SEEQUENT

UNEARTHED

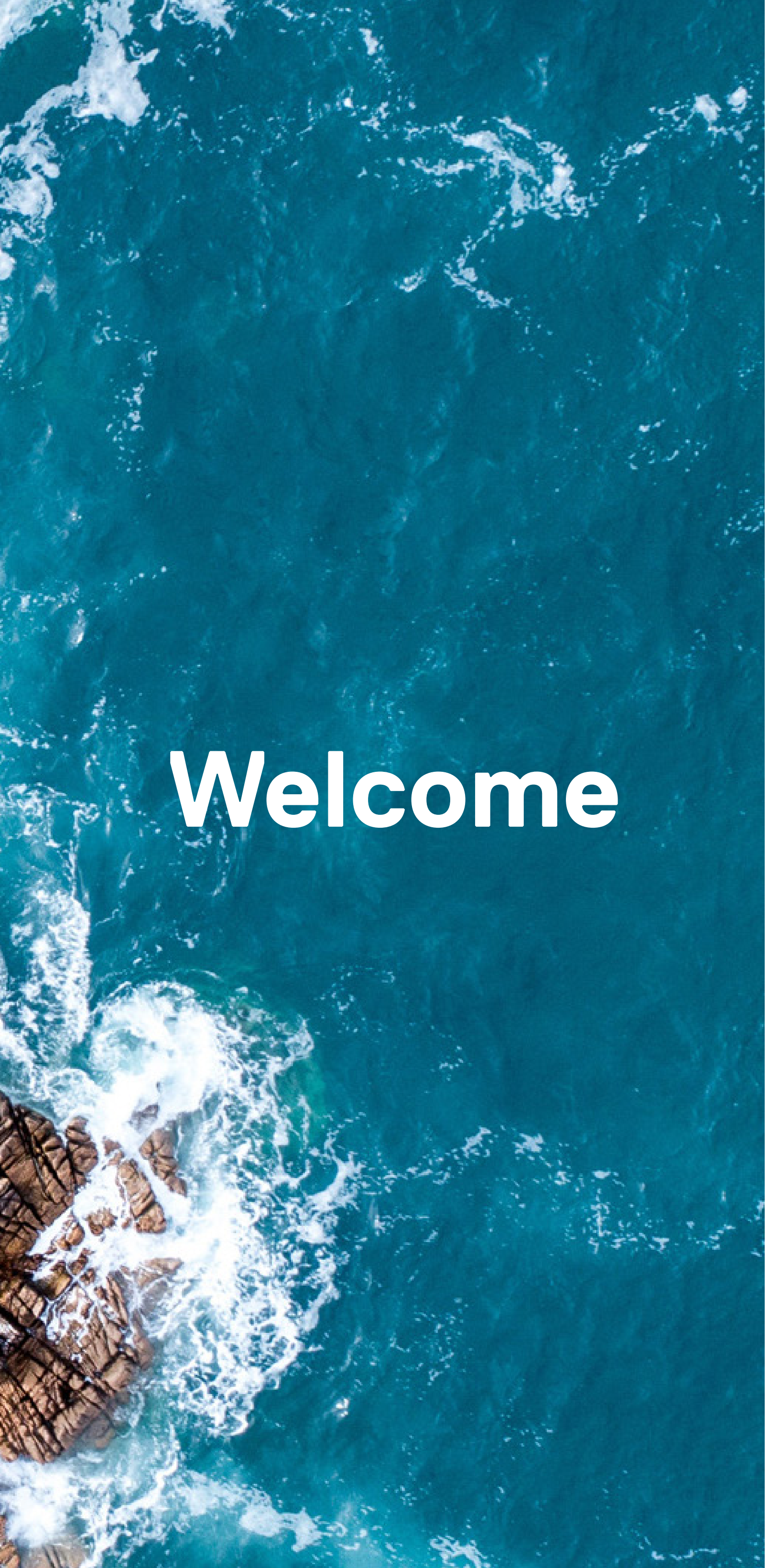
WATER SECURITY

WHY THE WORLD WILL TURN TO GEOSCIENTISTS AND ENGINEERS TO SOLVE ONE OF THE BIGGEST PROBLEMS FACING MANKIND

ISSUE 4

Technology and innovation for the Civil Engineering and Environmental industries.

Brought to you by Seequent, developers of Leapfrog.



Welcome

Safeguarding the World's Water

Water security is a topic that has increasingly concerned academia, government and NGOs in recent years – with good cause. Climate change, burgeoning populations and shifting lifestyles have all placed pressure on this critical resource.

Increasingly, we are seeing clients working to address issues around water availability (quantity) and water suitability (quality). The geology around these issues can be complex and it's not always understood.

In this edition of Unearthed, we examine some of these challenges and in particular, we focus on the roles we as geoscientists and engineers have to play in mitigating them. We are also delighted that in this edition, we have expert contributors from our Geosoft team. Geosoft joined Seequent in 2018 and brings a portfolio of software designed to visualise geophysical data. We also look at a number of innovative approaches being employed to comprehend these issues and take more effective action to reduce their impacts.

Water is the one resource for which no substitute exists.

At Seequent, we know that supporting our customers in helping them understand and manage this vital resource is an important part of the contribution we can make to ensuring water security for all.

2.7 billion

people are affected by water scarcity at least one month each year

"Water is the one resource for which no substitute exists."

Daniel Wallace
General Manager, Civil and Environmental Industries, Seequent

InterContinental Shanghai Wonderland

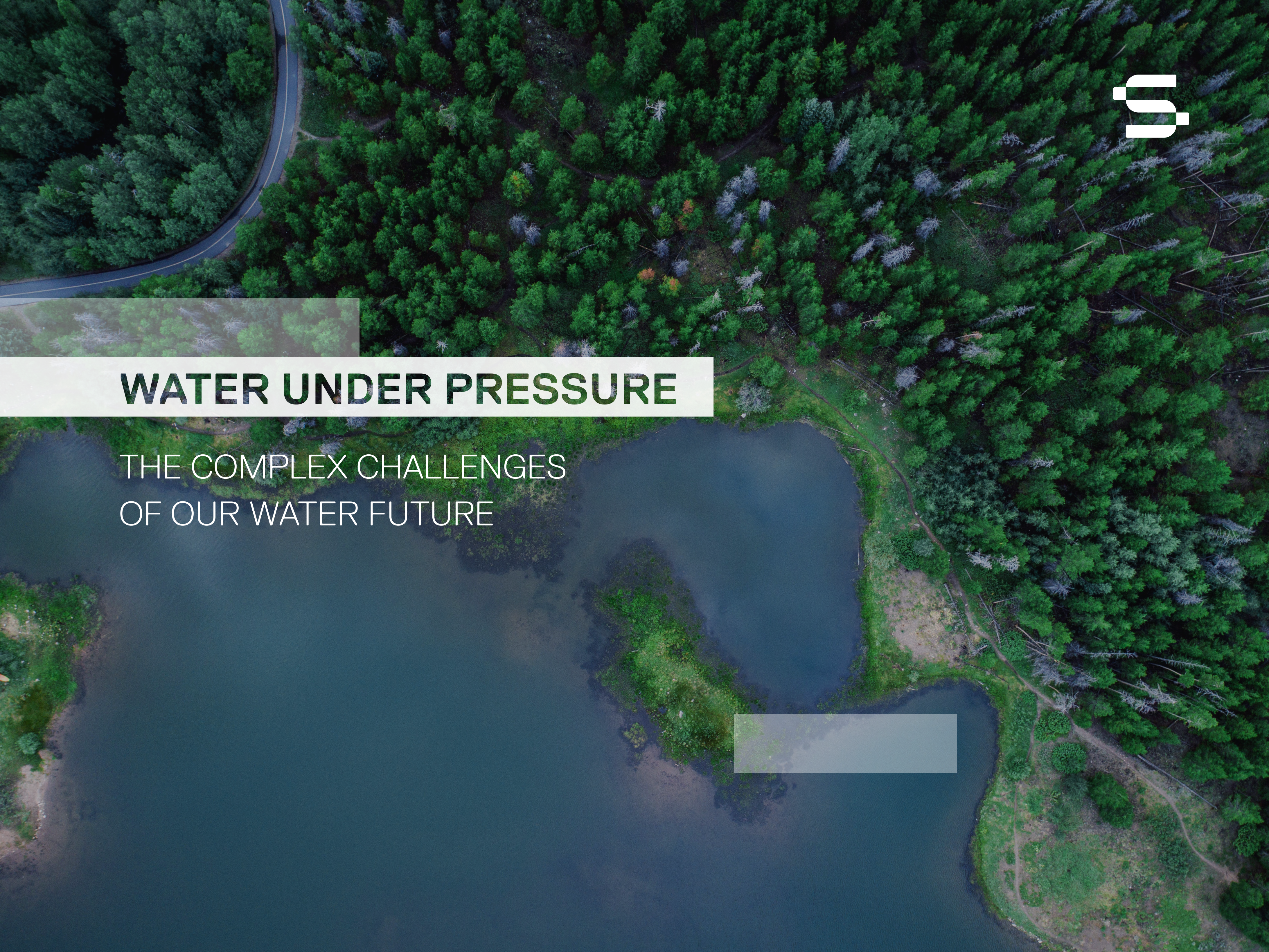
SONGJIANG, CHINA. Built, somewhat outrageously, inside a 100 metre high (328 feet) quarry outside Shanghai. The hotel has 19 storeys, with the bottom two underwater beneath an artificial lake. And yes, that is a waterfall on the cliff face. An international competition picked the winning design by engineering consultants Atkins back in 2006. Seven years of geological examinations and feasibility studies followed before construction began, and the $555 million hotel opened for business in late 2018.

