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17-19 NOVEMBER 2021

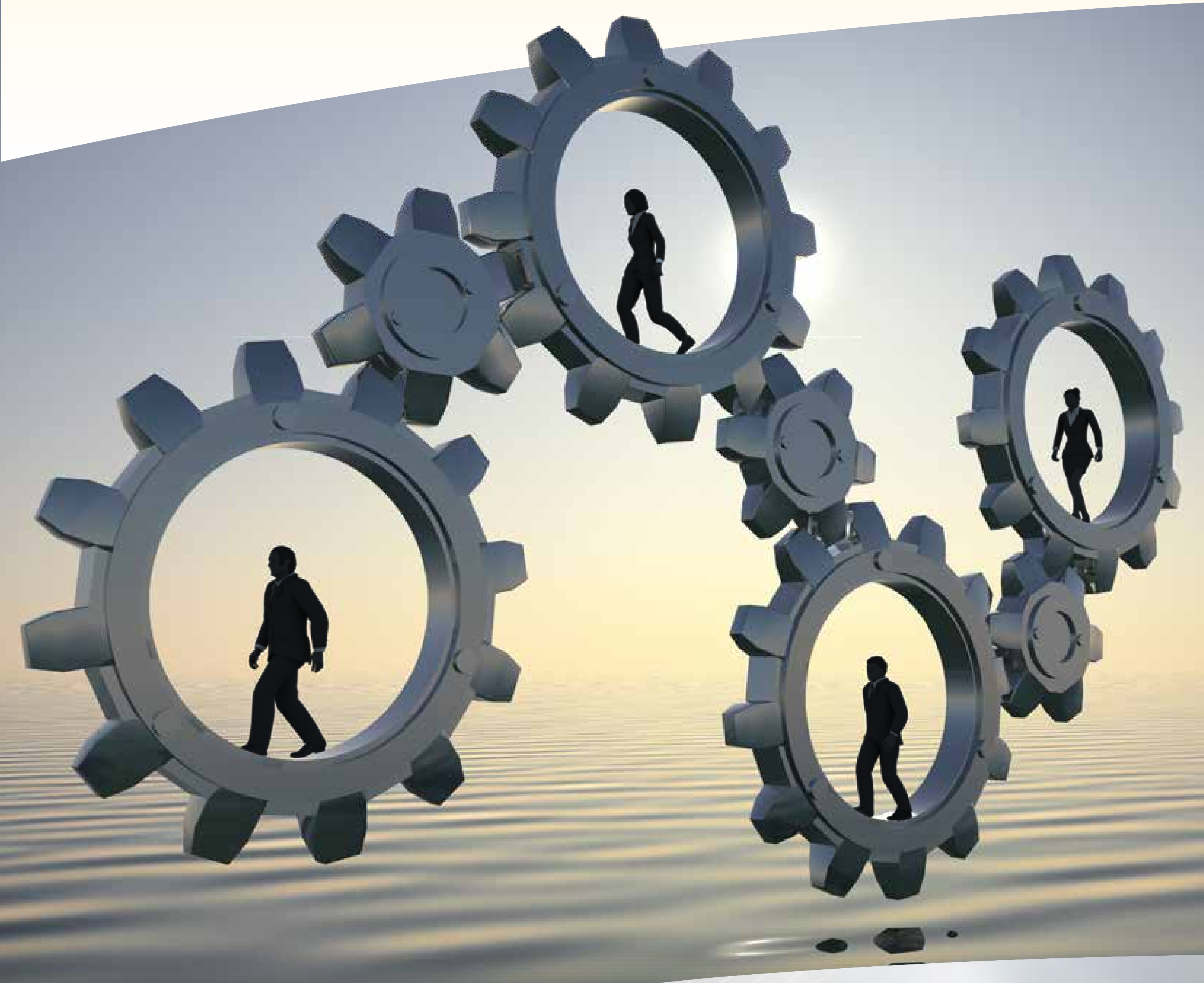
84TH IMESA CONFERENCE

IN COLLABORATION WITH IAWEES

IMESA CONFERENCE 17-19 NOVEMBER VIRTUAL 2021 IAWEES

Hosted by Cape Town

Synergy through Engineering



A JOINT INTERNATIONAL CONFERENCE

IMESA

International Association for Water Environment Energy and Society

IAWEES

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Proceedings of the 84th Conference of the Institute of Municipal Engineering of Southern Africa

A JOINT INTERNATIONAL CONFERENCE WITH IAWEES

IMESA

MISSION STATEMENT

To promote excellence in the engineering profession for the benefit of municipalities and their communities.

