertypes in the Baviaanskloof; thicket dominated vegetation, fire driven vegetation and a small minority of remaining patches of other vegetation types (figure 2, table 1, derived from Euston-Brown, 2006)

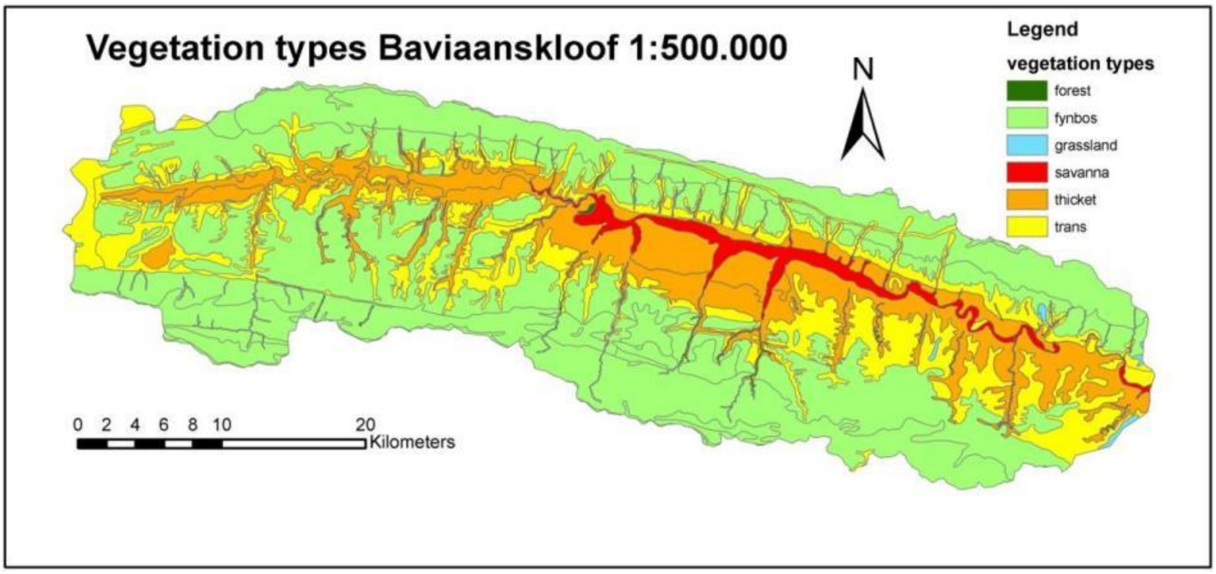

figure 2: vegetation types; (fynbos and renosterveld are both classified as 'fynbos,' (Euston-Brown, 2006))

table 1: surface distribution of vegetationtypes in the Baviaanskloof watershed

Vegetationtype	cover (%)	area (ha)
Thicket dominated	26,3%	32464
Fynbos/renosterveld	68,1%	84037
rest	5,6%	6899
Total	100%	123400

The geology of the Baviaanskloof is dominated by sandstone and quartzites of the table mountain group (Illgner and Haigh, 2003). There is a faultline running east – west in the watershed, the Baviaanskloof - Kouga fault. It is largely coincident with the main valley. The presence of this fault had a strong impact on the evolution of the drainage basin (ibid). Deep soils only occur on the flatter areas in the valley and on the plateaus (ibid). In the valley most of the soils are classified as stratified alluvial soils of Dundee type (having a high proportion of sand) with high drainage and high porosity. A soil survey showed that 47% of the soils had some clay (Jansen, 2008).

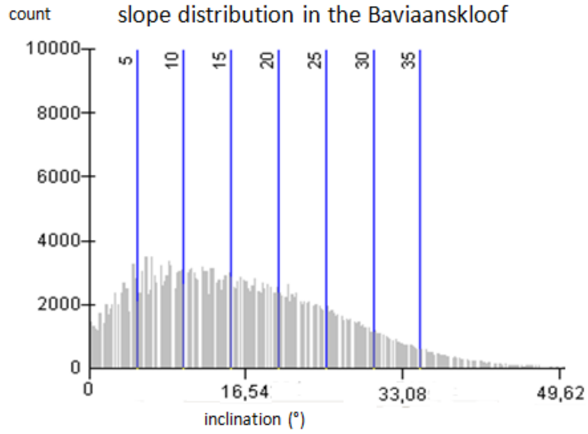

figure 3: Slope distribution in the Baviaanskloof in degrees (Draaijer, 2010)

Topography is dominated by steep slopes, only about 30% of the area has a slope of less than 30%. The most common slope in the valley ranges between 30 – 40%, and is 60% in some areas (Illgner and Haigh, 2003, figure 3). The confluence with the Kouga river is at <160 m above sea level; highest points of the valley are Scholzberg (1626m) in the Baviaanskloof mountains and Smutsberg (1758 m) in the Kouga mountains (ibid).

The climate of the Baviaanskloof can be described as semi arid. In the valley the average daily maximum temperatures range from 32 °C in January/February to 20 °C in June/July. The average minimum temperatures vary from 16 °C in January/February to 5 °C in July (Figure 4). In the winter the humidity is low due to inland dry winds. During summer winds come from the Indian ocean resulting in higher humidity (Jansen, 2008).

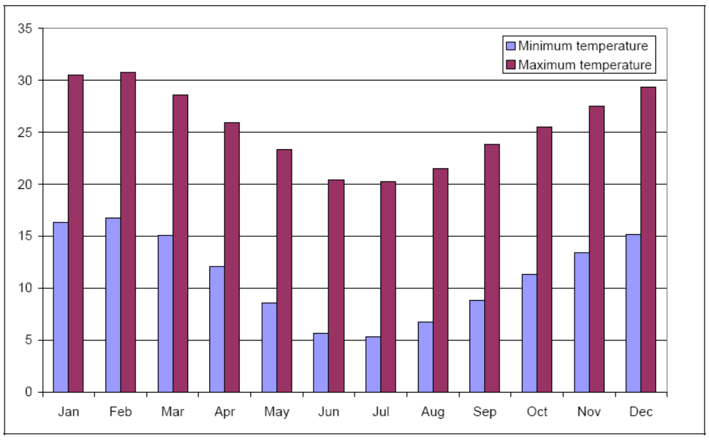

figure 4: Annual average max and min temperature distribution in the Baviaanskloof (Jansen, 2008)

Average annual rainfall in the valley is between 300-400 mm/yr (Illgner and Haigh, 2003). Feb/March and November are the wettest months, June/July the driest and during the remaining seven months between 20 and 30mm can be expected (ibid). Long term comparison of rainfall data shows however that the annual distribution is erratic and that anomalies between 100 and 700 mm can occur (figure 5).