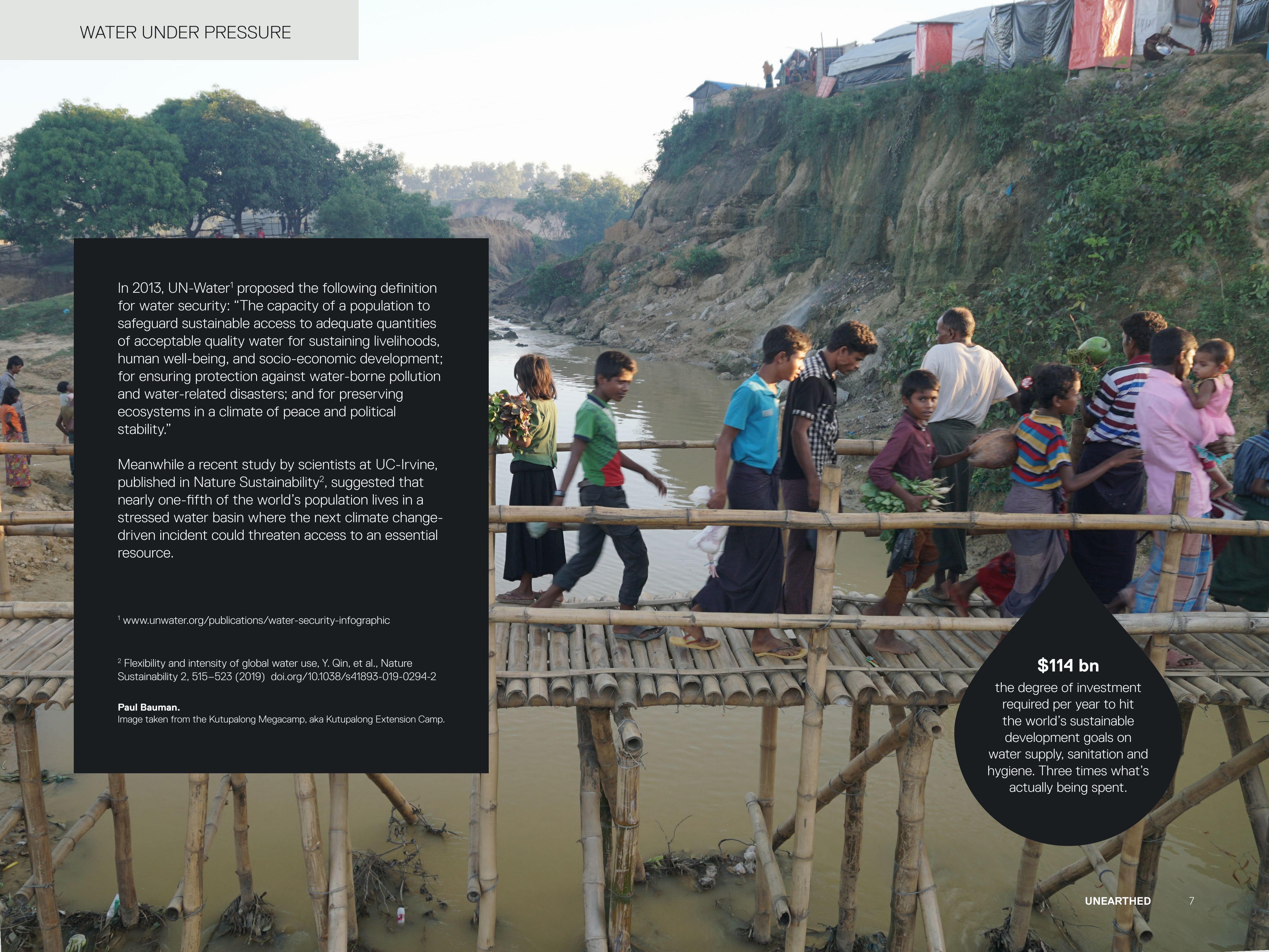
Hanford Nuclear Waste Site

WASHINGTON. Considered to be the world's largest environmental cleanup, with a staggering $500 billion dollars likely to be spent before completion (which could take another 50 years). Hanford was the site of the world's first plutonium reactor and processed radioactive material for most of the 60,000 nuclear weapons in the US arsenal during the Cold War. That left 177 underground tanks containing **¼ billion litres (56 million gallons) of radioactive waste** to dispose of – and all within sight of the Columbia River.

WATER UNDER PRESSURE

THE COMPLEX CHALLENGES OF OUR WATER FUTURE





In 2013, UN-Water[1] proposed the following definition for water security: "The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development; for ensuring protection against water-borne pollution and water-related disasters; and for preserving ecosystems in a climate of peace and political stability."

Meanwhile a recent study by scientists at UC-Irvine, published in Nature Sustainability[2], suggested that nearly one-fifth of the world's population lives in a stressed water basin where the next climate change-driven incident could threaten access to an essential resource.

[1] www.unwater.org/publications/water-security-infographic

[2] Flexibility and intensity of global water use, Y. Qin, et al., Nature Sustainability 2, 515–523 (2019) doi.org/10.1038/s41893-019-0294-2

Paul Bauman.
Image taken from the Kutupalong Megacamp, aka Kutupalong Extension Camp.

$114 bn

the degree of investment required per year to hit the world's sustainable development goals on water supply, sanitation and hygiene. Three times what's actually being spent.

Adam Pidlisecky
Chief Research Officer,
Seequent

With a Ph.D in Geophysics from Stanford and an associate professorship in Geoscience at the University of Calgary (specialising in hydrogeophysics), Unearthed didn't hesitate to ask Seequent's own Chief Research Officer, Adam Pidilisecky to introduce this edition's theme on Water Security and what this means for all the engineers and scientists around the globe.

WATER UNDER PRESSURE

By 2025
half the world's people will live in countries with high water stress

AT A GLOBAL LEVEL, WATER IS SIMPLY A FUNDAMENTAL, LIFE SUSTAINING RESOURCE.

It governs our ability to produce food and drives many aspects of industry. However, it is also seeing increasing demand and pressure due to factors such as growing population, rising incomes and accelerating consumerism. Couple this with increasing stress on water resources due to changes in climate and it is clear that the water scarcity (in terms of quality and quantity) is a looming issue.

Water security, however, is about more than just water availability. It also includes water related risks such as flooding, subsidence and slope failures.

While some of these issues may seem esoteric, they have actually never been more real.

In 2018 we saw Cape Town, South Africa, narrowly avert "day zero" – the day the city was expected to run out of water. In 2017, California emerged from a six-year drought only to be impacted by significant levels of flooding. In Mexico City, aquifer drawdown is causing differential settlement that is wreaking havoc with infrastructure. From the point of view of the Civil and Environment sector, we believe that we will all have a significant role to play to ensure future water security.

At Seequent, we see water security as a concept inextricably linked to society's continued growth and prosperity.

That is why in this edition we take a look at some ways our industry is contributing to water security. In particular we will explore two specific areas of water security: groundwater management and geotechnical risk. This is not meant to be an exhaustive study; it is simply meant to highlight some of the emerging issues. We also fully recognize that in most ground engineering applications, water and geotechnical performance are coupled.

