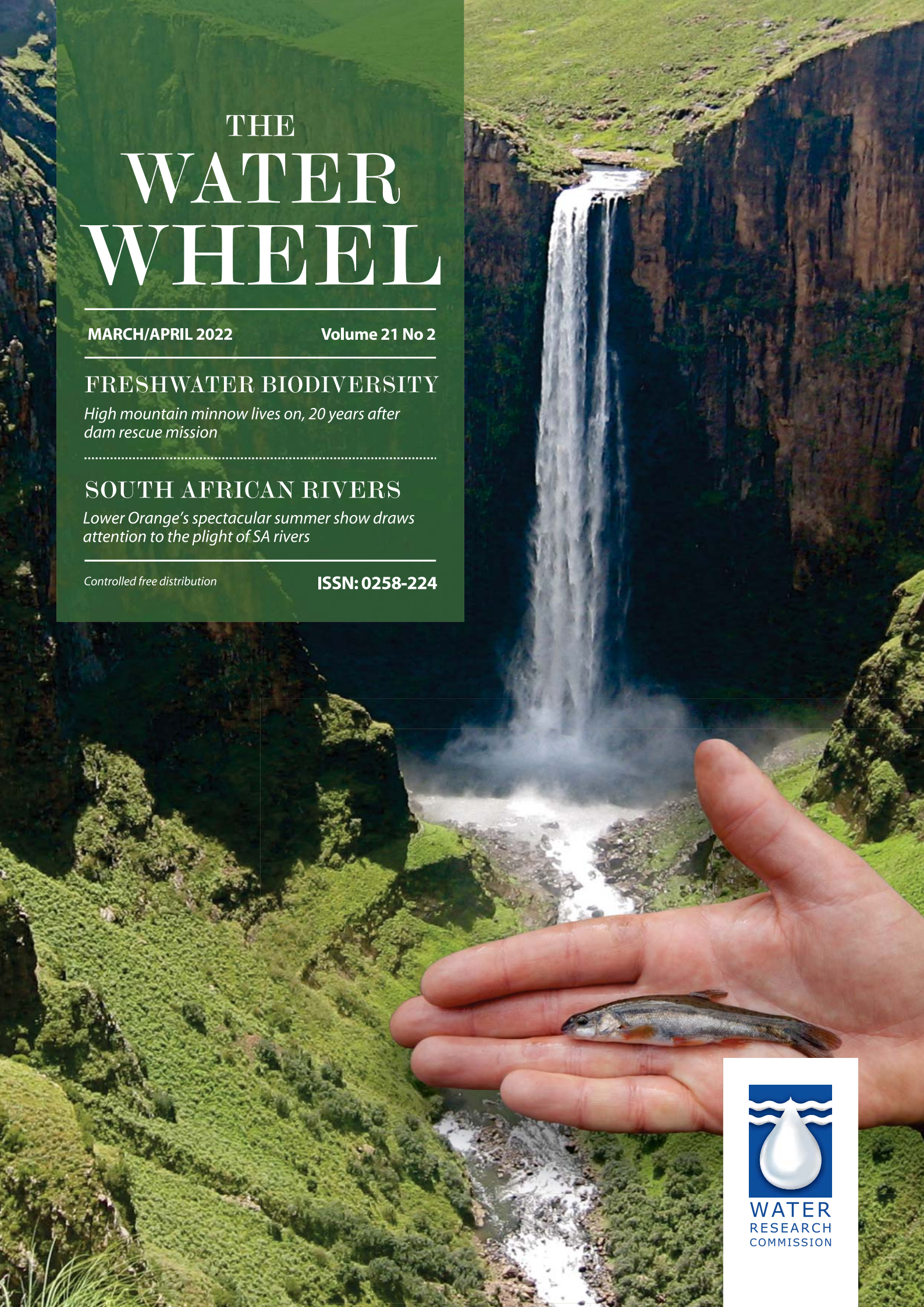

THE WATER WHEEL

MARCH/APRIL 2022 Volume 21 No 2

FRESHWATER BIODIVERSITY

High mountain minnow lives on, 20 years after dam rescue mission

SOUTH AFRICAN RIVERS

Lower Orange's spectacular summer show draws attention to the plight of SA rivers

Controlled free distribution

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WATER RESEARCH COMMISSION

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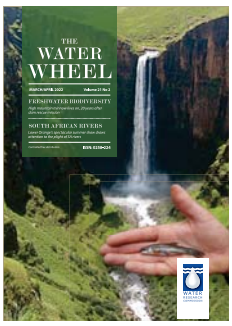

Tony Carnie looks back at the massive effort of aquatic scientists to ensure the future of the Maluti minnow as well as the current status of this iconic Lesotho freshwater fish. See article on page 10.

NEWS

Extracting value from acid mine drainage

The CSIR has developed a zero liquid discharge technology to minimise the ecological footprints of acid mine drainage (AMD). AMD has been a thorny issue in South Africa for many decades and continues to contaminate both freshwater sources and the environment. Acid mine drainage is a direct result of the weathering of sulphide-bearing minerals during and after the mining of valuable minerals, such as coal and gold. These hazardous chemicals have a direct effect on living organisms and the host environment; hence the urgent need to contain and mitigate the risk of contamination.

Conventional technologies to treat AMD often rely on the use of a lime and filtration technology that generated toxic sludge. This has prompted the need to look for alternative technologies with a minimum or zero ecological footprint. The CSIR's quest to find an alternative cleaner technology to curtail the impact of AMD on the environment resulted in the development of a robust treatment technology called magnesite softening reverse osmosis.

The game-changing technology relies on a combination of activated magnesite, softeners and reverse osmosis to recover valuable minerals at different stages of the process. The technology has been tested and validated at a laboratory and a pilot plant with a 20 000 litre per day capacity, located at the CSIR in Pretoria. The plant's robustness has been assessed against effluents that emanate from coal and gold mines.

The CSIR has designed and is at the advanced stage of constructing a modular pilot plant with a capacity of 0.5 million litres per day. This initiative will foster the concept of a circular economy, waste valorisation and beneficiation. Revenue generated from the re-sale of recovered minerals will offset the running costs of the system, making it self-sustainable.

The quality of effluent can be controlled through the installation of reverse osmosis membranes to produce high-grade water. The process has been patented and its efficiency as a means of converting waste streams into an environmentally friendly resource has been demonstrated over five years.

Research and development partners, to date, include Exxaro, one of the largest black-empowered diversified mining companies in South Africa; South32, a globally diversified mining and metals company and the Trans-Caledon Tunnel Authority.

Source: CSIR

Berg estuary joins list of SA Ramsar sites

On World Wetlands Day, 2 February, South Africa celebrated the declaration of its 28th wetland of international importance. The Berg Estuary in the Western Cape was declared as a Ramsar Site under the Convention on Wetlands of International Importance in time for the marking of World Wetlands Day.

"The declaration of South Africa's 28th Ramsar site is an indication of the importance of conserving and protecting these unique environments that are considered super ecosystems because of their contribution to the provision of water and because they provide habitats to a large variety of migratory birds, especially water birds," said the Minister of Forestry, Fisheries and the Environment, Barbara Creecy.

The Berg Estuary, which is one of 290 estuaries in South Africa, is the second wetland of international importance to be declared in the country in two years. In 2021, the Ingula Nature Reserve in the northern Drakensberg was declared the country's 27th Ramsar Site.

Situated at Velddrif, close to St Helena Bay where the Berg River flows into the sea, this estuary spans an area of 1 162 ha. The West Coast fishing village is situated in the Bergrivier Local Municipality.

The Berg River forms one of only four estuaries on the West Coast of southern Africa that always have water. This is in addition to the main estuarine channel which is a floodplain encompassing five major wetland types of importance to 250 species of waterbirds. These are ephemeral pans, commercial saltpans, riparian marshes, saltmarshes (which are the third largest on the Cape coast) and intertidal mudflats.

Although estuaries comprise less than 2% of South Africa's territory, these highly productive ecosystems contribute R4.2 billion per annum to the South African economy. They are focal points for development, tourism and recreation, as well as important for supporting biodiversity, livelihoods and marine fisheries. The Berg Estuary, in particular, contributes about 60% of the estuarine habitat on the West Coast and is therefore extremely important in terms of the biodiversity, cultural and economic activities that it supports.

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SA government still main funder of R&D, survey shows

The Minister of Higher Education, Science and Innovation, Dr Blade Nzimande, has welcomed the increase in government funding for research and development (R&D) activities, but expressed concern at the general decline in R&D funding from other stakeholders, as reflected in the latest national survey.

The results of the 2019/20 National Research and Experimental Development (R&D) Survey released late last year indicates that the main sources of funding for R&D in South Africa are the government (including science councils and university own funds) and business sectors. Whereas government funding of R&D increased by R1,942 billion from the previous year, business funding dropped by R5,175 billion. Funding from abroad, which went mostly to the private sector, increased by R664 million.

The national R&D Survey is undertaken annually by the Centre for Science, Technology and Innovation Indicators (CeSTII) of the Human Sciences Research Council (HSRC) on behalf of the Department of Science and Innovation (DSI), with support from Statistics South Africa (StatsSA).

The latest trends in R&D expenditure show a similar trajectory to that of the economy in general. Gross domestic product (GDP) growth decreased by 1,4 of a percentage point to 0,1% in 2019, after taking into account the revisions due to StatsSA's benchmarking and rebasing of the GDP series to the 2015 year.

Gross domestic expenditure on research and development (GERD) for 2019/20 amounted to R34,485 billion at current rand values. GERD is an aggregated measure of in-house R&D expenditure performed domestically in five institutional sectors, namely government, science councils, higher education institutions, the business sector, and the not-for-profit sector. The medical and health sciences and social sciences are key research areas. The 2019/20 results show the strongest focus of R&D activity to be in the medical and health sciences (21,5%), followed by the social sciences (16,9%) and engineering sciences (13,4%).

The minister requested the DSI, the HSRC-CeSTII and the National Advisory Council on Innovation (NACI) to convene a round-table engagement in February, where key role players including government, business, state-owned entities, universities, science councils and experts could reflect on the survey results and help formulate advice for consideration by Cabinet.

The focus of the round-table was on identifying the measures required to achieve the National Development Plan (NDP) target of raising the level of R&D investment in South Africa to 1,5% of GDP by 2030.

To access the report, Visit: http://www.hsrc.ac.za/uploads/pageContent/1046484/RD_StatisticalReport2019-20_%20WEB.pdf

Innovative sanitation solutions for Gauteng communities

Adequate sanitation remains a challenge especially in South Africa's informal settlements. The Water Research Commission through the South African Sanitation Technology Enterprise Programme (SASTEP) is working with its municipal and innovation partners to introduce next generation sanitation solutions to provide improved, hygienic, and dignified solutions to address sanitation service delivery backlogs, sanitation related – water scarcity issues and new sanitation innovations.

A SASTEP initiative involving Johannesburg Water and two commercial partners, Enviro Options and WEC Projects, was launched during the 2021 World Toilet Day at two informal settlements in Soweto. The Clear Recirculating Toilet System, installed at the Mofolo North informal settlement, uses a full water cycling process for the treatment of sewage. An advanced Biofilm-MBR treatment process is employed as the core technology for treatment, producing a stable and clean effluent that is further disinfected to ensure safety of the effluent for reuse.

The system has been licensed from Clear (Suzhou) Environmental Technologies Co. Ltd and will be manufactured locally by Enviro Options, a leading South African dry sanitation company with over 26 years of experience in manufacturing and supplying safe, off-the-grid, non-sewered sanitation. Enviro Options has successfully completed the transfer of technology and have started local manufacture of units. The installation at Mofolo North informal settlement will service 75 households. The NEWgenerator, installed at Time-house Informal Settlement, Soweto, is a compact, portable, and modular resource recovery machine that eliminates waste while recovering fertilizer nutrients, renewable energy, and clean water. The system uses an anaerobic baffled reactor design followed by a nanomembrane filter operated at subcritical water flux to extend the longevity of the membrane. Permeate from the filter is treated for reuse as flush water by electrochemical chlorine production from table salt. The unit is equipped with solar panels to generate sustainable energy for the operation of the NEWgenerator system. The NEWGenerator is an off-grid sanitation system developed by the University of South Florida (USF) which has been licensed and will be manufactured locally by WEC Projects, a leading provider of engineered solutions in the water and wastewater treatment industry. The installation at Time-house Informal Settlement, Soweto will service 25 households.

Through funding from the Bill & Melinda Gates Foundation (BMGF), SASTEP has supported the capital cost of these two installations as well as the operation and maintenance during the 12-month demonstration period. Post-demonstration, Johannesburg Water will take over the management of the facilities for the informal settlements.

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GLOBAL

Water is essential in the fight against AMR, study concludes

Responsible manufacturing of pharmaceuticals along with the provision of water and sanitation services are key to reducing the spread and impact of antimicrobial resistance.

Antimicrobial resistance (AMR) is one of the world's greatest health threats, according to a recent study published in the ***Lancet***. The analysis, which covered more than 200 countries and territories found an estimated 1.27 million deaths attributed to bacterial AMR in 2019. Nicolai Schaaf who leads the Stockholm International Water Institute's (SIWI's) work on tackling AMR says "To fight antimicrobial resistance, antibiotics manufacturing must prioritise the prevention of pharmaceutical waste polluting water."

SIWI's Responsible Antibiotic Manufacturing Platform (RAMP) was set up to put an end to the unsustainable practices of antibiotics production which is leading to the degradation of both human and environmental health. In a blog Rachael Kupka of the Global Alliance on Health and Pollution, called for a Science Policy Panel on Chemicals, Waste and Pollution which would bring visibility and focused attention to the critical issue of pollution such as water pollution. Tackling one of the key drivers of AMR – emissions from the production of antibiotics – through collaboration will be instrumental to tackling AMR on a global scale.

The World Health Organization warns that AMR could claim 10 million lives per year by 2050, jeopardising the efficiency of the treasure that antibiotics are to human health and a century worth of medical progress. The use and misuse of antibiotics in human health care, livestock and crops are the major drivers of AMR. Pollution from pharmaceutical production must not add to this risk.

"Water plays an essential role in the fight against AMR" says Nicolai Schaaf. "Access to safe water is not only a key determinant for health, reducing the dependency on antibiotics and the vulnerability to AMR. Curbing emissions of antibiotics to waterbodies prevents these from turning into incubators for resistant bacteria."

Dragonflies threatened as wetlands disappear around the world

The destruction of wetlands is driving the decline of dragonflies worldwide, according to the first global assessment of these species in the IUCN Red List of Threatened Species™.

Their decline is symptomatic of the widespread loss of the marshes, swamps and free-flowing rivers they breed in, mostly driven by the expansion of unsustainable agriculture and urbanisation around the world.

The assessment of the world's dragonflies and damselflies reveals that 16% out of 6 016 species are at risk of extinction, as their freshwater breeding grounds increasingly deteriorate. In South and Southeast Asia, more than a quarter of all species are threatened, mostly due to the clearing of wetland and rainforest areas to make room for crops such as palm oil. In Central and South America, the major cause of dragonflies' decline is the clearing of forests for residential and commercial construction. Pesticides, other pollutants and climate change are growing threats to species in every region of the world, and are the greatest threats to dragonflies in North America and Europe.