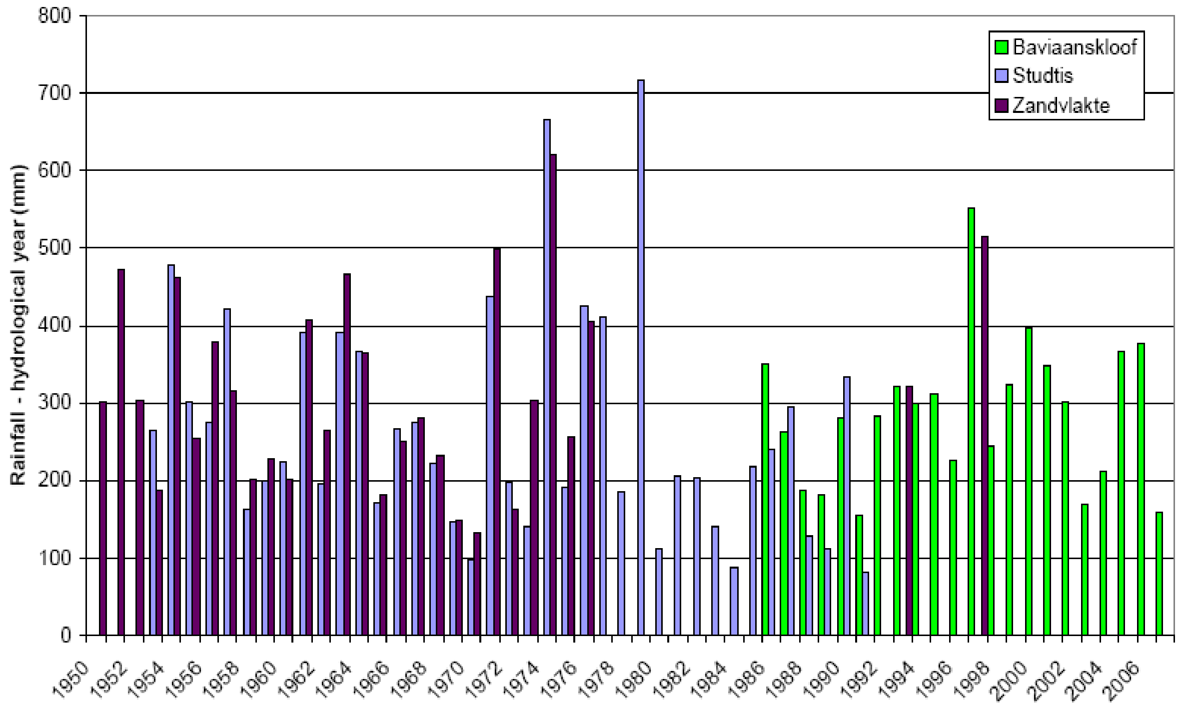

figure 5: Annual rainfall at three stations in the Baviaanskloof (Jansen, 2008)

The socio-economic situation of the valley is that of an isolated rural area with limited access to the outside world. Agriculture has become less viable in the area due to trade liberalization combined with a long distances to markets (the valley lacks paved roads and nearby basic services). This has resulted in declining returns on agricultural investments and unemployment amongst former farm laborers. Various farmers have diversified into alternative income generating activities such as (eco)tourism. Ecosystem restoration is desired to enhance the aesthetic value of the degraded area.

2.3 SAST in the Baviaanskloof

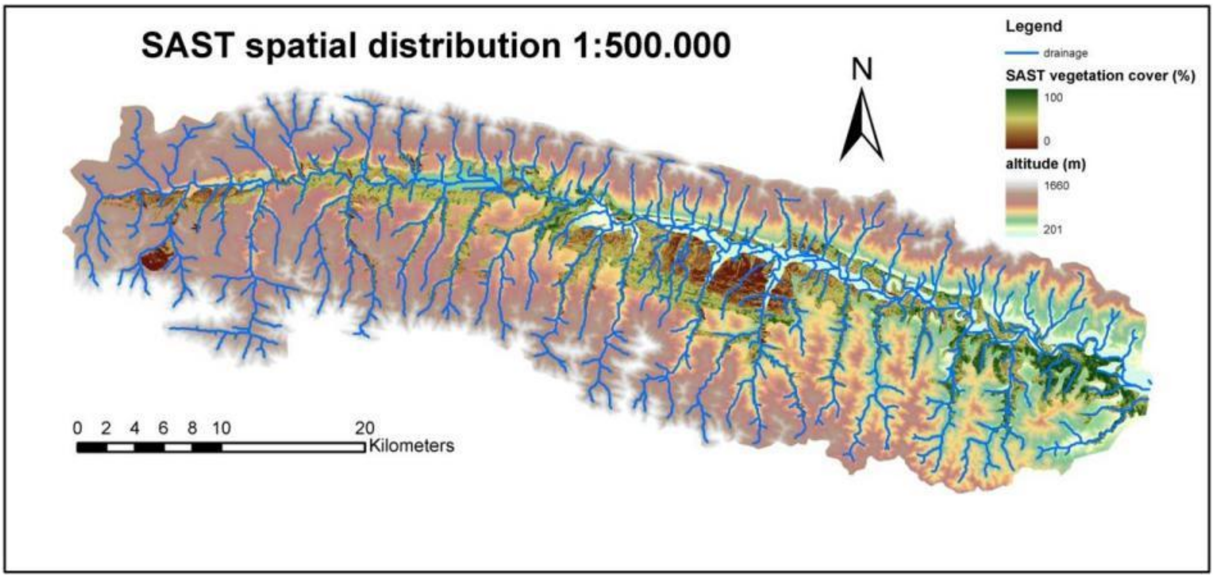

figure 6: Spatial and density distribution of SAST in the Baviaanskloof watershed

Monitoring will focus on restoration of South African Succulent Thicket (SAST) within the Baviaanskloof. This vegetation type is generally situated on the hillslopes in between fynbos on mountain plateaus upstream, and the valley bottom downstream. Current vegetation cover has been decimated by (historical) stock farming and covered in 2008 52% (Draaijer, 2010) of its original biome in the watershed (figure 6). The most distinctive feature in the degradation in the Baviaanskloof is a patch of severely degraded former SAST in the center of the valley, which coincides with the locations of several farms in the valley. Because of SAST's distinctive topographical setting in the valley, a monitoring site with representative characteristics of local geomorphology is desired.

2.4 Degradation and restoration

The degradation process of SAST has been quite intensively studied; SAST can sustain browsing by big game, like elephant and rhinoceros but is surprisingly sensitive to stock farming, especially with goats (Stuart-Hill, 1992). Heavy goat browsing can transform SAST into an open savanna-like system, possibly within a decade (Hoffman and Cowling, 1990; Lechmere-Oertel et al., 2005a). This results in a depletion of species diversity (Moolman and Cowling 1994; Johnson et al., 1999; Lechmere-Oertel et al., 2005a), carbon stocks (Mills et al., 2005), soil quality (Mills and Fey, 2004) and plant productivity (Stuart-Hill and Aucamp, 1993).

Sigwela et al. (2009) defined degraded SAST as sites in which livestock browsing decimated thicket clump cover to 10–15% of the area. Intact thicket was defined on sites where in which a dense cover (ca 70%) of thicket clumps (2–50 m in width and 2–5 m in height), interspersed with narrow tracts of bare ground was maintained (which is even possible with sustainable goat browsing).