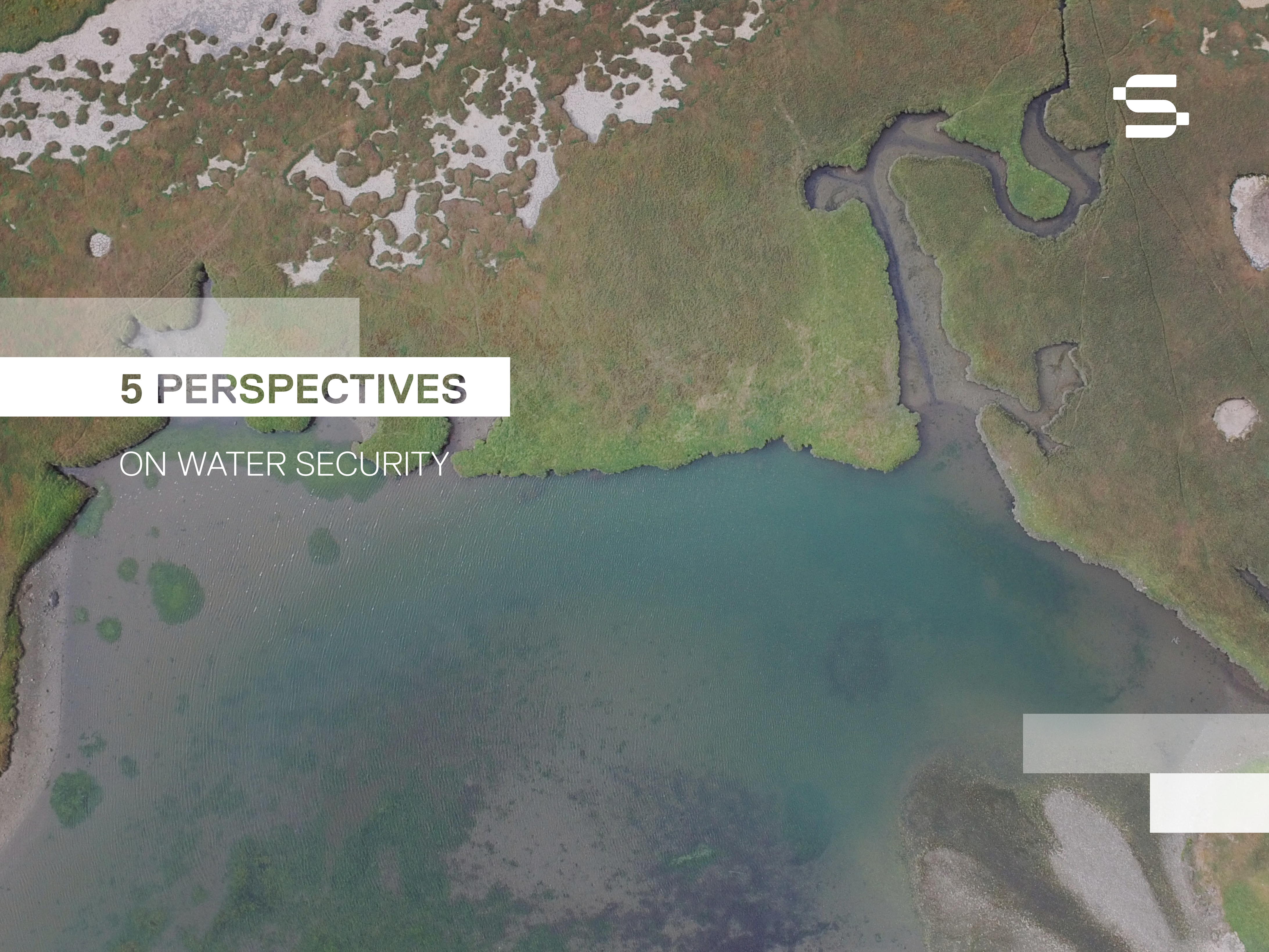
On the groundwater front we highlight examples that address water availability and quality. We look at the role managed aquifer recharge plays in ensuring water availability, highlight a UN initiative in Bangladesh aimed at ensuring access to quality water for refugees, and finally focus on the emerging use of geophysics to understand better the extent and vulnerability of groundwater resources.

On the geotechnical front we address two areas. First, we look at tailings dam safety and how we might be able to improve our ability to monitor and assess risk at these facilities. The second focus highlights the issue of groundwater related subsidence and the impact it has on infrastructure and engineered structures.

While water security is a daunting issue, it is one we feel has solutions. Society will look to the Civil and Environmental engineering sector to provide them.

5 PERSPECTIVES

ON WATER SECURITY



WATER SECURITY AND: **TAILINGS DAMS**

Tim Schurr
Solution Architect, Seequent

THE SITUATION

Tailings dams are the most common way mining companies deal with waste disposal when they're extracting base and precious metals. The water used in grinding and processing the minerals is stored in a dam, where the leftover mineral particles form a slurry.

They present two major dilemmas.

1) Tailings dams are far from the prestigious projects of embankment dams created to profitably store water. Instead they are often cost conservative spends to solve an unwanted problem at minimum expense. They are also built in stages as mines often close before expected. This can happen over many years, and staged construction may increase the risk of poorer supervision and additional flaws.

2) When they fail, the devastation and pollution caused by the slurry can be enormous, to a degree far outstripping water alone as it tears through buildings and deposits metals on its way.

THE IMPACT

In November 2015, the largest socio-environmental disaster in Brazil's history occurred when the Vale Mariana dam failed, spewing 50 million m^3 (11bn gallons) of mine tailings through the Doce River basin and out to the estuary, contaminating it with trace metals. It was the world's largest tailings dam failure, and the 11th such serious failure in a decade, prompting calls for stronger legal measures to force the industry into action, and better technology to support it.

In January 2019, the Brumadinho tailings dam similarly failed, with Brazil's National Water Authority estimating that the released tailings could pollute more than 300 kilometres of rivers. However, this is very much a global issue with tailings dam failures in India, Mexico, Australia, Canada, Russia, the USA, China and beyond during the last decade. In 2010 the failure of the Kolontár tailings dam in Hungary released 700,000 m^3 (15million gallons) of caustic red mud, killing ten people, injuring 120 and flooding 8 square kilometres. These are substantial events.

It doesn't help that, because of their nature, tailings dams can feature among the largest man-made structures on earth. Nor that because more mines are operating longer, often with reduction in ore grades, the degree of waste is growing, and the risk along with it.

That risk – especially to water supplies - was sufficient enough to lead the Central American country of El Salvador to ban mining altogether in 2017. It was a move prompted by a history of dealing with the environmental legacy and water contamination of previous mines. If such attitudes spread in the face of this threat to water quality, the mining industry may find the reputational damage could be outweighed by the more pressing issue of withdrawals of rights to operate and the losses in revenue they entail. And increasingly the societal view is that this is one more environmental issue that should not be left to our children to remedy.

THE GEOLOGY

Geology is important in two ways says Tim Schurr - Seequent's Solution Architect. It supplies the materials that compose both the tailings and the dam material. Secondly, geology provides the framework upon which the tailings management facility is placed.

Local geological conditions are very important for the short term especially says Tim, but also the long-term stability of these tailings' facilities. Since water management is the key factor for dam stability during operations, the hydrogeological conditions are critical. If the underlying strata are very tight, low permeability, then more water must percolate through the dam, decreasing stability. Subsidence due to the weight of the dam and tailings can also compromise integrity. Seismicity is also important since earthquakes can cause liquefaction of both tailings and dam material.

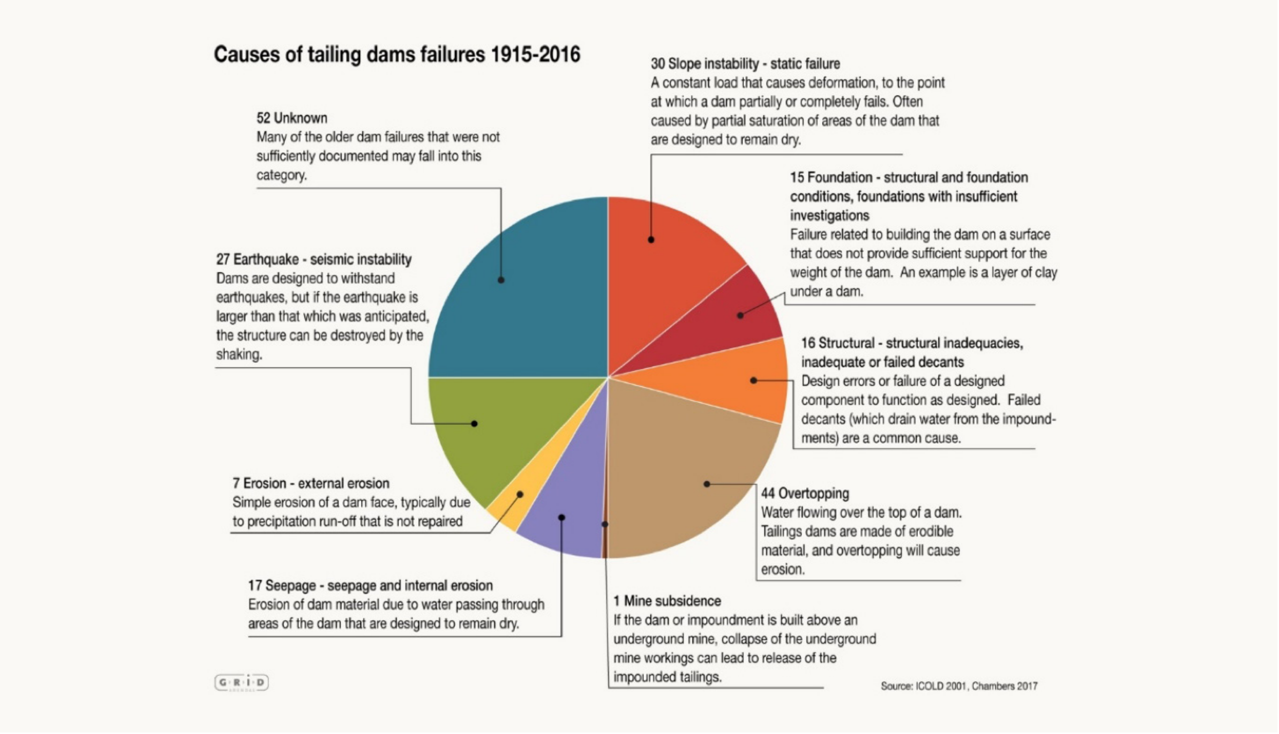
Indirectly the local geological conditions can both help and challenge stability. Tailings that have lots of pyrite (and some other minerals) have the potential to generate acid mine drainage. Therefore, those tailings are often kept underwater, which makes water management in the tailings dam more difficult. The more water there is in the facility, the more challenging it is to keep most of the dam's material unsaturated, so it won't liquify. On the other-hand, other minerals cause tailings to solidify (self-cementing), and that means the long-term stability of the facility is enhanced. Most failures occur in active tailings dams, and the later may be one of the reasons.