OVERVIEW

The Institute of Municipal Engineering of Southern Africa (IMESA) promotes the interests of municipal engineers and their profession, and creates a platform for the exchange of ideas and viewpoints on all aspects of municipal engineering with the aim of expanding the knowledge and best practices in all Local Government municipalities.

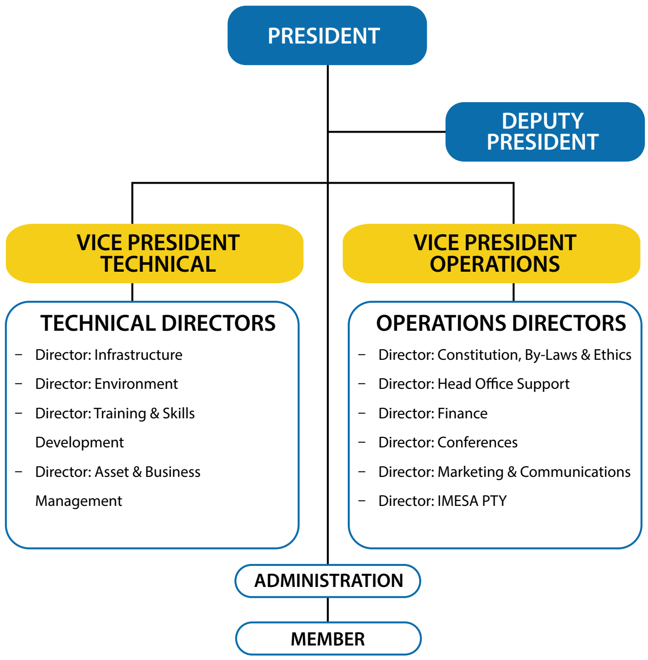
Since 1961, IMESA has played a significant role in municipal engineering, sharing knowledge and acting as a catalyst in developing new initiatives. Municipalities are key role-players in identifying needs, prioritising funding and implementing integrated development planning for community-based programmes. The Institute also advises Councils on municipal engineering matters and serves the broader community through representation on a number of national bodies, where it provides input from the municipal engineer's perspective.

IMESA HERALDRY AND MOTTO

The IMESA coat of arms was designed by Alan Woodrow and was registered with the South African Bureau of Heraldry in 1972.

Monumenta Circumspice means "For our monuments, look around you"

IMESA STRUCTURE



BENEFITS AND SERVICES TO MEMBERS

IMIESA JOURNAL

Members of IMESA are granted free subscription to the *IMIESA* journal, a highly informative monthly publication that serves as a mouthpiece for the engineering fraternity by disseminating cutting-edge technical news and developments. The journal has received the prestigious PICA Award for the best publication of its kind in the Urban Management, Civil Construction and Infrastructural Development categories.

IMESA WEBSITE

The IMESA website offers members and potential members a forum for opinion, news and support relating to the municipal engineering industry.

SEMINARS

Branches organise regular full- and half-day seminars, which feature speakers from both the technical and contemporary areas. These seminars also provide opportunities to introduce new products in the technical field and to brief members and politicians.

ANNUAL CONFERENCES

IMESA hosts an annual conference. Opportunities for members to gain valuable information and insight into issues facing the municipal engineering fraternity include the presentation of topical papers, product exhibitions and an opportunity to share and discuss ideas with like-minded engineers, municipal representatives and non-technical associates.

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BURSARY SCHEME

In 2000, IMESA established a bursary scheme for full-time studies in the field of civil engineering. Bursaries are awarded each year, as per our bursary policy. The aim of the scheme is to recognise achievements of students and prospective students who would not otherwise be able to continue studying or are dependants of IMESA members.

TRAINING

IMESA offers a range of training courses covering all aspects of infrastructure asset management and other priorities relevant to engineering and municipal environments.

IMESA MEMBERSHIP CATEGORIES/ GRADES

CORPORATE MEMBERS

PROFESSIONAL MEMBERS

They shall be persons who:

- Are registered by ECSA or an equivalent engineering council recognised by ECSA as full professionals in at least one of the following categories:
  - Professional Engineer
  - Professional Engineering Technologist
  - Professional Engineering Technician
  - Professional Certified Engineer
  - Registered Engineering Technician
- Have at least three years infrastructure engineering experience after achieving a qualification recognised by ECSA or an equivalent engineering council recognised by ECSA for registration
- Have been admitted as such by the Executive Committee
- Having failed to comply with the requirements of the clauses above, have been admitted by Council, on the unanimous recommendation of the Executive Committee based on their opinion that such persons have the experience, employment responsibility or involvement in infrastructure engineering or made such a contribution to infrastructure engineering that, in the interests of the Institute, justifies such admission.