Physical characteristics regarding degradation of spekboom dominated SAST have been studied by Mills and Fey (2004), Mills et al. (2005b) and Lechmere-Oertel et al. (2008). They found that spekboom made up the majority of vegetation cover in the ecosystem but was entirely eliminated in the degradation process. This resulted in a decline of leaf litter deposition by 30% (4126 vs 2881 kg dry matter/ha/ yr), biomass carbon by 75% (52 vs 8 t C/ha), soil carbon by 40% (0–10 cm, 71 vs 40 t C/ha), soil nitrogen by 30% (0.33 vs 0.24%), and rate of infiltration by 60% (51 vs 19 mm/h, laboratory test) (all values are approximates and can differ depending on local circumstances).

Sigwela et al. (2009) studied vegetative reproduction characteristics in degradation and restoration processes in SAST. They found that degradation negatively impacts the abundance of seeds and seedlings in P. afra-dominated subtropical thicket. Furthermore, patches of vegetation were found to be important since most seedlings were found underneath remaining shrubs. They state that the preservation of remnant vegetation clumps in degraded SAST is of paramount importance for restoration. Furthermore, the most effective way of restoring populations of canopy species is to rapidly recover closed-canopy structure and soil organic carbon. Mills et al. (2007) found that this can be achieved by planting truncheons of spekboom.

2.5 Identifying area and scale

Effect monitoring can be done spatially (compare two equal sites: one with the intervention and one without intervention) or temporally (monitor several single sites: before the intervention and then follow the situation in time) or both. The location should be representative for SAST occurring in the Baviaanskloof, preferably on a hillslope location. The scale of a hillslope monitoring size provides the opportunity to compare the same parameters on different locations on the hillslope (upslope, midslope, downslope). A location with two equal sites on a hillslope was scouted (a fence line contrast between Zandvlakte and Joachimskraal). Such a location was preferred over monitoring several different sites since data will be generated simultaneously and having all equipment on one location is better manageable.

The border between Zandvlakte and Joachimskraal is a hillslope site of approximately twenty hectares highlighted by a sharp contrast in vegetation. This provides the perfect opportunity to measure the effect on soil water interaction processes on a restoring site versus a degraded site. The SAST on the Zandvlakte side still contains vegetated patches and is not grazed anymore, therefore it should restore on its own. Effects can be constantly compared with the side on Joachimskraal, which has similar conditions without vegetation. To guarantee comparison in the future, it is important that in this case the area on Joachimkraal remains overgrazed, or else that the overgrazed situation in Joachimskraal will first be documented by extensive measurements so a reference will exist how this location behaves when it was degraded. In any case, for both situations it is essential that Joachimskraal will have to remain overgrazed in the starting years of the monitoring site.

The objective of this project is to monitor several key parameters by implementing various monitoring systems at Zandvlakte/Joachimskraal and make it a scientific test site. This monitoring will just measure the effect of restoration of the specific site.

2.6 Identifying key parameters

The water-related purpose of SAST restoration is to provide additional storage capacity for precipitation. It is hoped that this will delay and partly hold off peak flows from reaching the

Baviaanskloof river, resulting in a increased infiltration rates that will allow the groundwater table downslope to rise which should result in a more stable base flow there. However, these properties are to a large extent unknown because there are several parameters that influence soil moisture storage. The processes under which these parameters occur need to be conceptualized in order to understand how they interact and are related with each other. A hydrologic cycle is such a conceptual framework (figure 7). This framework has been modified from Anderson et al. (1975)to be of use for the specific location of the monitoring site.

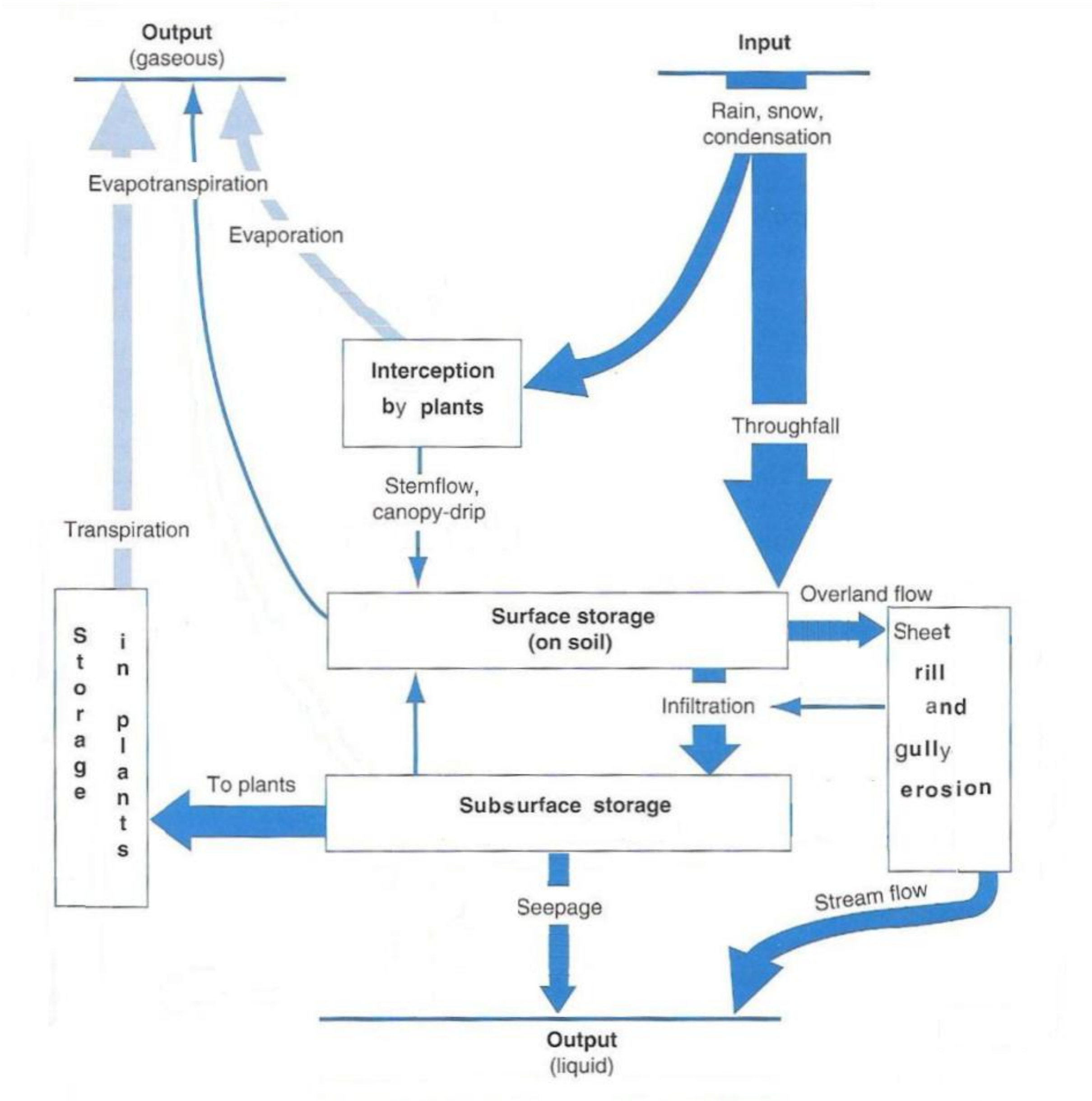

figure 7: Inputs, outputs and storage components of the hydrologic cycle for the monitoring site (Adapted from Anderson et al., 1976)

Key parameters can be identified from this framework, but have to qualify to several conditions. First; the parameter needs to be relevant to be monitored. Second, the parameters need to be measurable. Third, measuring has to be cost effective. Fourth, equipment to be used had to be stubborn to withstand the wrath of baboons that roam free in the area.

