THE WATER WHEEL

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CLIMATE RESILIENCE

Forecasting the future: Free weather risk app empowers South African farmers

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WATER RESEARCH COMMISSION

55 YEARS

Supporting Sustainable Water Futures

1971-2026

Contents

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A freely available weather app has been designed to support short-term agricultural planning and decision-making. Read the article on page 10.

NEWS

Researchers call for stronger community involvement in wetland management policies

A recent study, co-authored by Dr Mandla Dlamini, a researcher from the Unit of Environmental Management and Sciences (UESM) at North-West University (NWU), emphasises that floodplain wetland management and disaster risk reduction efforts are unlikely to succeed without the active participation of affected communities.

Wetlands play a crucial role in supporting agriculture and local livelihoods in countries such as South Africa, yet they face unique conservation challenges. The management of wetland ecosystems remains a pressing issue, as agricultural practices significantly contribute to wetland degradation through pollution, livestock overgrazing, and habitat clearance.

The research found that while conservation and flood-control frameworks exist in many regions, people living near wetlands often experience these policies differently from how they were intended. The study, titled 'Community perspectives and policy effectiveness: a study on floodplain wetland management and its socio-economic implications', analysed how wetland management policies are understood at the community level and how they affect access to land, water, and natural resources.

The findings revealed that wetland management policies, though primarily designed to conserve ecosystems and mitigate flood risks, often result in unintended socio-economic pressures. In several cases, restrictions on farming, grazing, and harvesting natural resources affected household income and food security, particularly in communities that depend on wetlands for daily survival.

Dr Dlamini said the findings show that policy success cannot be measured solely by environmental outcomes. "Wetland management policies are often designed with strong conservation intentions, but our research shows that their effectiveness depends on how well they respond to the realities of the communities who live within these ecosystems every day," said Dr Dlamini. "When local voices are not included in planning and implementation, policies may protect the environment but still create social and economic challenges."

The study also found that community members are not always involved in decision-making processes, even though they are directly affected by regulations. This lack of participation can lead to resistance, misunderstanding, or non-compliance, making it harder for authorities to achieve long-term sustainable environmental goals.

According to the researchers, community knowledge can help improve wetland management because residents often understand seasonal flooding patterns, land use pressures, and local risks better than external planners. Including these perspectives can help design policies that protect ecosystems while allowing sustainable livelihoods.

Dr Dlamini said participatory approaches are important for building trust between institutions and communities. "Inclusive governance is essential for balancing ecological protection with human needs. When communities are part of the process, policies are more likely to be accepted and more likely to work in practice," he said.

The study links wetland management to broader development priorities – including climate adaptation, disaster risk reduction, and poverty alleviation – while advancing key Sustainable Development Goals such as SDG 13 (Climate Action), SDG 11 (Sustainable Cities), and SDG 1 (No Poverty).

In conclusion, the authors argue that sustainable wetland management requires cooperation between policymakers, scientists, and communities, with greater emphasis on participation, local knowledge, and shared responsibility.

To access the study, visit: https://rdcu.be/fh3fh

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Study shows hidden groundwater loss due to invasive plants

New research from the University of the Western Cape (UWC) has provided critical insights into how invasive alien plant species significantly affect groundwater reserves, with implications for water security in South Africa's water-scarce landscapes.

The study, conducted by researchers from UWC's Institute for Water Studies, PhD student Mmasechaba Moropane, and Prof Cletah Shoko from Wits University, and published in the ***International Journal of Applied Earth Observation and Geoinformation***, examined the long-term spread of groundwater-dependent invasive plants in the Nuwejaars catchment in the Western Cape. Using high-resolution multi-date satellite imagery, machine learning and explainable artificial intelligence techniques, the research tracked vegetation changes over 12 years from 2013 to 2024.

The findings showed a marked expansion of invasive species, including Acacia, Eucalyptus and Pinus, which increasingly displaced native vegetation in groundwater-dependent ecosystems. Over the study period, invasive plants expanded from just over 40% to nearly 64% of the monitored areas, drawing heavily on groundwater reserves, particularly during prolonged drought conditions.

Researchers found that the most rapid expansion occurred after the 2015–2018 drought, highlighting how climate stress can weaken indigenous vegetation while favouring deep-rooted invasive species with higher water demands. This shift not only threatens biodiversity, but also reduces groundwater availability for agriculture, ecosystems and communities that rely on these resources.

Importantly, the research demonstrated that targeted clearing of invasive plants had measurable hydrological benefits. Periods of intensified clearing under government-supported initiatives were associated with a partial recovery of native vegetation and reduced dominance of invasive species in some areas.

This research underscores the urgent need to integrate invasive species management into national strategies on climate resilience, water conservation and sustainable resource management.

• To access the original study, visit: https://www.sciencedirect.com/science/article/pii/S1569843225007009

Celebration as Eastern Cape gets first Ramsar designated wetland

The Mkambati Nature Reserve in the Eastern Cape has been designated as South Africa's newest Wetland of International Importance under the Ramsar Convention, marking a significant conservation milestone.

The Ramsar Convention identifies and protects wetlands of global significance, known as Ramsar Sites. "The designation acknowledges that the many wetlands found at Mkambati have unique ecological, cultural and socio-economic value, placing the reserve firmly on the global map of internationally recognised wetlands," Deputy Minister of Forestry, Fisheries and the Environment Narend Singh said during an event held in April.

Situated along the scenic Wild Coast, Mkambati forms part of a unique ecological area, home to plant and animal species found nowhere else in the world. The nature reserve is home to rare wetland types, including swamp forests, and features multiple estuaries. It is also among the few places globally where waterfalls cascade directly into the ocean.

In recognition of the importance of Mkambati, Environmental Programmes' Infrastructure Projects have committed R17-million toward improvements to infrastructure and visitor access in the Reserve.

"A recent national biodiversity assessment shows that wetlands and estuaries are among the most threatened and least protected ecosystems in South Africa," noted Singh. "At a time when wetlands face growing pressures from pollution, poor agricultural practices and infrastructure development, finding ecosystems in such good condition [as they are in Mkambati] is rare and they must be protected."

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GLOBAL

Freshwater fish populations plunge 81% as river migrations collapse

Some of the longest and most essential animal migrations on Earth take place beneath the surface of rivers. A major new report from the Convention on the Conservation of Migratory Species of Wild Animals (CMS), a United Nations environmental treaty, warns that many of these migrations are now rapidly breaking down.

The ***Global Assessment of Migratory Freshwater Fishes***, released at the CMS 15th Meeting of the Conference of the Parties (COP15) in Brazil, finds that migratory freshwater fish are among the most threatened species worldwide. These fish are critical for maintaining healthy rivers, supporting major inland fisheries, and providing food and livelihoods for hundreds of millions of people.

The assessment provides strong evidence that fish relying on connected rivers across national borders are declining quickly due to dam construction, habitat fragmentation, pollution, overfishing, and climate-related ecosystem changes. In total, 325 migratory freshwater fish species have been identified as candidates for international conservation efforts, pointing to a largely overlooked biodiversity crisis across shared river systems. Key river systems identified as priorities include South America's Amazon and La Plata-Paraná, Europe's Danube, Asia's Mekong, Africa's Nile, and the Indian sub-continent's Ganges-Brahmaputra.

Based on extensive global datasets and IUCN assessments of nearly 15 000 freshwater fish species, the report provides the most comprehensive overview so far of the conservation challenges facing migratory freshwater fish. The report estimates that migratory freshwater fish populations have declined by about 81% worldwide since 1970. Nearly all (97%) of the 58 listed migratory fish species (including fresh and salt-water species) are now threatened with extinction.

• To access the report, visit: https://bit.ly/migratory-freshwater-fish-report-2026

Planets need more water for life than scientists thought

Desert worlds outside our solar system are unlikely to host life, according to new research.

The new work shows that an Earth-sized planet needs at least 20 to 50% of the water in Earth's oceans to maintain a critical natural cycle that keeps water on the surface.

While there are billions of planets outside our solar system, the search for life has focused on planets in the 'habitable zone', a sweet spot that is neither too close nor too far from a central star. Planets in this zone are considered viable because they can maintain liquid surface water.

Water, although essential, does not guarantee the existence of life. With this study, researchers worked to further narrow the search by investigating planets with just a small amount of water. The results, published in *Planetary Science Journal*, shows that habitability hinges on the geologic carbon cycle – a water-driven process that exchanges carbon between the atmosphere and interior over millions of years, stabilising surface temperatures.

The researchers ran a series of complex simulations to better understand how water might behave in these desert worlds.

