ECOLOGICAL INFRASTRUCTURE

Water resources in the semi-arid Baviaanskloof: A fascinating area with contrasting water-related ecological infrastructure

In South Africa's water-scarce landscapes, where every drop counts, the hidden dynamics between rivers, groundwater and the land itself are becoming increasingly important. Nowhere is this more evident than in the Baviaanskloof, a rugged, semi-arid valley where nature and human activity are tightly intertwined. Article by Lindie Smith-Adao, Kate Rowntree, Richard Bugan, Japie Buckle, Jeanne Nel and Evan Swartbooi.

Arid and semi-arid areas such as South Africa are defined by their harsh climate, high evapotranspiration rates, unequal rainfall distribution and extended dry seasons. Investments in ecological infrastructure are seldom considered as a way of augmenting water supplies and improving water quality over the long term. However, with few remaining undeveloped dam sites and little remaining streamflow (Hedden and Cilliers, 2014), ecological infrastructure can play a meaningful role in water resource management by sustaining, supplementing or, in some cases, substituting for built infrastructure such as inter-basin transfers and dams.

Ecological infrastructure refers to naturally functioning intact ecosystems that deliver valuable services to people (SANBI, 2013). Water-related ecosystem services include recreational services, soil formation, flood attenuation and water supply. Investing in water-related ecological infrastructure could therefore generate meaningful gains in water quantity and quality. Restoration of degraded ecosystems to mitigate negative impacts can deliver more clean water from our land. Restoration actions can vary from improving vegetation cover to catchment management and policy implementation.

Understanding the mechanisms by which water resources above and below ground are replenished and interact is also key for water resources management, especially in arid and semi-arid

lands. Surface water and groundwater (SW–GW) interactions constitute a vital yet complicated component of the hydrological cycle (Kuang et al., 2024). Research on the interactions between surface water and groundwater is urgent and very significant for conserving water supplies, managing water resources and sustaining ecological health. This is especially true in the Baviaanskloof, a fascinating area with a diverse number of freshwater ecosystem types that offers numerous water-related ecological infrastructure.

The Baviaanskloof, meaning 'valley of baboons', is an area of significant biodiversity located in the semi-arid south-western region of the Eastern Cape Province. This remote area is popular for its beautiful scenery, birdwatching and wildlife viewing. There are two main water sources in the area, namely groundwater in hardrock and alluvial aquifers and surface water flow in the Baviaanskloof River and its tributaries. The study area showcases a complex interaction between surface water and groundwater while exemplifying typical issues encountered in semi-arid regions concerning the complex relationship between human activities and the natural environment. The 75 km-long river valley is flanked by the parallel east-west running mountain ranges of the Baviaanskloof (north) and Kouga (south). A public gravel road winds along the valley floor crossing the river more than 20 times (Figure 1). The catchment provides many important ecosystem services, both locally and regionally.

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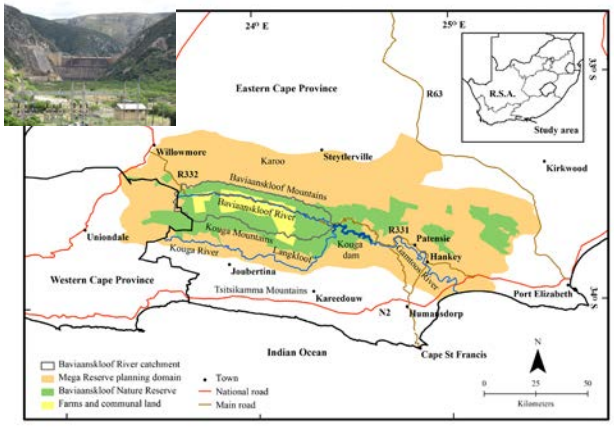

Figure 1. Location of the Baviaanskloof River valley within the south-western region of the Eastern Cape Province, South Africa. The inset shows the Kouga Dam.