Parameters in the hydrological cycle start with precipitation; precipitation is of paramount importance in the quantification of hydrological processes since this is the quantity of water where all process start with. The measured quantity of water in other parameters would be of significant less value if the ratio to precipitation is unknown. Rainfall quantity and intensity can be easily and relatively cheaply measured with a tipping bucket. To relate erosion to rainfall, it is essential to know rainfall quantity, but more importantly its energy (intensity), because the kinetic energy of raindrops hitting the soil surface determines rainfall's erosivity. Characteristics influencing this are rainfall amount, intensity, duration, wind speed and direction. However, a study in Palestine (Hammad et al., 2006) found that kinetic energy of rain is strongly correlated with runoff and erosion and can be predicted by rainfall intensity, provided that the energy of rain is not intercepted by vegetation before hitting the soil.

Interception is a parameter that has a nonlinear relationship with precipitation, because more rain is intercepted by vegetation during small rainfall events. Interception itself is defined as: "that part of the rain that falls on the vegetation and evaporates without reaching the ground" (Klaassen et al., 1998). The water storage in the canopy can be measured using microwave transmission (Bouten et al., 1991) with a vertically moving system (Klaassen et al., 1998). This device requires a power supply and is therefore unsuitable for extended monitoring use because it is rather expensive as well. For monitoring, interception evaporation is an interesting parameter to know since it is that part of a rainfall event that does not enter the soil-water interaction system. However, this parameter can be deducted indirectly when the rainfall amount and the surface storage are known from a rainfall event. It is expected that interception evaporation increases during the restoration process as the canopy of SAST will close. It is important to research the relationship between rainfall event, percentage vegetation cover and interception evaporation. Once this relationship is known it can be accounted for in the monitoring data.

Surface storage is the part of the water cycle that reaches the soil. Water can enter the soil directly from rainfall, or indirectly from vegetation (drip, stem flow). It can be measured cheaply with plots of a square meter of watertight material on the surface under the vegetation that collects the water reaching the surface during a rainfall event. Once water has reached the soil it can evaporate, infiltrate or runoff (overland flow). During a significant rainfall event, a fraction of the water will directly evaporate whereas the majority will infiltrate or runoff. The latter can happen on a sloping surface in which infiltration capacity is exceeded. Surface runoff is responsible for sheet, rill and gully erosion, is gravity driven and has a transport capacity depending on the discharge. Discharge can lose energy by contacting obstacles and/or a rough/vegetated surface (Prosser and Rustomji, 2000). Runoff (soil and water) can be measured with Wischmeier plots (Wischmeier and Smith, 1978) or sediment boxes, the latter being cheaper but lacking a fixed surface for their sediment donor area. Therefore sediment boxes can only be used relatively to each other and are unsuitable to quantify soil loss/area. However a percentage difference can be deducted when all other circumstances are the same and some boxes are placed in degraded areas whereas other boxes are placed in restored areas. The quantity and distribution of runoff can be measured (soil, water, ratio). The effect of runoff, erosion and sedimentation, can be measured with erosion pins or an erosion bridge, both being cost-effective ways. The latter is more sophisticated, being able to detect changes in micro-topography as well. Runoff and erosion/sedimentation are considered to be important to monitor since topsoil accumulation is one of the anticipated effects of restoration that will lead to a higher moisture holding capacity.

Infiltrating water will enter the subsurface storage and can further seep into the groundwater. Since the SAST biome is mainly located on hillslopes, groundwater can be considered as irrelevant since there is likely no groundwater level or if there is any groundwater level, then it will probably be highly variable independently from the situation on the surface. Groundwater levels on hillslopes are dependent on the geomorphologic situation. Different types of rocks (sandstone with large cracks vs. impermeable conglomerate) affects hydrologic properties, and restoration of SAST does not influence this. On the contrary, it will be important to deduct which part of surface storage will infiltrate. This can be done with infiltration tests, for which a rainfall simulator or an infiltrometer can be used. However, these devices are unsuitable to be employed for continuous data collection because they require an operator. Furthermore, infiltration is a dynamic parameter that changes with moisture content of the soil, crusting and character of the rainfall event (high intensity vs. low intensity). Infiltration is therefore a dynamic parameter that is hard to monitor. The consequences of infiltration can however be measured in the subsurface storage area. This parameter can indirectly give insight in the infiltration rate. In agricultural practice for irrigation requirements, moisture probes are devices that give continuous insight of water content in the soil-water storage. These probes are mass produced and are not extraordinary expensive. Moisture content can be measured with them, infiltration can be deducted by knowing the difference in moisture quantity in a time interval.

Water uptake by plants is lost to the air by transpiration. Evaporation from the soil with transpiration is called evapotranspiration. In agricultural sciences, evapotranspiration is represented by ET values, to account for irrigation requirements for optimal crop yields. These are fixed values under certain weather conditions and account for the amount of water a certain unit of land with a vegetation type can lose to the air by evapotranspiration, compared to reference evapotranspiration (which is a lawn), provided that this amount of water is available. Evapotranspiration is not easy to measure. Specific devices and accurate measurements of various physical parameters or the soil water balance are required. The methods are often expensive, demanding in terms of accuracy of measurement and can only be fully exploited by well-trained research personnel (Allen et al., 1998).

Evapotranspiration, overland flow and seepage flow are the outputs of water in the SAST. Evapotranspiration is affected by vegetation, but cannot be influenced within the restoration process and does not have negative side effects. Overland flow on the contrary is the undesirable component which is aimed to be reduced. Overland flow is measurable, whereas seepage is harder to quantify. A change is seepage could however be detected if soil moisture in a restored plot is different compared to a degraded plot, provided that all other circumstances are equal.

2.7 Expected results of restoration

The difference between the restoring plot vs. the degraded plot is vegetation. In general, when protective canopy cover increases, erosion is reduced (Elwell and Stocking, 1976). Vegetation intercepts rainfall, thereby reducing splash. It's root system enhances infiltration, increases soil roughness and stabilizes the topsoil. Furthermore vegetation is an obstacle for runoff, reducing its velocity and erosive power. It also adds organic matter to the soil, enhancing the moisture retention capacity of the soil (Baver, 1956). Additionally, vegetation adds a layer of litter cover to the soil surface. It was found that this layer of protection was fundamental for erosion control during intense rainfall (Bochet et al., 2006). Litter cover enhances infiltration as well which also is confirmed by Greene (1992) in Lechmere-Oertel et al. (2005b).