NON-CORPORATE MEMBERS

GRADUATE MEMBERS

They shall be persons who:

- Are registered/eligible for registration by ECSA or an equivalent engineering council recognised by ECSA in at least one of the following categories:
  - Candidate Engineer
  - Candidate Engineering Technologist
  - Candidate Engineering Technician
  - Candidate Certified Engineer
- Are admitted as such by the Executive Committee

SUBSCRIPTION FEES: JULY 2021 – JUNE 2022

NB: there is a separate information document and application for affiliate membership (for companies).

Membership category		Entrance Fee	Annual Membership Fee
Corporate membership	Fellows	R290	R1 130
	Retired fellows		R340
	Professional		R1 130
	Retired professional		R340
Non-corporate membership	Graduate	R290	R540
	Student		R300
	Associate		R690
	Retired non-corporate		R300
	Affiliate		
	Platinum	R4 230	R13 540
	Gold	R3 280	R8 950
	Silver	R2 220	R5 990

- Have been admitted by Council on the unanimous recommendation of the Executive Committee based on their opinion that such persons have the experience, employment responsibility or involvement in infrastructure engineering or have made a contribution to public sector engineering that, in the interests of the Institute, justifies such admission.

STUDENT MEMBERS

They shall be persons who are:

- Enrolled students at a local or international university/technical university recognised by ECSA
- Studying towards a degree/diploma in engineering
- Admitted as such by the Executive Committee.

ASSOCIATE MEMBERS

They shall be persons who:

- Have satisfied the Executive Committee that they are involved in an aspect of infrastructure engineering
- Are admitted as such by the Executive Committee.

AFFILIATE MEMBERS

They shall be those academic, research, consulting, commercial, industrial or other undertakings who:

- Are, in the opinion of the Executive Committee, involved in business related to infrastructure engineering
- Are admitted as such by the Executive Committee.

Background information for Affiliate Membership

DEFINITION OF AFFILIATE MEMBERSHIP

Affiliates shall be those consulting, commercial or industrial undertakings that have been admitted as such by the Executive Committee.

Any consulting, commercial or industrial undertaking may be admitted as an Affiliate, provided, in the opinion of the Executive Committee, it is involved in business related to municipal engineering.

MEMBERSHIP CATEGORIES

This type of membership offers **4 categories:**

- **Platinum:** Recommended for larger corporates operating countrywide with and/or ties abroad (20+ offices or outlet points).
- **Gold:** Recommended for medium-sized corporates operating in the major regional centres (10-20 offices or outlet points).
- **Silver:** Recommended for smaller corporates operating locally (<10 offices or outlet points).
- **Professional:** Reciprocal complimentary membership for synergy between associated organisations.

An Affiliate Member may request a change to its membership category once a year, when the renewal of its annual subscription becomes payable.

BENEFITS OF AFFILIATE MEMBERSHIP

IMIESA magazine

Official journal published monthly by 3S Media. This prestigious technical journal has won a number of awards, including SAPPI-PICA and other Mondi awards, since its launch in 1975. It also has a strong online presence through its infrastructurenews.co.za website and social media pages.

Citings and editorial

A citing is compiled by *IMIESA*'s editorial staff, and is valued at least twice that of a paid advertorial of the same size.

The following is offered to Affiliates:

MEMBER CATEGORY	EXPOSURE
Platinum	3 citings per annum
Gold	2 citings per annum
Silver	1 citing per annum
Professional	1 citing per annum

***Note:** Company logos are omitted in editorial/citings, as it will lead to losing its value as an editorial/citing. In order to retain editorial integrity, Affiliates will be entitled to expect exposure on this basis, which provides "clean exposure" in that it is not paid for. New appointments, contracts or important projects will receive attention.*

Discount on advertising

All Affiliate Members will automatically receive Most Valued Client status with 3S Media, meaning that advertisement positions are prioritised.

In addition to this, 3S Media offers a 10% discount on all advertisements on submission of publishable technical material by Affiliate Members. The 10% discount is also applicable to other advertorial products such as inserts and inside cover positions of the journal.