Local occupants of the valley currently rely on wells, pits, pools and springs linked to the Baviaanskloof groundwater system as a source of water, especially during droughts. Springs in the slot canyons and an artesian borehole provide a near constant source of high-quality water for domestic use. Farmers extract between an estimated 1.75 million m^3/year and 3.3 million m^3/year of water for irrigation from the alluvial gravel (Jansen, 2008). The Kouga and Baviaanskloof catchments together represent national Strategic Water Source Areas (SWSAs), being a critical water resource for downstream users. The Baviaanskloof River delivers about 35-40 million m^3/year to the Kouga Dam (Figure 1), roughly 20% of the total inflow (Jansen, 2008). The Kouga Dam, in turn, provides water to the Nelson Mandela Metropole (± 23 million m^3/year) (Boshoff, 2008) and the farmers in the fertile Gamtoos River valley (± 50 million m^3/year) (Mander et al., 2010).

There are strong interactions between surface flow and groundwater, which vary with the physiographic setting (Figure 2). Natural factors that affect these include the climate, geology and terrain as well as the various ecosystems. The climate is characterised by high spatial and temporal variability, and the rainfall is erratic and non-seasonal. Annual rainfall may vary from less than 80 mm on the lower-lying valley floor to more than 600 mm on the hillslopes and mountains. The annual average minimum and maximum temperatures in the Baviaanskloof are 5°C and 32°C, respectively. Aggravating the problem of low rainfall, most rainfall is lost to evapotranspiration. This climate is very typical of the arid regions of South Africa, contributing to difficulty in planning water use and tracking impacts of anthropogenic and climate change pressures in the landscape.

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Figure 2. The Baviaanskloof landscape with its steep mountains (foreground), flat valley floor with river (middle) and rugged topography (background).

The geomorphic diversity that characterises the Baviaanskloof is largely the result of its geological history and processes. Much of the area is underlain by sedimentary rocks of the Cape Supergroup, which formed the mountainous Cape Fold Belt some 300 million years ago. The landscape is dominated by quartzitic sandstones, shales and tillites of the Table Mountain Group. Numerous fault lines on the northern slopes of the valley have formed incised slot canyons or 'kloofs' (Figure 3). Quaternary deposits occurring along the river's main stem and its major tributaries are the youngest sediments in the Baviaanskloof, dating back to the last 1.5 million years. The local geology has given rise to deep, nutrient-rich sandy soils with some clay in the lower lying areas.

Figure 3. Fault (a) and intricate fold structures (b) and incised slot canyons or 'kloofs' (c, d). Note the upward-arching anticlines and downward-arching synclines in the fold structures. Photographs by L Smith-Adao.

The valley floor soils consist largely of loamy sand with gravel. Furthermore, alluvial layering in the soils is associated with the Dundee soil form, which dominates in the Baviaanskloof. Soils influence or facilitate infiltration, groundwater recharge, habitat provision, vegetation structure and surface runoff management. The latter also mitigates flood risk and enhances water availability. The valley floor in the foothills consists of alternating unconfined (wider) and confined (narrower) sections of between 7 and 16 km in length. Unconfined sections are approximately 900 m in width, whereas confined sections are 30 to 100 m in width. The alternating valley confinement settings are thought to be the product of past faulting and varied rock formations, which force erosion-resistant rocks together (narrow sections) and the lateral erosion of weaker rocks during flooding (wide sections, Figure 5).

Valley confinement controls fluvial geomorphic form and process, which ultimately affect vegetation patterns. In the unconfined sections, the river meanders across a floodplain; there is evidence from organic-rich layers exposed in channel banks that wetlands were a common feature throughout the wide sections in the past. During these wet years, organic material was deposited through river action, forming a dark layer of black peat. These sites indicate that a peatland-bearing wetland used to exist on Joachimskraal but has degraded since the 1960s due to river incision and fires. The peat is completely exposed in the bank and sits at about 1.5 m above the current average water table.

Estimates equate the surface flow of the Baviaanskloof River to a mean annual runoff (MAR) of between 20 and 50 mm. Steep tributaries flow via ravines to the valley floor and intersect with the river (Figures 1 and 2). These tributaries are often ephemeral on the southern side of the valley, whereas in the northern slot canyons, they are perennial because of surface-groundwater interactions related to the highly fractured Table Mountain Group. All tributaries are subject to flash floods in response to heavy rainfall over the mountains.