Carbon dioxide, which comes from volcanoes in a natural system, accumulates in the atmosphere before falling back to Earth dissolved in rainwater. Rain erodes and chemically reacts with rocks on the Earth's surface and runoff transports carbon to the ocean, where it sinks to the seafloor. Plate tectonics drives carbon-rich ocean plates below continental land. Millions of years later, carbon resurfaces as mountains form.

If water drops too low for rainfall, carbon removal – from weathering – can't keep up with emissions from volcanic eruptions and carbon dioxide levels in the atmosphere spike, trapping water. Rising temperatures evaporate the remaining surface water, initiating runaway warming that makes the planet too hot to support life.

"Unfortunately, that makes these arid planets within habitable zones unlikely to be good candidates for life," noted lead author, Haskelle White-Gianella, a University of Washington doctoral student of Earth and space sciences.

Although scientists have instruments that can measure surface water, rocky exoplanets are difficult to observe directly. In this study, the researchers ran a series of complex simulations to better understand how water might behave in these desert worlds.

• To access the study, visit: https://doi.org/10.3847/PSJ/ae4faa

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Drinking water near coasts is under threat worldwide

Coastal groundwater is a key source of drinking water in many regions of the world. However, it is threatened by over-abstraction and the potential of salinisation.

Rising sea levels are further exacerbating the situation. This is demonstrated by a recent study published in ***Nature Water*** by a research team led by Prof Robert Reinecke from the Institute of Geography at Johannes Gutenberg University Mainz and Annika Nolte from the Climate Service Centre Germany in Hamburg.

"Between 1990 and 2024, more than 20% of the coastal areas we studied showed significant changes in the groundwater level. In some cases, levels have dropped by more than 50 cm per year. This points to over-abstraction and, consequently, the potential intrusion of seawater and associated salinisation," explains Prof Reinecke. The interaction between over-abstraction and rising global sea levels due to global warming is particularly critical. "If groundwater levels drop, seawater can intrude more easily."

The study is based on data from around 480 000 wells across different countries, compiled by the researchers, making it the largest global dataset of coastal groundwater measurements to date. "Our study makes three key contributions. First, it translates available measurement data from different locations into globally comparable metrics, enabling large-scale assessment for the first time. Second, it identifies areas at particular risk and highlights the changes there. Third, it provides indicators that can be used to model developments along previously unmonitored coastline," noted Prof Reinecke.

• To access the study, visit: https://www.nature.com/articles/s44221-026-00619-8

Diary

Large dams
22-29 May
The annual meeting of the International Commission on Large Dams will take place in Mexico. The theme of the meeting is 'Water, energy, and society: The evolving role of dams in a changing world'.
Visit: https://www.icoldmexico2026.com/about-5-3

South African water
22-24 July
The biennial conference of the Water Institute of Southern Africa (WISA) will take place in Cape Town under the theme 'Rethinking Amanzi'.
Visit: https://www.wisaconference.co.za/

Non-sewered sanitation
9-12 July
The 2nd International Conference on Non-Sewered Sanitation Systems will be held in Kerala, India, with the theme, 'Reimagining sanitation systems for an inclusive and sustainable future.
Visit: https://nssconference2026.org/

Wetlands
19-23 October
The National Wetlands Indaba will take place in the Western Cape under the theme 'Wetlands and traditional knowledge: Celebrating cultural heritage'.
Visit: https://nationalwetlandsindaba.org/

Municipal engineering
28-30 October
The 89th conference of the Institute of Municipal Engineering of Southern Africa (IMESA) will take place In Durban under the theme 'Blueprints reimagined judiciously.'
Visit: https://imesa.org.za/

Sustainable Development Goals (SDGs)
2-4 December
The 2026 United Nations Water Conference will be held in the United Arab Emirates. The conference, focused on the SDGs, aims to bring the spirit of solidarity to life and help to build a water-secure future for all.
Visit: https://www.un.org/en/civil-society/2026-united-nations-water-conference

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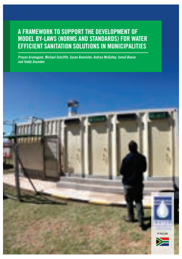
NEW WRC REPORTS



A framework to support the development of model by-laws (norms and standards) for water efficient sanitation solutions in municipalities

There is an urgent need to at least transition towards the inclusion of water-efficient sanitation solutions (WESS) as a service delivery option. WESS include non-sewered, off-grid or on-site and decentralised technologies and offer a sustainable response to challenges such as inadequate and unsafe sanitation, public health risks, environmental degradation and climatic impacts that result in disrupted services. WESS are highlighted as critical, especially because they address the needs of both low-income communities, who often live in informal settlements without direct sewer connections, and high-income groups, who may reside in estates that also lack easy access to sewer systems. However, several governance and institutional challenges need to be addressed for the effective implementation of these systems. In this report, a framework is provided to assist and guide municipalities (metropolitan, district and local) with approval, adoption, and regulation of WESS that facilitate full treatment of the input/influent for safe reuse or disposal through developing new sanitation by-laws or adapting their existing water services by-laws. Establishing this comprehensive framework for model by-laws (norms and standards) is essential to guide municipalities in implementing WESS effectively.

WRC report no. TT 961/25

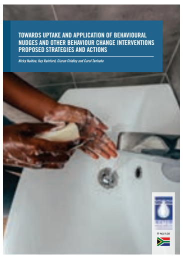
Link: https://bit.ly/4dbOTjz

Nudging for municipal water services revenue collection improvement (NuWRev): Scoping review

In countries such as South Africa, rising utility bill debt is a common challenge, with various conventional strategies for debt recovery proving inefficient. While disconnection is an option, the associated political costs faced by the authority are much higher than the financial costs of reconnection by the customer. As a result, water authorities (utilities) are running at a loss, which compromises the reliability and quality of water provided. This scoping report introduces the notion of a "moral price" as a latent sense of obligation that can be made more salient through behavioural interventions. Yet, there is limited empirical evidence on its existence and effective activation. The urgency is heightened by the preexisting 41% non-revenue water rate in South Africa. Rising default rates are intensifying a low-revenue, low-service equilibrium trap. The scoping review found that conventional, punitive approaches are neither efficient nor sustainable. By contrast, nudging strategies (low-cost behaviourally informed interventions) have demonstrated significant, persistent, positive effects on bill payment and resource conservation across multiple contexts.

WRC report no. 3238/1/25

Link: https://bit.ly/4wrhWak



Towards uptake and application of behavioural nudges and other behaviour change interventions

The National Water and Sanitation Master Plan (NWSMP) (2018) estimates that municipalities are losing as much as 1 660 million m^3 of water per year through non-revenue water (NRW), which increased from 37% in 2014 to 47% in 2023. Despite these constraints, South Africans still consume on average 233 litres per person per day, which is approximately 64 litres more per day per person than the average global daily consumption of 173 litres per person per day. In this context, it is imperative to consider different and innovative ways to decrease water demand and increase water conservation. The objective of the research was to provide a framework for a strategy that introduces behavioural change, including nudges, as a social change intervention available to municipalities to influence water usage behaviour to ensure the long-term sustainability and security of water resources in South Africa.

WRC report no. TT 962/1/25 (Volume 1 – Proposed strategies and actions) and TT 962/2/25 (Volume 2 – Strategic framework)

Volume 1 link: https://bit.ly/3QYDQ4t

Volume 2 link: https://bit.ly/4u8CjYc

Equity dimensions of the Nelson Mandela Bay water crisis and the implementing context as enabler or barrier for uptake of translatable lessons from the Cape Town water crisis

Drought in the Nelson Mandela Bay Metro is not new. Since 1969, the Metro has experienced at least four instances of severe drought, but the 2017 – 2023 drought was the most severe in the history of the Metro. This study focused on government-led interventions and the equity dimensions of these. The Metro implemented mostly technical interventions, raising questions regarding the place of social innovation, including those related to governance and institutions, and equity dimensions of the measures implemented throughout the city.

WRC report no 3242/1/25

Link: https://bit.ly/48UuAo3

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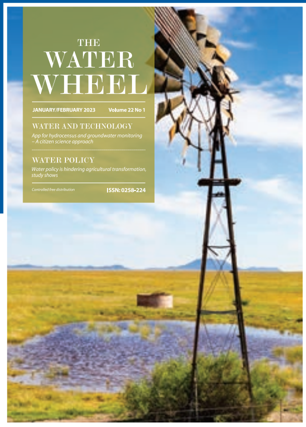

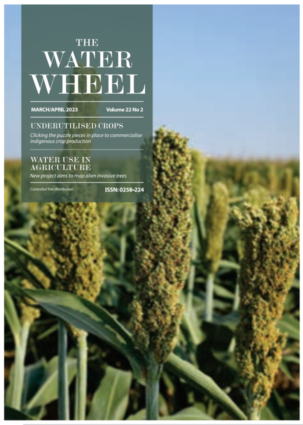

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CLIMATE RESILIENCE

Forecasting the future: Free weather risk app empowers South African farmers

The Agricultural Research Council (ARC) has developed a user-friendly app providing weather and water availability indices as part of a project funded by the Water Research Commission (WRC). Article by Sue Matthews.