Free copies

Affiliate members will receive free copies of the *IMIESA* journal:

Platinum	Max 15
Gold	Max 10
Silver	Max 5
Professional	Max 5

Affiliate showcase

This is a dedicated full page in each issue of *IMIESA* journal identifying Affiliate Members. Their logos are presented in colour and company names are listed.

ANNUAL CONFERENCES

Sponsorship at conference

"First refusal right" towards sponsorship at the annual IMESA Conference. The conference organising committee/professional organisers will contact all Affiliates in advance, prior to seeking sponsorships from the rest of the industry.

Exhibition stand cost at the annual IMESA Conference

The following discounts are afforded on the cost of exhibition stands at the conference:

Platinum	10%
Gold	7.5%
Silver	5%
Professional	5%

Conference registration fees

Affiliates will enjoy special membership registration fees for the annual IMESA Conference for each delegate, with further discount for 3 and more delegates. Delegates representing Affiliate Members will enjoy the same discount as ordinary IMESA Members.

IMESA WEBSITE

IMESA's website is one of the main communication mediums. IMESA Affiliates can receive exposure with their logos displayed on the Affiliate Membership sub-site and a link to their website. Additional advertising benefits are being explored.

CERTIFICATE

Affiliate Members will be supplied with a framed certificate from IMESA for their head office, reflecting their Affiliate Membership status. Additional certificates may be requested for other offices of the Affiliate Member.

ATTENDANCE AT IMESA BRANCH PROCEEDINGS

An IMESA Affiliate may send an unlimited number of attendees to branch meetings and similar proceedings. Affiliates will be included on the contact lists of all IMESA branches countrywide.

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Welcome & PROGRAMME

President's Welcome Message

After the Covid-19 challenges we have all faced – and not being able to hold a conference in 2020 – it is my pleasure to welcome you all to this 84th IMESA Conference, which is hosted by our Western Cape branch under the theme of 'Synergy Through Engineering'.

This is our first ever joint international conference, as we partner with the International Association of Water, Environment, Energy and Society (IAWEES). We are excited to have them on board and I am sure we will gain a lot from their international perspectives in the interesting and interactive presentations ahead.

This conference is also our first to be held on a virtual platform. While it is sad not to have the opportunity to network and chat directly to one another, the programme will incorporate most of the key aspects you would expect – with a few digital extras to build on the good relations with our loyal Exhibitors and Sponsors. We are very grateful for their continued support.

Everyone hoped that we'd see the back of Covid-19 going into 2021, but this was not to be. The best we can do is continue to adhere to health and safety protocols. Our thanks go to the Local Organising Committee (LOC) and head office staff for their dedication and hard work to enable this conference after a very challenging 18 months.

One silver lining to all the mayhem is that this conference is now accessible to those who were unable to attend the live event previously due to cost and time constraints. We look forward to seeing many new delegates participate this year.

The conference papers are based on a common theme that supports environmental stewardship and responsible, engineered responses to climate change. These include water security and water demand management, the maintenance and construction of sustainable infrastructure, geospatial planning, renewable energy, and bankable funding models.

I am particularly looking forward to the final session on Friday, which is the panel discussion chaired by Professor Wikus van Niekerk, entitled 'Can municipalities become independent of Eskom?' It will no doubt generate an interesting debate.

I invite you all to get comfortable wherever you are and take full advantage of the wealth of experience and information offered over the three days.

Bhavna Soni
President, IMESA

President's Welcome Message – IAWEES

On behalf of IAWEES – the International Association of Water, Environment, Energy and Society – I thank IMESA for the invitation to partner in this prestigious conference, which has a long history in the field of municipal infrastructure engineering. It is an honour to be presenting in this forum and we hope that our presentations will bring some special insights from our international experiences. Our members represent universities, government organisations, research institutes and industries in such diverse countries as Australia, Brazil, Canada, China, Egypt, France, Hong Kong, India, Japan, Kenya, Malaysia, the Netherlands, Poland, Romania, South Africa, Tunisia, the UK and USA.

The core focus of IAWEES is to empower society with water, environment and energy sustainability through promoting the benefits of sustainable integrated development. We feel this is of enormous importance for municipal engineers who must deliver the services that provide for community needs in all these areas.

Like IMESA, our mission is to promote the advancement and exchange of knowledge on methods, policies and technologies for sustainable development. One of the best ways to do this is in a conference environment like this one.