The valley floor alternates between narrow sections, where the road can easily cross the river, and sections where the road skirts a much wider floodplain that supports agricultural activity, an area also referred to as the Baviaanskloof Hartland (Figure 2 middle). In the narrow sections, surface flow is continuous for much longer periods of time, being maintained by both baseflow and surface runoff. In the wider sections, the groundwater aquifer does not intersect the channel surface during a dry cycle. Water flow proceeds via subsurface flow (Figure 4). The river mostly carries surface water during or immediately after floods. However, the river can flow for significant periods of time after prolonged rainfall. There are two primary groundwater systems in the Baviaanskloof, the Table Mountain Group aquifer and alluvial aquifer.

The Table Mountain Group aquifer refers to the water movement in the fractures and joints of the quartzitic sandstones. It is a secondary aquifer usually associated with good water quality. However, groundwater storage in this aquifer is often limited. Groundwater recharge is estimated at 2% to 5% of the total rainfall, or 6 to 15 mm/year. Springs feed the perennial streams found in the kloofs of the northern slopes. These springs are part of the tributaries and the main Baviaanskloof River and therefore considered lotic (flowing) in nature. Seven of these springs are natural fountains that originated from quartzitic sandstones. They are located in the Sewefontein Wild Fig Tree Forest on a community farm (Figure 6c). These seven springs generally deliver 108 000 litres of water per hour (Webley, 2011). A 110 m deep artesian borehole drilled in 1937 discharges 49 500 litres of water per hour and is being monitored by the Department of Water and Sanitation, DWS (Figure 6a).

Photographs by L Smith-Adao.

Figure 5. Incised river channel bank located just downstream of the confluence of the Tchandokloof tributary and Baviaanskloof River, showing gleyed (gray) soil layers. This is clear evidence of the former existence of a peat deposit and permanent wetland which had been dried by erosion and lowering of the water table. Peat fires had destroyed much of the former peat as indicated by ash layers above the peat deposit.

Photographs by L Smith-Adao and K Rowntree

Figure 6. Groundwater sources in the Baviaanskloof. An artesian borehole (a and b) and spring water at Sewefontein (c).

The alluvial aquifer is located on the valley floor alongside and beneath the Baviaanskloof River and is in direct contact with it. This primary aquifer, which is mainly recharged by surface runoff from the mountain slopes, helps to sustain baseflow in the main river during dry periods. Water stored in the alluvial fans is a further source of water to the alluvial aquifer. Alluvial fans are a common feature on both sides of the floodplain where sediment-laden tributaries emerge. Often composed of coarse material, including large boulders, these permeable landscape

Photographs by L Smith-Adao

Figure 4. Valley confinement settings, confined (a) and unconfined river reaches (b).

features are able to regulate tributary storm flow. However, in many cases, they have become incised due to erosion of their 'toes' by the main channel as it migrates laterally, or channels have been artificially confined using berms, so they have lost some of their buffering capacity.

With a net average groundwater recharge of 25 to 40 mm per year, the alluvial aquifer stores much larger volumes of water than the secondary aquifer. It usually also has good water quality. Electrical conductivity (EC), a measure of salt content, is low, ranging from 20-40 mS/m, mirroring that of the Baviaanskloof River (Jansen, 2008). The water can be extracted through pumping and taken from springs, shallow pits, or windmills (Figure 6). Most of the water farmers extract in the Baviaanskloof is linked to riparian areas. Of the water extracted, farmers use almost all for irrigation purposes, as well as domestic consumption. If extraction exceeds recharge, the groundwater table will be lowered. Investments in SWSAs are particularly important where ecological infrastructure assets are under-protected and degrading. Given the water sources described above, we now explore the links between human activities in the landscape and the subsequent degradation of ecological infrastructure from a catchment-scale perspective, while the restoration interventions in the area are also considered.