"Red sky at night, shepherd's delight; red sky in the morning, shepherd's warning," the saying goes. For areas where weather systems primarily move in from the west, this old folk proverb has some scientific credibility. Not so for another common one that claims cows lying down is a sign of impending rain!

Fortunately, farmers of today have more accurate information at their fingertips. With a smartphone in their pocket and a good internet signal, they can check the weather forecast while out in their fields and prepare accordingly. Back in their home office, they can use their computer to peruse the seasonal outlook and recent rainfall records, or explore retrospective indicators derived from satellite imagery, such as the Normalised Difference Vegetation Index (NDVI) depicting vegetation health. Well-resourced farmers might even install weather instrumentation and soil probes for site-specific data, and pay subscription fees for advisory services tailor-made for their farm.

The new app developed by the ARC's Agrometeorology Division at the Soil, Climate and Water Campus makes information freely available for all. Named the Weather Risk app, it is designed to support short-term agricultural planning and decision-making, typically on daily to weekly timescales. Currently available only as a web-based tool for desktop and laptop computers, it will be useful not only to farmers but also to a variety of other stakeholders, including agricultural extension and field officers,

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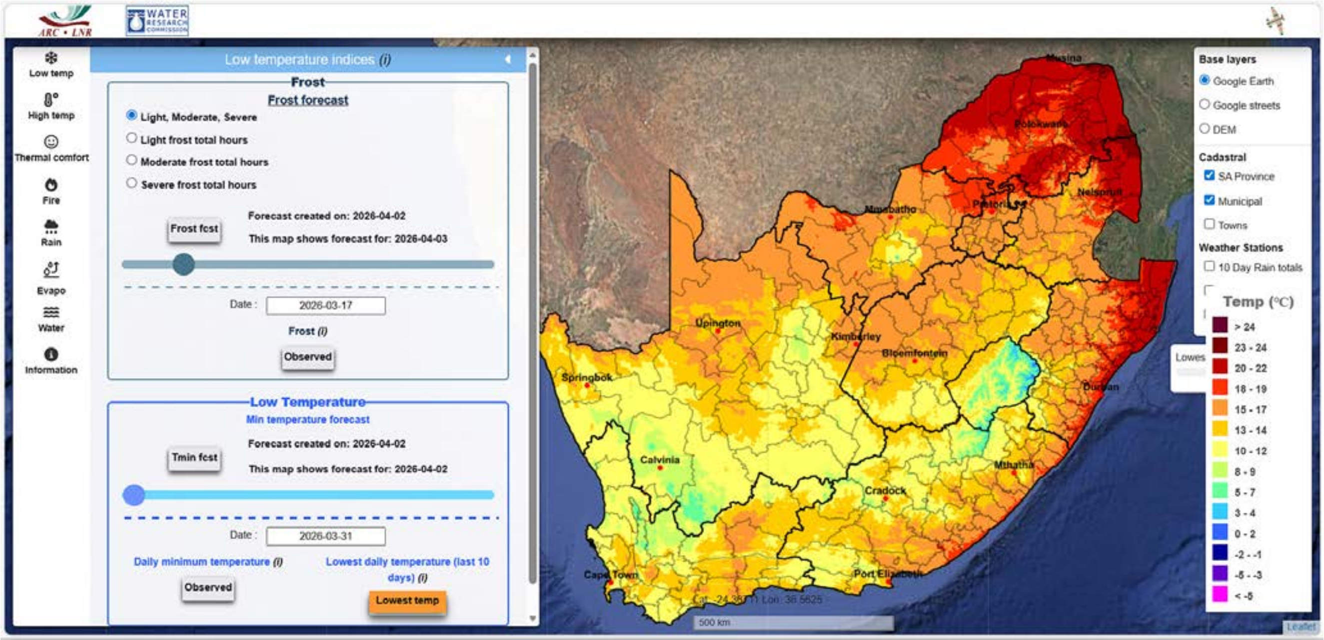

The Weather Risk app displays the index 'Lowest daily temperature (past 10 days)' for the period leading up to 31 March 2026, as selected in the corresponding date box and based on observed data from the ARC's weather stations. The forecast for minimum temperature can be displayed by toggling the button above the dashed line and then clicking along the slider to view the Day 1 to 7 forecast.

farmer organisations and cooperatives, seed and agrochemical companies, agricultural insurance providers, local government, policymakers and researchers.

"We recognise that a large proportion of the farmers that the ARC supports through research and development are smallholder farmers who may not have a computer, or they're in a rural area without good internet access," says project leader Dr Sarah Roffe, a Senior Researcher at the ARC. "But extension officers are more likely to have connectivity and can use tools like the Weather Risk app to interpret information, which they could then share with farmers via WhatsApp groups or SMS, so we see them as a key target audience."

Ensuring the app filled a genuine gap and provided relevant information to users in a clear, easily accessible way was an important part of the WRC-funded research project. A literature review was conducted to identify rainfall, temperature, and water availability indices widely used in South Africa, and an evaluation of existing web-based weather and climate services (WCS) and the principles behind them was undertaken. Those initial steps revealed that stakeholder engagement was vital before deciding on the app's design and functionality, so a focus group meeting was held in Tzaneen in October 2023 to discuss needs and expectations. The participants – primarily representatives from national and provincial government departments, local municipalities and NGOs – completed a questionnaire that was subsequently refined and made available online for broader dissemination within the agricultural sector. Of the 42 online responses received, most were from individuals within national or provincial departments of agriculture (40.5%), the ARC (14.3%) or universities (9.5%) and the rest from agribusiness companies, associations or consultancies. The results yielded valuable insights on sector-specific perceptions about climatic risks, the uptake of existing WCS, as well as constraints associated with accessing and using them.

Interestingly, while respondents indicated that they mainly use forward-looking WCS in the form of daily to seven-day weather forecasts, seasonal forecasts and early warning systems, the most frequently reported need was for access to historical weather and climate records. It is fitting, then, that the Weather Risk app provides recent historical information, currently from 2023 onwards, derived from the ARC's network of more than 600 weather stations countrywide. Rather than displaying raw data, though, the app allows indices such as 'Daily minimum temperatures', 'Heat index (human thermal comfort)', and 'Days since last rain' to be mapped. Clicking anywhere on the colour-coded map displays the pixel value at that location, although these values should be treated with some caution. This is because the weather stations are not evenly distributed across South Africa, and the data they record is summarised and interpolated to produce daily GeoTIFF files at a 1 km grid resolution. As such, the indices provide a useful overview of conditions but may not fully capture farm-scale microclimatic influences, such as slope orientation, windbreaks and small water bodies.

Although weather station data can be purchased from the ARC, indices typically provide more intuitive and actionable information on past weather and climate conditions for agricultural decision-making. Clicking on the (i) next to each of the app's indices links to the supporting text in the User Guide, which includes a dedicated section on agricultural relevance and practical application. As an example, the index 'Maximum daily rainfall (last 30 days)' represents the highest single-day rainfall total recorded over the previous 30 days from the date selected using the drop-down calendar. The User Guide states: "This index is useful for evaluating the effects of intense rainfall on agricultural systems. For crop farmers, it helps identify

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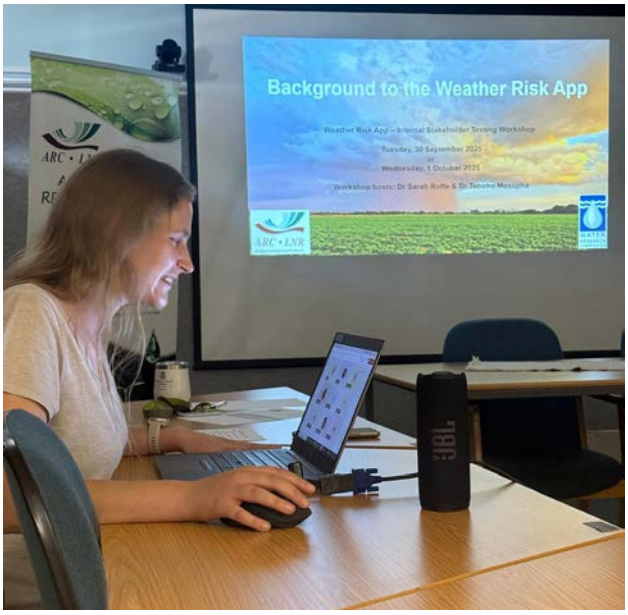