WHAT COULD BE DONE

Since most failures are preceded by one or more warning signs, vigilant monitoring could aide in timely mitigation before failure. An exception would be failure due to earthquakes or major storm events, where the design needs to have taken such potential events into account. So, a good maintenance programme is an essential requirement for effective tailings impoundment management, a vital component of which is a comprehensive surveillance programme. Both of those ought to be considered during the design phase.

60km/hr

or 37mph is the speed that several millions of cubic metres of slurry can travel when a tailings dam fails



WATER SECURITY AND: **EMERGING CONTAMINANTS**

Lorraine Godwin
Global Business Director,
Seequent

THE SITUATION

'Contaminants of Emerging Concern' are generally those introduced into water sources from industrial waste, agricultural runoff and personal care (eg. cosmetics and medicines). They are important because the risk they pose to human health is not yet fully understood.

Industrial pollution, landfill waste disposal, fertilisers and pesticides, and wastewater runoff have all been major contributors. Non-aqueous organic solvents like trichloroethylene (TCE) - commonly produced in petrochemical industries such as automotive, textile, and fumigation - are dense, so subsurface environments absorb them more readily. They can percolate quickly through soil and bodies of water and pollute large areas faster than other pollutants like gasoline or diesel fuel. Up to 90% of orally administered drugs can also pass through the human body and end up in the water supply.

Around 2 billion people across the globe rely on water supplied from underground aquifers as their main source of freshwater. Some 40% of Americans depend on groundwater. California has lately increased its uptake to 60% of its water supply as its rivers and above ground reservoirs dry up.

However, in the US, water has not been properly monitored according to the Safe Drinking Water Act of 1974 and other regulatory measurements in around 25% of U.S. cities. Some estimates put more than half of US stream and river miles in violation of water quality standards. When it is monitored, researchers find that hazardous contaminants such as lead, arsenic and cyanide have continued to pollute drinking water for 14 million Americans in the United States alone.

Once polluted, an aquifer may be unusable for decades, or even thousands of years. Groundwater can also spread contamination far from the original polluting source as it seeps into streams, lakes, and oceans.

THE IMPACT

The impact can be devastating. TCE contaminated water has been linked to kidney and liver damage as well as leukaemia[1].

Detroit schools are plagued by heavy metals in their water, especially lead and copper, and both have been linked to reduced cognition and a host of other medical conditions.

The problem doesn't just exist in the United States; it is ubiquitous. In Lanzhou, China, a plant using benzene (a carcinogen) in its processes suffered a series of explosions from 1987 to 2002, resulting in groundwater contamination more than 20 times the "legally safe" limit. The toxicity was first detected in 2014. It is estimated that more than 30 tonnes of benzene has been absorbed into the groundwater from the explosions. In India, the Yamuna River has been a dumping ground for sewage, chemicals, and other waste for decades. It is considered the most contaminated river on Earth, although it is the source of 70% of the country's drinking water. Mining operations in western Ghana, West Africa, caused cyanide contamination after an incorrectly installed wastewater dam failed. Starting in October 2001, the leak continued and endangered and killed fish and humans.

Contaminated subsurface environments can be difficult to treat or clean up, and the costs can spiral into millions of dollars.

THE GEOLOGY

Lorraine Godwin, Global Business Director explores the geology. "These problems can be compounded when the geology and hydrogeology are complex. An example would be areas such as unconsolidated sediments interfingered with volcanics and underlain by sedimentary rocks and a Precambrian basement of gneisses and schists. Faced with such challenging scenarios, a modern approach to finding the aquifers and tracking the contamination is needed."

1 - https://www.ewg.org/news-and-analysis/2018/07/ewg-news-roundup-727-carcinogenic-tce-tap-water-food-additives-avoid-and#.W3cdNOhKiUn

WHAT COULD BE DONE

One district in Nebraska is using 3D models generated from geophysical airborne electromagnetic (AEM) survey results and borehole data to manage land use in an area where groundwater availability and nitrate contamination is a concern. The borehole databases contain a wealth of information, from stratigraphic logs documented by the Nebraska Conservation Survey Division dating to the 1930s, to water discharge rates included in the state's well registry.

The resultant models created by integrating the geophysical and borehole data allow state districts and regulators to understand better the plumbing of the underground system, and that helps them improve water quality by managing sources of contamination in the area. A 3D model of the hydrogeology also gives a better grasp of the layout and function of the wells in the area, and provides insights about the impact of recharge on water quality and drainage.

Tying disparate georeferenced datasets such as borehole, geophysics and geochemistry from soil and water sampling together into a 3D mapping platform transforms complex data into deep insights and clarity about contaminated subsurface environments.

But even with those insights in place, it's just as important to ensure that ongoing monitoring with robust tools continue to track that contamination, over time, as it moves through soil or groundwater.

3/4

of all Americans live within 16km (10 miles) of polluted water

WATER SECURITY AND: **SALTWATER INTRUSION**

> Climate change, growing water demands, and manipulation of natural hydrologic systems have led to saltwater intrusion being considered a significant threat to future fresh water resources globally.

"Saltwater intrusion is the biggest untold water story in the world today. It's a silent problem. It's easy to ignore politically but it can spoil the water source for future generations."
Ron Duncan, interim general manager,
Soquel Creek Water District

THE SITUATION

Saltwater intrusion occurs when too much groundwater is pumped from coastal aquifers, upsetting the subterranean balance between inland freshwater and the relentless ocean. Water moves through the ground, from high elevation to low, as it does in rivers. At the margin of a coastal aquifer, fresh water and saltwater mix, and when the rate of groundwater pumping increases, the equilibrium shifts. As aquifer levels drop, the saltier water trickles in, filling the gaps in the sandy soil where fresh water used to be.

While this process has been observed throughout the world for over a century, climate change, growing water demands, and manipulation of natural hydrologic systems have led to saltwater intrusion being considered a significant threat to future fresh water resources globally.

THE IMPACT

Nowhere is this problem felt more keenly than in California. The combination of groundwater and good climate has built the region into a year-round agricultural powerhouse. But farmers have drunk deeper than the basin could sustain. The California Department of Water Resources has now designated groundwater basins in Soquel, the Pajaro Valley, and the Salinas Valley as "critical" because of saltwater intrusion. In Monterey County, the saltwater boundary, at its farthest reach, is more than 10 kilometres (6 miles) inland.

THE GEOLOGY

A recent study, which included geophyisicists from Stanford university have shown that the intrusion is highly veriable, and heavly influenced by the complex geology of the area.

Saltwater intrusion is traditionally monitored using measurements made in wells and predictive flow models. However, well measurements have a number of drawbacks. They may provide point data but fail to capture the spatial complexity in subsurface conditions. Salinity measurements can be flux-averaged concentrations, and head measurements are affected by the density of the water column, so can be misinterpreted in the presence of unknown saltwater. They are also susceptible to measurement, instrument and time lag errors. Given these limitations there is significant opportunity for additional methods of mapping and monitoring the distribution of saltwater in the subsurface for improved management of coastal aquifers.

WHAT COULD BE DONE

Many facilities are trying to halt the intrusion. In Monterey County, a new water recycling system produces 3,700,440m^3 (814 million gallons) of recycled water from industrial wastewater, farm drainage, and stormwater, for injection into the aquifer and for farm irrigation. But these facilities are expensive and the state agencies have no clear picture on the speed or seriousness of the intrusion and where they need to focus.