Human activities and linked ecological infrastructure degradation

The Baviaansksloof has complex vegetation, being situated in an area where seven biomes (Fynbos, Albany Thicket, Grassland, Succulent and Nama Karoo, Savanna and Forest) converge, producing unique plant assemblages. It also supports a diverse plant life (Figure 7). The Baviaanskloof Nature Reserve, a World Heritage Site declared in 2004, alone has about 1 199 species (138 families and 570 genera) and is part of the Cape Floral Region Protected Areas. It is one of the richest plant regions in the world, covering less than 0.5% of the surface area of Africa, but home to nearly 20% of the continent's fauna and flora. The area is dominated by fynbos vegetation types (69 883 ha) found in the higher altitude areas. Almost 70% of the fynbos species are endemic. These include the threatened Willowmore ceder (***Widdringtonia schwarzii***) and Cliff ox-tongue (***Gasteria rawlinsonii***), which grows in slot canyons.

The aridity of the area has largely prevented the successful establishment of exotic species in the Baviaanskloof. Invasive alien plant (IAP) infestation in the valley is limited to scattered low-density species such as the shrub ***Opuntia ficus-indica*** (prickly pear) in the productive lands, as well as riparian species such as eucalyptus species, castor oil (***Ricinus communis***), which have mostly been cleared from the riparian zone due to ongoing management by the Baviaanskloof Bewarea NPC.

Two human activities in particular have impacted the area, namely grazing on the mountain hillslopes and cultivation of the floodplains. Firstly, land degradation has resulted in severe and widespread soil erosion. In turn, vegetation loss on the hillslopes of the subtropical thicket has been driven by unsustainable grazing practices rooted in inadequate extension support and limited understanding of thicket ecology, compounded by grazing pressure from Dorper sheep and Angora goats.

The pressures are further intensified by the economic realities facing farmers, particularly in dry years. Dense closed-canopy vegetation has been transformed into an open savanna-like system dominated by grasses (***Cynodon dactylon***), dwarf karroid shrubs (***Atriplex lindleyi***), and umbrella shaped trees like ***Pappea capensis***. This reduced cover and numerous stock paths have led to increased downslope runoff and soil erosion with increased flooding and sedimentation on the valley floor. It has also resulted in lower groundwater recharge, which is crucial for maintaining aquifer water levels. High siltation rates pose a serious threat to water quality.

Photographs by J. Raath and L. Smith-Adao

Figure 7. Examples of typical Baviaanskloof vegetation. Fynbos components include Ericas spp (a) and proteas (b). Baviaanskloof Spekboom Thicket (c) is found on the lower mountain slopes. Succulents include Aloe ferox (d) and Crassula rupestris (e). Riparian vegetation includes, for example, wild fig trees (f), sedges (i.e., Cyperus longus) and grasses (i.e., Pennisetum clandestinum).

Furthermore, the floodplain of the unconfined sections has been extensively cultivated and restructured. Cultivation accounts for only 1% of the Baviaanskloof valley (de Jong, 2013), but is widespread on the alluvial floodplain. The vegetation along the channels in the unconfined sections is more terrestrial in nature, with sweet thorn (***Vachellia karroo***) being dominant. The deeper groundwater table and ephemeral flow associated with these channels promote sparse vegetation and channel instability. Here, irrigation is used extensively, relying on groundwater from the alluvial gravels, or leading water in furrows from the kloofs to support crops such as wheat and maize, barley and pasture legumes like lucerne. Drought is a constant threat to this endeavor as groundwater levels are lowered and, if abstraction for irrigation remains at constant levels, total failure of water sources has occurred in the past.

A second impact of cultivation is the many kilometres of berms (***keerwalle***), that have been constructed along the main and

side channel banks to prevent flooding of farmland. These high banks prevent replenishment of the floodplain groundwater and confine flood water to the main channel, increasing the energy of the flow and causing erosion of the bed and banks. These levees are thought to be responsible for channel incision and the consequent erosion of alluvial fan toes and fan incision by tributaries. Channel incision triggers groundwater table lowering, which negatively impacts available water. Terrestrialisation of channel banks can also cause instability, which can result in erosion and deposition, leading to changes in channel morphology.