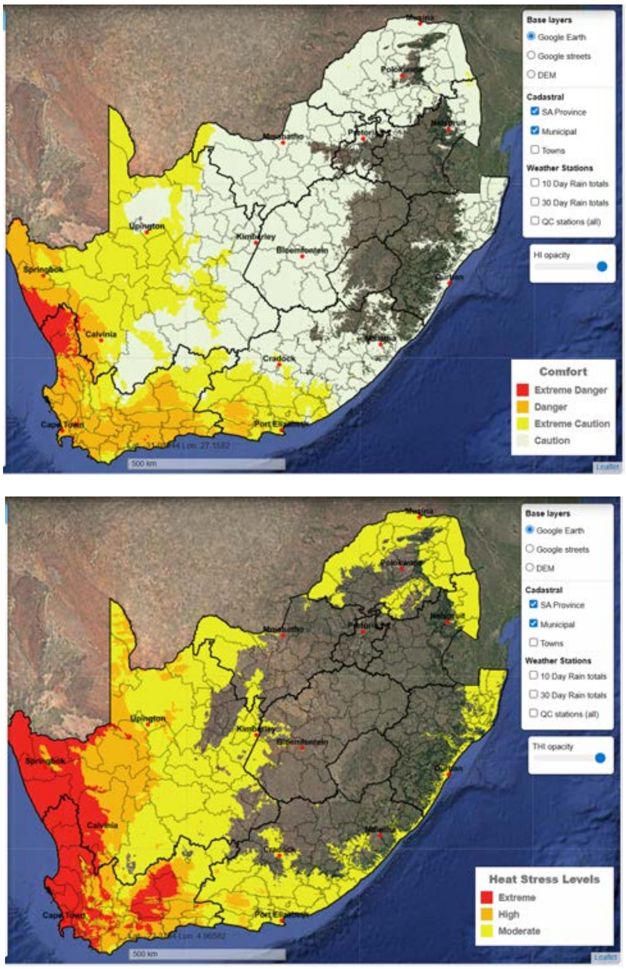
Project leader Dr Sarah Roffe introduces the Weather Risk app at the ARC's internal stakeholder testing workshop.

areas at risk of erosion, surface runoff or waterlogging, all of which can damage soil structure and reduce plant health. For example, a farmer who observes a recent extreme rainfall event might inspect fields for ponding or adjust nutrient application schedules to account for leaching. For livestock farmers, the index supports decisions around grazing access and infrastructure maintenance. Heavy rainfall may limit access to paddocks, damage roads or fencing, or increase the risk of animals becoming trapped in wet conditions, prompting changes in movement plans or sheltering arrangements."

The research report also provides a number of case studies, using indices derived from various weather station observations and selected gridded datasets, including ERA5-based temperature and rainfall datasets. These are global reanalysis products produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), which assimilates satellite and weather station observations from around the world into a numerical weather prediction model to generate hourly data spanning 1940 to the present. One case study, for example, examined how well ERA5 datasets capture heavy rainfall events across South Africa, while another assessed their ability to represent extreme low temperature events during winter. A case study focusing on climate indices derived from ARC weather station data explored the indices' relationship to agricultural outcomes – more specifically, the effect of seasonal thermal conditions on cattle production in the Thabazimbi district in Limpopo Province, and the effect of summer temperatures, rainfall and potential evapotranspiration on maize production in the Koppies district in the Free State Province. Taken together, the case studies effectively demonstrate the value of climate indices in providing a bridge between complex data and practical decision-making, while highlighting dataset-specific differences, context dependence and sources of uncertainty that must be taken into account in operational use.

The indices currently available in the Weather Risk app are as follows:

- **Low temperature indices:** Frost, Daily minimum temperatures, Lowest daily temperature (last 10 days)
- **High temperature indices:** Daily maximum temperature, Heat stress days (last 10 days), Highest daily temperature (last 10 days)
- **Thermal comfort indices:** Heat index (human thermal comfort), Temperature-humidity index (livestock thermal comfort)
- **Fire danger index (FDI)**
- **Rain indices:** Daily rainfall, Number of rain days (last 30 days), Days since last rain (up to 60 days), Maximum daily rainfall (last 30 days), Total rainfall (last 10 and 30 days)
- **Evapotranspiration indices:** Daily total potential evapotranspiration (PET), Total PET (last 10 and 30 Days)
- **Water availability indices:** Irrigation extent per quaternary catchment, Blue water irrigation demand, Monthly surface water anomaly, Groundwater harvest potential.



The images above depict 'Thermal comfort indices' for 11 March 2026, when the western parts of South Africa were experiencing a heatwave. On the top, the 'Heat index (HI)' for humans shows that conditions were potentially dangerous for farm workers unless activities were adjusted. On the bottom, the 'Temperature-humidity index (THI)' indicates the risk of heat stress in poultry. Separate THI values can be displayed for goats, sheep, cattle and pigs.

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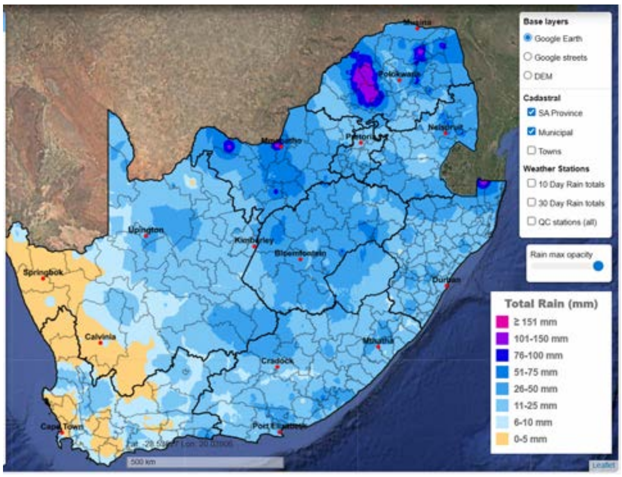

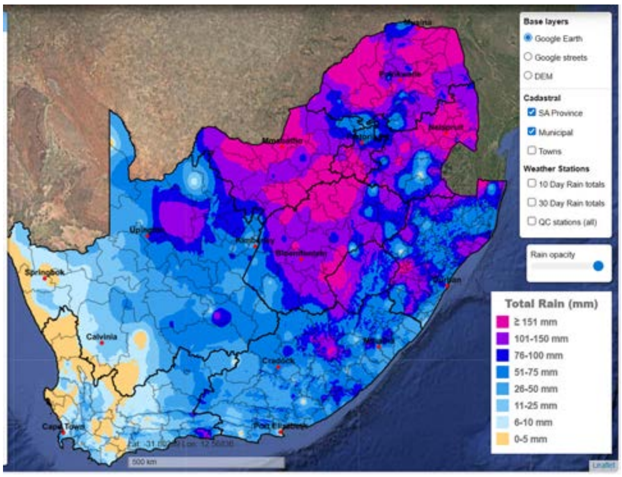

The above images for 31 March 2026 reveal the difference between the indices 'Maximum daily rainfall (last 30 days)' on the top, showing the highest single-day rainfall total recorded over the previous 30 days, and 'Total rainfall (last 30 days)' on the bottom, showing the cumulative rainfall total recorded over the same period.

Of these, the water availability indices are based on datasets obtained from external data providers, and only the 'Monthly surface water anomaly' index updates regularly; the rest are static layers representing long-term hydrological conditions. All the other indices are based on ARC weather station data and are updated in near-real time, typically with up to two days of delay.

"That's just the time it takes for us to be able to load the observation data onto the site," explains Roffe. "The data from the ARC weather station network has to be checked by a team of technicians who do quality control on a daily basis, so the process is slightly slowed by weekends or by any technical glitches."

While looking back at recent conditions helps farmers and other stakeholders understand the current situation, they really want to know what weather impacts they can anticipate in the short term. Several of the app's indices include daily forecasts over a seven-day period. By selecting the forecast button and then clicking along a slider, the map will display individual forecast days during that period. For some indices, a seven-day total or average forecast can be viewed by selecting the far-right end of the slider.