The Stanford research team led an electrical resistivity tomography (ERT) study[1] along a 45 kilometre (28 mile) stretch of Monterey Bay coastline to determine the extent of saltwater intrusion (ERT measures the electrical conductivity of water, which is increased by salt). The hope is that local water managers can use the findings to identify the regions most impacted and better target interventions.

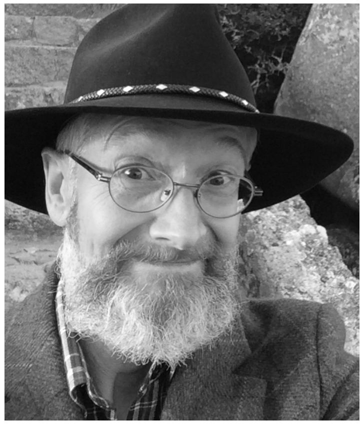
Earth imaging using geophysical methods has the potential to revolutionise the approach to managing groundwater systems, say those involved with the technology. It has even been likened to the impact that medical imaging has had on human health, delivering a wealth of previously unachievable insight.

ERT can identify where geologic features are impacting the pattern of intrusion, where surface water is changing the salinity of underlying sediments, and where anthropogenic actions (such as pumping from individual wells) is causing saltwater intrusion. It can often deliver insights not available through traditional data, or in regions where data is limited, highlight where further information could be most usefully gathered. Such uses could greatly improve predictions and management of saltwater intrusion and should be transferable to other basins around the world impacted similarly to Monterey.

20%
increase in salinisation of the world's irrigated land area due to inefficient use of water for crop production

1 - https://www.sciencedirect.com/science/article/pii/S0022169417301154

WATER SECURITY AND: **SUBSIDENCE**



Thomas Krom
Director of Sustainability,
Seequent

THE SITUATION

Shifts in tectonic plates, geological faulting and soft clay geology have long been contributors to the abiding problem of subsidence, but water security is adding its own complications. For example, the combination of excessive groundwater extraction and increasingly heavy construction has doomed Jakarta, Indonesia, to be the world's fastest sinking city – 2.5 metres (8 feet) in the last 10 years and 25cm (9.8 inches) a year in some parts.

There is no reliable source of piped water, so a thirsty population pumps it from deep aquifers setting off disastrous results. Meanwhile lax regulations fail to control the problem, with just about anyone able to carry out their own groundwater extractions, from individuals to massive shopping malls.

The issues for these coastal cities is made worse by the rising sea levels due to climate change, and Jakarta isn't the only one in crisis. The National Reform Council's committee recently warned that Bangkok could soon be submerged if more corrective action wasn't taken. They reported that ground water extraction was contributing to nearly 70% of its subsidence.

On the other side of the globe, Mexico City, Louisiana and Las Vegas are well known case studies of sinking cities. With a huge population of more than 8 million people, Mexico City is subsiding on a grand scale – more than 9 metres (30 feet) in the last hundred years.

THE IMPACT

Without action the impact will be devastating; millions of homes underwater and entire city populations displaced. Some models predict that 95% of North Jakarta will be submerged by 2050, and it's already possible to find abandoned office buildings with ground floors awash in stagnant water. With 1.4 million people living in North Jakarta alone, this is no small problem for the Indonesian government.

In addition to ground subsidence, Bangkok also faces land erosion - up to 4 metres (13 feet) a year in some areas of coastline, due to changes in climate such as higher tides, more ferocious waves and monsoons. Coupled with land clearing for development, this has wiped out the mangrove plantations, forcing inhabitants to move further inland. Coastal erosion has also troubled Louisiana, though here the problem is so extensive, the loss equates to the disappearance of 65km^2 (25 square miles) of wetlands each year. That's a football field sized area every 30 minutes.

THE GEOLOGY

"Each city has its own geological make up", says Seequent's Head of Sustainability Thomas Krom, "and this causes groundwater extraction subsidence to manifest differently in every place."

A 2015 academic paper[1] identified Mexico City as being located above a sequence of deformable unconsolidated lacustrine sediments interlayered with strong volcanic rocks. Combining these natural conditions with massive groundwater extraction, sunk the city unevenly, at rates from 0 to ~370 mm/yr (1.2 feet).

In Las Vegas Valley nearly all the groundwater supply comes from a zone of confined and semi-confined principal aquifers at depths of 200-300m (656-984 feet). Since 1968, annual withdrawals have been gradually reduced (in 1991 the water district began re-injecting water into the subsurface) but have consistently exceeded natural recharge levels by factors of two to three. As a result of continued long-term overdraft, water levels have declined more than 90m in some portions of the valley.

WHAT COULD BE DONE

Tighter regulations could slow the groundwater extraction and reduce the risk of subsidence, believes Thomas. For example, the Thai government banned groundwater extraction 38 years ago, helping to slow Bangkok's subsidence to 1cm (0.39 inches) per year. But recent droughts have forced people to ignore the ban.

A 32km (20 mile) outer sea wall across Jakarta Bay could create an artificial lagoon, which the city's rivers could drain into. However, there is no certainty the $40bn project would provide a permanent solution. It's an interim measure only, says Jan Jaap Brinkman, a hydrologist with the Dutch water research institute Deltares, and will buy Jakarta no more than an extra 20 to 30 years.

1 - Solano Rojas, D. E.; Wdowinski, S.; Cabral, E.; Zhang, Y.; Torres, Y

40%

The gap expected between water demand and water availability by 2030

WATER SECURITY AND: HUMANITARIAN CRISES

CASE STUDY How a deeper understanding of geology was able to alleviate water shortages for thousands of refugees in Bangladesh.

> “The data revealed that the geology of the Leda and Nayapara camps was far from the continuous, thick sandstone aquifer presupposed for the peninsula.”

THE SITUATION

The plight of nearly three quarters of a million Rohingya refugees in Bangladesh is just one example of how the desperate need for water can become entwined with so many humanitarian crises across the globe. In 2017, fleeing human rights abuses in neighbouring Myanamar, the refugees crossed by raft and by foot through jungle to camps on the Bangladesh's Teknaf peninsula.

In the Kutupalong-Balukhali Expansion Camp, which holds more than half a million people, 6,000 shallow boreholes had been dug to provide water, but 80% of these were contaminated by E. coli from overflowing latrines and fecal sludge pits. A not unfamiliar problem in such dire circumstances.

The camp needed deeper, aquitard-protected, high-yielding aquifers to supply a sustainable source of clean drinking water through both the wet and dry seasons. Meanwhile the smaller but hard-pressed Leda and Nayapara refugee camps were trucking water in during the five-month dry season of November to March. Long term, these camps needed groundwater resources to support the 70,000 strong refugee population through the most arid time of year.

THE GEOLOGY

We generally think of Bangladesh as a densely populated, low-lying country that is periodically subject to flooding during seasonal monsoons, so it's hard to imagine water scarcity being an issue. Yet, in the southern Teknaf peninsula, a combination of unfavourable hydrogeological conditions and inadequate infrastructure means exactly that. Although monsoon rains bring up to 4,500 mm (15 feet) of precipitation a year, during the pronounced dry season any rainfall has a negligible impact on the recharge of groundwater aquifers or surface water reservoirs

A geophysics team, from resource and infrastructure consultants Advisian was given the job of identifying drilling locations that would provide access to safe water as rapidly as possible in these camps.

To characterise the water resources available, the team turned to a number of Seequent products including Leapfrog and View (for 3D visualisation, collaboration and modelling) and Geosoft's Oasis montaj (for geophysical analysis and modelling).

Paul Bauman, of the Advisian geophysics team, said that being able to look at the information in 3D made a valuable contribution to the success of the project. "View, being cloud-based, is particularly valuable for these overseas humanitarian water relief projects. There may be United Nations users on the ground in Bangladesh, but United Nations High Commissioner for Refugees, their watch program, is headquartered out of Geneva. So there may be people on three continents: Asia, Europe, and North America [where Advisian is located].

"They're all looking at the same datasets, all having questions and queries, but perhaps have different interests. With View, everyone has control of the scale, and they can highlight the particular model features they're interested in."

THE OUTCOME

The data revealed that the geology of the Leda and Nayapara camps was far from the continuous, thick sandstone aquifer presupposed for the peninsula. The continuous aquifers found elsewhere in Bangladesh did not exist here, and the aquifers present were actually small and relatively discreet. This led the UN to amend their strategy and expand existing water storage reservoirs, which were able to tide over the camps between rainy seasons.

Meanwhile in the Kutupalong-Balukhali Expansion Camp, the data prompted a move away from the thousands of easily contaminated shallow hand-pumped wells (that would go dry in the drier season) to newer, deeper aquifers whose existence was demonstrated by the findings. The newer aquifers are both highly productive and better protected. The UN can also drill fewer wells (which are costly to do) and can create centralised chlorinated water systems.

THE FUTURE

While Seequent technologies played their part in this crisis, this role was minor compared to the enormous contributions made by the people and teams on the ground. Their efforts have guided the installation of hundreds of water-supply wells for the Rohingya refugees and deserve recognition for the suffering they have helped alleviate. Though the camps have drinking water, the future of the Rohingya refugees is still uncertain and will remain arduous.