My life's work has focused mostly on the management of water resources and promoting the cause of their conservation and sustainable use, and I think this is even more essential now with the impact of climate change and increasing populations.

I have had the privilege to travel to many countries and am very sorry that I could not add South Africa to the list. The Covid-19 pandemic has changed so much in how people will interact in future but does not change the importance of sharing knowledge, skills and expertise from research findings and studies, as well as practical experiences. This virtual platform does have the advantage of sharing the accumulated information with many delegates who might not be able to travel to the physical venue.

I am sure that I speak for all IAWEES members in saying that we look forward to learning a great deal from this conference on the municipal infrastructure engineering environment and various challenges, and in return we hope that you will benefit from the information shared by IAWEES presenters.

Distinguished Professor Vijay P. Singh
President, IAWEES

2021 Presidential Address

As IMESA President, one of my key mandates is to motivate that ethics be made a compulsory part of the CPD cycle for registration with the Engineering Council of South Africa (ECSA), by requiring registered practitioners to attend an ethics presentation annually during their five-year registration cycle. My husband and two children are qualified medical doctors, and their professional lives are governed by their Hippocratic Oath. In my view, civil engineers should take a similar oath that determines the moral principles for ethical practice, since their actions have a direct bearing on civilised society.

With the economy looking grim and infrastructure development being disrupted in an unprecedented manner, the unbearable truth is that Covid-19 has changed – and will forever change – the world as we know it. It's impossible to quantify the extent of the impact it will have on the South African economy and the development of future infrastructure. However, what remains clear is that we, as engineers, need to support recovery and development in South Africa in whatever way we can.

In everything we do, our actions define who we are and our underlying value systems. As municipal engineers, we have an extra responsibility because our outcomes in terms of infrastructure service delivery are so integral to the socio-economic success or failure of the towns and cities in which we operate.

Both civil and municipal engineers must stand together in ensuring that we live up to the Code of Conduct for Registered Persons in terms of the Engineering Professions Act (No. 46 of 2000).

Being a member of IMESA makes you a willing and welcome participant in the endeavour of maintaining and growing professional engineering excellence at local government level. We can create a real difference in terms of micro- and macro-development. Our pool of IMESA specialists provides an excellent sounding board for public and private sector stakeholders, and invaluable input on past and current infrastructure projects. This is so important for South Africa's infrastructure-led economic recovery.

IMESA Projects

The IMESA technical courses that were scheduled for 2020 had to be postponed due to Covid-19 lockdown restrictions and are on hold until 2022.

It was with great sadness we received the news that Professor Carel Schoeman passed away in June this year. He developed the **Capacity Building in Urban and Regional Planning** course, which IMESA rolled out around the country in 2019. The course materials have been made available and ways for IMESA to continue to disseminate the content are being investigated.

The **Small Coastal Stormwater Outlets** guidelines from the project initiated by Stellenbosch University and sponsored by IMESA can be downloaded from the knowledge base library on the IMESA website.

IMESA also sponsored the development of a pre-feasibility tool for **Water Conservation and Water Demand Management**, which was identified as a critical activity after droughts in the Western Cape and significant problems experienced by many municipalities with the impact of non-revenue water on the ability to fund and execute water and sanitation infrastructure projects. The tool was developed by Emanti Management and was demonstrated to members in training workshops held at IMESA branches at the end of 2019.

Guidance regarding the **Reuse and Reclamation of Water** for local authorities was identified as a priority in 2019 and IMESA was called on to support the development of guidelines for local municipalities in a project sponsored equally by the WRC and IMESA. After some delays due to administration requirements, this is now progressing well.

A new project initiated by IMESA and co-funded by the WRC is the development of a best practice guideline for **Design Flood Estimation in Municipal Areas in South Africa**. This project addresses another critical aspect for municipalities, and we look forward to sharing the guidelines when completed.

Strategic Liaisons

Although engagements with external bodies have been limited this past year, IMESA has continued to interact with ECSA, SALGA, CESA, SAICE, the WRC, CoGTA and National Treasury, among others.

Civil Engineers South Africa (CESA) – CESA and IMESA jointly present the Excellence Awards every second year and have been liaising to evaluate this year's submissions for the awards to be announced in November 2021 and showcased at the IMESA Conference.

Engineering Council of South Africa (ECSA) – IMESA has met the new requirements to be registered with ECSA both as a CPD Licensed Body and CPD Service Provider, and continues to keep up to date on relevant legislation and regulations.