"Dragonflies are highly sensitive indicators of the state of freshwater ecosystems, and this first global assessment finally reveals the scale of their decline. It also provides an essential baseline we can use to measure the impact of conservation efforts," said Dr Viola Clausnitzer, Co-chair of the IUCN SSC Dragonfly Specialist Group. "To conserve these beautiful insects, it is critical that governments, agriculture and industry consider the protection of wetland ecosystems in development projects, for example by protecting key habitats and dedicating space to urban wetlands."

The Pyrenean desman (***Galemys pyrenaicus***), a semiaquatic mammal and found only in rivers in Andorra, France, Portugal and Spain, has moved from Vulnerable to Endangered. This unusual species is related to moles and has a long, sensitive nose and large webbed feet. It is among the last of its evolutionary line; one of only two remaining desman species in the world. The Pyrenean desman population has declined throughout its range by as much as 50% since 2011, largely due to human impacts on its habitats. Disruption to river flow and reduced water levels as a result of hydropower plant, dam and reservoir construction and water extraction for agriculture make significant areas inhospitable to the desman, isolate populations, and markedly reduce desman prey and shelter. Invasive alien species, illegal fishing using poison, nets and explosives, increasing droughts due to climate change, excavation of riverbeds and banks and water pollution further threaten the desman. Preserving and restoring the natural flow of rivers and surrounding vegetation, controlling invasive alien species and tackling climate change are key for this species to recover.

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AI could boost accuracy of lightning forecasts

Machine learning – computer algorithms that improve themselves without direct programming from humans – can improve lightning forecasts, a new study shows.

Lightning is one of the most destructive forces of nature, but it remains hard to predict. Better lightning forecasts could help to prepare for potential wildfires, improve safety warnings for lightning, and create more accurate long-range climate models.

"The best subjects for machine learning are things that we don't fully understand. And what is something in the atmospheric sciences field that remains poorly understood? Lightning," says Daehyun Kim, an associate professor of atmospheric sciences at the University of Washington. "To our knowledge, our work is the first to demonstrate that machine learning algorithms can work for lightning."

The new technique combines weather forecasts with a machine learning equation based on analyses of past lightning events. The hybrid method, presented at the American Geophysical Union's autumn meeting towards the end of last year, can forecast lightning over the southeastern US two days earlier than the leading existing technique.

"This demonstrates that forecasts of severe weather systems, such as thunderstorms, can be improved by using methods based on machine learning," says Wei-Yi Cheng, who did the work for his University of Washington doctorate in atmospheric sciences. "It encourages the exploration of machine learning methods for other types of severe weather forecasts, such as tornadoes or hailstorms."

Researchers trained the system with lightning data from 2010 to 2016, letting the computer discover relationships between weather variables and lightning bolts. Then they tested the technique on weather from 2017 to 2019, comparing the AI-supported technique and an existing physics-based method, using actual lightning observations to evaluate both.

The new method forecast lightning with the same skill about two days earlier than the leading technique in places, like the southeastern US, that get a lot of lightning. Because the method was trained on the entire US, its performance wasn't as accurate for places where lightning is less common.

The researchers hope to improve their method using more data sources, more weather variables, and more sophisticated techniques. They would like to improve predictions of particular situations like dry lightning, or lightning without rainfall, since these are especially dangerous for wildfires.

The researchers believe their method could also be applied to longer-range projections. Longer-range trends are important partly because lightning affects air chemistry, so predicting lightning leads to better climate models.

"In atmospheric sciences, as in other sciences, some people are still skeptical about the use of machine learning algorithms—because as scientists, we don't trust something we don't understand," Kim says. "I was one of the skeptics, but after seeing the results in this and other studies, I am convinced."

Source: University of Washington

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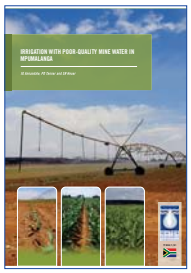
NEW WRC REPORTS

Guidance for attaining regulatory approval of irrigation as a large-scale, sustainable use of mine-water

The beneficial reuse of treated mine-impacted water is not currently a priority in South Africa. Although the discharge of effluent to water resources should be the option of last resort, it is often the first choice of many in the mining industry and industry as a whole, due to its simplicity and low cost. While pollution from mine-impacted water is a significant problem with high costs often associated with treatment, the potential increase in water availability if this water can be used untreated or partially treated for irrigation offers opportunities for making additional water available to supplement traditional water resources. The current regulations surrounding mine closure certification and water use licence applications do not prevent irrigation with mining-impacted water, but there is an absence of guidance to sufficiently inform both mining companies and regulators too make informed decisions regarding irrigation in the post-mining landscape. Guidance for attaining regulatory approval of irrigation. In this light, this project aimed to review the policy and regulatory framework to provide guidance for the establishment of the irrigation of agricultural land as a large-scale, sustainable use of mine water during mine operation and post-closure. The goal is to ensure that this water is viewed as a national agricultural asset for beneficial use, not as problematic wastewater that requires disposal, in an enabling regulatory environment with clear guidelines as to the process to follow in order to get regulatory approvals. The outcome of this project is therefore a comprehensive guideline for the relevant stakeholders engaged in a decision-making process regarding whether a specific mine water source can be applied for irrigation, as well as what ongoing monitoring would be required to maintain the applicable licences and approvals once implemented, considering community and environmental safety.

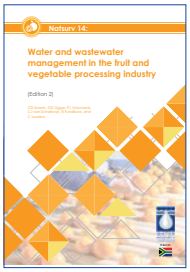
WRC Report no. TT 837/21
Web link: https://bit.ly/3JQQF82



Irrigation with poor-quality mine-water in Mpumalanga

The mining industry in South Africa produces large volumes of mine-impacted water and the agricultural industry requires large water inputs to improve and maximise crop yields. A noteworthy opportunity, therefore, arises for the use of mine water for irrigation, if monitored and correctly managed, to facilitate sustainable mine closure. It could also provide an alternative strategy for operating mines, and for the use of mine water, with or without treatment, depending on the quality. Success with mine water irrigation has been demonstrated in several previous Water Research Commission (WRC) studies. However, this approach to using suitable mine water has not received traction, partly due to the difficulty of authorising such use, which is partially due to a lack of confidence in the viability of this practice. This project evaluates and demonstrates successful irrigation with untreated mine water on a single unmined site, and evaluates issues associated with setting up irrigation on a rehabilitated site. In addition, factors that are likely to affect the success of using untreated acid mine drainage (AMD) and partially treated AMD for irrigation are investigated in depth. The economic viability of mine water irrigation projects is analysed, which leads to the development of a technical guideline to assist mines and regulators to establish irrigation projects using mine-water.

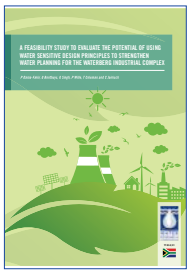
WRC Report no. TT 855/1/21 (main report) and TT 855/2/21 (technical guidelines)
Web link main report: https://bit.ly/3JPII2U
Web link technical guidelines: https://bit.ly/33OZrEh



Natsurv 14: Water and wastewater management in the fruit and vegetable processing industry (Edition 2)

In the 1980s, the Water Research Commission (WRC) and Department of Water and Sanitation (DWS), as it is now known, embarked on a series of national surveys of the water and wastewater management of several industries in South Africa. These so-called 'NATSURV reports' have been well used over the past three decades. However, the South African economy and its industrial sectors have either grown or in some cases shrunk considerably since the 1980s, leading to a changed economic landscape. New technologies and systems have been adopted by some of the industries, meaning that certain information contained in the national surveys can be considered outdated or obsolete. Furthermore, initiatives like the UN CEO mandate, water stewardship initiatives, water allocation and equity dialogues, and others suggest a growing awareness of water use, water security, and wastewater production. In this context, it is now considered an opportune moment to review the water and wastewater management practices of the different industrial sectors surveyed in the NATSURV reports and make firm recommendations on directions for change. This project is a revision and update of one of the NATSURV reports, namely 'NATSURV 14: Water and Wastewater Management in the Fruit and Vegetable Processing Industry'.

WRC Report no. TT 863/21
Web link: https://bit.ly/350i5K1



A feasibility study to evaluate the potential of using water sensitive design principles to strengthen water planning for the Waterberg Industrial Complex

The focus on water management has changed from traditional methods where water supply, water treatment and stormwater management were considered separately, to more integrated approaches taking sustainability into consideration. The

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Water Reconciliation Strategies collated by the Department of Water and Sanitation (DWS) identified various water-stressed catchments in South Africa. The need for optimisation of reuse options, water efficiency and conservation and water demand management are highlighted in several water management studies carried out in South Africa. One such area is the Limpopo Water Management Area (WMA) North which experiences low rainfalls and high evaporation. Applying the principles of WSD holds potential to reduce the risk of water shortage in the area by reducing the need to abstract water from resources while also protecting the area from flash flooding. The present study investigates the potential of implementing the WSD options in the Waterberg District Municipality within the Limpopo WMA considering the existing infrastructure, planned development, institutional arrangements, existing partnerships and taking retrofitting current infrastructure into consideration. The project team incorporated Biomimicry Life's Principles in the approach to water management systems.

WRC Report No. TT 854/21

Web link: https://bit.ly/355wuo8

The dynamics and predictability of rainfall producing systems in the South African domain

Medium-range forecasting (MRF) is an initial value forecasting problem, during which the forecast skill (and therefore predictability of synoptic weather systems) diminishes exponentially by the end of the ten-day cut-off period. This reduction in forecast skill has been attributed to inadequate observations that have errors, imperfect numerical weather prediction model physics and poorly understood dynamical processes that underlie the evolutions of the weather systems. Based on these problems aforementioned, the motivation behind this project was that to improve the predictive forecast skill at this MRF time scale, it is necessary to identify and understand the dynamical processes that precede the weather systems of interest. In the case of this project, the weather systems of interest were the ridging South Atlantic anticyclones and the cut-off low (COL) pressure systems.

WRC Report No. 2829/1/21

Web link: https://bit.ly/3lj1AXG

Pilot-scale semi-passive treatment of ARD – Evaluation of treatment products for downstream use

The project aimed to evaluate, at pilot scale, an integrated semi-passive system for the treatment of acid rock drainage (ARD). Specifically, the system is designed to treat water originating from diffuse sources, such as waste rock dumps, coal discards, tailings impoundments and low-volume discharges. The technology is not aimed at treating high-volume discharges that are actively pumped from underground basins. The project draws on recent research that aimed to address three of the primary constraints that have prevented the more widespread implementation of technologies based on biological sulphate reduction. These are the high cost of the organic electron donor, the retention of biomass within the sulphate reducing unit and the management of the sulphide product.

WRC Report No. 2762/1/21

Web link: https://bit.ly/3taSdTP

A conceptual framework for the costing of deteriorating water quality and identifying mechanisms to better fund water quality management

In 2019, the Institute of Natural Resources (INR) was awarded a research project through a WRC solicited call entitled: "CONCEPT NOTE 10: A Research Framework to accurately determine the financial impact of deteriorating water quality and identify mechanisms to better fund water quality management". This report is the final deliverable in the associated project entitled "A Conceptual Framework for the Costing of Deteriorating Water Quality and Identifying Mechanisms to Better Fund Water Quality Management". The aim of the project was to develop a holistic, but conceptual water-quality costing-framework as a tool to give focus and support to assessing the various costs of deteriorating water quality. The result of this project was the development of a conceptual framework that sets out the landscape of potential costs of deteriorating water quality and costing approaches. The framework guides the user to identify potential costs for a particular context. This information can be used towards identifying suitable water resource management actions and potential economic policy instruments to incentivise and / or fund these actions.

WRC Report no. 2948/1/21

Web link: https://bit.ly/3lmd9gK

Design of acid mine drainage remediation plant

Basic oxygen furnace slag (BOFS) is a final waste material in the steel making process and contains high concentrations of oxides which have the ability to substantially increase the pH and alkalinity of acidic waters. This research investigated AMD treatment or pre-treatment using BOFS by assessing the extent of remediation achieved in a laboratory (1-25 ℓ/day) and pilot scale (200-1000 ℓ/day) system. Another industrial by-product, sugarcane bagasse, was also used in the study to further remediate AMD after the BOFS treatment step and the efficacy of this biological treatment step is also evaluated. The aluminium, calcium, iron, manganese, magnesium and sulphate removal efficiency as well as the pH and alkalinity rise of the system were determined in order to evaluate the effectiveness of the scheme. Dissolution of the BOFS in the system was also assessed to determine the reduction of free oxide content in BOFS that causes volume instability. Following the collection and interpretation of laboratory and pilot scale data, a larger scale design for the process was proposed.

WRC Report no. 2757/1/21

Web link: https://bit.ly/3CPLeD9

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FRESHWATER BIODIVERSITY

High mountain minnow lives on, 20 years after dam rescue mission

The massive Lesotho Highlands Water Project was still in the planning phase when scientists predicted a major threat to a very rare fish species. Racing against the clock, they used off-road motorbikes, horses and mobile fish tanks to move hundreds of the fish out of harm's way. Thanks to their dedication, the Maloti Minnow lives on. Tony Carnie reports.

James McCafferty

Much like tossing a pebble into a pond, the ripple effects of building massive dams and water engineering projects can spread out far and wide. The power of those ripples can be devastating to certain life forms, especially when the project involves storage dams that are big enough to supply the vast Gauteng industrial area, and an artificial channel to link two separate river systems.

That was the situation several decades ago when group of fish scientists saw trouble on the horizon for a very small and rare species of freshwater fish due to the imminent construction of the Lesotho Highlands Water Scheme.

The original scheme involved building five large dams and several tunnel systems to provide electricity for Lesotho and to transfer billions of cubic metres of water to South Africa. Good news for people and industry . . . but the potential death knell for the largest population of the Maloti Minnow ***(Pseudobarbus quathlambae)***, a critically endangered fish species that had adapted to living in several freezing, high mountain river systems in Lesotho.

Dr Johann Rall was one of the South African fish scientists who helped to translocate hundreds of these fish to other rivers as an insurance policy for their survival. He was so worried about their future that he began a captive breeding project to multiply their numbers. As a further safeguard, he also initiated a cryopreservation project to store fish sperm at very low temperatures.

At the time, Rall was a young zoology student at Rand Afrikaans University, where he later completed both his MSc and PhD

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degrees on the ecology and conservation of this globally-unique minnow.

Why was this fish in trouble?
The Maloti minnow (prior to a more recent re-discovery in KwaZulu-Natal) was endemic to Lesotho. On average, the adults grow to a length of about 8 cm – slightly longer than a torch battery – and the majority of the population lived in mountain streams protected by the towering Semonkoangeng Falls.

For millennia, this giant 192 m barrier of vertical stone had prevented alien trout, yellowfish and other indigenous predatory fish from migrating upstream to eat or displace the rare minnows that had evolved over many, many centuries in a unique natural river sanctuary.

While the minnows also faced other threats due to human impacts, the Lesotho Highlands Water Scheme would involve flooding large sections of critical river habitat following construction of the Mohale and Katse dams. Another very significant threat was the new artificial tunnel that would link the Katse and Mohale. This tunnel would effectively bypass the Semonkoaneng Falls and allow predatory fish to eat the upstream minnows once protected naturally by the waterfall.