"Our forecast runs every morning at 7:30, it takes about two hours, and then by 11:30 it's updated on the app," says Roffe. She explains that the ARC uses the Weather Research and Forecasting (WRF) model, a numerical weather prediction model originally developed by the United States' National Center for Atmospheric Research (NCAR) but now maintained and extended by an international user community. The WRF model dynamically downscales data from the NCEP/NOAA Global Forecast System (GFS) from a 28 km grid to a 12 km grid to produce the app's forecasts for South Africa. The User Guide advises caution in interpreting these forecasts because validation is ongoing and forecast skill may vary across regions, seasons and variables.

A few months prior to the Weather Risk app's public release in December, the project team hosted two one-day workshops with ARC staff members from a wide range of disciplines to test the app and gather feedback. The insights obtained have guided refinements to the app and identified priorities for future development, such as including advisory-style features to help farmers apply the information provided in the app.

In March, two launch events were held to showcase the app and demonstrate its practical value to stakeholders. The first targeted government departments and agricultural organisations such as AgriSA and FANRPAN, while the second reached a broader audience of interest groups.

"We had good attendance, with people there from insurance companies, a leading commercial bank, government, academia and research institutes, plus a few farmer groups," says Roffe, speaking a few days after the second event. "The farming community doesn't often come to events like this, so we still need to do some proper engagement with them. The session was very interactive, though, and a lot of useful feedback came our way."

It is still early days for the Weather Risk app, so it should be viewed as an operational service that is being tested, refined and enhanced as feedback is incorporated and the robustness of indices and datasets is evaluated. In any case, the app's outputs are best used for situational awareness, and decision-making should always be informed by local expertise and multiple information sources.

Clearly, though, the app is a welcome addition to the ARC's stable of tools for sharing information – the monthly ***Umlindi*** climate watch newsletter, the Agricultural Drought Early Warning System (ADEWS) platform, and the subscription-based ARC Weather App offering access to the ARC's weather station data.

"We felt it's very important that we create this app because the ARC has all this data and is mandated to support the agricultural industry," says Roffe. "So for those of us in the Agrometeorology Division, developing tools like this forms part of our goals in striving to support farmers as best we can."

WeatherRisk

The Weather Risk app is available at:
https://www.weatherrisk.arc.agric.za/

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WATER SECURITY

Measuring the liquidity of the SA Bank of Water

Researchers are developing a new web-based application to estimate and summarise the volumes of water available in South Africa on a national and local scale. Sounds simple, right? Not so fast, writes Tony Carnie.

A business accounting system is an organised framework to record and analyse financial transactions. It tracks income, expenses, assets and liabilities to produce regular statements on the financial health of business and banking groups across the world. In much the same way, says research project leader Dr Stefanie Schütte, the proposed South African (SA) water resources accounting system will help guide the wise use of one of South Africa's most crucial national assets.

Schütte, from the Centre for Water Resources Research (CWRR) at the University of KwaZulu-Natal (UKZN), has been commissioned by the Water Research Commission to lead a five-year research project entitled 'Setting up an operational water resources accounting system for SA'. In very simple terms, the new accounting system aims to estimate the volumes of water coming 'in' versus the water going 'out' of the account.

Mainly, this will include the volume of precipitation (rain) in any given month compared to the volume going out due to flows going downstream, as well as total evaporation, and consumptive uses for the irrigation of crops, industrial and domestic use or loss.

Unfortunately, notes Dr Schütte, comprehensive rainfall and

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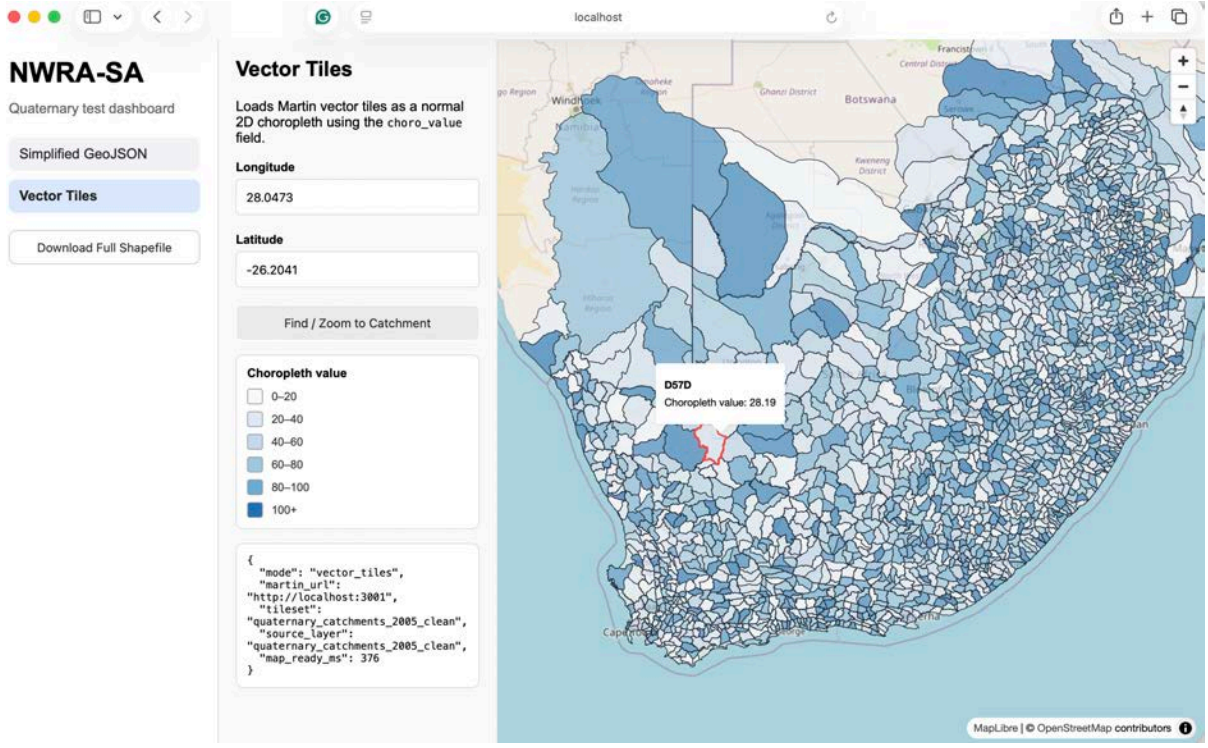

The Water Research Commission is developing a new clickable, water resources accounting system. This early concept image of the new web-based application shows South Africa's 1 946 quaternary water catchments.

temperature records are no longer available at no cost due to financial cutbacks from the fiscus to the SA Weather Services (SAWS). As an alternative, the new accounting system will rely largely on remotely sensed climate datasets rather than physical (observation) methods.

Along with Dr David Clark, Schütte and her CWRR colleagues have already conducted considerable research on water accounting over the last several years, based largely on hydrological modelling of flows. In a previous collaboration with Statistics South Africa (Stats SA) and the South African National Biodiversity Institute (SANBI), the UKZN Centre for Water Resources Research produced a detailed set of experimental water resource accounts for three catchment areas in 2024.

These are for the Mooi and uMngeni Catchments (important water sources for Pietermaritzburg and eThekwini), and the Breede Catchment (an important water source for Cape Town).

Now Schütte and her colleagues are extending the scope of the work to cover more than 5 000 altitudinal zones nationwide in order to report on water availability in the country's 1 946 quaternary catchments. Where possible, this will also include groundwater-surface water interactions, as well as engineered water flows (e.g., inter-basin transfers, dam releases, water abstractions and releases), where the information is available.

The team also hopes to make use of water quality data collected by the national Department of Water and Sanitation (DWS), including the Green Drop, Blue Drop and No Drop reports. "We will be very much dependent on information from the DWS and other institutions and we will also partner with the SAWS to get some of their data . . . but we are not trying to reinvent the wheel."

However, the research team hopes to make water information more visible and accessible to a wide range of users and decision-makers via an updateable, web-based application. This will allow users to click on a particular area to see what the account is for that area. "We still don't really know how much water we have exactly, although we have a lot of desktop information," says Schütte.

She concedes that the initial national water accounting estimates are very unlikely to be 100% accurate – or even 90% accurate – but suggests that an imperfect start is better than not starting at all. There are several reasons for this, including the scarcity of comprehensive data (many rivers do not have measuring gauges, for example). The existing weather and climate observation network has also declined, and there is still limited information on water use, abstraction and return flows.

WRC research manager, Wandile Nomquphu, has emphasised the strategic importance of this project in a water-scarce country like South Africa. The combination of semi-arid conditions, high variability in rainfall, significant inter-basin water transfers and growing demand from several sectors creates a complex water management environment. "In this context, the need for consistent, integrated, and decision-relevant water accounting systems is both urgent and non-negotiable," he says, noting that water accounting must go beyond isolated datasets and sectoral analyses.