1/2

of the world's hospital beds are estimated be occupied, at any one time, by patients with waterborne illnesses

Paul Bauman.
All images taken from the Kutupalong Megacamp, aka Kutupalong Extension Camp.

THE ROLES OF TECHNOLOGY AND BEHAVIOUR

IN THE FUTURE OF WATER SECURITY

Geoff Plastow
Technical Analyst,
Seequent

Geoff is a Geophysicist with over 10 years of experience, in exploration and groundwater mapping, spanning five continents.

Geoff focuses on delivering practical solutions to real-world Geoscience problems.

THE TECHNOLOGY REVEALING THE EARTH'S GROUNDWATER SECRETS

Electromagnetic (EM) surveying is a technique that has traditionally been used to map mineral resources. However, in recent years EM has been embraced by governments and private organisations around the world as a faster and more cost-effective way of aiding groundwater mapping.

Geoff Plastow, Technical Analyst at Seequent, was involved in some of the earliest uses of EM to map aquifers in Canada and has watched its use expand rapidly.

In North America and many other parts of the world, governments, organisations or groups of local individuals may have some knowledge of the aquifers in their region, but it will be limited to what they've discovered by drilling into the earth. In some cases the groundwater can be at the surface, or it might be more than 100m below, but that's about all they'll know. They're not aware of what else may be going on directly beneath their feet unless they actually drill there.

And drilling is challenging. It can be difficult, inconvenient, slow, expensive and comes with a number of environmental concerns. And what are you going to do to get more information? Drive every kilometre, drill a hole into the ground and analyse what you find? Across large areas that's simply impractical and would be enormously expensive.

So the practice of using geophysics and remote sensing to rapidly cover a survey area has considerable appeal, and its adoption has been growing significantly in recent years. EM surveys can be done from the air, cover large areas 50 or 100km (19 or 31 square miles) square in a week or two and there is absolutely no ground access required. You can have a fast turnaround on 3D models of the subsurface, which means better-informed decisions can be made more quickly.

A helicopter view of the Earth's resistance
Airborne surveys use a technology call Time-Domain Eletromagnetics, which involves creating an electromagnetic signal that varies with time. Equipment that resembles an extremely large hoola-hoop is towed under a helicopter as it flies about 100m (328 feet) above the ground.

The equipment transmits an electromagnetic signal into the earth and depending on how resistive or conductive the earth is, we can use the returned signal to infer the nature of the subsurface. Rocks will have different physical properties that will affect how the current flows, and that can tell us, for example, if there are clays or unconsolidated sediments present.

In the geophysical processing and modelling of the result we can derive a pretty realistic earth model of what is below our feet, and from that we can work with a team of geoscientists to assemble a hydrogeological model based on the resistivities and other known rock properties.

Time Domain Electromagnetic surveying (TDEM) uses induction to measure the electrical conductivity of the subsurface. The primary magnetic field created from a transmitter coil generates eddy currents in conducting bodies (including those beneath the surface). A receiver coil measures the secondary magnetic field from the subsurface, and it's this that helps geoscientists establish the nature of the subsurface conductor.

This sort of EM survey has really become the gold standard of aquifer mapping, and the 'deliverables', if you like, will be a series of maps and subsurface models that infer where there are aquifer materials. Predominantly it's Oasis montaj that users turn to as their main geophysical processing and visualisation platform to plan, collect and do quality control on the data, then visualise it as an integrated geoscience dataset. This incorporates geology, borehole data, geophysics and hydrological properties (the collective hydraulic characteristics of a soil or rock, such as the conductivity, permeability, water content, and pressure head, plus the interrelationships among those properties). It's definitely a team process to build a full hydrogeological model.

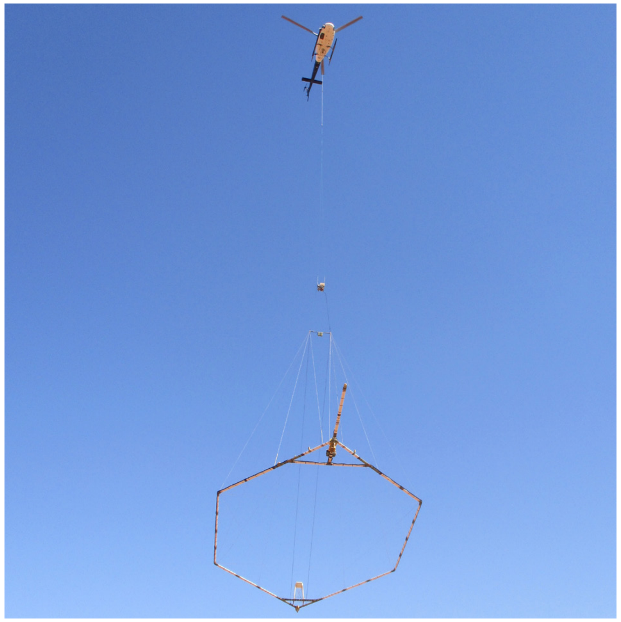
> EM surveys can be done from the air, cover large areas in a week or two, there is absolutely no ground access required, and you can have a quick turnaround on 3D models of a subsurface aquifer material.

Helping stakeholders see the water under their feet

Providing a hydrogeologist or a government or a farmer with that information is very empowering. Some of those stakeholders will want the nuts and bolts of ohmmeters and conductivities; some will be government officials who want to be certain how far the aquifer extends under their land; but others are farmers who just want to know, do they drill 10 metres or 50 metres (33 feet or 164 feet) to get to the water they need?

And because of that survey, which may have covered thousands of kilometres in a matter of weeks, now we do know where the aquifer boundaries are, how deep it extends, whether it pinches out and is confided, whether there's a impermeable layer and so on.

You can see the aquifer boundary under the earth, and that would never have been possible – certainly not cost effectively – without this type of work. And while EM may initially have been used to support irrigation planning, it's not just farmers using it today. Severe groundwater shortages in California, for example, are starting to impact people's access to drinking water. The applications of EM surveying have grown and grown, and I think they are only going to continue.



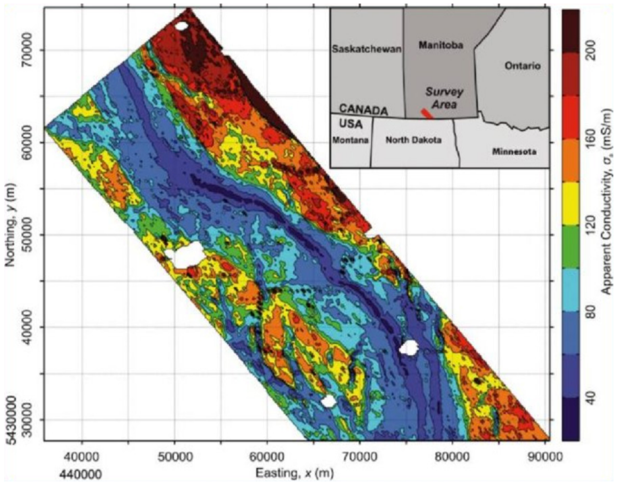


FIGURE 1

Figure 1 is from one of the first groundwater focused airborne Time Domain EM surveys done in Canada (2010). The image represents a depth slice through the earth 75m (246 feet) below the surface. The areas that are blue represent the buried valley and aquifer material. The areas that are red represent boundaries, interfluves, and non-aquifer material. Needless to say, the geophysical model is not only mapping the main extents and boundary of the Spiritwood aquifer, but all of the small deviations and interplay of the aquifer in the southern part project area. This type of detail would be impossible to achieve without aid of geophysical mapping.

30%

of the Earth's freshwater is in the ground

4 EMERGING TRENDS FOR WATER SECURITY

Water security has traditionally been challenged by factors such as degradation in quality and decline in availability. But it is in areas of growing urbanisation that concerns are now advancing, leading to four emerging trends.

1) BETTER GOVERNANCE

Factors such as urbanisation and climate change are increasingly challenging the way water is governed. A case in point would be California's Sustainable Groundwater Management Act that aims to prevent excessive groundwater extraction causing "overdraft, failed wells, deteriorated water quality, environmental damage, and irreversible land subsidence that damages infrastructure and diminishes the capacity of aquifers to store water for the future."

2) REUSE AND RECYCLE

Zero Liquid Discharge is becoming common in industry and society. At the industry level, it means water in a factory is kept in the factory and re-used via cleaning and treatment. In potable water situations it means once you have used the water, you use it again. Currently sewage (used potable water) is recycled for another use such as irrigation and infiltration ponds. But that will likely change...

3) CONSERVATION

Certainly, one of the best ways to improve water security is to make sure that water is used efficiently and not lost. This has been a focus in many parts of the world for a long time, but there are still places it has not been implemented well. On top of that, there are constantly new technological advances that improve water efficiency such as waterless toilets and urinals.