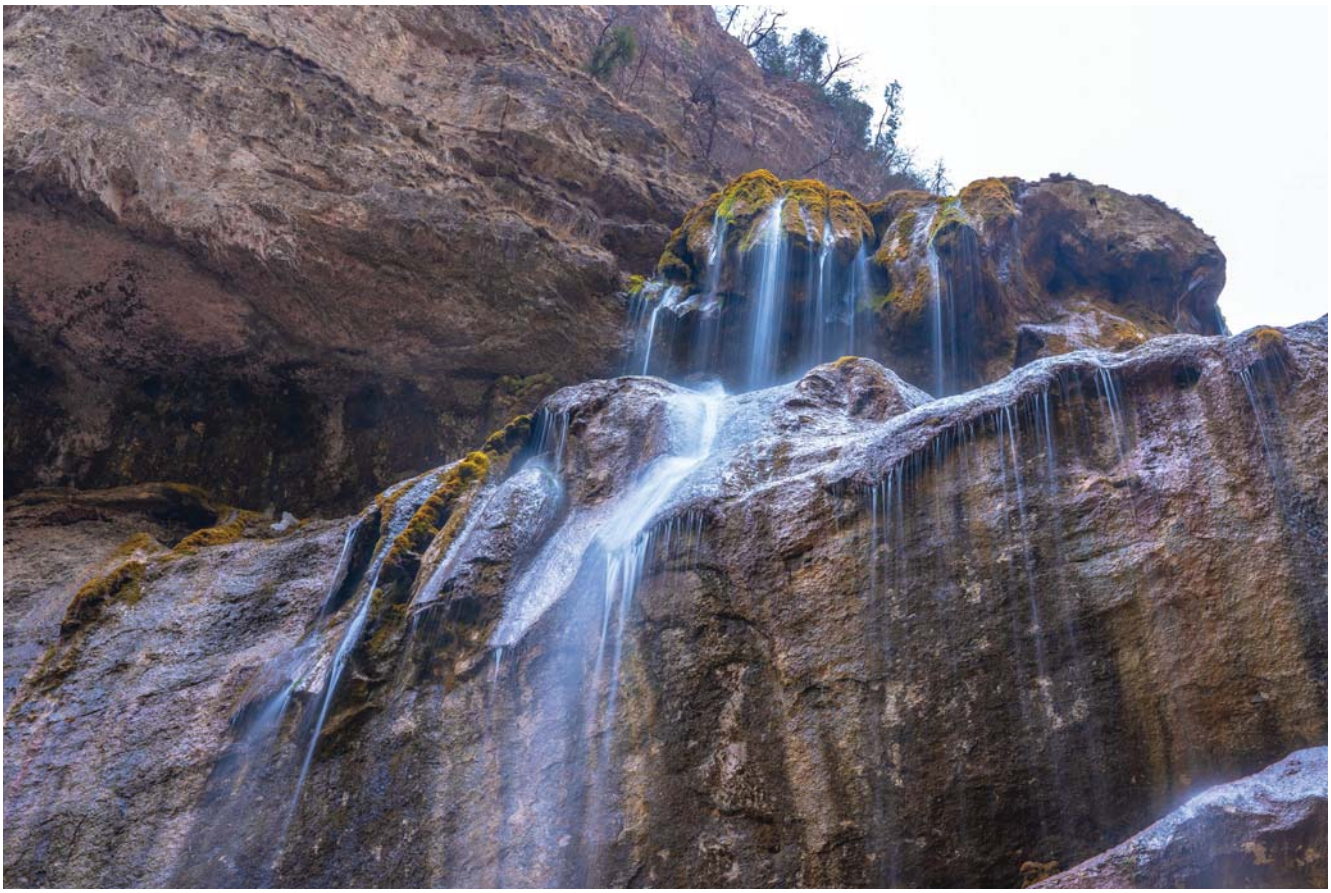
Freshwater fish expert, Prof Paul Skelton, noted that this inter-basin transfer scheme would allow smallmouth yellowfish (***Labeobarbus aeneus***), Orange River mudfish (***Labeo capensis***), rock catfish (***Austroglanis sclateri***) and exotic trout species to migrate upstream. "The Maloti minnow is now a really small fish in a big pond, with other larger, more aggressive fish," he warned at the time.

"My intuition is that that the yellowfish will prey on small minnows, and compete with adults for food and habitat. The mudfish may also compete with the minnows, and could also change the stream habitat by suspending benthic sediments while feeding," he said.

While some minnows were found in other rivers within Lesotho, Rall noted that the Mohale population was a separate, evolutionary significant unit (ESU) compared to minnows in the eastern part of the country. Rall estimated that the Mohale ESU also made up 77% of the total extent of occurrence of the Maloti Minnow and the new Mohale Dam was expected to affect 97% of the Mohale ESU from the introduction of trout and yellowfish if no mitigation measures were put in place.

"Thanks to the efforts of conservationists in the early 2000s – and their foresight – the future is not all that bleak."

So, during 2002/03 Rall and his colleagues sprung into action to translocate insurance populations to at least three distant river systems. Time was tight, the terrain was remote and roads



Lesotho's secluded rivers, fed from mountain streams, have provided a perfect habitat for the Maloti minnow.

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James McCafferty

Nthabiseng Morokole collects fish samples from the Senqunyane River.

rudimentary in many places. But over a period of several months, the team managed to capture and move nearly 1 700 of the tiny fish.

"We collected from the three main rivers (Senqunyane, Bokong and Jorodane) to ensure maximum genetic diversity. We had a 1 000 ℓ water trailer equipped with oxygen cylinders, zeolite and a water pump."

The cylinders were needed to ensure that the fish had enough oxygen to survive a long trip, while the zeolite mineral additives were used to purify ammonia and other organic waste from the temporary fish holding tanks (as captured fish often vomit and defecate due to the collection stress).

The captured minnows were then kept for 24 hours in a "fresh out tank" to ensure the best quality water for the journey to their new homes – trips that could take up to 48 hours.

This was largely due to cold weather and poor terrain, forcing the team to use off-road motorbikes and horses at some points, recalls Rall, who now works in New Zealand as a consultant. Incredibly, none of the captured fish died during the journeys.

A future ensured

Twenty years down the road, the wisdom of translocation has been confirmed by a recent research project led by Dr Jim McCafferty an ichthyologist and freshwater fish consultant with Advance Africa Management Services. Speaking at the annual Conservation Symposium hosted by Ezemvelo KZN Wildlife and other nature conservation groups, McCafferty noted that the minnows still face an "uphill battle for survival".

"But thanks to the efforts of conservationists in the early 2000s – and their foresight – the future is not all that bleak," he said.

James McCafferty

Refiloe Ntsohi, Nthabiseng Morokole, Mpho Baholo and Tseou Terai on a biodiversity unit survey along the Makhaleng River.

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During a recent (2017 - 2019) survey McCafferty and his colleagues revisited the remote rivers to monitor the current status of the translocated fish in the Jorodane, Makhaleng, Maletsunyane, and Quthing Rivers.

A previous survey in 2006 showed that the fish had survived in only three of the four rivers to which they were translocated near 20 years ago. As no follow-up surveys had been undertaken since 2006 it was critical to assess the status of the translocated populations (potentially representing the last remnants of the Mohale ESU).

More recent surveys suggested that while the minnows had disappeared from the Makhaleng and Quthing rivers, they were still alive in parts of the Jorodane and Maletsunyane.

The Maletsuyane population was also at high risk because of its proximity to a recreational trout fishing area. Alien brown trout were currently isolated from the minnows by a small weir, but there were serious risks if trout were to released above the weir.

As a result, the Lesotho Highlands Development Association has developed a conservation action plan which includes proposals for a new zonation plan for those rivers which still host the minnows.

"It is critical that these minnow populations, and activities in the catchment areas, are routinely monitored and managed to prevent the introduction of non-native fishes and to limit poor land-use practices," McCafferty told the symposium.

More recently, however, further research has indicated that minnows are still present in the Quthing and Makhaleng rivers, suggesting that relocations to each of the four rivers may have worked. The conservation project has also been supported by staff from the Lesotho Highlands Development Authority Biodiversity Management Unit survey team.

"They are an incredible group of ladies that I mentored and who have been involved in the surveys throughout," says McCafferty. "They are now responsible for ongoing monitoring of the minnow populations and are immensely passionate about conserving them."

The Katse Dam. While the Lesotho Highlands Water Project has brought much needed water resources to South Africa and income for Lesotho it has not been without its environmental impacts.

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CLIMATE CHANGE

South Africa facing a weather extreme future as world heats up

The severe rainfall experienced over last parts of South Africa at the start of 2022, coupled with unprecedented heat waves in the Western Cape, again placed the consequences of climate change in the spotlight. In 2021, the United Nation's (UN's) Intergovernmental Panel on Climate Change (IPCC) released its most comprehensive assessment of our planet's future. This document informed global climate negotiations in November. Jorisna Bonthuys unpacks some of the findings with regards to water.

The UN's ***Sixth Assessment Report*** (AR6) has been described as a 'code red for humanity'. Climate negotiators grappled with its findings during the UN's recent climate negotiations (COP26) in Glasgow. This landmark study, which will be released in four stages over the next few months, warns of a key temperature limit being broken in just a decade.

The scientists involved say there is serious cause for concern. They foresee the crossing of the 1.5 °C threshold rise in temperature from pre-industrial levels may likely occur in the early 2030s. This latest assessment was compiled by 234 climate scientists who considered 14 000 peer-reviewed studies to inform its content.

The report contains five scenarios based on varying levels of CO_2 and other greenhouse gas emissions. Under the high and very high emissions scenarios outlined in the assessment, global heating is predicted to reach 3.6 °C and 4.4 °C above pre-industrial levels, respectively, by the end of the century. Even in the intermediate scenario, global warming of 2 °C would be extremely likely to be exceeded.

"Earth is warming faster than previously thought, and the window is closing to avoid catastrophic outcomes," says Prof Francois Engelbrecht, a distinguished professor of climatology at the University of Witwatersrand's Global Change Institute. Engelbrecht is one of the lead authors of this report, considered the IPCC's starkest yet.

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"We are getting close to exceeding dangerous thresholds of global warming," he warns. "Unless there are immediate, rapid, and large-scale reductions in greenhouse gas emissions, limiting warming to 1.5 °C (over pre-industrial levels) will also soon be beyond reach."

The IPCC's recent findings should serve as a serious wake-up call for governments and industry sectors, including the water and agricultural sector, as well as disaster risk management, Engelbrecht says.

Changing world, changing realities

It is now indisputable that human activities are causing climate change, making extreme climate events, including droughts and heatwaves, more frequent and severe.

This was highlighted by Dr Pedro Monteiro, the chief oceanographer of the CSIR, during an online media briefing on the topic. Monteiro is another of the South African scientists who participated in the IPCC's process as one of the report's lead authors.

Some of the strongest drying trends that are projected globally are to be found in Southern Africa. As a result, the region is forecast to warm at twice the average global rate.

"This is a region that is projected to become drastically warmer and at the same time generally drier," Engelbrecht says. "'Drastically warmer' applies to the case of low mitigation climate change futures where we reach 3 °C or 4 °C of global warming somewhere in the second half of this century."

Massive change is already underway, and this is expected to have significant impacts on livelihoods, peoples' wellbeing, and ecosystem services. Periods of drought are already projected to occur more frequently at 1.5°C of global warming, and more so as the level of global warming increases.

"That is why our region is considered so vulnerable and why it is regarded as a climate change hotspot — when a dry and warm region becomes warmer and drier, the options for adaptation are greatly limited," Engelbrecht says.

Every bit of warming matters

"With every 0,5 °C of warming, there are clear increases in the intensity and the frequency of a large number of extreme event types," Engelbrecht says. "This means every bit of global warming matters."

Although rapid-onset disasters often have devastating effects, slow-onset climate events, such as droughts, can also be detrimental. The recent multi-year drought conditions in many parts of South Africa are still having a severe impact on the sustainability of many farms, says AgriSA. Many farmers in the Northern Cape, Western Cape, Eastern Cape and Limpopo are still under threat from the continuous drought.

In cities and towns, climate-related challenges such as increased flooding and droughts also pose significant challenges. In recent years, the Western Cape experienced a high frequency of flooding events associated with intense winter frontal systems and cut-off low-pressure systems. Ten significant flooding events occurred from 2003 to 2008, followed by five high-impact flooding events between 2011 and 2014.

Unprecedented climate impacts

Engelbrecht says scientists have already documented examples of unprecedented climate impacts in southern Africa in recent years.

Included on this list is Cape Town's 'Day Zero' situation in 2018 and the devastating effects caused by cyclone Idai in Beira (Mozambique) in 2019. "During the last major El Niño event, we also had a four-year drought that ended in September 2016," Engelbrecht adds. "This particular El Niño was the strongest event of its kind measured yet."

Cape Town came close to a 'Day Zero' scenario during the recent multi-year drought. Dealing with water scarcity during the water crisis threatened a shutdown of the water supply to the city's inhabitants. According to the IPCC report, climate change added to the city's water woes. The frontal systems that bring South Africa its winter rainfall are increasingly being shifted towards the South Pole as the planet warms, leaving cities like Cape Town increasingly vulnerable to drought.

But a potential Day Zero situation where the taps could run dry is not only a problem in Cape Town and its surrounding areas. Engelbrecht considers a potential Day Zero drought for Gauteng as the "single biggest climate risk South Africa faces in the near term" (over the next 10 to 20 years).

"We already came close to such an event in Gauteng in recent years and too few people realise that," Engelbrecht points out. "During that drought, the Vaal Dam, which supplies around 50% of Johannesburg's water, dropped below 25%.

"If you speak to water engineers or people concerned with water quality, for example, colleagues in Rand Water, they will tell you that should the dam's level fall to below 20%, Gauteng's supply is compromised for water quality and engineering reasons in terms of pumping the water uphill towards, for example, Johannesburg."

More agricultural droughts, more heatwaves causing human mortality, and the potential of tropical cyclones making landfall in the region are according to Engelbrecht some of the other major climate-related risks for the region.

Risk of agricultural droughts

There are "clear indications" that southern Africa should expect more droughts in the future, he says. Also, climate change poses a biophysical risk related to heat stress and heat tolerance in cattle and maize production.

"We are faced with serious risks of agricultural and ecological drought in our region," Engelbrecht says. "There is a risk that the maize crop, our staple food in the region, and the cattle industry may completely collapse at 3 °C of global warming, which means about 6 °C of regional warming. But is that the tipping point in terms of the maize crop and the cattle industry perhaps at even smaller levels of global warming? Can we reach that

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Ashraf Hendricks/GroundUp

Residents cross a makeshift bridge in Copa where 63 houses disappeared under mud and rocks brought downstream by Cyclone Idai's torrential rain in 2019. Climate change is expected to bring more intense tropical cyclones to the region.

Did you know?

- The year 2020 was tied with 2016 as the hottest years globally since measurements began.
- The five warmest years in the period 1880-2019 have all occurred since 2014.
- Ten of the hottest years occurred since 2005.
- In 2021, scientists recorded devastating extreme weather and climate events across the globe. A signature of human-induced climate change has been identified in the devastating North American extreme heatwave and the floods in western Europe.
- Based on data until July, the global average mean surface temperature from 2017–2021 (based on data until July) is among the warmest on record, estimated at 1.06 °C to 1.26 °C above pre-industrial (1850–1900) levels.

Source: www.wmo.int; www.naoo.gov

point at 2 °C (of global warming)?
"We must remember that sustainable agriculture is not only affected by the biophysical impacts of heatwaves and drought — it also has socioeconomic aspects. How long can a farmer keep going amid three or four or five years of severe drought before it is no longer sustainable?