"It must provide a coherent framework that links hydrological processes with economic use and institutional governance." Specifically, he hopes the project will lead to:

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Image: Supplied

Research project leader, Dr Stefanie Schütte.

Image: Supplied

Water Research Commission research manager, Wandile Nomquphu.

- improved quantification of stocks and flows across surface water, groundwater, water quality and return flows,
- better attribution of water use by different sectors, including agriculture, industry, and municipalities,
- integrating ecological water requirements into national accounting systems,
- greater transparency and comparability of water data to aid policy and planning.

But there are huge technical challenges ahead, Nomquphu notes, including the current fragmentation in data ownership as well problems with data availability and resolution. "We see this project as an opportunity to build a foundation for long-term, systematised water accounting in South Africa. If we get this right, we are not just improving datasets – we are strengthening how South Africa makes water decisions.

"No single discipline or institution can do this alone. The strength of this project is in this platform – in the collective expertise, the willingness to engage, and the shared commitment to getting it right. This is just the starting point. What we build from here has the potential to become a lasting national system, not a once-off exercise," he concludes.

The CWRR, set up in 2012, is the project leader and has expertise in both hydrological modelling and water resource accounting. Other partners include the SAWS, which will contribute to bias-correction of remotely sensed climate datasets using around 250 observed climate stations.

The SA Environmental Observation Network (SAEON) has expertise in data management and visualisation of water resource accounting through online user interfaces; while the Agricultural Research Council (ARC) will explore synergies with the WRC's Water Research Observatory Data Portal.

The DWS will be involved in providing data and guidance on procedures for accessing data for the whole country, and North-West University will be providing expert knowledge on groundwater.

The project team is made up of Dr Stefanie Schütte, Richard Kunz, Dr Shaeden Gokool, Dr Maqsooda Mahomed, Dr David Clark, Prof Jeff Smithers, Mark Horan, Tinisha Chetty, Marsha Chetty, Prof Emer Roland Schulze, Prof Seifu Kebede Gurmessa, Prof Alistair Clulow, Prof Andries Kruger, Dr Michael van der Laan, Dr Marc Pienaar, Samukelo Jiyane, Lindsay Callaghan, Sandile Ngwenya and Sifiso Mbatha.

Ethekwini Municipality

Contractors install new sections of piping to the eThekwini Southern Aqueduct in Durban.

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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

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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.

Image: Supplied

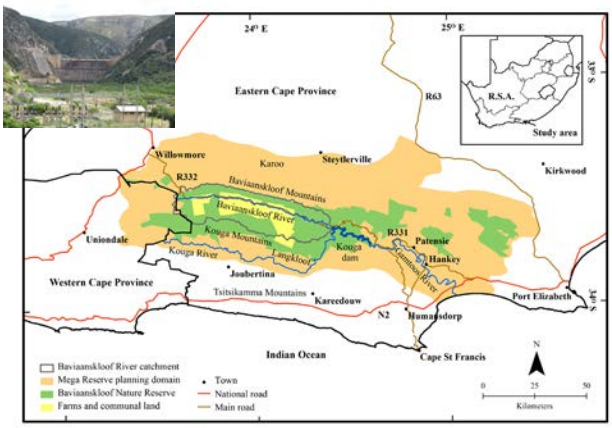

Figure 1. Location of the Baviaanskloof River valley within the south-western region of the Eastern Cape Province, South Africa. The inset shows the Kouga Dam.

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.

H Janse van Rensburg

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.

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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

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Photographs by L Smith-Adao

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

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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

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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

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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.

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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).

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

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SMALL-SCALE FARMERS

The missing link in smallholder farming: Meeting farmers where they are

Recent research funded by the Water Research Commission (WRC) shows that successful support for small-scale farmers lies in rethinking how we define success. Petro Kotzé reports.

Once heralded as the answer to food insecurity, unemployment and rural decline, the development of smallholder farmers into large-scale commercial farmers in South Africa has yielded uneven results. Billions of Rands have been channelled into infrastructure, inputs, irrigation systems, packhouses, and training programmes. Yet across many initiatives, the anticipated transformation into thriving commercial producers has not materialised.

A recently completed WRC-funded study set out to understand why. What the project team uncovered did not point to a need for more funding, land, or training, but instead, asked for something more fundamental. They realised, says project leader and specialist researcher at the Nova Institute, Dr Betsie le Roux, that almost all stakeholders' visions were misaligned with the farmers' lived realities. "We are setting them up for failure." And instead of asking the government to find another novel solution, their results call for a complete change in how current ones are applied.

Welcome to Rooiwal

The research team selected the Rooiwal Agri-Park in Pretoria as a case study. Launched in 2015, South Africa's Agri-Park programme aimed to revitalise rural economies through

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integrated farming hubs that combine production, processing, logistics, training and market access. Agri-parks focus on the country's most deprived rural and peri-urban areas. They aim to uplift previously disadvantaged emerging farmers to, among other things, produce food, eradicate poverty, and redress past inequalities.

Their success has largely been measured in income. In the Department of Rural Development and Land Reform's report to Parliament on Agri-Parks progress in 2016/17, successes were reported in the form of auctions held, cattle sold, and income generated.

At Rooiwal, like at many of the Agri-Parks across South Africa, farmers struggled to achieve the commercial momentum they were intended to have. Located in the Apies River catchment and bordered by wastewater works and an old power station, farmers grow predominantly vegetables and keep chickens. Like many Agri-Parks, however, Rooiwal does not function according to its original design model. For one, it is smaller than planned, focusing only on a plot a few hectares in size, rather than covering the originally stipulated 20 km radius around an Agri-hub, which provides financial and technical support.

In earlier work at Rooiwal and Soshanguve Agri-Parks, researchers observed the low uptake of technologies designed to improve efficiency. For example, soil water sensors were vandalised due to contractor misunderstandings and a chameleon irrigation sensor was left disconnected in an abandoned field. Mulching, promoted as a low-cost water-saving measure, proved impractical once fields expanded beyond a manageable size.

In the latest report, both farmers and officials describe deep frustration. Farmers blamed government support when expected profits did not materialise. Officials reported resistance to financial oversight and inconsistent participation in training. Funding failed to achieve its intended purposes. Funds meant for infrastructure were sometimes diverted to personal needs. Equipment was occasionally sold. And, farmers became permanently dependent on government support. Then, seedlings sometimes arrived later than the recommended planting dates due to bureaucratic delays.

Yet, Dr le Roux cautions, these were the symptoms that signalled a larger problem, and not the root causes themselves.

A three-year struggle

The research team followed a co-design approach, a methodology defined as the process of active collaboration between stakeholders in designing solutions to a prespecified problem. But in order to do it well, they also had to let go of aspects common to agricultural research projects.

Initially, they included agricultural experts in discussions with small-scale farmers, but they noticed that, instead of collaborating with them to work towards solutions, the farmers looked to these experts for answers. The problem, she says, is that an agricultural expert is not necessarily familiar with the context in which a small-scale farmer operates.

"The system is immensely complex," she says. "It responds in unexpected ways to interventions. Often, the solutions make sense outside the context, but not inside it."

In comparison, Dr le Roux, with a general background in ecology and agronomy, alongside colleagues including a theologian, a social scientist, a water specialist, and a marketing expert, decided to look to the small-scale farmers themselves for answers to their multitude of questions. "A big part of the answers [lies] in the farmers," she says. "They are the only ones that know what works in their specific contexts."

But beginning with what WRC assistant research manager, Dr Samkelisiwe Hlophe-Ginindza, calls "a blank page" was not easy. Dr Le Roux recalls the difficulty they experienced over the three of the project after years in making sense of the problem and in offering support to farmers. Good Agricultural Practice (GAP) training sessions were well attended, but farmers indicated that the administrative requirements were too much. Only a single farmer undertook the process through the project and recently obtained her SA GAP certificate. Engagement was inconsistent, and adoption remained low. At the same time, the farmers continued to struggle. Farmers purchased centre pivots that were not suitable for the land, water and skills they had and their crops failed during drought.

"A big part of the answers [lies] in the farmers. They are the only ones that know what works in their specific contexts."

"Every time we thought we had identified the problem," she says, "another layer appeared."

Like diagnosing a limp, she explains, one may first notice the wound. In policy terms, the wound is hunger and food inequality. The immediate response is to provide inputs: electricity, seedlings, compost. When that fails, we add packhouses, training, and capital. Yet still, commercially successful farmers do not emerge. The team realised that they were still not at the core of the problem.

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One of the farms in Lefatlheng, Hammanskraal, that the researchers visited for answers to their questions.

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A farmer shows off his crops at Lefatlheng, Hammanskraal.