Berms have also been constructed alongside tributaries crossing the alluvial fans, thereby directing flow into furrows or straight to the main channel. This increases storm flow and exacerbates floods while inhibiting recharge of groundwater in the alluvial fans. Increased storm flow also leads to channel erosion and incision of the main channel and fan tributary channels.

River-floodplain engineering in the Baviaanskloof has thus been at the expense of sustained groundwater recharge and baseflow.

Restoration and ecological infrastructure protection

Several changes to farming conditions in recent decades have resulted in significant shifts in the land use in the Baviaanskloof. For one, the reduction of water retention capacity and the lowered groundwater table have affected the livelihoods of farmers. Extensive small stock farming in the mountainous areas is only feasible in years of good rains and/or has moved to intensive production on irrigated lucerne lands. There has also been a reduction in formerly flourishing cultivation and vegetable seed production. Commercial agriculture, in general, has become less resilient due to high input costs, low producer prices and predation. Agrotourism is an important additional income for most farming ventures. Investment by the public sector in the restoration and protection of ecological infrastructure is now seen as a cost-effective option for achieving water resource planning objectives in the catchment.

Restoration work has started in the valley with the aim of increasing the water retention in the landscape and restoring the baseflow. Catchment-scale ecological restoration across the Baviaanskloof has been carried out in partnership with a range of institutional, government, and private partners over the last two decades; working across hillslopes, alluvial fans, wetlands, and the main river channel to restore hydrological function/connectivity. They include the Gamtoos Irrigation Board, Living Lands, Commonland, Eastern Cape Parks and Tourism Agency, Rhodes University, Wageningen University, the Department of Forestry, Fisheries and the Environment (DFFE), Coca-Cola Beverages Africa and the South African Environmental Observation Network (SAEON). Baviaanskloof Farmers Association, Baviaanskloof Hartland Conservancy.

Hillslope restoration interventions

The Subtropical Thicket Restoration Programme (STRP) was instrumental in the restoration of degraded subtropical thicket in the Baviaanskloof. This programme was established in 2004 by the Department of Water Affairs and Forestry (DWAF), now the DWS. Funding for spekboom revegetation was provided by the Expanded Public Works Programme (EPWP). Active intervention is required as a severely degraded thicket is unable to recover naturally. This involves reforestation of degraded hillslopes with cuttings of spekboom (***Portulacaria afra***), a plant considered an ecosystem engineer. Degraded areas exhibit a significant loss of above-ground and below-ground carbon stocks, and consequently provide an opportunity for restoration through the formal and informal carbon markets. Between 2010 and 2015, about 1 100 ha were planted with spekboom to reduce degradation trends and assist the recovery of the degraded thicket vegetation (del Río-Mena et al., 2021). Tourism and payments for ecosystem services (PES) such as carbon sequestration are now seen as opportunities for an alternative source of income for farmers.

In addition, a primary intervention by Living Lands (https://www.livinglands.co.za/) has been the construction of infiltration ponds (both manual and mechanical), designed to capture surface runoff, reduce erosion, and promote groundwater recharge on the hillslopes (https://youtu.be/y-KxHB5dbjE?si=8j60y7bOjoxNJh13). Living Lands' history started in 2006 with EarthCollective creating the platform and idea to launch PRESENCE, a learning network and supporting the initiation of Living Lands. An initial phase of ponding covered 2 000 ha between 2016-2019, followed by a further 53 000 micro- and macro-ponds installed across 110 ha between 2022-2024, with an estimated annual water capture benefit of over 100 million litres per year at peak capacity. This work complemented broader hillslope interventions, including silt traps, swales, brush-packing, and revegetation, which together aimed to slow overland flow, improve infiltration and build soil organic matter, and increase vegetative cover across the degraded areas.

Berm removal on the alluvial fans

On the alluvial fans, which serve as critical buffers between the mountains and the floodplain and are essential to groundwater recharge and sedimentation control, artificial berms were identified as a primary driver of degradation. These structures, many dating back to flood-protection measures implemented after a major 1981 flood, had forced water directly into incised channels rather than allowing it to spread across the fan surface, resulting in lowered groundwater recharge, altered river morphology, and the decline of natural wetland areas. Alluvial fan restoration work by Living Lands during 2018 addressed this by removing or breaching these berms and constructing blocking structures to redirect flow back across the fan surface, slowing water velocity, promoting infiltration, and allowing sediment deposition to reverse channel incision.