"This risk is, of course, substantially more significant for the subsistence farmers, and we still have millions of subsistence farmers in Mozambique, Zimbabwe, Madagascar and South Africa. In a world that becomes drastically warmer with more evaporation, with more of these droughts that we've been seeing in the last decade in South Africa, that risk is increasing," Engelbrecht warns.

"Although we are more aware of this risk for Cape Town and Gqeberha, and all along the Cape south coast, multi-year drought risks are a risk that affects the entire country. Many smaller municipalities can also experience 'Day Zero' type droughts," he says.

For humans, heatwaves pose one of the deadliest climate risks. In June this year, nearly 500 people may have been killed by record-breaking temperatures in British Columbia (Canada's westernmost province) due to an unprecedented heatwave.

"This type of disaster can also happen in South Africa," Engelbrecht warns. "The IPCC's findings are very clear — we can also expect unprecedented heatwaves in our region as global warming continues. Extreme heat is life-threatening when living in informal housing without cooling or access to cool water," he says. Authorities should take the potential effects of heatwaves very seriously."

Tracking tropical cyclones

The fourth climate-related risk that Engelbrecht is concerned about is the possibility of more intense tropical cyclones making landfall in the region. In March 2019, more than 1 300 people lost their lives when the tropical cyclone Idai caused havoc in Mozambique, Zimbabwe and Malawi.

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"The IPCC's report is very clear that increases in intense tropical cyclones can already be detected across the world," Engelbrecht says. "We are, unfortunately, not exempt from such a risk. As the level of global warming increases, the risk for such events also increases. Already over the last two decades or so, we can detect an increase in these types of cyclones.

In the southwest Indian Ocean, the number of intense tropical cyclones are likely to increase in their frequency as we move to increasingly higher levels of global warming.

"Of course, this risk is highest in Mozambique, but these cyclones can certainly extend southwards into southern Mozambique and the northern parts of South Africa. It is even possible that such a cyclone can reach Richards Bay," Engelbrecht adds. "Just imagine the immense impact this could have in terms of loss of life and also on the South African economy."

The second aspect of concern regarding tropical cyclones is that when these systems make landfall over Mozambique or generally across the world, they bring significantly more rainfall than in the past (between 10% to 20% more than before). This is because a warmer atmosphere can hold more moisture than a cooler atmosphere. Tropical cyclone events coincide with flooding, posing planning challenges.

New approaches needed

The IPCC's AR6 assessment shows that limiting global warming to the temperature threshold of 1.5 °C is still possible. This will mean that all countries achieve net-zero emissions within a calculated remaining carbon budget by mid-century.

Some changes could be slowed and others could be stopped by limiting warming "This is important," Monteiro emphasised. "Even though we are committed to centuries to millennia of impacts of our CO_2 emissions and warming, some aspects can actually be reversed."

But even as the world looks to step up efforts to cut greenhouse gas emissions, the need to adapt to the impacts of climate change remains critical.

An important step towards adaptation to future climate change can be to reduce vulnerability and exposure to present climate variability and risk.

"How we have managed water in South Africa over the last 30 or 40 years is, for instance, not sufficient experience to handle the next 30 or 40 years," Engelbrecht says. "Because we will increasingly be challenged by these long-lasting droughts in future, we also have to find ways to improve how to allocate and manage our available water resources.

"Dealing with the risk of increased droughts requires a critical rethink of our water planning en management in the region, especially in urban settings and given the rising competition for limited water resources among users."

Engelbrecht concludes: "The likely decarbonisation of the big industrial economies in response to the 1.5 °C poses a serious economic, financial and social constraint for South Africa. Are we ready?"

An empty Nqweba Dam, outside Graaff-Reinet. The Southern African region is projected to become drastically warmer and at the same time generally drier.

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AGRICULTURAL WATER USE

Growing more with less – helping pecan farmers flourish

Research is underway to quantify the water use and water efficiency of mature pecan trees grown in local conditions and establish the effect of water stress on irrigated orchards. The Water Wheel provides a snapshot of the findings so far. Article by Jorisna Bonthuys.

How much water do mature pecan orchards need to flourish? What happens to the yield and quality of pecan orchards if there is not enough water? How does a pecan tree's water use change with changing environmental conditions and canopy size? And: What is the water use efficiency and water use productivity of pecan trees grown in South Africa?

These are some of the questions being answered in a study currently underway in the Northern Cape. The project is funded by the Water Research Commission (WRC) and the South African Pecan Nut Producers Association (SAPPA) (**WRC Project No. K5/2814/4**). This study is part of ongoing efforts by the WRC to help ensure sustainable water use and agricultural production in key regions.

Dr Nicky Taylor, a researcher in the University of Pretoria's (UP) Department of Plant and Soil Sciences, is the lead researcher involved. She is collaborating with scientists at the Stellenbosch University and the University of KwaZulu-Natal on this project.

Given the added pressures of climate change, population growth and decline in water quality, the need for improved assessments of available water resources and how it is used remain critical. With irrigated agriculture being labelled the largest water user in the country, it is vital to gather accurate data on water used by different irrigated crops.

The demand for research into the water use of horticultural crops, particularly pecan (***Carya illinoinensis)***, has increased in recent years. This is linked to efforts to ensure sustainability in the industry, including in the context of potential water stress in key production areas.

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The backdrop of this research is the growing pressure among water users and indications of future pressures on water availability, including for irrigation purposes. Therefore, producers must implement good water management strategies to sustain production and expand the industry. Producers also need to know if and when they can make water savings during a season without a major impact on yield or quality. During droughts, if less water is available local water boards or catchment management agencies are likely to reduce the amount of water allocated to growers.

"Understanding the water needs of the pecan trees is crucial for farmers and efforts to ensure responsible water use in the sector," Taylor points out. "Irrigation systems must also be designed to meet the maximum daily (water) need during warm and dry periods."

Understanding pecan water requirements

South Africa has a long history of pecan production, which has gradually shifted to the west of the country as the industry matured.

The oldest commercial pecan operation in South Africa was established in 1913 outside Nelspruit (now called Mbombela) in Mpumalanga. Since then, pecan orchards have been established in the Northern Cape, KwaZulu-Natal, Mpumalanga, North West, Gauteng, the Free State, the Eastern Cape and the Western Cape.

Most of South Africa's pecan production now resides in the Northern Cape, specifically around Upington, Prieska, Douglas, and Hartswater. More than 90% of all new plantings are also being established in the country's drier western production region. This region has scab-free growing conditions. Pecan scab is a fungal disease, often causing major headaches for producers.

Currently, South Africa is the world's third-largest pecan producer. In 2021, the annual production of pecans was 19 100 tons (compared to 21 377 tons the previous year). Most of the nuts are exported to Europe and the Far East.

Production is booming, and this trend is expected to continue. This has led to many farmers replacing their cash crops with nut trees in certain areas, including the Vaalharts region. But growing pecans requires long-term planning, including from an irrigation perspective. It takes approximately six to eight years for a tree to start producing nuts and around ten years until a farmer can turn a profit. So, while water requirements are quite low when trees are small, these will increase dramatically as trees mature. Therefore, these and other factors should be taken into consideration by producers.

Pecan trees consume large amounts of water compared to other fruit trees and crops. Yet very little is known about the exact water requirements of mature pecan orchards grown under local conditions. (Till now, most of the research on pecan water use has been done in the United States.) Seeing that most pecan orchards are also irrigated, the need exists to measure and estimate pecan water use under local conditions to ensure the best irrigation practices are followed.

Whilst some research on pecan water use was done in Cullinan (Gauteng), knowledge on the water use of pecans in the hotter production regions of South Africa (Upington and Vaalharts regions) is, for instance, almost non-existent. This could mean that the existing irrigation schedules may be resulting in excessive volumes of water irrigated or water stressing of trees, which impacts yields.

By doing measurements in these regions, the scientists can ensure that their water use model is suitable for all the production regions in South Africa.

Taylor and her collaborators want to determine the actual water use or evapotranspiration of pecan orchards and the factors that drive water loss (including weather conditions and the strategies trees use to combat water loss). Evapotranspiration is the sum of the water lost through plant transpiration and soil and plant evaporation from the surface to the atmosphere. Transpiration refers to the evaporation of water from stomata (the tiny pores found in the epidermis of leaves, stems and other plant organs). This natural evaporative 'cooling system' reduces the temperature of the trees and allows gases such as carbon dioxide, water vapour and oxygen to diffuse into and out of the trees, which is critical for photosynthesis. The scientists focus on two popular cultivars called 'Wichita' and 'Choctaw'.

Photo supplied

Aerial view of the 18-year-old mixed cultivar pecan orchard on the banks of the Orange River between Groblershoop and Grootdrink. Both transpiration and evapotranspiration measurements are conducted in this orchard.

Photo supplied

The infrared gas analyser and 3D sonic anemometer which forms part of an eddy covariance system. These instruments aid in the determination of water vapour and CO_2 fluxes, which when combined with other measurements can be used to estimate evapotranspiration.

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By quantifying water use and yield, they want to establish how many kilograms of nuts are produced per cubic meter of water used in an orchard (defined as water use efficiency). Also, if the quality of the nuts and the price per kilogram are considered, it is possible to determine how much money was earned per cubic meter of water used (defined as water use productivity). "Hopefully, these values will assist growers with a benchmark for achieving optimal water use efficiency," Taylor says. "It will also allow growers to determine how to maximise income with their water allocation."

The team also considers how water stress at different phenological stages (flowering and nut set, nut sizing, nut filling and hardening and shuck split) impacts pecans' yield and quality. This work is being undertaken in Pretoria, on the University of Pretoria's Experimental Farm (Innovation Africa@UP), to ensure good control over the irrigation treatments.

Closing knowledge gaps

The researchers now have three full seasons of measurements of pecan water use in the Vaalharts region and two full seasons of measurements in an orchard close to Groblershoop. They have also finished four seasons of water stress treatments in the orchard on the experimental farm. There will now be one last season of monitoring in all three locations.

To gather water use information, they use different techniques, including quantifying the transpiration of pecan trees using sap flow systems (the heat pulse velocity sap flux density technique) and evapotranspiration with micrometeorological methods. Using sap flow systems involves placing sensors into tree stems and then measuring water flow in plant tissue or xylem, using a short pulse of heat as a tracer.

The experimental set-up includes an automatic weather station erected at each study site, which measures rainfall, solar radiation, temperature and relative humidity, wind speed, and wind direction. In addition, soil water content within the root profile is tracked. Irrigation volumes are determined to assess any possible water stress within the orchards.

Tree physiological measurements (stomatal conductance and leaf water potential) help to assess plant stress. The researchers also consider canopy size to determine the relationship between canopy cover (leaf area) and water use.

In the water stress trial, irrigation for the control is scheduled by assessing changes in soil water content and predawn leaf water potentials (an indication of plant water status). The stress level in each treatment is determined in the same way.

In the 202/21 season, the team started a trial to determine if remote sensing, using a multispectral and thermal camera mounted on a drone, could be used to detect pecan tree stress.

As expected, transpiration and evapotranspiration in the Vaalharts and Groblershoop regions follow a seasonal pattern, with the highest values recorded in summer and the lowest in winter. This reflects the varying weather conditions at the different study sites and that pecan trees are deciduous (meaning they lose their leaves in winter).

Seasonal evapotranspiration (1 September to 30 June) in Vaalharts was 1245 mm for the 2019/20 season and 1103 mm for the following season. During the same season, evapotranspiration in the Groblershoop orchard (1245 mm) was 150 mm higher than in the Vaalharts orchard. This data reflects the slightly hotter conditions in Groblershoop and the slightly bigger trees in this orchard.

Although pecans are considered to use more water than most other fruit tree crops, these values are fairly comparable to evapotranspiration measurements in apple and avocado orchards (both use approximately 1000 mm) in South Africa.

Taylor says this could reflect the big differences in planting densities between the orchards. Planting density in the apple orchards studied varied between 1250 and 1667 trees per hectare, whilst in the avocado orchard, it was 357 trees per hectare. In pecans, it is only 100 trees per hectare. So although individual pecans may use more water than most other fruit trees, water use is not proportionally higher when scaled to a hectare, she says.

The maximum daily transpiration over three seasons for the Wichita trees was 370 litres per tree per day. For the Choctaw trees, the maximum transpiration rate was 425 litres per tree per day.

Typically, transpiration did not increase at the same rate in summer as atmospheric evaporative demand. However, differences in total seasonal transpiration for the two cultivars at the two sites reflected differences in atmospheric evaporative

Photo supplied

The eddy covariance tower in the 15-year-old mixed cultivar pecan orchard outside of Jan Kempdorp, which determines total water use or evapotranspiration of the orchard.

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demand and canopy size. Interestingly, the researchers found that when atmospheric evaporative demand is fairly low, transpiration increases steadily as the atmospheric evaporative demand increases.

As it starts getting hotter and drier, transpiration no longer increases at the same rate and begins to plateau. This suggests that as it gets hotter and drier, the transpiration of pecan trees will remain more or less at the same rate.

The trees may not necessarily require a lot more water in the hotter and drier regions. This results from stomata starting to close under these conditions, which limits water loss. Taylor says this finding will be significant to consider in future modelling approaches.

When comparing pecan water use efficiency and water use productivity to other fruit crops, water use efficiency for pecans was generally lower than most other crops, including other oil storing crops such as avocado and macadamia. The researchers attribute this to lower yield and higher water use. In addition, the price per kilogram of pecans is slightly lower than for macadamias. However, pecans compared very favourably when comparing water use productivity (R m^{-3}) with other crops grown in the Vaalharts region. In most instances, it resulted in higher income per unit of water used by the crop.

Taylor says they have a good data set for understanding the impact of water stress on the yield and quality of pecan orchards.

She says it is essential to assess the impact of water stress across a number of seasons due to the alternate bearing nature of pecan trees. This is when trees bear a good crop in one year, referred to as an 'on' year and in the next year, some trees will have a much lower yield, referred to as an 'off' year.

Water stress at various phenological stages decreased yield and/or quality. During the trial, water stress during flowering and nut set generally reduced yield due to an increase in nut drop shortly after nut set.

Whilst yield was not decreased during the nut sizing stage, nut size was generally smaller in this treatment, which would reduce the overall quality of these nuts and, therefore, the price fetched per kilogram. Water stress had the most profound effect on yield and quality when implemented during nut filling. A large percentage of nuts failed to fill properly. These nuts are referred to as 'pops'. In two seasons, water stress during shuck dehiscence resulted in an increased percentage of stick-tights (dry, mature nuts in husks that stay attached to the tree and do not fall naturally).

According to the results, producers should avoid tree water stress as much as possible during flowering, nut set, and nut filling. This includes avoiding prolonged water deficits during this time and no over-irrigation, which causes waterlogging in orchards.

In years where farmers' water allocations are reduced, it may be possible to reduce irrigation during nut sizing and shuck dehiscence to make water savings without significantly impacting yield and quality.

Photo supplied

Sap flow sensors inserted at various depths into the trunk of a 'Choctaw' pecan tree in the orchard outside of Jan Kempdorp. These sensors determine the rate at which sap moves in the xylem and from this the rate of transpiration of a tree can be determined.

"Our understanding of the water use of pecan orchards and their response to water stress is improving," Taylor indicates. "In the next year, we should be able to produce a more robust water use model which applies to a wider range of growing regions in the country."

