GROUNDWATER SOURCES

Microbialite seeps harnessed to monitor aquifer health

A project funded by the Water Research Commission (WRC) investigated whether coastal microbialite seeps could be used to monitor local aquifer resources. Article by Sue Matthews.

Gavin Rishworth

Mineral precipitation and/or sediment trapping by communities of cyanobacteria and algae at the coastal seeps promotes the formation of Supratidal Spring-fed Living Microbialite Ecosystems, or SSLiME.

Over the past decade, researchers in the Eastern Cape have been studying microbialite ecosystems associated with freshwater seeps along the province's south coast. Initially, when the first few sites were identified in 2012 on the outskirts of Gqeberha (formerly Port Elizabeth), they were referred to as 'living stromatolites' in accordance with the first report of such structures along the South African coast in 2003, near Kei River mouth. Derived from the Greek words for 'layer' (***stroma***) and 'rock' (***lithos***), the term stromatolite is used for layered sedimentary structures that are formed by microbial organisms and that first appeared in the fossil record almost 3.5 billion years ago. Microbialite is a more all-encompassing term that includes non-layered forms.

Where calcium-rich groundwater is discharged as seeps and springs onto the highest zone of the south coast's rocky shores, mineral precipitation and/or sediment trapping by communities of cyanobacteria and algae promotes the formation of microbialites. The research team have dubbed these Supratidal Spring-fed Living Microbialite Ecosystems, or SSLiME – an appropriate acronym given their appearance.

Recently, the research team completed a WRC-funded project to explore the connectivity between the seeps and groundwater. Project leader Dr Gavin Rishworth, a senior lecturer in the Zoology Department at Nelson Mandela University (NMU), explains that the research was largely the work of Carla Dodd and Tristin O'Connell for their respective PhD and MSc theses, but other scientists from NMU, the South African Environmental Observation Network (SAEON) and the Council for Geoscience made contributions too, as reflected in the list of authors on the final report.

Titled 'Coastal microbialite seeps as accessible monitoring locations of local aquifer resources' (**WRC report no. 3161/1/24**), the report suggests that SSLiME may be useful as indicators of groundwater quality and quantity. In other words, they could potentially act as a proverbial canary in the coal mine in response to pollution and over-abstraction of coastal aquifers.

This is particularly relevant because a drought between 2015 and 2023 meant that many homeowners, businesses and public facilities in Gqeberha installed boreholes to supplement their water supply, while the Nelson Mandela Bay Municipality implemented a massive groundwater development programme – conceptualised in 2010 during a previous drought – that has come online over the past two years. What's more, the small settlements along the largely rural southern coast of the municipal area rely on septic tanks for sewage treatment, so contamination of groundwater with pathogens and nutrients is highly likely, at least in the immediate vicinity.

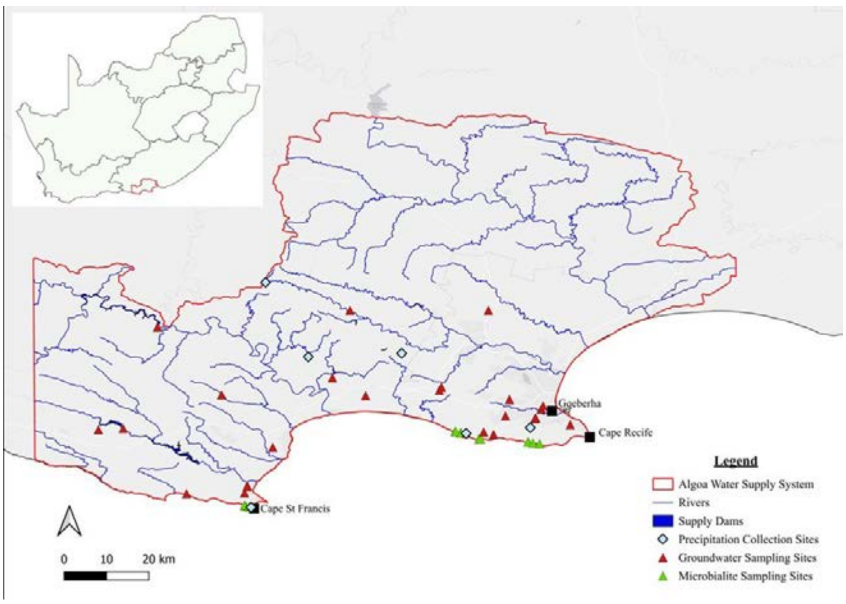
The groundwater resources of Gqeberha consist of the primary Algoa Group Aquifer, where water moves through porous calcareous sands, and the secondary Table Mountain Group (TMG) Aquifer below it, where water is stored in fractures, joints and faults in the hard quartzitic sandstones. While septic tanks lie close to the surface, abstraction boreholes generally target the deeper TMG Aquifer for its high-quality water, which is typically soft and acidic, with low levels of nutrients, calcium carbonate and total dissolved solids.