4) WATER HARVESTING

Urbanisation means grassland, lawns or fields are now an urban landscape. Hard roofs, roads and sidewalks impede the recharge of aquifers whereas the previous surfaces allowed rainfall to percolate down. There are practices to ensure all water falling on those roofs, etc, is recharged as close as possible to where it fell. In addition, open landscapes could be used to capture runoff to serve as temporary storage or increase aquifer recharge. Constructing infiltration systems to capture roof water can also mitigate the flooding seen in modern urban landscapes.


THINGS YOU MAY NOT KNOW
ABOUT H_20

The biggest cloud...

...is around a massive black hole 12 billion light years away. The NASA scientists who discovered it estimated that it contains 140 trillion times more water than all the oceans of Earth.

Water should be a gas

Similar molecules such as hydrogen sulphide and ammonia are, but water molecules' stickiness holds them together as a liquid.

Or it could be glass

Supercool water to -135deg C in the right way and it will pass into a fourth state partway between its solid and liquid forms – glassy water.

68.7%

of the Earth's freshwater is trapped in glaciers.

In 100 years

A water molecule will spend 98 years in the ocean, 20 months as ice, 2 weeks in lakes and rivers, and less than a week in the atmosphere.

95%

How much water is in a cucumber.... and a jellyfish.

120

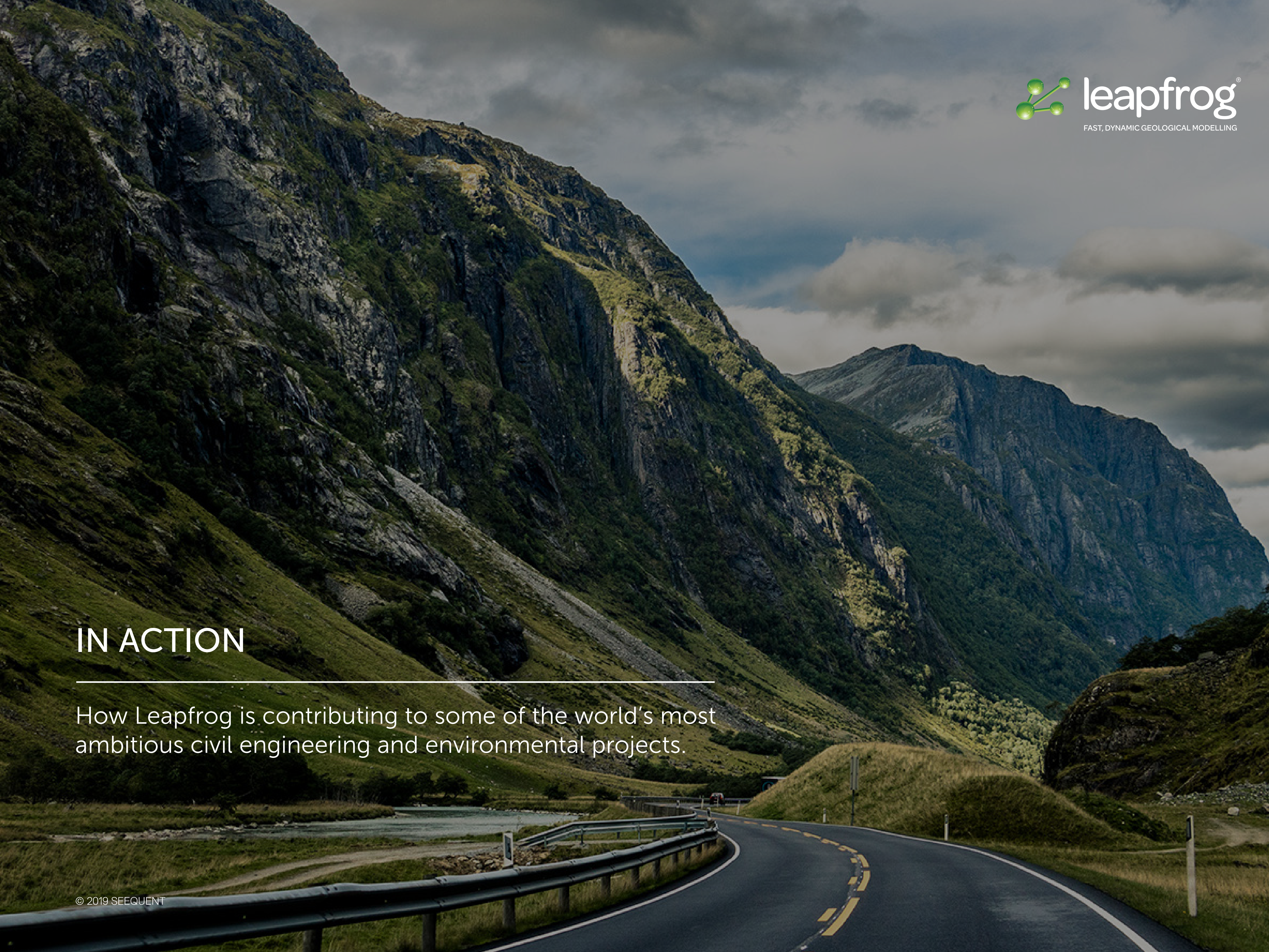
How many gallons of water it takes to create one egg.

Less than 1%

of the Earth's water is actually drinkable and available for consumption.

326,000,000, 000,000,000,000

The estimated number of gallons of water on earth (that's 326 million trillion). Less than 3% is freshwater.



IN ACTION

How Leapfrog is contributing to some of the world's most ambitious civil engineering and environmental projects.

The Emu Swamp Dam...

...is a proposed 12,100 megalitre urban and irrigation supply dam on the Severn River in Stanthorpe, Queensland. This $84 million project aims to increase water security and agricultural proficiency for an area known for drought, benefiting the local economy, increasing production for Queensland fruit farmers and viticulturalists (who currently truck water in from New South Wales) and securing an estimated 700 local jobs.

Jacobs, one of the world's leading providers in technical, professional and construction services, was contracted to complete a detailed business case, including a reference design.

One significant challenge they faced was assessing the project's geological risks and then communicating them effectively to a wide range of stakeholders, many without technical expertise. For this they used 3D subsurface modelling solution Leapfrog Works.

12,100 megalitres
Capacity of the project

"We were also able to use Leapfrog Works' movie feature to create fly-throughs and these impressive visualisations really helped to bring the project to life."