During the last year of the project, the focus will be on improving canopy size measurements at remote study sites. This will involve efforts to refine the parameters of a radiation interception model for pecan orchards. In addition, the team wants to improve their understanding of the physiological control transpiration by the trees and continue using remote sensing to detect the onset of water stress in the trees.

The study continues till March 2023.

Average in shell yield for the different stress treatments in the 2017/18 season, 2018/19, 2019/20 and 2020/21 seasons. Yield was adjusted to 4% moisture content. Treatments with the same letter are not significantly different from each other ($p < 0.05$).

	Yield (t ha^{-1})			
Treatment	2017/18	2018/19	2019/20	2020/21
Control	1.70a	1.53a	2.70a	0.67a
Flowering and nut set	0.89b	1.03b	2.80ab	0.43a
Nut sizing	1.37ab	1.42a	3.22a	0.83a
Nut filling	1.05b	1.16ab	2.24b	0.70a
Shuck dehiscence	1.66a	1.44a	3.09a	0.51a

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ECOLOGICAL INFRASTRUCTURE

(Re)connecting fish, rivers and people in the Kruger National Park

Many migratory fish species are swimming upstream in the ongoing race for their survival. The Water Wheel reports about efforts that are underway in the Kruger National Park to connect fish, rivers and people through the restoration of ecological infrastructure. Article by Jorisna Bonthuys.

Globally, migratory freshwater fish have been declining since 1970 throughout their distribution ranges at a staggering rate. Many species are now exposed to threats such as habitat change, climate change and pollution. A recent study found that populations of migratory freshwater fish have declined by 76% globally since 1970, with an even greater decline in Europe: a staggering 94%.

Experts indicate that this could be directly attributed to river fragmentation. Human-made impoundments are also creating problems. Artificial barriers, like dams and weirs, are one of the biggest threats to river ecosystems. They stop the natural flow of sediments and prevent migratory fishes from travelling up- or downstream to complete their lifecycles.

Many of these concrete and earth barriers that block fish migration routes were constructed in the last century and are nearing the end of their concession, with increasing calls for their removal. This global movement towards re-establishing free-flowing rivers is also underway in South Africa's flagship nature reserve – the Kruger National Park (KNP).

Rivers in a sea of dams

The KNP is known internationally as a 'hotspot' for aquatic

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biodiversity. It is home to 46 fish species, of which more than 20 are considered long-distance migratory species. The park has 600 km of perennial river systems and 30 000 km of seasonal and ephemeral streams (dry stream beds that flow as rivers or streams after rainfall periods). These waterways are crucial for maintaining biodiversity in the area. The benefits of these waterways extend beyond South Africa's borders, notes South African National Parks (SanParks) scientist: aquatic ecology, Robin Petersen.

Many rivers in the park are transboundary waterways that extend into neighbouring Mozambique, Botswana and Zimbabwe. In the Zambezian Lowveld eco-region, which covers most of the park, 22 fish taxa are long-distance migratory species that can travel more than 100 km. These migratory fish face several human-induced threats and physical barriers, such as dams and weirs, during their lifecycles.

In the KNP, conservation authorities are rolling out plans to do away with the unintended environmental consequences of decades of building a network of dams in the park. Between 1930 and 1990, the park established the artificial water-for-game programme where boreholes, troughs and concrete reservoirs and dams (concrete and earthen) were constructed to improve water availability and distribution across the park.

In 1931, the first concrete dam was constructed in the park. Since then, 53 concrete and earthen structures have been constructed along various watercourses in the KNP. With hindsight and the accumulation of knowledge through research, conservation authorities realised that this (historic dam building in the park) has led to ecological problems and landscape degradation. These barriers disrupt the natural river flow and migration patterns, especially breeding fish and aquatic system processes.

In some cases, the provision of artificial water storage has also been to the detriment of rare herbivore species such as roan and sable antelope because of ongoing competition from other species and an increased predation pressure due to large concentrations of prey species around water. Other ecological consequences include serious erosion of dongas on sensitive soil, changes in grass and woody vegetation cover and species composition and an overall decline in biodiversity.

KNP's conservation units assist these ecological consequences in line with SANParks biodiversity values for managing the natural functioning of ecosystems in terms of landscape processes. They use a 'systems approach' rather than an 'issues-based' or 'species-based approach'. A systems-based approach necessitates flexibility and adaptation in conservation planning and management instead of specific issues and species.

Efforts are now underway to remove selected redundant and obsolete dams and weirs in the park and establish completely free-flowing catchments in the area.

"We want to ensure a near-complete free-flowing river situation within the KNP by removing some of these artificial structures," says Petersen. He adds that such free-flowing rivers provide many ecosystem services, including water purification and the delivery of nutrients and food. These rivers are also critical for the life history of migratory fish species that depend on river connectivity to access habitats necessary to complete their lifecycle.

A total of 21 dam structures have already been demolished in

A grey heron at Sunset Dam with its morning catch. The Kruger National Park's rivers are considered a 'hotspot' for freshwater fish biodiversity in South Africa.

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Images supplied

The Kanniedood Dam before, during and after demolition in 2018/19. The dam was removed completely after the wall was breached by flood in 2013, causing the river to open a new channel bypassing the dam wall on the southern bank of the Shingwedzi River.

the KNP, including the Kanniedood Dam and the Mingerhout Dam, situated in the Shingwedzi and Letaba catchment areas. This has been undertaken in collaboration with the South African Defence Force (SANDF), which volunteered to assist with the removal of these structures.

To ensure the rivers or streams are returned to their most natural state, the Expanded Public Works Programme (EPWP) helps to rehabilitate the site by removing and reusing rubble. Thus, these projects also allow for much-needed job creation opportunities for neighbouring communities and artisan training. The beneficiaries are contracted to clear the site by hand, where rubble is sorted and then recycled for use in other projects such as stabilising gullies and landfilling in the park. This creates value-add for the rehabilitation effort.

These efforts also provide data that will inform further river restoration efforts in the region. The Kanniedood Dam has, for instance, had major ecological and physical effects on the river system. Petersen notes that fish species richness declined in the Shingwedzi River following the construction of the dam. "In 1988, 11 years after the dam was completed, 19 fish species were no longer to be found downstream. A total of 13 species were absent upstream."

Spotlight on the Letaba River

The Letaba River is one of five major rivers that flow throughout the year and forms part of the larger Olifants River system within the transboundary Limpopo River Basin. The river is also a vital hotspot for aquatic species, including more than 30 fish species.

Historically, the river was also affected by the historical water-for-game interventions. Park authorities constructed a series of broad, shallow impoundments along its watercourse within the KNP. Some of these had already been breached due to flood damages, for instance, at Shimuwini in 2001.

Several human-induced threats and physical barriers such as dams and weirs along the river negatively impact migratory fish during their lifecycles. More recently, protracted dry conditions following the drought of 2015/16 have been a significant challenge to sustain the river's flow through the park.

Whilst the river's Water User Association and the Department of Water and Sanitation have made a concerted effort to mitigate the impact of these dry conditions to meet environmental water requirements (a set of legal minimum flows for ecosystem services, under South Africa's National Water Act) the Letaba River remains a rather stressed river.

The KNP's team re-prioritised removing some of these structures that still exist in this river due to continued drought stress and restoring the aquatic connectivity of the system. This is so that the fish and other aquatic organisms can respond to environmental cues, especially in small early-season floods, which enable the spawning movement of fish. Some of the species in the river are of conservation concern.

Studies are underway to determine the ecological benefits of removing redundant dams and barriers on river connectivity, natural flow regimes, sediment and nutrient dynamics, and the possible re-colonisation of locally extinct species in this river. In collaboration with researchers from the University of Mpumalanga, SANParks scientists monitored the ecological impacts of this dam's removal to inform management actions.

Their findings confirmed suspicions that the dam was creating a disconnect in the river due to temperature changes upstream and downstream, affecting the natural cues for movement of tigerfish downstream in winter due to cooler waters in the system upstream. The researchers also spotted differences in species composition upstream and downstream of the dam, with only four species present upstream and 12 downstream of the structure.

As a result, the Mingerhout Dam was successfully removed in March 2021, albeit during extreme weather conditions

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experienced during Cyclone Eloise.

Ecologists hope that the fish species composition will increase in the dam site's reaches upstream. In the process, the river's connectivity will be improved. Any changes will be tracked and documented as part of long-term monitoring efforts. "This is only the beginning of understanding the long-term changes for the betterment of the KNP ecosystem and the river system more broadly for those that depend on them downstream," Petersen says.

When dam removals are not an option, Petersen says fishways offer an alternative to improve river connectivity. Fish ladders (or fishways) enable fish to migrate beyond obstructions such as dams. Most fishways enable fish to pass around the barriers by swimming and leaping up a series of relatively low steps into the waters on the other side. There are now 16 fishways in the park, including the Engelhardt fishway along the Letaba River. These structures were built in the 1960s and 1970s. Many of them are not considered effective anymore.

Meanwhile, the new natural water distribution work in the KNP is yielding benefits for the ecosystem and abundant biodiversity it contains within the savanna landscape and its river systems.

Promoting river connectivity

The lack of consideration of river connectivity and fish migration management are shortcomings of the existing management approach for dealing with multiple freshwater stressors. This view was expressed by Dr Gordon O'Brien, an aquatic ecologist at the University of Mpumalanga's School of Biology and Environmental Sciences, during a recent online symposium.

In South Africa, legislation has established resource-directed measures to attain a sustainable balance between the use and protection of water resources. These procedures have been implemented in most of the country's nine water-management areas, resulting in new legislation to protect these resources. But, unfortunately, very little protection has been afforded to river connectivity maintenance and fish migrations, O'Brien pointed out.

Changes in land cover have resulted in the majority of all river types in South Africa now occurring in a threatened or unsustainable ecological state. In addition, many of the main-stem rivers are now also classified as being severely modified or critically endangered.

Water resources of the Upper, Middle and Lower Vaal, Olifants, Crocodile West, Limpopo, Luvuvhu and Letaba, Mvoti to Umzimkulu, Berg and Olifants–Doorn WMAs are, for instance, all heavily used and, as a result, highly threatened.

Images supplied

Rehabilitation underway following the demolition of the Kanniedood Dam.

A free-flowing river occurs where natural aquatic ecosystem functions and services are largely unaffected by changes to connectivity and flows, allowing an unobstructed exchange of material, species and energy within the river system and its surrounding landscapes.

The growing demand for domestic, mining, agricultural and industrial water in the upper and middle reaches of the Olifants River have, for instance, progressively reduced flows in the river's lower reaches in the park. In addition, surface flows have ceased for short periods during recent dry spells.

There are still many challenges with human-made barriers to promote river connectivity and fish migration. For water storage and flow regulation for agriculture and other resource use activities, 610 formal dams and 1 430 gauging weirs have been constructed as partial or complete barriers to fish migration on river ecosystems in South Africa. Only 60 fish passage structures have been built, but many are not functional.

Decision-makers should elevate river connectivity and fish migration management practices, O'Brien highlighted. This can contribute to the sustainable use of water resources and ensure the resilience of fish populations in the region. More research is also needed to ensure science-based decision-making and natural resource management, he emphasised.

**Additional information for this article supplied by members of SANPark's freshwater research and conservation management team.*
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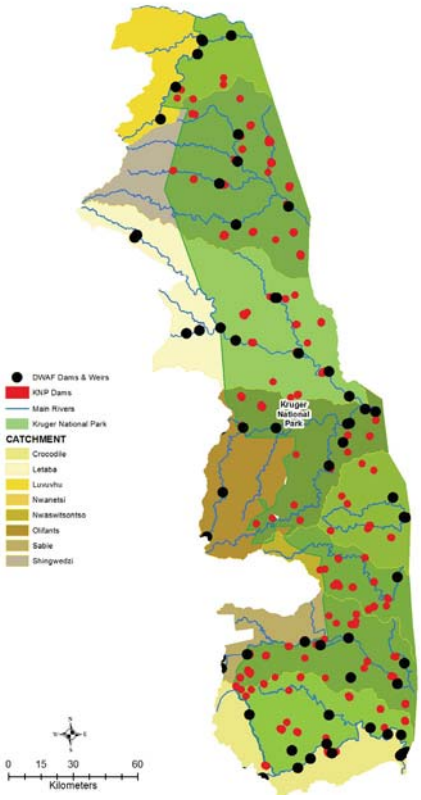

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Decades of dam building have left concrete and earthen structures scattered all through the Kruger National Park.

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THE WATER WHEEL

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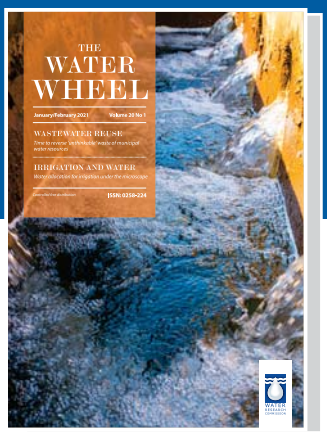

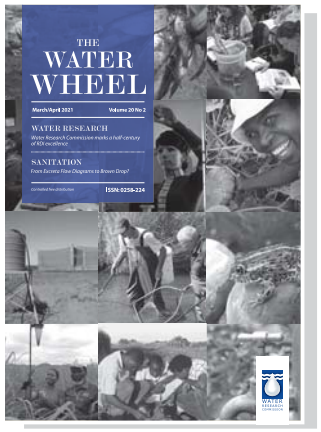

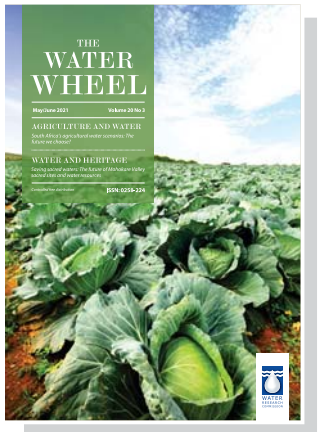

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SOUTH AFRICAN RIVERS

Lower Orange's spectacular summer show draws attention to the plight of SA rivers

The Orange is a behemoth on any day but, this year, egged on by a second consecutive robust summer rainfall season in the catchment, the river's lower reaches roared into epic proportions. This, 2022, was the first year since 1988 that the river's flow reached over 3 000 cubic meters per second (cumecs) as it thundered over the enigmatic Augrabies Falls. The spectacle drew thousands of people to enjoy the show that Mother Nature put on but, the flow of the river today is as much a result of large-scale human engineering and activities, as it is of rainfall and climate. Petro Kotzé reports.

Hanno Langenhoven

According to a study published in ***Nature*** in 2019, only 37% of rivers longer than 1 000 kilometers remain free-flowing over their entire length, and only 23% flow uninterrupted to the ocean. Very long free-flowing rivers are today largely restricted to remote regions of the Arctic, the Amazon, and the Congo basins.

Intensely managed rivers like the Orange have become pillars of development in the vast tracts of land that they run through, and their management entails a balancing act of the needs of a large number and variety of users that depend on the river's water. As a result, and ironically for a country like South Africa so intimately associated with drought, high levels of flow in the Orange do not only bring blessings anymore. There are prices to pay too, as this summer rainfall season has shown. The mechanics behind the water that becomes both gift and curse as it traverses more than 2 000 km over the country, start in Lesotho.