Given that the primary aquifer is porous and is underlain by hard rock, one would expect the coastal seeps to be fed by groundwater originating from relatively recent rainfall that has infiltrated the soil and then percolated through the primary aquifer to discharge at the coast. The presence of calcium carbonate formations within the SSLiME, with cyanobacteria and algae sustained by nutrient-rich water, would support this conceptual pathway. However, the TMG quartzitic sandstones are exposed along stretches of coast to the west of both Cape Recife and Cape St Francis, where the SSLiME are concentrated, and TMG-fed springs are believed to occur here. The primary aquifer can also be recharged by the TMG Aquifer through faults and fractures at the contact zone, making the source of coastal seep water uncertain.

In an effort to unravel this conundrum and understand the linkages between rainfall, groundwater and discharge via the coastal seeps, the project team compared stable isotope ratios of hydrogen and oxygen in water samples collected both inland and at the coast. Six rainfall stations were set up, each equipped with a dip-in precipitation totaliser as well as a duplicate totaliser, which was protected from rain but partially filled with 100 ml of 'standard' water with known isotopic composition. Once per month, samples were collected from both of the totalisers and the standard water was replaced, allowing the effect of evaporation on isotope ratios to be assessed. Groundwater samples were collected from 27 boreholes and 18 springs and seeps in a once-off sampling campaign conducted over the last two months of 2022, with the coastal seeps sampled again in March 2023 for a seasonal comparison.

Analysis of the samples revealed differences in isotope ratios of coastal groundwater discharge and inland groundwater, but an overlap in isotopic signatures indicated some hydrological connectivity between the catchment and coastal aquifers, or a common recharge area. This means that the SSLiME may well receive groundwater from both the primary aquifer and the TMG Aquifer.

Findings from another component of the project would seem to support this conclusion. A year-long study was conducted on a 40 km stretch of coastline between Cape Recife and Maitland



A map of the Algoa Water Supply System area showing locations of monthly precipitation collection sites, groundwater sampling sites and microbialite sampling sites.

Beach to quantify the amount of groundwater discharging to the coast through the Gqeberha SSLiME. Five main sites were selected with four monitoring points at each, where flow rates were measured on a monthly basis using simple capture-cup or tracer-instrument methods depending on whether the flow was concentrated or diffuse. Assessing the results against South African Weather Service data on rainfall measured at the city's airport for the year of the study and the preceding year revealed that the relationship between rainfall and discharge was highly variable. However, there appeared to be a monthly or seasonal lag between rainfall and discharge, as well as a more consistent baseflow that the research team hypothesise may be contributed by the TMG Aquifer.

Apart from these flow measurements, a once-off estimate of flow rate according to five categories was made at all the other SSLiME locations identified within the 40 km stretch of coastline. Of the 1 533 freshwater seeps, 1 208 (78%) were recorded as having microbialite deposits. Using both the flow estimates and the monthly flow measurements from the 20 study sites, groundwater flowing through the Gqeberha SSLiME was calculated to total some 4 Ml/day.

In addition, water samples for nutrient analyses were collected from both the inflow and outflow of the 20 SSLiME study sites in four seasonal sampling campaigns. For inflowing water, the study sites at Seaview – the largest village along Gqeberha's south coast – had the highest dissolved inorganic nitrogen (DIN) load over the year, followed by those at the smaller Schoenmakerskop village. The highest dissolved inorganic phosphorus (DIP) load was at the eastern extent of Schoenmakerskop, known as Sappershoek. Comparing the inflow and outflow concentrations, the SSLiME systems seemed to be more effective at attenuating DIN than DIP.