The breakthrough: Levels

Eventually, toward the end of the project, the researchers began to make sense of the complex circumstances they were studying. They realised there was a pattern in the farming operations of successful smallholder farmers they observed. Farmers were operating at different but distinct levels that defined how they should grow and what kind of support they needed.

Based on this insight, the team produced the Sukuma Transformation Tool. It determines at which level a vegetable farmer currently operates, assesses a farmer's efficiency at that level, and identifies constraints that must be addressed before moving to the next level. The tool combines key factors, such as land area, water availability, the available market, the required technology (e.g., solar pump, truck), labour requirements, input costs, and weather.

The team identified five broad levels of irrigated vegetable operation that can broadly be described as follows:

- At level 1, the farmer is cultivating a small food garden and grows crops for their own survival. Farms are typically 20–100 m^2, and crops are irrigated with buckets or a hosepipe. They typically use 100 –150 litres of water a day and can potentially plant, on average, 200 cabbages every 4 months (the crop used as a measure in the report). The operation requires minimal time investment and no resources, such as transport. The farmer is not in need of any employees, nor do they gain an income from their crops.
- Level 2 is an 'early livelihood' farmer. The cultivated area is 200 – 400 m^2, and at least 600 litres of water is needed per day. The farmer typically relies on a family member for labour. The crops are primarily for sustenance, but this farmer also sells some crops to neighbours, and as such, there is a casual form of marketing involved. Farmers can produce 800 cabbages every 4 months.
- A Level 3 farmer has access to 400 to 600 m^2 of land for crops. This level is called 'livelihood expansion.' At this point, more time is necessary for marketing and sales, and seasonal workers are employed. The farmer spends a full day farming – either in the field or on activities like marketing and sales – and crops are sold at the local, informal market. Profit increases, but so do necessary resources like seasonal workers and transport, even if it is a wheelbarrow. These farmers typically need access to 1 200 litres of water per day to plant around 1 600 cabbages every 4 months.
- Level 4 is the 'early commercial' stage. The farm is 1 200 to 1 500 m^2 large and uses 3 600 litres of water per day, and the farmer employs permanent and seasonal workers. The farmers work full-time, half a day in the garden, and the rest of the time on planning, marketing, managing the farm workers, and selling. The farmer uses a tractor and a plough, and employs a contractor to transport crops to a local commercial market.
- At Level 5, a farmer is seen as 'emerging commercial,' and farms are sized 5 000 m^2 and above. The operation entails irrigation systems, scheduling programmes, and permanent and seasonal workers. Most of the time is spent on planning, compliance, labour management and selling crops at a formal market. They typically require 15 000 litres of water a day to potentially plant 20 000 every 4 months.

It is important to note that at these small scales, profitable farmers are making full use of available resources such as compost, producing their own seedlings and buying only low-cost equipment. It is also important to note that an efficient level 4 farmer can make more profit than a less efficient level 5 farmer, because of the increasing input costs required at level 5. To get to level 5 from level 1, le Roux explains, a farmer must move through all the stages in between – there are no short-cuts. "The mistake," says Dr Hlophe-Ginindza, "is moving a farmer from stage one to stage three without them achieving at least 75% of what is required at stage one and then stage two."

A farmer should not expand hectares before mastering year-round production, for example. One cannot leap from livelihood farming to formal market supply without satisfying the intermediate administrative, labour, and compliance requirements, le Roux says. The same applies to the support provided to small-scale farmers. A level one or two farmer, for example, should not be given a pivot irrigation system meant for commercial farmers, no matter their aspirations.

"It's like giving a primary school student the handbook for a third-year university course," le Roux explains. "They cannot use it until they have completed the grades in between."

The project concluded that failures in Agri-parks often stem from attempts to push farmers from lower levels directly into large-scale commercial farming.

Not every farmer wants to be commercial

Perhaps the most uncomfortable insight emerged from conversations in Rooiwal. Very few small-scale farmers expressed a desire to become large commercial operators, le Roux says.

Some aspired to feed their neighbours. Others wanted to empower women locally. Some sought community cohesion.

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Farmers mostly cultivate vegetables at Rooiwal.

Few were chasing large-scale profit – a prerequisite for surviving in highly competitive commercial markets. Most did not want to deal with the administration required to obtain compliance to sell their produce at formal markets (such as GAP Training).

"The vision to create a commercial farmer out of every small-scale farmer is a problem," says le Roux. "We must stop trying to commercialise everyone."

Only a small percentage, she argues, have both the desire and the capacity to move into formal commercial agriculture. Identifying and supporting that small percentage makes sense. For others, sustainability may lie in remaining at earlier levels and being supported accordingly to optimise effectiveness on each level.

This misalignment of visions has profound consequences. Providing sophisticated irrigation systems to a level-one farmer does not build capacity. It produces demotivation and wastes resources that could have helped another beneficiary.

And importantly, all levels, the researchers stress, are necessary in a decentralised food system. None is inferior.

A mindset shift

The implications extend beyond agriculture. Dr Hlophe-Ginindza argues that technical solutions alone cannot address adoption barriers. Social scientists must form part of research teams from the outset. "You cannot arrive with a solution and expect people to accept it," she says. "People must embrace it. They must want to participate, not because they receive funding, but because the idea resonates."

Without full participation and contextual relevance, technologies are easily disregarded.

With the help of the Sukuma Transformation Tool, the farmers could also assess their current level and identify realistic next steps. For some, it proved an eye-opener to the needs and responsibilities of a commercial farmer. For others, it offered reassurance that remaining at their current level is not failure. "It's not a box to keep someone small," Dr Hlophe-Ginindza says. "It's a roadmap to prevent failure."

A different future

The broader question is whether South Africa is attempting to solve hunger through the wrong model, Dr le Roux asks. Commercial agriculture functions effectively within urbanised, centralised food distribution systems, she explains. It does not necessarily reach remote rural communities where hunger persists. Decentralised small-scale production may be more appropriate in such contexts, but only if supported according to its own logic.

"If the vision is to make everyone commercial, we will not succeed," she says. "We must decide if we are trying to solve hunger, or trying to create commercial farmers. They are not the same goal."

The hope emerging from this research is not dramatic reform, but disciplined progression. Meeting farmers where they are. Supporting each level fully before moving to the next. Aligning vision with reality.

Blue Zones: a visionary experience

During a visit to Hammanskraal, close to the Rooiwal Agri-park, the research team identified what they came to call a Blue Zone homestead. Blue Zones are regions known for exceptional longevity and strong community networks, often centred around small-scale farming and local food systems. Dr Le Roux describes it as a healthy and whole household. "It was beautiful," Dr le Roux says, "with a lush garden abundant with corn, beetroot, and other vegetables." The homestead also had clean and functioning sanitation facilities. The homestead is operating at level 1 according to the Sukuma Transformation Tool, and is managed by a mother and daughter. They told the researchers they enjoyed a good, healthy relationship, and that working together in the food garden helped facilitate it. "They said they were in a good and happy place in their lives," Dr le Roux explains, and they offer a tempting example of how small-scale farming can look like in South Africa.

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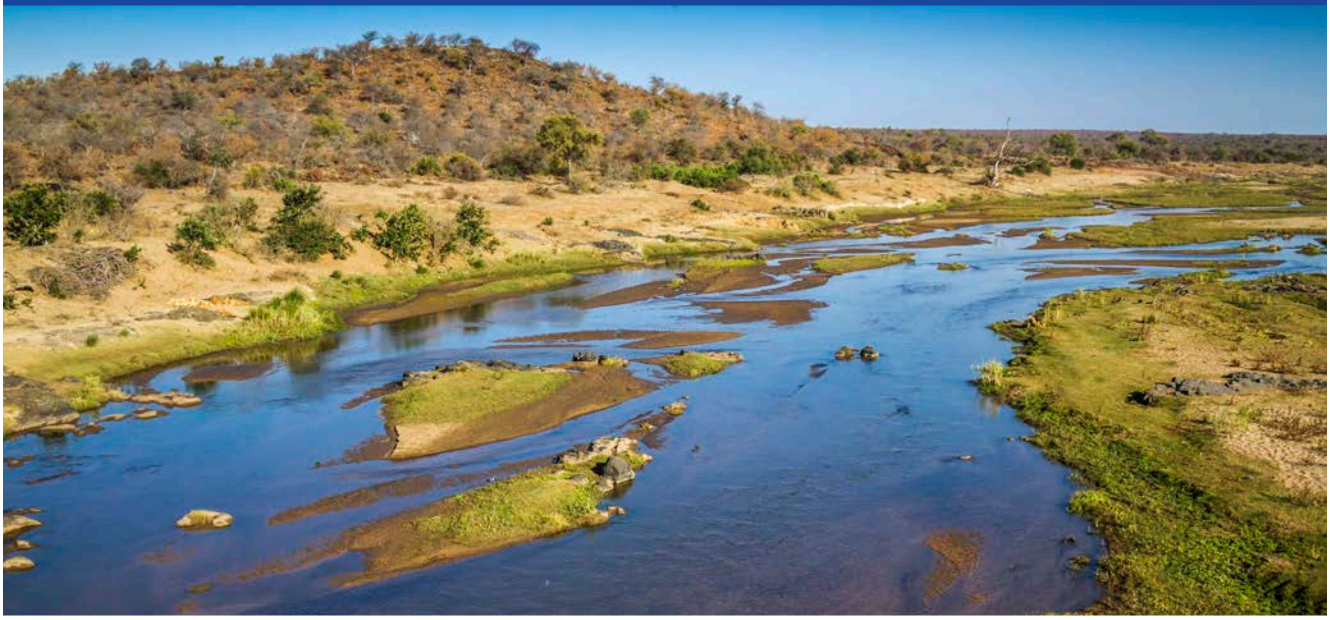
OPINION