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The birth, and taming, of the Orange River

The source of the Orange River is officially recognised as the Senqu River, which rises on the Lesotho Highlands, about 3 300 metres above sea level. Although only about 3% of the Orange River Basin lies in Lesotho, the high mean annual rainfall in this comparatively tiny area contributes much of the Orange River's annual flow (figures vary from 40% to 60%). The contribution is astounding, taking in mind that the drainage basin of the Orange (together with its main tributary, the Vaal) is at least 855 000 m^2 in size.

As the river enters South Africa it flows south and west through open country and erodes in a broad valley almost 50 km wide and 300 m deep. The Caledon River joins as a tributary at what is now the head of the Gariep Dam, the largest storage reservoir in South Africa and the main storage structure on the Orange River. From here, water is supplied in two directions, southwards through the Orange-Fish tunnel to the Eastern Cape, and westwards, down the river to the Vanderkloof Dam. The river then swings northwest and is joined, at Douglas, by the Vaal River on which the Bloemhof and Vaal dams are main storage facilities.

The rainfall in the catchment of the upper Orange, and the management of dam sluices impact flow in the lower reaches of the river. In general, annual rainfall decreases as the river runs west, as temperatures (and evaporation) increases. This past December, on the back of a second La Niña event in two years, the South African Weather Service announced that the mid-summer season started off with above-normal rainfall over almost the entire country, which continued into January.

Serious rains arrived a little earlier than usual, and dams, especially Bloemhof, filled up and spilled in early December, as was expected, says Sputnik Ratau, media liaison for the Department of Water and Sanitation. Bloemhof Dam filled up on 8 December and rose to 110% but the level was reduced to below 104% through controlled releases ensuring that the flow downstream was not excessive, he reports. The highest average inflow into Bloemhof Dam this season so far occurred on 22 January, when it was about 2300 cumecs, a recurrence of about one in five years.

Ratau says the decision to open or close sluice gates is made on a balance of factors. "Ensuring the safety of the water infrastructure, that of communities downstream, and the need to ensure that the reservoirs are full (if they were likely to be) at the end of the rainfall season are the key objectives of our flood control operations." The decision on how much water to release from the dams, and when to do so, safely, without causing avoidable damage downstream, Ratau explains, is based on data from continuous real-time monitoring of river flow and dam levels that enables the calculation of the quantities and timing of inflow into the dams and the likely capacity increase.

Ratau adds that some dams, including the Vaal and Bloemhof, have additional capacity above full supply level for limited flood control. This extra capacity (even the entire reservoir capacity) is, however, still too small to store all the water produced by most flood events.

Still, though limited, this flood storage capacity can contain floods somewhat, as water can be released during significantly lower flow levels, delaying flow peaks to enable the evacuation of people and movable property. "This season, water was held in the Vaal Dam and Bloemhof Dam to ensure that it did not combine with about 2 000 cumecs outflow from Vanderkloof Dam (which has an uncontrolled spillway) and form a bigger flood in the Lower Orange. This ensured that the flow did not go much higher than 4 000 cumecs, which would have been the case otherwise." As the department cannot manage all risks with the available infrastructure, it also depends on legislation, early warnings, insurance, awareness, and preparedness to minimise impacts.

The highest flow this summer rainfall season (at the time of print) along the lower Orange was close to Prieska, below the dams, where the river bends sharply northwest. The flow at the Katlani, Prieska, and Upington gauging stations reached 3 800 cumecs, Ratau notes, a level with a return period of about 1 in 10 years. Water levels of this caliber are felt keenly by the surrounding agricultural community.

Flood in the lower Orange

The lower Orange River region, from around Groblershoop towards Upington is known for, among other crops, its sweet

SANParks

The Augrabies Falls put up a spectacular show when flow in the river reached record highs earlier this year.

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Hanno Langenhoven

The Orange River in flood remains a sight close to South Africans' hearts.

grapes. This year's high flows saw a number of negative impacts on producers being reported on. These include overflowed drainage slopes and vineyards (blocks), at times, "knee-deep" in water. The conditions are conducive to diseases like downy mildew and white rust that led to fruit rot and, over and above that, it was reported that farmers could not reach some of the vineyards to apply pesticides. The vines can take up to two years to recover from the stress and produce optimally again. On the flipside, famers that decided to harvest earlier based on weather forecasts, will pay in the form of lower sugar content and lighter tonnage.

Onwards, about 30 km from Kakamas the river enters the Augrabies Falls National Park and tumbles down the iconic falls that the protected area is named after. Here, the increased flow has been welcomed with open arms. By and large, the impact on the park has been positive, says Genevieve Maasdorp, Communications Manager for the SANParks Arid Region, and, in some cases, even spectacular.

NASA/Flickr

For much of its lower reaches, the Orange River is a life-giving artery in an otherwise arid landscape.

Augrabies Falls – the place of great noise

Normally, visitors that enter the protected area through the main gate will not be aware that a river is flowing almost parallel with the entrance road but, during high flows as experienced this year, the broad river can be seen from the gate all the way to the rest camp. The noise of the gushing water is "tremendously loud" Maasdorp says and, together with the high levels of humidity, creates a very strange experience in the arid environment.

The park itself is actually in the grips of harsh, long-term drought, notes Maasdorp, and the surrounding parched veld is in strong contrast to the millions of litres of water that have flowed down the river and stormed over the series of rapids to plunge into the deep pool at the start of the near vertical-sided 20 km gorge.

The park's long-term average rainfall is only 125 mm per annum, and it decreased over a ten-year period from 125 mm to only 41 mm per annum in 2020, with the exception of a slight increase in 2012/13. In contrast, for the past two years, the river logged particularly high January flows. In January 2021 the flow was at 1 018.40 cumecs and, this year, 2 557cumecs. In comparison, the average flow for the five years from 2016 to 2020 was only 79.16 cumecs.

The highest flow on record was in 1974 at just over 8 000 cumecs, followed by 7 800 cumecs in 1988. At the time, the floods cut the park off for at least three weeks as the bridge outside the main gate was washed away. Since 1988, the Orange River flow here only topped 3 000 cumecs twice; in 2011 when

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flow reached 4 776 cumecs and, this year, when flow reached 3 566 cumecs.

Once the numerous falls on the northern bank start tumbling down together with the main falls, Maasdorp says it creates immense amounts of spray. This year, the column of spray could be seen from the Augrabies town 15 km away. The spray lasted so long park management had to close a large lookout deck at the falls, which became green and slippery from being continuously doused in water. Spray and wind rose up with such force at the deck people couldn't look down with their eyes open.

When news starts to break that the Augrabies Falls is putting up a show, tourists flock to the park. From April 2019 to March 2020 when there was no exceptionally high flow, tourist numbers were 55 375. The following year (April 2020 to March 2021, when flow increased), 72 601 people visited. From April 2021 until mid-February 2022, over 87 000 people have visited the park (mostly South African citizens). The financial benefit to the park extends to the surrounding tourist accommodation facilities, which have benefited greatly from the overflow, Maasdorp says. More benefits have become the form of media and social media coverage – "very positive marketing that really puts the park on the map."

However, it's not all a proverbial walk in the park. Staff are pushed to the limit, and volunteers from the SANParks Honorary Rangers have to help with law enforcement duties. From about 2 600 cumecs, certain areas, including the day visitor area, have to be closed. The game area becomes inaccessible for sedan vehicles and the staff village is cut off from the shortest route to the reception area, adding time, kilometers, and fuel to expenses. Another major impact, Maasdorp notes, is the increased volume of waste left behind by tourists. Boundary fences that end in the river are also damaged.

From about 3 100 cumecs the lower viewing decks have to be closed too. Management of water supply and infrastructure becomes crucial and "very time consuming". The park pump needs to be extracted every day, and rising water levels monitored constantly. When the flow reaches 3 500 cumecs, the pump is approximately 150 metres from its original position. During such high flows, the rest camp is also packed with tourists so water is used much more quickly and, as a result, does not have enough time to settle in the filters, resulting in discolouration.

The ideal is a peak at 2 500 cumecs, Maasdorp says, when the waterfalls are absolutely spectacular, but everything is still accessible – exactly what visitors want.

When business relies on flow – kayak trips

Further along the river, at Onseepkans, there lies the so-called gorge section, a popular strip for kayak tour operators. "Extremes in flow, both high and low, have a detrimental effect on our business," says Marie-Louise Kellett, co-owner and director of Gravity Adventures, which offers rafting trips in the Orange.

They cancelled their trips on the gorge during the drought that recently ended, because the water level became too low to run

Danie Swanepoel/Flickr

The Gariep Dam is not only the largest dam on the Orange River, but also the largest in South Africa. Water releases are carefully managed by the Department of Water and Sanitation to meet the needs of water users and the environment.

safe or enjoyable trips. They then started to run trips much further upstream, on the Thunder Alley section near Hopetown, she says, where the river is close to the outflow from Vanderkloof Dam. The capacity to run trips on two sections of the river has enabled them to be far more flexible, which was an advantage during the high flow period. "Whilst we cannot run trips on the gorge section below the confluence of the Vaal and the Orange (where the flow was still at about 1 600 cumecs at the time), we can usually run on the Thunder Alley section, where the river is far wider and more forgiving than the tight channels of the gorge section." However, Kellett says they still had to cancel three trips in January, when the flow was at its peak. Their cut-off on the gorge section is at about 500 to 600 cumecs, and on the Thunder Alley section around 1 600 cumecs.

The knock-on effects of cancellations for their business are significant. "Our guides are all freelancers so they lose income, and the decreased income to the business means we may have a lean winter period." In addition, their suppliers, such as catering and accommodation, also lose money.

Where the river meets the sea

The river meets the arid Atlantic coast a few kilometers north of Alexander Bay thousands of kilometers from its source in Lesotho. The Orange River mouth today is described as a "highly disturbed, modified ecological system as a result of years of degradation due to diamond mining activities, flow regulation of the river, and poor management of the mouth." It has been classified as an IBA or, an Important Bird and Biodiversity Area (a site of global significance for bird conservation) by BirdLife International and a Ramsar site in 1991 (as was the Namibian side of the mouth in 1995) but, in 1995 the South African portion was placed on the Montreux Record – a list of Ramsar wetlands in need of urgent conservation action. Among the numerous conservation issues at play is increasing stress due to the increased demand for water from the Orange River for people, industries and agriculture. The Orange River remains a crucial life artery for South Africa.

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INDIGENOUS CROPS

Why 'forgotten' foods are a key ingredient to food security

Lablab, spider plant, and taro might feel like foreign words on South Africans' tongues today, but once, these crops were staples on local plates. Instead, we now prefer imported crops that have become indigenised over the years, like maize and wheat, but decades-long research has now proven beyond a doubt that our forgotten foods should be brought back for a sustainable and healthy future. So writes Petro Kotzé.

So-called neglected and underutilised crops refer to those edible plants that were once popular within certain geographies and communities, but have been displaced by mainstream crops, explains Prof Tafadzwanashe Mabhaudhi, who has been studying these plants since 2008 when he started his Master's on a WRC-funded project on their water use and tolerance to drought. Mabhaudhi, Co-Director of the Centre for Transformative Agriculture and Food Systems at the University of KwaZulu-Natal (UKZN), refers to sorghum as an example. The crop is popular in some countries, he says, but underutilised in southern Africa relative to its potential and the levels it was used historically, before the introduction of maize.

We are not alone. Nearly the entire global population relies on a relatively small handful of food choices, far removed from local biodiversity and traditions. This dependence on global cultivars is one result of the Green Revolution, a movement in the sixties that transformed how and what we eat, in an attempt to thwart global hunger.

We are not what we eat

The revolution involved the scientific adaptation of select crops to flourish far beyond their natural ranges. When high-yield varieties of cereal crops such as rice, wheat, and maize were combined with the ideal mix of chemical fertilizers and exact

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irrigation needs, global food production sky-rocketed. It tripled in the sixties, feeding a population that more than doubled in the same time, on only 15% more land. Today, 75% of the global food supply comes from only 12 plant-, and five animal species. Just three crop types (rice, maize, and wheat) make up nearly 60% of the plant-based calories for the near-8 billion people on Earth.

In South Africa, a megadiverse country that harbours a majority of the Earth's species, bread (from wheat native to West Asia), rice (believed to be first domesticated in China), potatoes (native to the Peruvian-Bolivian Andes), and ***mieliepap*** (corn is widely agreed to hail from Mexico) are the most popular starches enjoyed. In research conducted by Nielsen, commissioned by Knorr on our eating habits, ***mieliepap*** is identified as the most popular traditional or indigenous food consumed in the country – proof of how indigenised alien crops have become.

The Green Revolution had several unintended consequences. We lost agricultural diversity, biodiversity, environmental and socio-economic sustainability, especially among the rural poor who cannot easily enter the value chains of a globally commercialized agricultural system. Over and above, the considerable progress towards combating food and nutrition insecurity on a global scale was not distributed equally. In sub-Saharan Africa, 23.8% of the region is undernourished and most countries identify as food and nutrition insecure.

Furthermore, our major crops are input-intensive. For optimal yield, they need optimal water and fertilizer. For sub-Saharan Africa especially, the warning flags have been raised. Water is set to be a major constraint for agriculture in the region, where the impact of low rainfall in general, will likely be exacerbated by climate change. Additionally, the amount of people in the region that need to eat is fast increasing. But a food secure future goes beyond filling people's tummies.

According to the Food and Agriculture Organization of the United Nations (FAO) "food and nutrition security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life."

"The aim is to build a foolproof argument that these crops can address food insecurity within hotspots, or projected future hotspots from both a quality and quantity perspective."

In South Africa, we have now laid a solid case in support of a return to our roots to achieve this. "Indigenous crops are the food for the future," says Dr Luxon Nhamo, WRC Research Manager for Water Utilisation in Agriculture. Thanks to early support from the WRC, among others, our country has been at the fore of what has slowly become a global movement that increasingly recognises the potential of so-called 'forgotten crops'.

Minette Lontsie

Taro (amadumbe) being sold at a local market.

As a result, we have largely overcome one of the biggest hurdles to introducing 'new' crops to our shelves – namely, the necessary research. Major crops dominate the market thanks to the support of sustained scientific knowledge, says Prof Albert Modi, UKZN Deputy-Vice Chancellor and Head of the College of Agriculture, Engineering and Science. With scientific support, certain crops like maize have outcompeted others, like sorghum, that could provide the same value, he says. Now, we have the facts in hand to prove that forgotten crops deserve a space on our plates once again.

The research that makes a case for traditional crops

Initially, WRC funding was geared towards establishing the water use of underutilised crops in comparison to locally adapted, common crops, explains Nhamo. People were saying that indigenous crops were more drought-tolerant, Mabhaudhi explains, and initial research questions aimed to build up empirical evidence to confirm or dispel such anecdotes. "In many cases, we found them to be true."

"We then added a nutrition dimension to crops that were drought and heat-stress tolerant," Mabhaudhi says. Researchers found several of the crops to be nutrient dense. These crops fit in that aspect of food security beyond simply filling tummies, says Modi, who was an early champion of neglected and underutilised crops in South Africa. "More than access to energy or caloric value, they provide access to the nutrients and other elements essential to help people survive."

The work resulted in a list of 13 priority underutilised crops for South Africa, published in 2017. "These crops present the most potential for success," Mabhaudhi says, and they recommend that resources should be targeted on improving and developing value chains for them.

The list also aims to dispel the perception that these traditional crops offer fewer returns on investment than major crops. The identified traits (drought and heat-stress tolerance and nutrient density) promise prospects for success even over major crops.