The findings suggest that human occupation – with concomitant disposal of sewage and greywater laden with food waste and detergents, as well as fertiliser use in gardens – is responsible for elevated nutrient concentrations. The largest contributor to the DIN content was nitrate, followed by ammonia, which gives a clue as to what may be happening, although this is not addressed in the report. In septic tank treatment systems, most nitrogen in the effluent exiting the tank is in the form of ammonium, but this is converted through nitrification in the drain field to nitrate. If the septic tank is too full of sludge, sewage and greywater flows out of the tank before it has been properly digested by anaerobic bacteria, resulting in clogging of the drain field. This will inhibit nitrification, as will compaction of the drain field or extended saturation that results in anoxic conditions. Both nitrate and ammonium may contaminate groundwater, but nitrate is known to be especially mobile. Septic tanks are not very efficient at removing phosphorus, but it readily adsorbs onto soil particle surfaces once in the drain field. However, calcareous soils provide fewer opportunities for phosphorus removal and are therefore more vulnerable to phosphorus migration in groundwater.

Now that the WRC-funded project has been completed, the research team has embarked on a long-term SSLiME monitoring programme based on a protocol described in the final report.

"A year of monitoring is not enough to draw any well-founded interpretations – at least a decade would be ideal to understand what's really going on here," says Rishworth. "Most of our research to date has been short-term student projects looking at one component or another, or tying together various pieces of the puzzle, but we realised it's now time to bring together all of that research towards an intentional monitoring vision, without a specific hypothesis-driven research question. Knowing that there's likely to be increased groundwater abstraction and other pressures on the groundwater system in the region, having a robust long-term dataset will be important to be able to monitor change."

The monitoring programme will continue the rainfall stable isotope work with a view to generating a reliable local meteoric water line (LMWL) aligned to the standards of the Global Network of Isotopes in Precipitation (GNIP), but will otherwise focus on the SSLiME themselves, as groundwater-dependent ecosystems. This will include monitoring of stable isotopes, hydrochemistry (major ions), physicochemistry (nutrients, pH, temperature, electrical conductivity, etc) and flow rates of seepage water, as well as SSLiME status (accretion, erosion, bioturbation) and distribution counts, possibly making use of lidar or drone imagery.

Certainly, groundwater-dependent ecosystems form an important part of the monitoring programme for the City of Cape Town's TMG Aquifer Scheme at the Steenbras Wellfield, high in the Hottentots Holland mountains. Here there are two aquifers in the TMG – the upper Nardouw and the deeper Peninsula Aquifers – and both are targeted, explains Dylan Blake

Gavin Rishworth

An underwater view of SSLiME in a rock pool.

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The research team at the Schoemakerskop study site.

of Umvoto, the earth sciences consultancy appointed under engineering firm Zutari to undertake groundwater studies and wellfield development for the City.

"There are numerous wetlands, seeps and springs associated with the Nardouw Aquifer at surface within the wellfield area, and where abstraction occurs there is a potential drawdown risk to these groundwater-dependent ecosystems. The Peninsula Aquifer is less of an issue because it's deeply confined in the wellfield area, with the boreholes only tapping into it 700 to 800 m underground, and its groundwater-dependent ecosystems are all in the high mountain recharge zone areas. So it's unlikely that drawdown in the very deep boreholes in the Steenbras Wellfield will impact those, but an extensive monitoring network for both aquifers has been set up to make sure that is the case."

Each ecological monitoring site includes a stream channel and the seep or wetland associated with groundwater discharge, and a wide range of parameters are monitored. Surface to depth monitoring of soil moisture and water levels helps in understanding how the ecosystem is linked to the aquifer, and can identify red flags before serious impacts occur.