With expected higher infiltration rates on the restored plot, more water will go to the soil-water storage and less to overland flow. It can be expected that after high intensity rainfall events, runoff (soil and water) and erosion will be lower on a restored plot compared to a degraded plot, and that infiltration and soil moisture storage will be higher. This will likely result in more water availabiltiy for subsurface flow and seepage, but also to transpiration for plants, since more plants are present. On the other hand, evaporation from the soil could be lower since the soil surface is not as much exposed to wind and heat, but this comparison also depends on the topsoil of the degraded surface. When the degraded surface is compacted or has crust that is impermeable, infiltration and soil surface evaporation are likely to be negligible. This can be different when the surface is covered with stones; Zougmoré et al. (2004) found that stone rows induced more surface water storage and infiltration than the grass strips, because stone rows allowed the runoff velocity to be reduced more than grass strip, though stone rows induced also a greater evapotranspiration rate than grass strips.

In any case, it can be expected that ET in restored SAST will be higher than in a degraded area, but it is hard to tell how much higher. Many species in SAST plants are drought resistant, a good example is spekboom, this shrub can alter its metabolism from C3 photosynthesis to Crassulacean Acid Metabolism (CAM). The latter is much more efficient with water and will kick in when the plant suffers from water stress. With this knowledge it can be expected that ET-values of spekboom dominated thicket are significantly higher when water is in adequate supply compared with circumstances in which water is scarce.

To sum it all up, all the parameters are listed with monitoring relevance, measurability and cost (table 2).

table 2: Monitoring parameters and criterions that assist in decision making to monitor certain parameters

Parameter	relevance	measurability	costs
rain	++	++	++
Intercepted rain	+/-	-	--
Interception storage	-	+/-	--
interception evaporation (loss)	-	--	--
stemflow	+	+	+
drip	+	+	+/-
surface storage	++	+	++
overland flow	++	+/-	+/-
erosion/sedimentation	++	++	++
infiltration	+	+	+
soil-water storage	++	+	+/-
evapotranspiration	++	-	--
sub-surface flow	+/-	-	--
seepage	--	--	--

++ very desirable, + desirable, +/- neutral, - undesirable, -- very undesirable

Identified key parameters for effect monitoring of SAST restoration are rainfall, overland flow, erosion/sedimentation, surface storage, soil-water storage and evapotranspiration. Stemflow, drip, and infiltration are considered as important, but were not considered of paramount relevance since the water quantity stays within the system or is measurable indirectly. Intercepted rain, interception storage, interception evaporation, subsurface flow and seepage are considered as irrelevant to monitor for effects of SAST restoration, mainly because measurements of these parameters are either very expensive or will highly probably yield random results which will not yield relevant information about restoration.

2.8 Measurement; continue vs. event based

Rainfall, overland flow, erosion/sedimentation and infiltration do not happen all the time, they are event based parameter. Evaporation/plant uptake and subsurface flow/seepage are parameters that withdraw water from the soil-water storage and plants buffers and are therefore likely to occur on a continuous basis (unless there is no water left at all in the soil-water storage layer). The proportion of water that enters the surface storage is likely to differ during each rainfall event since high intensity rainfall events tend to have lower interception and evaporation by plants than low intensity rainfall events. In order to measure rainfall intensity, a continuous rainfall monitoring should be required as well.

Overland flow, erosion, and infiltration should be monitored per event, because for effect monitoring only the quantity per event and not the rate is required to deduct the difference in the effect of restoration. On the other hand, Rainfall, evapotranspiration/plant uptake and soil water storage should be monitored on a continuous basis, otherwise it is hard to relate the quantity of the event-based parameters to rates of water withdrawal from the system.

Measurement can continue all year round, because the rainfall pattern in the area is erratic. Generally, there is a prolonged dry period during the winter in which it can be expected that almost no rainfall events will happen, and during this period it can be expected that trips to the monitoring site to collect data will be few and far in between. There can however always be an exception, so it is essential that also in winter time the batteries and data loggers of continuous monitoring equipment will be on stand-by.

3 Results

3.1 Equipment and field lay-out

3.1.1 Field lay out

The field lay out will be divided into three equal measurement locations for the measurement of rainfall, runoff, erosion/sedimentation and soil moisture and the collecting and analysis of soil samples. An artist impression (created by the author) is shown (figure 8). Everything on the monitoring site looks clustered, but in reality the equipment on the three different locations is more spread out. The red color indicates the location of the Gerlach troughs, the green color represents the moisture probes, the blue color represents the erosion bridge and the yellow color the weather station with the tipping bucket rainfall measurement device. The tiny yellow circle indicates the location of a tipping bucket, in which plans exist to place additional tipping buckets under the canopy of intact/restored thicket. However, there is still uncertainty whether this equipment will be placed or not. Other measures that were not yet undertaken because of resource constraints but are highly recommended are discussed as well; surface storage, evapotranspiration, and assessing vegetation cover.

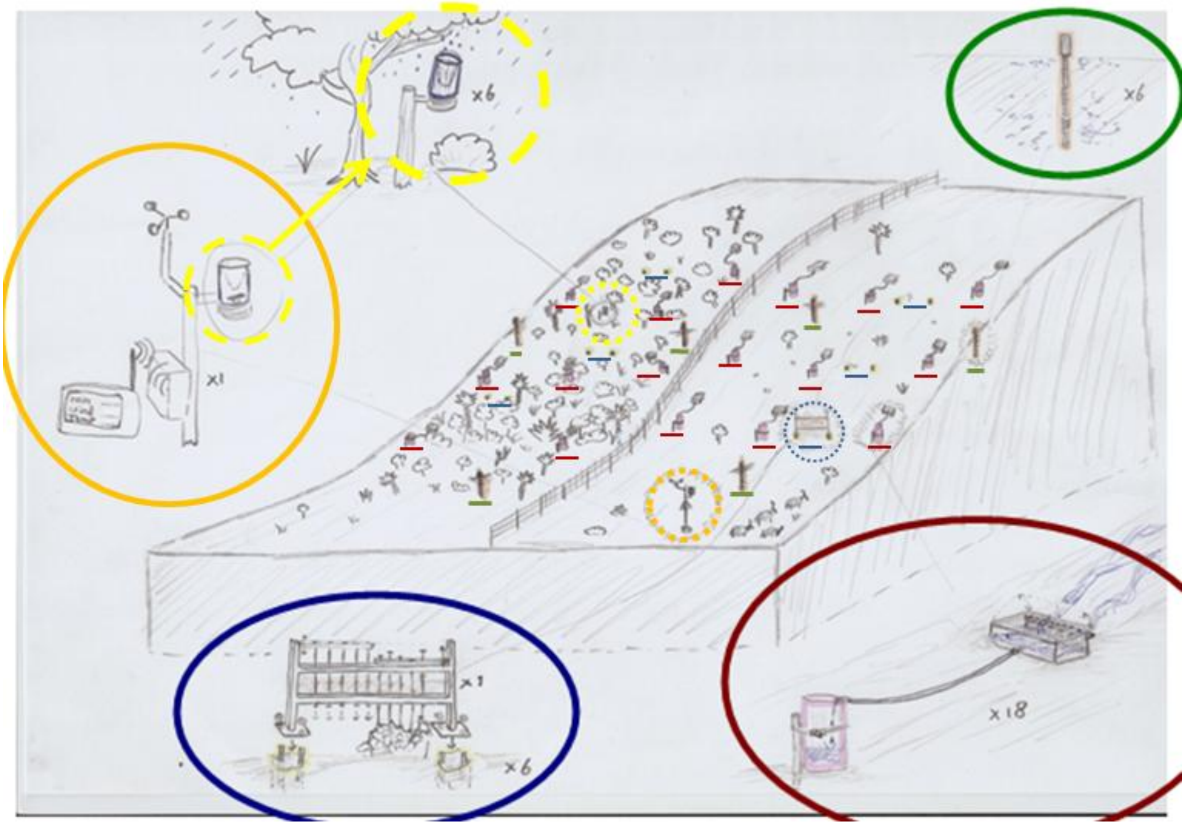

figure 8: Field lay out of the monitoring site, all the equipment appears much more clustered than in reality