Researchers then turned their attention to the crops' performance under future climate change predictions. In work that is close to completion, they investigated whether the crops' water use and efficiency will likely increase or decrease and if the areas suitable for their production will shrink or expand. "By

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Wikimedia/Prenn

A closeup of Jews mallow.

and large the results are promising," notes Mabhaudhi. "In most instances, the crops will be able to expand into new areas for production, and there will be some gains in productivity, both from a yield and water productivity perspective."

The next step, set for completion next year, is to link this information to food insecurity hotspots in the country. The aim is to build a foolproof argument that these crops can address food insecurity within hotspots, or projected future hotspots from both a quality and quantity perspective, Mabhaudhi says.

The bricks in the research foundation to build a new food future with the help of underutilised crops are now standing strong. Scientists have proven that several of our forgotten crops are drought and heat stress tolerant, resistant to pests and diseases, adapted to semi-arid and arid environments, and nutrient dense. They are suitable for marginal conditions, suggesting they could be used to champion sustainable and resilient agriculture and food systems for smallholder farmers residing in these environments.

"We are at the point where we have done enough research to prove beyond any doubt that these crops can be commercialised, be of nutritional value and the water use is such that it deserves space in the South African agricultural industry," says Nhamo. "The remaining, fundamental question," he adds, "is how to mainstream these crops into the food chain."

Tentative steps have already been made in this direction.

Remembering our forgotten crops

For one, ***amadumbe*** (taro) has made it from the small-scale farmer's field to store shelves nationwide. The flagship uMngeni Resilience Project, the first to be funded in South Africa by the Adaptation Fund, is another example. The project saw more than US$ 7 million channelled towards efforts to increase the resilience of vulnerable communities in the nMgungundlovu District Municipality in KwaZulu-Natal through interventions

Lablab, also known as hyacinth bean, with its distinctive purple pods.

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Table 1. Priority drought tolerant and nutrient dense underutilised crops for South Africa

	Common name	Scientific name
Cereals	Sorghum	*Sorghum bicolor*
	Tef	*Eragrostis tef*
Legumes	Bambara groundnut	*Vigna subterranean (L.)*
	Lablab	*Lablab purpureus (L.) Sweet*
	Cowpea	*Vigna unguiculata (L.) Walp*
	Marama bean	*Tylosema esculentum*
Root and tubers	Taro	*Colocasia esculenta*
	Sweet potato	*Ipomoea batatas*
Leafy vegetables	Jews mallow	*Corchorus olitorius*
	Spider plant	*Cleome gynandra*
	Amaranth	*Amaranthus sp.*
	Nightshade	*Solanum nigrum*
	Wild watermelon	*Citrullus Lanatus L.*

such as early warning systems, climate smart agriculture, and climate-proofing settlements. Mabhaudhi, the Project Director, says it offered them the opportunity to implement the existing research into practice.

"As part of building resilience in smallholder farming communities we reintroduced some of these crops that we know from our research," he says. The project provided a myriad of support mechanisms to make it happen, including seeds and training to grow the crops, how to harvest and use them. It highlighted a serious concern. In many cases, people have forgotten how to use the crops, Mabhaudhi says. "The knowledge has been lost."

"We're left with one or two generations of people in the rural areas that know these crops, notes Modi. "When they die, the next generation won't even know the names of wild, edible crops and underutilised indigenous crops."

If this knowledge disappears, South Africa will suffer a great loss, according to Modi. Indigenous knowledge includes the ability to feed ourselves and to protect ourselves from diseases. It gives us a place in the economy of the world, he says, and taps into vastly different aspects of our livelihoods. Modi points out that the danger goes beyond the knowledge on the propagation and use of the plants disappearing. Ignored, unknown and undervalued, the plant populations themselves might dwindle to the point of extinction and with it, we also risk losing the associated biodiversity that depends on them.

Research alone cannot change the fate of these crops. South Africans' mindsets need to change too. "There's a huge need to address how these crops are perceived in society and to change the narrative of them being viewed as poor people's or as poverty crops," says Mabhaudhi. Instead, Nhamo says, South Africans should be proud of the cultural heritage embedded in our traditional foodstuffs.

While research has created the space to talk about the crops' potential, we need to get to the stage where this potential is being realised, Mabhaudhi adds. To make this happen, partnerships are essential.

A possible plate of the future

Moreso than research, the realisation of the potential that traditional crops hold for our future, calls for a broad range of actors. These include communities, policy practitioners, and private-public entities, "all of them," Mabhaudhi says. If, he points out, policy changes for maize meal to be mixed with 5% of millet, that would change things overnight. Or, to take another example, if McDonald's served a meal that featured indigenous food, it would change the narrative completely. That happened, he says, when Woolworths, a brand associated with quality products, started stocking ***amadumbe***.

These crops will not replace maize, or common vegetables like cabbage, Swiss chard, and spinach, Modi explains. Those have been scientifically proven to make a significant contribution to our diet but, he says, they have limitations. Instead, their research has proven that underutilised crops can complement the value of our current diet, even in small amounts. Even more so, you can create new opportunities for economic growth at the household level, especially in poor households. Then, there is the matter of germplasm resources, Modi explains. These crops, including crop wild relatives, could be used to improve the traits for nutritional value and stress tolerance of future crops.

For a sustainable future in South Africa, the food system has to change, adds Nhamo. "We do not only have to change what the system feeds us, and how, but also the role that we play in this system."

After decades of shining the light on underutilised and traditional crops, Modi says he would now like to champion broader participation in research on the topic, opening the door for ordinary citizens to become involved too. You might not know it yet, he says, but you are part of this project too.

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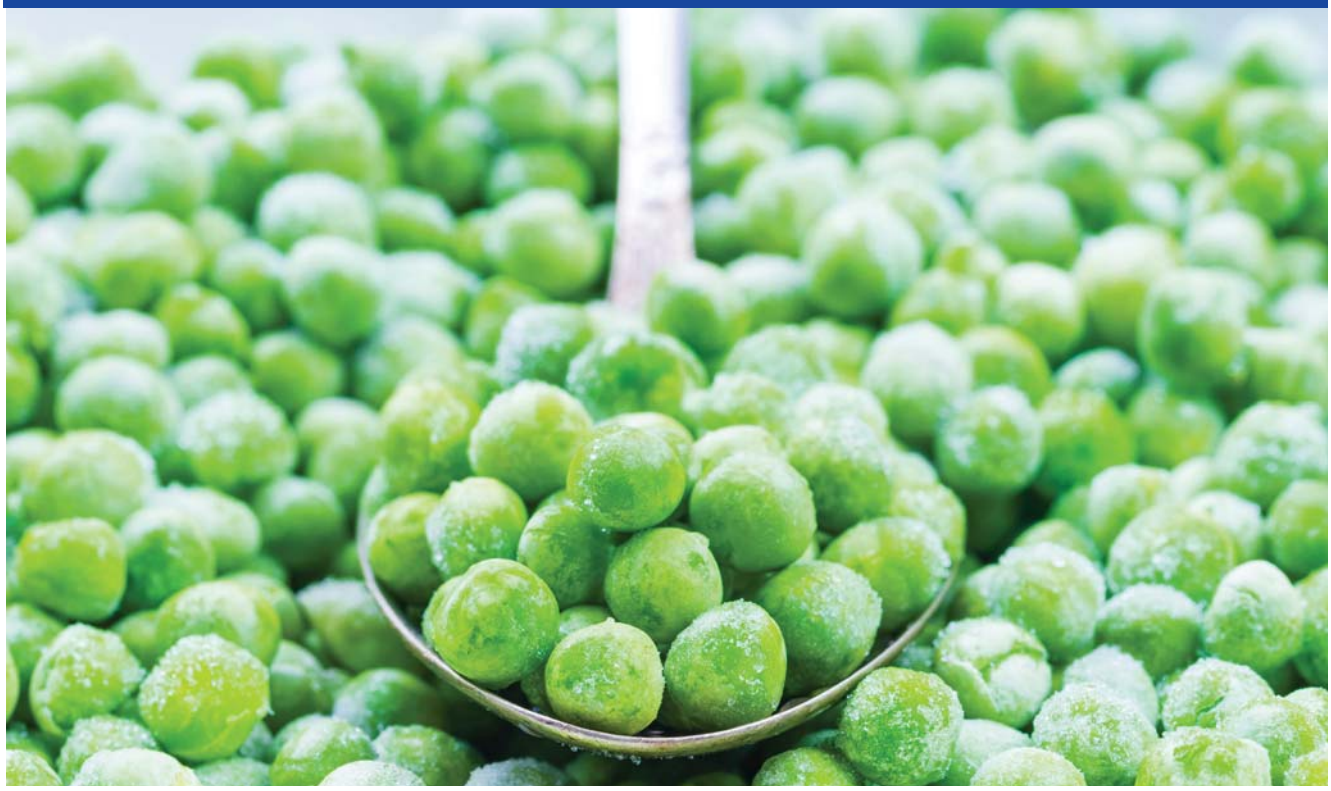
INDUSTRIAL WATER USE

Project places water use of fruit and vegetable processing under the spotlight

The latest in the National Survey (NATSURV) series of reports on industrial water and wastewater management provides an update on the fruit and vegetable processing industry. Article by Sue Matthews.



Sweet treats, common condiments, pantry staples and freezer essentials – we have South Africa's fruit and vegetable processing industry to thank for providing everything from juices, preserves, purees and sauces to a variety of canned and frozen fruit and vegetables. But how well is the industry performing in terms of water and wastewater management?

A six-member team from Chris Swartz Water Utilization Engineers, Stellenbosch University's Department of Food Science and the non-profit organisation, GreenCape, recently completed a Water Research Commission (WRC) project to update the relevant NATSURV report. The original report, by Binnie & Partners in 1987, was part of a series of national surveys conducted under the auspices of the WRC and the then Department of Water Affairs (now the Department of Water and Sanitation) on the water and wastewater management of various industries in South Africa.

Given the rising cost of water, with many municipalities applying a stepped tariff based on monthly consumption, as well as water shortages experienced during periodic droughts over the intervening decades, one would expect processing facilities to have reduced their overall water consumption, or at least increased the efficiency of that consumption. A measure of the latter is the specific water intake (SWI), and while Binnie & Partners defined this as the volume of water taken in over a period per ton of raw material, the Swartz et al. report assessed the SWI in terms of both raw material and finished product.

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Effluent disposal is subject to more stringent standards nowadays too, whether it be for discharge back into the natural environment, irrigation of crops or lawns, or treatment at a municipal wastewater treatment works (WWTW). Municipalities generally have limits on a range of parameters determining the effluent quality that their WWTW will accept, although these are not uniform. For example, the limit for chemical oxygen demand (COD) in Tshwane, Cape Town and Ekurhuleni is 5 000 mg/L, but 10 000 mg/L in Nelson Mandela Bay and only 3 000 mg/L in Mossel Bay. Surprisingly, effluent from food processing commonly has extremely high COD levels, often 10 to 100 times higher than those for domestic wastewater. Businesses may therefore need to pre-treat their effluent before sending it to a WWTW – or, of course, discharging it or using it for irrigation.

Fortunately, a variety of technologies for water minimisation and effluent treatment are now available, but they are still quite costly to implement. Many fruit and vegetable processing facilities do not even operate all year round, being dependent on seasonal supplies, so a lengthy pay-back period will understandably discourage investment in these technologies.

The project team's first step in assessing progress with regard to water and wastewater management was to conduct a literature review on the industry's size, nature and status, both locally and internationally. Particularly useful references included the Statistics South Africa report on the 2014 National Census data, which yielded information on the size and value of the industry, and an Optimal Agricultural Business Systems (OABS) report for the Western Cape Government's Department of Economic Development and Tourism (DEDAT). This covered the findings of a 2018 survey to assess the water risks, challenges and impacts faced by the province's agri-processing sector, and detailed how the fruit and vegetable industry had coped with the drought prevailing at the time. In addition, a guideline published by the European International Pollution Prevention and Control (IPPC) bureau in 2006 provided comprehensive background information on processing techniques and best practices in the food industry, as well as recommendations about wastewater treatment technologies.

The project team attempted to identify all facilities involved in the fruit and vegetable processing industry countrywide by acquiring membership lists from the three main industry bodies – the South African Fruit and Vegetable Canners Association (SAFVCA), the South African Fruit Juice Association (SAFJA) and Dried Fruit Technical Services (DFTS). These lists were rather outdated, though, as many of the factories had either ceased operating or had been bought out by larger corporates. Internet searchers were conducted in an attempt to resolve this, and to identify facilities that did not belong to any of the industry bodies. In all cases, contact was established with the production managers, who were considered likely to be best-informed about the main water-using operations and to have access to water management data.

An online questionnaire was then sent to these managers, containing sections on the factory's production, water usage, water minimisation efforts, wastewater generation and management, as well as energy usage. The response was relatively poor, but nevertheless yielded some valuable information. A representative sample of all the different types and sizes of facilities within the industry was subsequently visited for more detailed assessment. Unfortunately, some refused to share information they considered confidential, including water usage statistics.

Combining the data collected during these visits with that from the literature, the project team calculated the average SWI to be 6.81 m^3/ton of raw material and 8.22 m^3/ton of product for canning, 3.79 m^3/ton of raw material and 4.45 m^3/ton of product for juicing, 16.3 m^3/ton of raw material and 4.8 m^3/ton of product for freezing, and 1.3 m^3/ton of raw material and 15.0 m^3/ton of product for drying. The average SWIs for all these processing types were 6.71 m^3/ton of raw material and 7.96 m^3/ton of product.

These figures can be compared with those reported by Binnie & Partners in 1987 from the first NATSURV on the industry: 8.79 m^3/ton for canning, 1.29 m^3/ton for juicing, 14.5 m^3/ton for freezing, and an average of 9.29 m^3/ton for all the process types (drying processes were not surveyed). As mentioned previously, these were all expressed in terms of tons of raw material.

"It is encouraging that some of the facilities reported SWI figures comparable to or better than that of their international counterparts," note the project team. "In addition to this, some facilities performed well in relation to the SWIs established for certain products in the original 1987 NATSURV. Many of the facilities have dedicated long-term strategies for improving water use, with one facility in particular having almost halved water consumption over a three-year period."

The survey of effluent streams discharged from the different types of processes found average volumes of 298 m^3/d for canning, 274 m^3/d for juicing, 595 m^3/d for freezing, and an average of 407 m^3/d for the industry as a whole. This information was not available in the 1987 report, although it did provide some detail on effluent volumes and levels of COD and suspended solids for the juicing, canning and freezing of various fruits and vegetables. There was no indication that the factories surveyed back then were implementing any kind of wastewater management, but Binnie & Partners made recommendations in this regard. It mainly involved keeping solid waste out of the effluent stream in the first place, but also applying either a filtration or sedimentation step to separate out suspended solids.

These measures seem to have been taken up by the industry. The more recent survey found that most facilities perform at least one kind of primary wastewater treatment, such as screening, coarse filtering and sedimentation, sometimes followed by a neutralisation step to adjust the pH. Yet only 47% of the facilities make use of secondary treatment, which relies on microorganisms to remove suspended solids under either aerobic or anaerobic conditions. And only 16% add tertiary treatment, generally considered a 'polishing' step and involving techniques such as biological nitrification/denitrification, ammonia stripping, biological phosphate removal, membrane filtration, as well as disinfection and sterilisation.