"Soil moisture probes are used near the surface along with shallow piezometers at 2–3 m depth, and then for the Nardouw Aquifer we have monitoring boreholes at 50 m depth and 150–300 m depth, whereas for the Peninsula Aquifer the monitoring boreholes are at 100–200 m depth in the mountainous recharge areas and at 700–1 000 m depth within the wellfield areas. The various Nardouw and Peninsula Aquifer boreholes used for abstraction are also closely monitored in terms of groundwater levels and abstraction volumes," says Blake. "The first red flag would be non-pumped groundwater levels in the production boreholes declining over time, followed by long-term groundwater level declines in the monitoring boreholes. The City is busy developing Thresholds of Potential Concern for the various groundwater-dependent ecosystems using a monitoring and modelling approach, so that wellfield operational decisions can be taken long before any impacts become evident in the ecosystems."

Dr Ricky Murray of Groundwater Africa, who has been appointed by the Nelson Mandela Bay Municipality to conduct monitoring and auditing of their recently developed wellfields, agrees that groundwater levels are the most important parameter to monitor. He adds that this monitoring is relatively easy to do, and understanding the results is far more straightforward than trying to interpret ecosystem changes that might be due to other factors.

"What I stipulated in my recommendations, which have been incorporated into the water use licenses for the wellfields, is to limit drawdown so that it doesn't go below sea level," he says. "It's fine if this happens for short periods of time, if an emergency supply of water is needed, but the principle is that you don't want to change the hydraulic gradient – you want groundwater to flow as it has done over the millennia from land to sea. The general hydraulic gradient won't be affected if it is reversed in a small area around the production borehole for a short while, but it's critical to ensure that water levels in the monitoring boreholes are not drawn down below sea level, because they represent the regional hydraulic gradient."

He adds that at the Bushy Park Wellfield, which is situated close to the southern coast where the SSLiME occur, there is a risk that over-pumping of the production boreholes could induce saline intrusion into the aquifer if the hydraulic gradient is reversed. A monitoring borehole has therefore been installed between the wellfield and the coast, and this will give a clear indication of the effect of abstraction from the wellfield in relation to the broader area.

"The monitoring programme here does not include monitoring of groundwater-dependent ecosystems, but there's very close monitoring of groundwater levels. The municipality has a state-of-the-art SCADA system that is continuously capturing electronic data, and the staff keep a watchful eye on it all. Besides electronic cut-off switches that prevent borehole water levels being drawn down below stipulated depths, hourly water level, abstraction and water quality data are stored so that the performance and status of the wellfields and aquifers can be reviewed on an annual basis, as required by the water use licenses. In addition, since data sets of hourly readings would simply become too cumbersome after 20 to 50 years, daily data are stored for future assessments of the effects of long-term groundwater abstraction."

Murray and Blake both point out that private groundwater use in Gqeberha is more of a concern, because it is not being adequately monitored. The municipality's Water & Sanitation Services By-Law stipulates that the use of water obtained from a source other than the water supply system is not permitted without the prior consent of the Executive Director, and in November 2024 the borehole registration form was updated to include details on borehole usage (domestic, commercial or industrial), yield, depth, borehole construction and other information. Anything more than small-scale use classified under Schedule 1 of the National Water Act would also require a water use licence, which would include a range of monitoring conditions and a schedule for submitting reports to the regional office of the Department of Water and Sanitation (DWS). However, compliance is believed to be low, and DWS lacks the capacity to perform the regulatory function effectively.

For the moment, private use of groundwater has likely declined dramatically, because the drought has ended and water levels in the dams supplying Gqeberha have recovered. Nevertheless, the NMU researchers will continue in their quest to improve understanding of the relationship between groundwater and coastal seeps, with their fascinating SSLiME.

"We know that early modern humans would have used this coastline for its rich food resources, but they would have needed readily accessible freshwater sources too, and the seeps likely acted as stepping stones in this regard," says Rishworth. "So they have value not just as monitors of our modern groundwater aquifer resources, but also as a unique cultural heritage asset for South Africa as a whole."

• To access the report, ***Coastal microbialite seeps accessible monitoring locations of local aquifer resources*** (**WRC report no. 3161/1/24**), visit: https://wrcwebsite.azurewebsites.net/wp-content/uploads/mdocs/3161%20final.pdf