Now is the time for us to rally behind South Africa's catchment management agencies

Catchment management agencies (CMAs) were designed to bring decision-making closer to the rivers, communities, and ecosystems they serve, promising more responsive, inclusive, and sustainable water resource management. With all six CMAs finally in place, South Africa stands at a turning point. The question is no longer whether these institutions should exist, but whether they can be supported to succeed. This is according to Dr Roderick Juba, former Senior Knowledge Coordinator at the Water Research Commission.



Chapter 7 of South Africa's National Water Act (NWA, Act No 36 of 1998) provides for the establishment of CMAs with the intention to "***delegate water resource management to the regional or catchment level and to involve local communities, within the framework of the national water resource strategy…***" However, the establishment of these (six) institutions has been slow, leaving a significant vacuum in South Africa's water resource management. As of 2024, all six of the CMAs had been established, but with significant sustainability challenges, as evidenced by the experience gained from the operations of the first two CMAs established more than two decades ago.

Following the establishment of the remaining four CMAs, the country is in a good position to improve the state of its water resources, but it is envisioned that all CMAs will continue to require significant support to effectively perform their mandated functions. South Africa now stands at a pivotal moment in water resource management.

This article argues for patience and strategic support to help CMAs evolve into effective, well-resourced institutions capable of coordinating catchment conservation, curbing resource deterioration, and unlocking global funding opportunities. The next five years are critical, and the sector must rally behind CMAs to give them the best shot at success.

Since the promulgation of the NWA, the establishment of CMAs has been slow and plagued by several hurdles. This prolonged delay in finalising the CMA rollout has held back progress in implementing decentralised water governance and advancing catchmentbased decision-making as envisioned in the Act, with several impacts on water resource management in South Africa articulated as (Munnik, 2020):

- An inability to manage water allocation in light of droughts, current variability and the challenges of climate change.
- Ineffective water allocation reform, and support to resource-poor farmers and land reform.
- Inability to properly license water use, monitor compliance, and act on non-compliance.
- Inability to protect water resources against pollution from dysfunctional wastewater works, mines, industry, and agriculture.
- Inability to engage the public for awareness, and active participation of stakeholders in water resource management.
- Inability to plan strategically and respond to challenges through adaptive management.

As a result, the continued decline in the state of the water resource has been evident, such that many other interested institutions have increased their contribution to its improvement. Prominent roleplayers include water boards and non-governmental organisations (NGOs). NGOs have generally been at the forefront of securing funding (locally and internationally) for specific catchment-level activities and contributing to the collaboration and coordination efforts of such activities. Water Boards are empowered under section 30 of the Water Services Act to "...*perform an activity other than its primary activity*…" and may include (Section 30-2c) "*providing catchment management services to on or behalf of the responsible authorities*".

Other public institutions, such as the South African National Biodiversity Institute (SANBI), are also starting to play a more prominent role in the space through projects focused on water-related ecosystems and their role in enhancing water security. What has been especially positive is the commitment from the City of Cape Town to support catchment management activities through the Greater Cape Town Water Fund, which is managed by The Nature Conservancy. The growing interest from sector partners has resulted in increased investment in catchment-level conservation, with funds that do not necessarily flow through the CMA. Now is the time for improved integration and coordination.

Within these examples lies a collaborative and integrated way forward, anchored by strong institutions. A current study on CMA support networks[1] has already uncovered an extensive network of institutions that are working alongside CMAs. The activities of roleplayers within these networks and the investments already made need to be coordinated at a catchment level to maximise their impact, and this does not necessarily require increased investment. Recent observations from the Breede Olifants water management area (WMA) and the Pongola uMtamvuna WMA suggest that this is as much an issue of coordination as it is about resourcing.

Catchment collaborating platforms have historically been great feedback mechanisms to provide insight into work done by various partners and identify potential priorities. However, these have not always adopted systematic work packages that partners agree to and endeavour to collectively put bulk resources towards. Such a proposed agenda should, ideally, be led by local CMAs as part of such institutional and catchment-based groupings. Thus, while it has been widely accepted that degradation of water-related ecological infrastructure has largely been a result of underinvestment, this is not always the case.

So, what are CMAs established to do?
According to the Act, the initial functions of CMAs are:

- To investigate and advise interested persons on protection, use, development, conservation, management and control of the water resources in its water management area;
- To develop a Catchment Management Strategy;
- To coordinate the related activities of water users and of the water management institutions within its water management area;
- To promote the coordination of its implementation with the implementation of any applicable development plan established in the Water Services Act (Act No. 108 of 1997); and
- To promote community participation in the projection, use, development, conservation, management and control of water resources in its water management area.

The Pricing Strategy for Raw Water Use Charges provides a framework within which raw water tariffs are set to enable CMAs to recover the costs of performing a set of ten water resource management functions within each WMA, as well as through parliamentary appropriation for augmentation. In addition to these sources, CMAs are able to solicit grant funding to increase the amount of resources available to them. However, the latter has historically been under-explored but presents an opportunity for these institutions to increase the resources available to them towards performing their core functions. Through a recently concluded agreement between SANBI and the Breede Olifants CMA (under the Ecological Infrastructure for Water Security project reported on in a special issue of the Water Wheel, https://bit.ly/3RiEXfk), this was recently shown as an intricate but desirable addition to CMA resourcing.

The WRC has been working alongside CMAs to contribute to their continued development towards sustainable and effective organisations. During a CMA-focused discussion at the 2025 AWSISA Africa and Global South Dialogue, stakeholders articulated the following as urgent considerations for improved sustainability of CMAs:

- Shared services across CMAs are essential for improving efficiency, but they must be underpinned by formal agreements between the relevant institutions.
- CMAs need greater visibility to build public trust and reinforce their role as the mandated authorities for Water Resource Management functions.
- Landscape-level partnerships are becoming increasingly valuable, and CMAs should actively strengthen collaboration with other watersector institutions with aligned mandates.
- CMA budgets require additional support, especially in

[1] Synergies Across South Africa's Water Governance Institutions: Strengthening Integrated Management in Water Management Areas; WRC project 2025/2026-01823.

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regions with high levels of indigency, to supplement revenue from wateruse charges.

However, while CMAs play a critical role in the initial stages of the water value chain, the challenges experienced and addressed within this space often go unnoticed due to the popular focus on water service delivery. For instance, unabated pollution of waterways does not get the attention it deserves due to the proliferation of water weeds like water hyacinth and water lettuce. Within-sink responses to this problem show short-term improvements in percentage cover of these aquatic weeds but do not address the core problem of nutrients entering the system.

Urban flooding has received great attention over the last few years, with little consideration for the role of upstream ecological and engineered buffer zones. Similarly, the country's response to drought conditions has not been aggressive enough towards the complete eradication of invasive alien plants from waterways and the rehabilitation of riparian zones.
CMAs need to be empowered to respond to these challenges, and this requires an interrogation of the current modes of operation, funding models, and organisational structure to make these institutions fit-for-purpose. Most importantly, it requires time to figure things out. Through a growing Community of Practice, the challenges identified are being addressed urgently, starting with increasing attention to processes like the development of Catchment Management Strategies, and interrogating the implementation of the new Pricing Strategy for Raw Water Use Charges, including the Waste Discharge Charge System.

CMAs will likely experience significant sustainability challenges for at least the next five years because these are not small issues to deal with. However, with the right sectoral support, effective and sustainable water resource management could be achieved through these critical institutions.

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