3.1.2 Rainfall

A single weather station is available and will be implemented for the measurement of rainfall parameters (figure 9). Additionally, from this weather station other parameters can be monitored that can assist in deducting values for evapotranspiration like wind speed, air temperature and surface temperature. These weatherstations have been used in the area and have proven to be baboon proof.

figure 9: Davis Vantage pro weather station with anemometer, tipping bucket and console displayed

3.1.3 Runoff

Runoff, the quantity of soil and water, is proposed to be monitored with Gerlach troughs. This sturdy stainless steel box is able to collect and contain runoff when a storage device (a drum, bucket or tank) is connected to it with a buried hose (figure 10). After a rainfall event, the quantity of soil and water that has run through the Gerlach trough's opening can then be measured. Gerlach troughs can only be used to assess the percentage reduction in runoff of the degraded versus the degraded site. Once under a given situation the runoff yield from a fixed degraded area under a given rainfall event is known, this value could be reverse calculated to runoff yields from the Gerlach troughs, to relate runoff to runoff yield/area/event. In order to have significant results from the Gerlach troughs, it is necessary to have a substantial sample size. The yield of these trough in the same situation can change because the donor area is unknown, and can vary due to differing flowpaths and local microtopography. Attention should be put into these characteristics when placing them. In order to compensate for this irregularity, it is suggested to have 18 Gerlach throughs: 3 upslope, 3 midslope and 3 downslope in the degraded and restoring site. These devices require to be monitored after each significant rain event. Approximately 23 throughs should be manufactured (including 5 spares).

figure 10: Layout of Gerlach troughs; left: field set up, middle: close up, right: close up with Gerlach trough open, down at the bottom in the middle is a hole on which a hose is connected to one of the partly submerged steel drums under the tree visible in the left image

3.1.4 Erosion/sedimentation

For erosion measurement, erosion pins were considered as inferior as they are sensitive to disturbance by baboons (which already happened with other erosion monitoring sites in the area). Use of an erosion bridge is proposed, as this is a portable device that can be withdrawn from the site once a measurement has been done. It consists of a frame that is elevated above the soil surface with poles. These poles can be fixed onto a mounting site wit bolts. Pins can move within the frame and have a reference line, hence the micro profile of the soil can be read from these pins. The frame is 50 cm wide and can have up to 25 measurements on the beam, 2 cm in between them (figure 11). Repeated measurements after rainfall events allow quantifying erosion or sedimentation. It is proposed to have two erosion bridges, one operational and one spare. Six erosion bridge mounting position are proposed, each one placed nearby a set of three Gerlach troughs. These mounting positions can be constructed with concrete and wired rods, provided that in between the mounting poles soil is left. These poles should furthermore be as high or lower than the topsoil, so that water is not forced to flow around it, thereby concentrating runoff and altering the erosion pattern, hence the measurement.

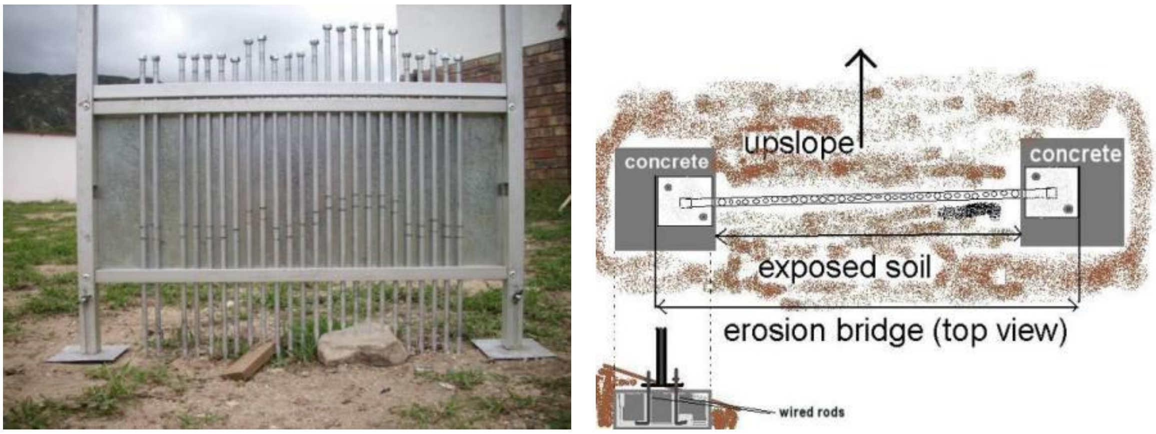

figure 11: The erosion bride (left) and a schematic top view (right) when it is connected to a measurment place. Notice that the erosion bridge was not yet finished, a sheet with reference lines will be conected onto the aluminium plate and the rods will get nuts on the bottom as well (so they cannot fall out). Additionally, reference lines will be drawn onto the rods as well.

3.1.5 Soil moisture

Nearby each position for erosion bridges, it is proposed to have a moisture probe. This device measures and stores data of soil moisture and soil temperature at six different soil depths in a data logger (figure 12). Collection of data from the datalogger needs to commence every five months when the logging interval is set to one hour. This logging interval is however adjustable; for example: when the logging frequency doubles, and is set to thirty minutes, then the probe requires to be read every two and a half months instead of five. A tripod can be created to overtop the device so it cannot be disturbed by baboons.

figure 12: DFM instruments soil moisture probe

3.1.6 Soil sampling

Random soil samples from the degraded and intact area (so not from the Gerlach troughs) can be taken and sent out for analysis of organic matter content and sieve analysis to deduct if there is a difference in organic matter and soil particle distribution in the topsoil on the degraded and intact sites. If on one side, there is more erosion detected, it should be possible then to deter which particles are easier washed away there, as they should be in shorter supply. Additionally, with organic matter analysis, it then would be possible to quantify the effect of regrowth to organic matter increase in the soil. To save costs, it is advised to take several samples on each site and mix them to have two generalized batches, one for the degraded and one for the restored side that will be sent to a soil laboratory.

3.1.7 Surface storage

Surface storage, the amount of rainfall that reaches the soil surface, could be measured cheaply with plots of a square meter (or another known surface area) of watertight material that collects the water reaching the surface during a rainfall event under the vegetation (this measurement is only required in vegetated areas because in open areas surface storage equals the rainfall amount). The plots have require to surface at least a certain area so that the measurement will not be a point measurement, but will provide significant data. With larger surface areas, more accurate data can be expected. Furthermore, the possibility to deduct stemflow should be looked upon into as well since stemflow also contributes to surface storage.