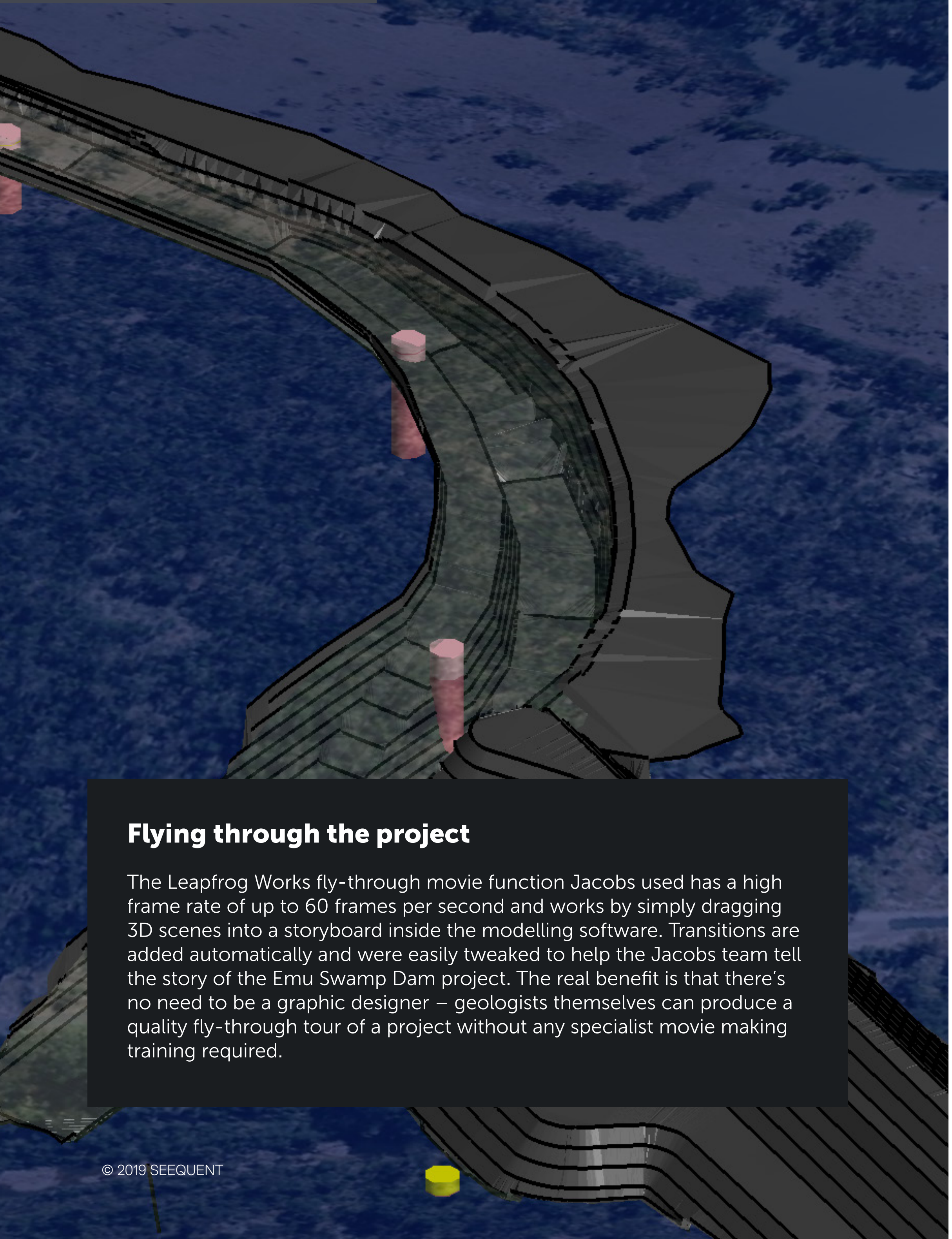
The Challenge

The risks associated with any dam project are considerable, not least due to the threat of the valley bulging and associated permeability. The Emu Swamp Dam project faced many challenges including determining an economic and safe design, securing significant water resources without affecting downstream flows, incorporating the project into State Water plans and liaising and communicating with a variety of stakeholders from local councils, chambers of commerce and government to private farmers, developers and the local community.

Graeme Jardine, APAC ME Technical Director Engineering Geology, Jacobs Australia, said they used Leapfrog Works specifically as a communication tool to demonstrate to the community and non-technical forums what they had discovered through their drilling programme.

"Leapfrog Works had a very positive impact on our understanding and communication of the geology. Using 3D visualisation gave clarity and meaning, and allowed us to effectively communicate to all stakeholders. This 3D visualisation was particularly beneficial for those with no technical background. We were also able to use Leapfrog Works' movie feature to create fly-throughs that we could easily pause during consultations to explain key aspects. These impressive visualisations really helped to bring the project to life.

"And using an industry-specific tool like Leapfrog Works really helped with the successful delivery of the business case."



Flying through the project

The Leapfrog Works fly-through movie function Jacobs used has a high frame rate of up to 60 frames per second and works by simply dragging 3D scenes into a storyboard inside the modelling software. Transitions are added automatically and were easily tweaked to help the Jacobs team tell the story of the Emu Swamp Dam project. The real benefit is that there's no need to be a graphic designer – geologists themselves can produce a quality fly-through tour of a project without any specialist movie making training required.

The Investigation

By using Leapfrog Works to create a subsurface model, Jacobs were able to gain a clearer understanding of the geology and take action to mitigate the risks they faced.

- It prompted them to propose a grout curtain to stop seepage and piping failure.
- The subsurface model also identified weathered decomposed granite in the south-east abutment, which meant that the dam footprint could require widening and/or the use of anchors.
- It allowed Jacobs to plan for the use of spillway rock in the construction work, helping to determine that clay for the embankment dam would need to be hauled from outside the local area.
- Other environmental considerations identified included use of the rock from the spillway excavation in the construction work, and efficient management of the significant surplus.

Identifying all of these sources quickly and accurately is essential as they have an impact on the overall project cost and delivery.

The Outcome

"Leapfrog Works was able to save us considerable time as it's designed to meet the specific needs of the industry," concluded Graeme Jardine. "We don't need to switch between software packages, we can carry out all of the modelling in one place. Works is also extremely versatile and means we can interact with Building Information Model (BIM) designs and ground investigation databases, such as gINT & Holebase, as needed. This meant that we could bring all information into Works' highly visual environment, giving us a holistic view of the whole project, further helping reduce risk in decision making."

The Future

A decision regarding the Emu Swamp Dam's go ahead is likely in 2019 and could result in more borehole drilling to fully understand ground permeability. The Leapfrog model will help to inform this work when the project progresses to the detailed design phase. This new drilling data can be easily incorporated into the subsurface model using Works' dynamic updating feature. New data, gained from the field, can be loaded into Leapfrog Works and will automatically flow through to the end model and rapidly update it, with associated time saving and efficiency gains.

Jacobs are now using Leapfrog Works as their preferred geological modelling tool for other significant projects in the Asia-Pacific region, and are looking to expand its application into the Americas and the UK.

$84 million
Estimated cost of the project

Sponge Cities

Michaela Crum,
Customer Solution Manager,
Seequent

$100m

of flood damage in one city

By 2020 China hopes to turn

15 major cities

into Sponge Cities

Why it fascinates me

Last year, Houghton, Michigan, where I went to University, experienced a 1,000-year storm event with 14 centimetres (5.5 inches) of rain falling in six hours. Massive flooding destroyed property and infrastructure. Roads I once lived on were ravaged by sinkholes and converted to rivers. The governor declared a state of disaster for the counties affected, and the total cost of damage to public infrastructure alone sits at approximately $100 million, not including the devastation to homes and businesses. It made me think of what can be done to prevent such a disaster in the future. How can cities flood proof to become more resilient in an environment of growing urbanization and changing climate? That's when I became interested in the concept of 'Sponge Cities.'

How it works

A Sponge City is designed to absorb, clean, and reuse rainfall in a safe, ecological manner that reduces potential damage from flooding and pollution. Techniques include replacing concrete pavements with wetlands, permeable roads or new forms of porous asphalt; plus green rooftops and rain gardens. By 2020 China hopes to turn 15 major cities into Sponge Cities with the ability to absorb and re-use at least 70% of rainwater. This, of course, comes with major challenges. Retrofitting existing infrastructure in cities is difficult and expensive - China's program will cost hundreds of billions of dollars – so creating cities with sponge models from the start makes more sense, and leads to lower investment and maintenance costs.

What it offers

The initial driver for Sponge Cities was flood proofing in urban areas, however, 'spongy' infrastructure is beneficial in many other ways. It allows cities to capture and store water for various uses and enhancing water supplies. Water absorbed into the soil is naturally cleaned and purified, and stored as groundwater reducing the burden on sewer systems. This also helps clean polluted runoff creating a better quality of life. These green initiatives help Sponge Cities become more resilient, sustainable, and provide a holistic approach to water management for growing urban areas.

Geology's role in Sponge Cities

Geology plays an important role in planning for Sponge Cities. The subsurface properties of soil are crucial to determining how well water will be absorbed and stored for future use. Properly modelling the soil can enable cities to plan ideal locations for water retention. It would be hugely rewarding to use Leapfrog Works to model the geology and infrastructure for a Sponge City plan – especially when the terrible damage flooding can create has such a personal relevance for me. Being able to incorporate geology with the infrastructure models to view sewer networks, pipes, and water storage areas would be highly useful in this special corner of the Water Security story.

AS WE WENT TO PRESS...

In June, Scientific Reports published news of **the discovery of a vast, low salinity aquifer** extending 90km (56 miles) offshore from America's east coast (around New Jersey and Martha's Vineyard). It was mapped via marine EM methods, using passive receivers on the seafloor and a transmitter towed behind a ship to look for the bulk electrical resistivity typified by porosity and pore fluid salinity in offshore sediments. The presence of an aquifer had been suspected since the 1970s when oil drilling would occasionally encounter relatively freshwater. Now analysis of the EM results suggests the find is enormous – around 2,800 cubic kilometres (670 cubic miles) of water. It may even go on to extend along this entire stretch of coastline, separated from the overlaying seawater by hundreds of feet of sediment. The aquifer does contain low levels of salt, so would need some degree of desalination before being suitable as drinking water, but it could be significant in easing water shortages, especially if it's the start of similar discoveries along this part of the American shoreline.

The southern Indian city of Chennai (formerly Madras) was declared in crisis in mid June after it **effectively ran out of water**. Delays in the monsoons and a major heatwave have seen its four main reservoirs completely run dry, with many of its 5 million residents queuing for hours to get water from government tanks. However, the crisis has not arrived overnight. The rains, responsible for the majority of Chennai's water, have been poor for the last three years. Meanwhile, 50 years of urbanisation have filled in the surrounding wetlands that have previously helped store and purify the city's water. Chennai is one of 20 world cities The Nature Conservancy has predicted will experience critical water shortages by the middle of the century. That this is already happening is a sign of both the rapidity with which water security circumstances can change, and the unpreparedness of authorities on the ground to address them.

If you have feedback, questions or any thoughts on what you'd like us to cover in future editions, please contact:

support.civil@seequent.com

For more information about Seequent's Civil and Environmental solutions, visit:

www.seequent.com/engineering