"The lack of tertiary treatments is however expected, as it is generally only applied if previous treatments were not sufficient,"

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The project team identified 82 main fruit and vegetable processing facilities in South Africa (as at 2019), their locations generally being determined by proximity to raw inputs.

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It is encouraging that some of the South African facilities reported SWI figures comparable to or better than that of their international counterparts.

explain the project team. "The adoption of technologies may also be dependent on what is done with the final wastewater effluent. For example, facilities that discharge their effluents into municipal systems are likely to only apply primary treatments, while those that intend to reuse the water for irrigation or other processes may be more inclined to apply more extensive treatment options."

Two examples show some of the different strategies used for wastewater management in the industry. Example A processes mainly tropical fruits, with three different on-site facilities producing juice concentrates, blends, purees and fruit cubes from November to January and then individually quick-frozen (IQF) fruit pieces and canned products from March to early July. Primary wastewater treatment involves the neutralisation of pH and then physical screening before the effluent is pumped to sedimentation tanks, and eventually to a dam that serves to further separate the liquid effluent from floating solids. Secondary treatment is accomplished in anaerobic lagoons covered with tarpaulins, followed by aerobic lagoons. The final effluent is pumped into a holding dam, and then used for orchard irrigation.

Example B is a dried fruit producer, making use of tree fruit from a variety of sources to operate all year round. Wastewater management involves an initial filtration step by means of a bag filter, after which the effluent is mixed with sewage from the facility and discharged into a three-stage aerobic bioreactor. After this, the treated water is passed through a peat bed for a final filtration step. The treated water is then held in a reservoir, from which it is either discharged into the municipal system or used to irrigate the lawn. Its wastewater treatment process was reported to be able to reduce COD levels from above 4 000 mg/L to below 100 mg/L.

The report provides a good overview of all modern-day treatment technologies that could be implemented within the country's fruit and vegetable processing industry, as well measures that could be taken for improved water-wise operation within a facility or particular processes. In the final chapter, the project team point out that the catchphrase "reduce, reuse, recycle" should form part of any best-practice hierarchy for improved water and wastewater management, since reduced water consumption translates into reduced wastewater generation, while reduced chemicals use improves wastewater quality. In general, the cleaning of raw materials and facilities were found to be the main consumers of water, so these operations should be targeted for initial water-saving endeavours, providing this does not compromise food safety. Likewise, the requirement for high-quality water for food processing presents challenges when considering water recycling as a means of reducing water intake, and warrants further research.

Nevertheless, by sensitising industry stakeholders to water and wastewater issues, and providing a comprehensive guide and benchmark tool, the NATSURV 14 report is sure to achieve its main objective – to stimulate water saving and pollution mitigation by the fruit and vegetable processing industry.

To access the report, ***Natsurv 14: Water and wastewater management in the fruit and vegetable processing industry Edition 2*** **(WRC Report no. TT 863/21**)
click here (https://bit.ly/3LZ50RG)

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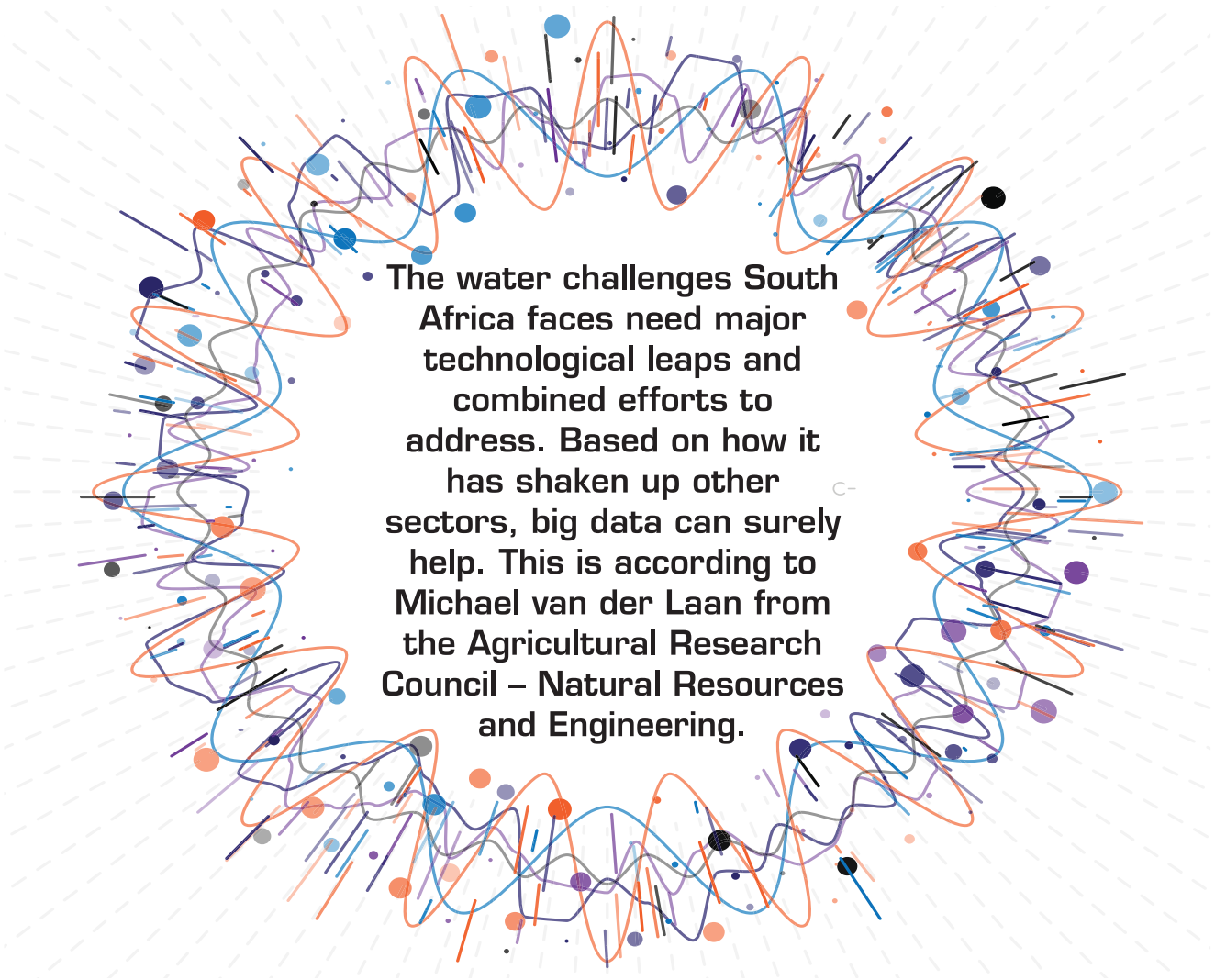
FOURTH INDUSTRIAL REVOLUTION

Water research in South Africa: Getting ready for big data analytics



Defined as very large and growing datasets from a variety of sources, big data cannot be processed using our traditional tools and digital infrastructure. A few decades ago, electronic spreadsheets revolutionised the workplace. They meant no longer having to add up long columns of numbers with a calculator, and enabled one to easily test different scenarios by changing a value in a cell or modifying a formula.

Although big data can be way more powerful, it is much more difficult to work with. Higher level policy development (e.g. custodianship, pricing of products and services) is also needed to ensure that big data is used in a scientifically robust and ethical manner that benefits all.

Commercial companies that have reaped the benefits of big data are plentiful. Biomedical research has also traditionally tackled large volumes of data with great success. In South Africa, institutions conducting water-related research are now proceeding with the development of cloud-based platforms for big data analytics, such as machine learning exercises. New techniques to analyse data, to create predictive models, and to link water management communities around heterogeneous

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data sources are exciting.

The potential to produce multiple lines of evidence towards scientific facts as never before is also brilliant. In time we will be able to detect a chemical spill or illegal activity with satellite imagery, receive confirmation via social media streams, hold the perpetrator accountable using this evidence, and then monitor the recovery of the system in real-time using citizen science. We will also be able to better quantify the benefits of social development spending and policies on actual quality of life at various levels and scales. Internet-of-things (IOT) technology means a water quality sensor can be dropped in a river to flow downstream and report flow rate and water quality wirelessly.

For different groups selecting host platforms and designing their big data architecture, the main focus should be on ensuring inter-operability so that systems can communicate and work together. This will include the use of common metadata standards, file types and translation tools. However, ensuring legal inter-operability and the governance and protection of sensitive data will be more complex. Massive strides are still needed to develop policy documents and protocols around this aspect, not only in South Africa, but around the world.

A paradox of big data is that as the quantity goes up, the quality goes down. We are now in the zettabyte era (that's 1,000,000,000,000,000,000,000 bytes). There are over 60 zettabytes today and by 2025 there will be around 175. The skills needed to perform big data analytics (***software intensive science***) still mostly sit with highly experienced computer scientists. Applying artificial intelligence actually first needs a great deal of human intelligence. Application of big data analytics with wide ranging data sources may produce strong correlations, for example, but these may be spurious correlations and may not contribute to actual systems understanding or the generation of new knowledge. Still, the possibility of improved predictive models and many other applications is undeniable.

But does South Africa have the resources and skills ready to leverage big data to better manage our water resources? Right now, natural scientists with computer science skills are in short supply (or computer scientists with strong natural science theoretical knowledge for that matter). The training and upskilling of well-equipped water scientists will require careful thinking through of curricula, and not just in the STEM (science, technology, engineering and mathematics) disciplines. Digitising historical information and digitalising systems will require high levels of creativity from artists and graphic designers to improve user experience and interaction. Historians, anthropologists and language experts will be needed to help develop software applications that make use of natural language processing, as an example, to understand material ranging from ancient documents to real-time social media text and videos. Drama graduates could help better discuss important concepts such as risk and uncertainty with the public on critical issues such as climate change and vaccines.

With all the free online learning opportunities, we have the ability to adopt a lifelong learning philosophy and continually upskill as never before. Basic understanding of how software code is written and run in a model can go a long way in launching a career in data science, or facilitating collaboration between programmers and natural scientists. So, if you are an early career water scientist and have some time to spare, consider doing a coding course on Python, Java or something similar. You won't regret it.

The Water Research Commission is developing a cloud-based big data platform called the Water Research Observatory (www.waterresearchobservatory.org) in a collaborative project between the Agricultural Research Council (ARC) and the universities of Pretoria, Free State and KwaZulu-Natal in South Africa, as well as the University of Florida and Texas A&M University in the USA (**WRC Project No. C-2020-2021-00440**). The objectives are to digitise previous WRC-funded research projects, demonstrate the application of big data analytics to current challenges in three case studies (agricultural water, surface water and groundwater), and suggest a protocol for digitally archiving future WRC research project data and information.

A commitment to data democratisation will mean that even non-computer specialist citizens will be able to access and visualise the data in a way that hopefully serves their interests. For example, dropping a pin on any point on a map of South Africa will indicate the data available for that particular location. All sorts of applications can also be built on it by third parties using a range of digital tools. As computing costs continue to fall, even projects on a shoestring budget will be able to utilise big data technology, including powerful cloud processing where researchers have hardware limitations.

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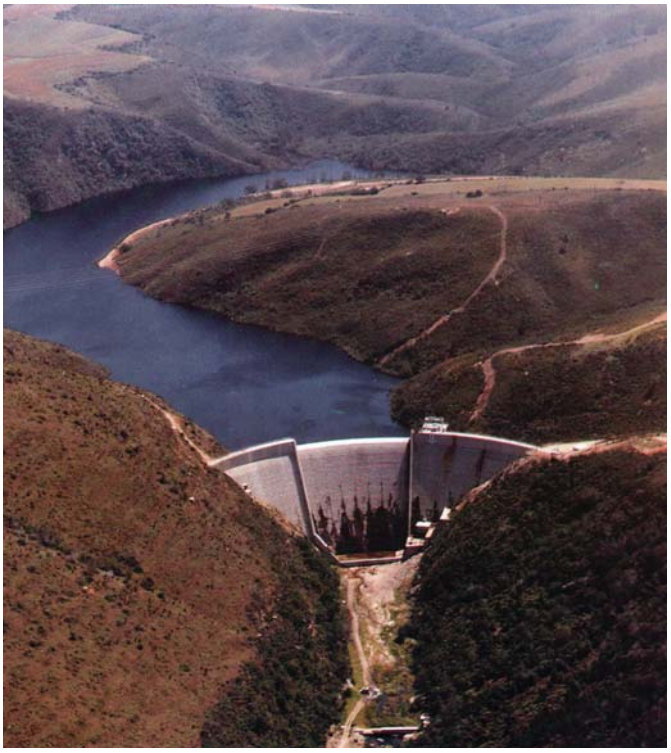
WOLWEDANS DAM – A DAM CONSTRUCTED WITH THE ENVIRONMENT IN MIND

DWA-eWISA



Wolwedans dam aerial

Wolwedans dam spilling

Wolwedans dam construction

The Wolwedans Dan on the Greak Brak River near Mossel Bay was completed in 1989. It was constructed mainly to supply water to the Mossgas plant that converts oil from the natural gas reserves below the ocean bed. This dam was the fifth dam in the country constructed with roller compacted concrete (RCC), and one of the world's first two RCC arch-gravity dams, the other being the Knellpoort Dam in the Free State.
The dam was designed and constructed by the Department of Water Affairs (now the Department of Water and Sanitation). The dam contains close to 200 000 m³ of rollcrete, placed over 14 months between 1988 and 1989.

With a downstream slope of 0,5 (horizontal) to 1 (vertical) the dam has to rely on arch-action for stability. Shrinkage of the rollcrete and the associated cracks would therefore pose serious problems especially if they are not grouted. A groutable system of induced crack joints was developed to overcome this problem.

Environmental considerations played a major role in the planning, design, construction and operation of Wolwedans Dam. The dam site was chosen after thorough investigations, which included a comprehensive environmental impact report. There was some concern over the potential impact of the dam on the Great Brak estuary and, after an intensive study led by the CSIR; it was decided to reserve 1 million m³ of water/year for the estuary from the dam's yield (the first time this had ever been done in South Africa). The capacity of the Wolwedans Dam's outlets was also designed in such a way as to allow for the river mouth to be washed out by a release from the dam whenever necessary (and when water is available).

Source: SANCID

Wolwedans Dam statistics

Type	Rollcrete arch/gravity
Height above lowest foundation	70 m
Gross capacity of reservoir	24 million m³
Crest length	270 m
Arch radius	135 m
Total volume of RCC	178 000 m³
Total volume of mass concrete	22 500 m³

(All photographs courtesy DWS)

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DEEPLY ROOTED IN SOUTH AFRICA WATER SOCIETY

www.wrc.org.za

The Water Research Commission not only endeavours to ensure that its commissioned research remains real and relevant to the country's water scene, but that the knowledge generated from this research contributes positively to uplifting South African communities, reducing inequality and growing our economy while safeguarding our natural resources. The WRC supports sustainable development through research funding, knowledge creation and dissemination.

The knowledge generated by the WRC generates new products and services for economic development, it informs policy and decision making, it provides sustainable development solutions, it contributes to transformation and redress, it empowers communities and it leads various dialogues in the water and science sectors.

The WRC Vision is to have highly informed water decision-making through science and technology at all levels, in all stakeholder groups, in innovative water solutions through research and development for South Africa, Africa and the world.

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THE POWER OF KNOWLEDGE TO THE PEOPLE