3.1.8 Evapotranspiration

It is currently unknown what the Evapotranspiration values are of thicket and bare soil. Exact measurements of ET is expensive. Therefore, this option was currently postponed. It should be helpful if standardized ET values of SAST will be researched in the future, then it should be relatively easy to make an estimation of the ratio between evapotranspiration and subsurface flow in the monitoring area. Data of soil moisture, rainfall and temperature could assist with ET research.

3.1.9 Vegetation cover

Finally, it is useful to assess vegetation cover. This can be done with aerial photographs, or field measurements by measuring the vegetation cover along transects. The vegetation monitoring is relevant to evaluate the impact of vegetation on erosion. It would also be good to make regularly pictures at some strategic locations to have time series of pictures that can be compared with each other. Another option would be to use remote sensing, Draaijer (2010) found an alghorhytm for SAST to calculate vegetation cover values from Landsat NDVI data (30m resolution) after a slightly wet period. For such analysis to be undertaken a computer with GIS software and an operator with GIS knowledge are required.

3.2 Data collection and storage

3.2.1 Overview

All the proposed equipment is listed (table 3). Data collection from the devices differs. Some devices will automatically and continuously collect their data, whereas other equipment requires a management and revisiting plan for its operation and to collect data. To access data efficiently, data should be stored chronologically in such a way that it can be linked to certain rainfall events.

table 3: Overview of all proposed equipment for the monitoring site

Equipment	Data collection	parameters
Weather station	Data logger	weather parameters
Gerlach trough	Manual	runoff quantity of soil and water
erosion bridge	Digital photograph	erosion and sedimentation
moisture probe	Data logger	soil moisture (%) and soil temperature
soil samples	Manual	OM content and particle analysis

3.2.2 Weather station data

Data from the weather station is stored in a datalogger that can be uploaded to a laptop. This data can be read with software from the manufacturer (Davis Instruments, 2001) or freeware (WXdata, URL 1). From these software packages it should be possible to export the data to spreadsheet formats that can be read in e.g. excel. In the spreadsheet formats it should also be possible to extract the rainfall data, which will be the backbone of the monitoring data, for further analysis.

3.2.3 Gerlach trough data

Data from the Gerlach troughs has to be collected manually after a rainfall event. Water will be collected in a bucket (sheltered in a steel drum) connected with a hose to the Gerlach trough. The water quantity can be assessed by measuring the surface area of the bottom of the bucket (πr^2) and multiplying it with the height of the water with a ruler. After measuring water quantity, sediment can be collected, for which plastic bags can be used. It is essential that these bags will be labeled and stored so that the samples can later be analyzed if this would be necessary. When taking the samples, most sediment will probably remain in the Gerlach trough, though additional sediment can be expected in the bucket as well. Sediment quantity can be measured by weigthing it, but before doing so it needs to be dry. If the amount of sediment is significant compared to the amount of water, it is then also advisable to weight the sediment when it is wet and when it is dry to deduct the amount of water in the sediment, and to assess the volume of sediment in the bucket so that amount can be subtracted from the measured water amount in the bucket. The data of the 18 Gerlach troughs should be stored in such a way that it can be related to the occurring rainfall event.

3.2.4 Erosion bridge data

The erosion bridge has been created in such a way that data collection can be done quick and efficient with a digital photo camera. The device will be equipped with a reference line sheet to assess the difference in distance of a reference point on the pins compared to the base line. When a photograph of a location is taken, the photograph can be analyzed in the office in which data can be stored in a database file. It would be advisable to make a directory for every erosion bridge position and to save photographs with a name of their position and with the YYYYMMDD (year, month, date) format, so they will automatically be sorted in a chronologic way when listed alphabetically.

3.2.5 Soil moisture probe data

Data from the moisture probes is stored in a data logger that can be uploaded to a mobile device. This device can collect a large amount of moisture data and can later be connected to a computer.

The moisture probes comes with a software package in which it is possible to export the data to spreadsheet formats that can be read in e.g. Excel. Data for soil depths at intervals of 10 cm up to 60 cm are recorded, as well as the soil surface temperature.

3.2.6 Soil samples

Soil sample analysis will not be undertaken by the project team, but has to be done by a soil laboratory. This laboratory will supply data that can then be entered and analyzed.

3.3 Data analysis

The purpose of this monitoring scheme is to quantify the effect of SAST restoration by comparing a restoring area to a degraded area. In this scheme, several parameters will be monitored. The advantage of monitoring multiple parameters is that it will be possible to compare them with each other.

Before parameters can be compared with each other, it needs to be defined how this has to be done. There are two parameters that will define the effects of restorationin the monitoring; rainfall and restored vs. degraded SAST, because these parameters are independent. Rainfall is independent because it is not influenced by other parameters. Most other parameters that will be measured are influenced by rainfall. On the other hand, vegetation cover, or lack thereof, hence restored vs. degraded SAST, is independent as well. The standing biomass is not directly influenced by other parameters (indirectly it is of course, but it takes some time for plants to grow). During a rainfall event, standing biomass influences most parameters except rainfall. The properties of rainfall (quantity and intensity) can be compared with many other parameters in charts; e.g. max. rainfall intensity vs. occurring erosion or sediment yield, and to see what the effect on erosion and sediment is of vegetation cover for a given rainfall intensity or quantity. An example of how things could be plotted with a trendline included (such an option is available in spreadsheet programs like Excel) is shown below (figure 13).

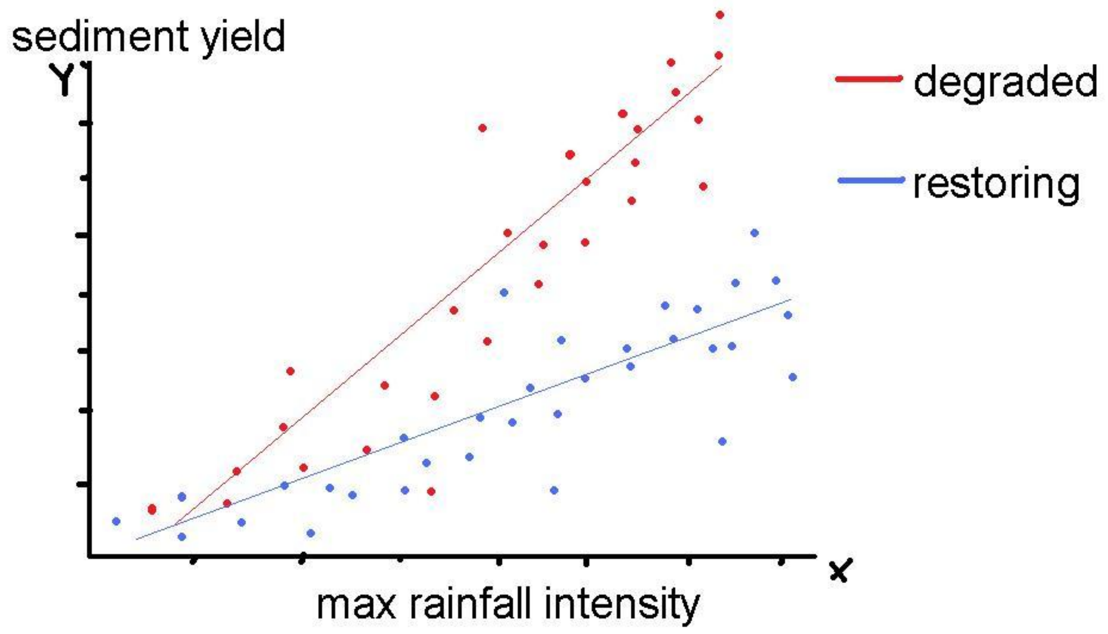

figure 13: example of how a chart of monitoring cata can be plotted to compare degraded vs restored sites for particular parameters