Mainstem berm removal and gabion construction

On the main riverbed, the removal of artificial berms from the floodplain by Living Lands was designed to allow water from tributaries to flow freely and unrestricted, reducing erosive energy and working towards the restoration of a more natural flow pattern. In contrast, in the wetland areas small gabion structures were installed to stabilise headcuts and raise local water levels, supporting the recovery of depleted wetland

ecosystems. Working for Wetlands also built two large gabion structures in the Baviaanskloof River at Joachimskraal and Zandvlakte between 2013-2016 to address the river incision caused by diverting and channelling the Baviaanskloof River. The programme's primary focus is wetland restoration and the protection and sustainable use of wetlands.

Research and monitoring

Due to the absence of a long-term monitoring programme in the valley, detailed recharge, flow and groundwater level data are mostly lacking. However, there have been a number of research projects and academic theses or dissertations published between 2008 and 2018 investigating the water resources in Baviaanskloof. The SAEON (https://fynbos.saeon.ac.za/?p=3188), for example, have supported research activities by postgraduate students in the Baviaanskloof since 2012. Monitoring equipment include the installation of tipping bucket rainfall gauges and temperature loggers. Hydrological instrumentation include the installation of pressure transducers at several sites in the river and boreholes for continuous monitoring. Several sites have been selected for manual monitoring during seasonal sampling campaigns. This includes water level readings and basic hydrochemistry in piezometers, boreholes, and rivers, as well as streamflow measurements. The departure of the students has resulted in a reduction in monitoring however, data continues to be collected at key sites by the SAEON staff until today.

In summary

The above-mentioned interventions in the Baviaanskloof River catchment are fundamentally interconnected with strong interactions between surface flow and groundwater: the restoration of an alluvial fan supports wetland recovery upstream, which in turn contributes to the restoration of the main riverbed downstream, all linked within a single dynamic hydrological system and all oriented towards improving water security for the valley and the downstream users dependent on the Kouga Dam. Moreover, modelled outputs by Glenday (2015) suggested that hillslope thicket restoration would have the most significant impact on streamflow, driven by large reductions in storm event runoff, while floodplain channel restoration would have the largest impact on the floodplain water table, driven by decreased drainage into the channel and increased recharge due to overbank flooding.

To carry this work forward on a lasting institutional footing, in 2014 Commonland (https://commonland.com/landscapes/boosting-biodiversity-through-ecological-restoration/) partnered with Living Lands to identify business opportunities and facilitate large-scale regeneration. During this collaboration, the Baviaanskloof Development Company (essential oil production) and Baviaanskloof Bewarea (ecological restoration) were established. The Baviaanskloof Bewarea company brings together landowners, conservation partners and local stakeholders to coordinate ongoing stewardship and restoration across the valley. Associated long-term monitoring and research would further improve knowledge of this system and provide support for the continued protection of ecological infrastructure in the catchment.

References

Key information is drawn from De Villiers (1941), Taljaard (1949), Euston-Brown (1995), Boshoff et al. (2000), Illgner and Haigh (2003), McCarthy and Rubidge (2005), Crane (2006), Boshoff (2008), Jansen (2008), Bobbins (2010), Ellery and Rowntree (2011), Hattingh (2011), Living Lands (2011), Webley (2011), Knight (2012), de Jong (2013), SANBI (2013), Hedden and Cilliers (2014), Petz et al. (2014), Commonland (2015), Glenday (2015), Smith-Adao (2016), Mander et al. (2017), Joubert (2018), del Río-Mena et al. (2021), Rebelo et al. (2021), Jin et al. (2024), Kuang et al. (2024), Okello et al. (2024), Omalanga and Onyari (2025).

Photo supplied

Figure 8. An example of a rehabilitation intervention in the Bavaanskloof valley.