The suggestion for plotting data is to have different data point colors, by having separate colors for restored and degraded sites. On the horizontal axis, rainfall quantity or intensity should be plotted, whereas on the vertical axis the other parameters (sediment yield, erosion/sedimentation, moisture content) should be plotted. Several options exists to make trend line interpolations in between these data points, when a lineair relationship is expected, then a straight line can be plotted, whereas if a curved line is expected, a representation by a second order polynomial is most suitable. A second order polynomial could have been used on the red line in figure 13, since the trendline is not starting in O, and is above quite a few datapoints in the middle of the x axis.

table 4: Examples of parameters that can possibly be plotted when sufficient data has been collected

Parameter		Expected results	
X-axis	**Y-axis**	**Degraded**	**Restored**
Max. rainfall intensity	Gerlach sediment yield	high yield	reduced yield
Max. rainfall intensity	Gerlach water yield	high yield	reduced yield
Max. rainfall intensity	erosion/sedimentation	high rates	reduced rates
Max. rainfall intensity	soil moisture	high runoff	more infiltration
Rainfall quantity	Gerlach sediment yield	high yield	reduced yield
Rainfall quantity	Gerlach water yield	high yield	reduced yield
Rainfall quantity	erosion/sedimentation	high rates	reduced rates
Rainfall quantity	soil moisture	high runoff	more infiltration

Examples of which data can be plotted against what and what the expected result should be according to chapter 2.7 is shown in table 4. Figure 13 is an example of how the first example in table 4 could look like.

4 Discussion and conclusion

4.1 hydrology

The water related objective of the SAST restoration project is to provide additional water storage and infiltration rates that will allow the groundwater table downslope to rise which should result in a more stable base flow in the Baviaanksloof river downstream. The objective of this research was to come up with cost-effective ways to monitor the effect of SWI in the restoration process of SAST; to answer whether SAST restoration will give a net benefit to water resources in the long run so the intervention can be evaluated at some point in the future.

When taking the proposed measurement equipment (table 3) and the hydrological cycle into account (figure 7), it becomes clear that complete understanding of the hydrological cycle cannot directly be monitored because evapotranspiration will not be measured. Evapotranspiration can have a significant impact in the scope of the restoration process since vegetation transpires water, therefore it can be expectable that additional vegetation consume most water resources under low rainfall events and years with drought. Therefore it is unlikely that SAST reforestation will provide additional water resources under these circumstances. Contradictory, under high intensity rainfall events/flooding events, it is hoped that restoration will make a difference. It can be concluded that the lack of evapotranspiration data collection is a shortcoming, and that the scope of future research programs should at least try to focus more on this aspect.

4.2 equipment

Another critical note can be made about the proposed measurement equipment, regarding the accuracy of some devices. The rainfall rainfall and soil moisture measurement devices are probably quite accurate (when justly calibrated); According to the specifications, the deviation of measured rainfall quantity and intensity is allowed to be +/- 4% and 5% respectively with tipping bucket attached to the Vantage pro (Davis Instruments, 2001), and the moisture probe is regarded to be more accurate than a neutron probe or tensiometers (pers comm..). Hesitancy was present when choosing the moisture probes as a device because of baboon vulnerability; though this was omitted by creating iron tripods that will protect the devices. Baboon infestation was amongst the greatest danger in picking the right equipment and during revisiting times attention should be paid if anything has been disturbed by these primates.

The placement of Gerlach troughs can provide a wide range of inconsistent data if the specific location of microtopograpy is not accounted for. According to Vigiak et al. (2006), Variability of overland flow and sediment load in Gerlach troughs was high due to local changes in topography and the unbound run-on areas to these troughs. It should be advisable to take photographs of all the Gerlach troughs and to scout the upstream area to deduct flowpaths. Doing so can assist in explaining differences in sediment yield when local circumstances appear the same but upstream hydrologic properties are not. Additionally, It is debatable if under extreme conditions the Gerlach troughs will overtop when the bucket that is connected to them is full and/or the hose cannot transport the oversupply of water to the bucket resulting in flooding of the trough.

The argument about the placement and investigation of upstream flowpaths is also applicable to the erosion bridge. The erosion bridge was chosen because it is more baboon proof than erosion pins and it is expected that this device will be easy to handle to collect large amounts of useful data. However, a previous study working with such a device (Shakesby, 1990), suggested that the process of measurement itself caused some compaction of the soil, by slightly disturbing the top layer of the soil, giving lower second readings. The main implication of his results was that variations of up to about 1.5 mm could be the result of the measurement process, particularly when a decomposing litter layer or thin soil crust was present. This has been attributed by the stakes falling onto the soil, but the design of our erosion bridge has taken this into account by applying a nut to the end of the stake so that it has a greater contact surface with the soil, having less impact. Additionally, the stake has been made out of lightweight aluminium. Lastly, the initial 1.5 mm measurement error could already be considered as acceptable, only our design tries to do anything possible to bring it further down.

4.3 location

The location of the monitoring site is situated on a fence line contrast on a hillslope, one side is degraded and one side is restoring (figure 14).

figure 14: Location of the monitoring site at the fence line contrast with restoring SAST to the left and degraded SAST to the right (left). A close up of the same location (right).

Proposed monitoring in the restoring side will be done in an area that is currently managed by a hands-off approach, no vegetation is planted. The proposed intervention is to plant spekboom; if no spekboom will be planted in the restoring area in the future, then the monitoring outcomes will not represent a vegetation type that can be considered as representative for an area that has been restored under the intervention with the planting of spekboom, because it is debatable if a spekboom monoculture will have the same soil-water related properties of spekboom dominated thicket. Furthermore, at the time of the research, it was yet unclear which practice of spekboom reforestation is best when ecosystem restoration will be taken into consideration as well, and whether or not other seedlings/seed is required to be planted as well.

Another option for restoration would be to let the restoring side continue to grow, and to start with a reforestation scheme in the degraded area when sufficient data from this side has been gathered. However, to gather 'sufficient' data is debatable, since extreme floods in the Baviaanskloof occur once every 10 years on average. 'Sufficient' would imply that at least one such event will be captured in the monitoring data on both sides, which would mean that it will take at least 20 years (10 years to wait for an extreme event, and 10 years for the vegetation to mature) before full intact restored spekboom planted area will be monitored there.

4.4 conclusion

- With a limited budget (€30.000), it has been possible to make a plan to monitor the effect of a wide variety of SWI parameters in the restoration process of SAST. Out of many devices, only few were selected that were applicable to the environment, because they were easy to maintain, being baboon proof, able to produce accurate data and being cost effective.

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URL 1: WXData versie 1.3 downloaden www.wxgr.nl/Software/WXData.htm