South African Forum for Engineering (SAFE) – The focus in 2019 was mainly on construction issues and SETAs, with meetings continuing into 2020. No meetings have been held this year, but IMESA has confirmed commitment to take part when the forum is active again.

South African Local Government Association (SALGA) – Although there have been fewer opportunities for interaction this year, IMESA has maintained contact with SALGA at a national level for support on communication with municipalities.

Water Research Commission (WRC) – IMESA has sponsored two projects in joint ventures with the WRC, as described above. Work on both projects is in progress and the completed guidelines will address critical issues in municipal engineering.

National Treasury – In August 2020, IMESA invited high-level representatives of National Treasury, CoGTA, CIDB, SALGA, MISA and SAICE to an online workshop to raise urgent issues related to supply chain management and the interpretation of various policies. The representatives from National Treasury and CIDB took note of the issues raised and have addressed some of them. A National Treasury City Support Programme (CPS) water team is now in the process of facilitating the clearing of procurement impediments and is collaborating with professional bodies like IMESA to resolve the issues.

International Federation of Municipal Engineers (IFME) – The importance of international knowledge sharing was underscored during the IFME meeting held in May 2021, which I attended virtually as South Africa's representative.

Evolving urban patterns were a common viewpoint shared by the IFME country members in attendance. Prime examples include how the growing work-from-home culture is influencing city planning. If remote working becomes a more permanent feature – as many believe it will – this will influence key areas. These include reverse migration from cities, and transportation planning.

In countries worst affected by the virus, like South Africa, the focus is on economic recovery plans with public infrastructure investment a key driver to improved service delivery within the local government arena.

Sadly, IMESA was not able to host the IFME Board Meeting scheduled for Cape Town in October 2020 but we look forward to future opportunities to contribute our input for global solutions to municipal issues.

EXCO and Council

The election of a new IMESA President as well as the Executive Committee and Council for the 2020-2022 period was completed and implemented with effect from 30 October 2020; however, with Covid-19 restrictions preventing an IMESA Conference last year, the ceremonial traditions were not possible. I take the opportunity now to thank Randeer Kasserchun as Immediate Past President for his valuable contribution to IMESA activities from 2018 to 2020.

IMESA has reduced the number of EXCO Technical Directors to four, with broad portfolios that will be broken down to establish work groups of Council members in specific portfolios. One Technical Director

portfolio, for example, is Infrastructure, which will have the support of Council workgroups for projects in Transportation, Roads, Stormwater, Water & Sanitation, and Building Structures & Town Planning.

Membership and Branches

Our head office staff continue to keep IMESA's administration and finances in good order despite the challenges faced through various lockdowns and the impact of Covid-19 on membership and conference income. It is encouraging that our membership base has remained stable and that we are receiving new applications on a regular basis.

Our branches have faced similar challenges, and most had to convert their branch activities to online events and communication. We encourage members to get involved and are always open to ideas on how we can provide more technical development opportunities and assist members to conquer common engineering challenges.

IMESA has branches covering the following regions:

- Northern Provinces (Gauteng)
- Free State/Northern Cape (Bloemfontein/Kimberley)
- KwaZulu-Natal (Durban)
- Border (East London)
- Eastern Cape (Port Elizabeth)
- Southern Cape/Karoo (George/Mossel Bay)
- Western Cape (Cape Town)
- SADC Countries.

IMESA

CALL FOR ABSTRACTS

CATEGORIES

- Buildings, Structures and Housing
- Electrical and Electronic
- Ecological, Environmental and Social
- Water and Sanitation
- Financial, Legal and Regulatory
- Transport, Roads and Stormwater

ABSTRACTS SUBMITTED BY

11 March 2022
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CONFERENCE ENDORSED BY

SOUTH AFRICAN LOCAL GOVERNMENT ASSOCIATION
SALGA
Inspiring service delivery

IMESA

ORGANISER
THE INSTITUTE OF MUNICIPAL ENGINEERING OF SOUTHERN AFRICA (IMESA)

Finances and Investments

The loss of income from not being able to hold the 2020 IMESA Conference has had to be carefully managed, but the Institute's financial status continues to be stable thanks to the efforts of Eddie Delport, Operations Director: Finance, with the support of EXCO and Council. Our investments provide long-term security, and the Institute continues to be fully compliant with the requirements of SARS and other regulatory bodies.

Covid-19 has highlighted the collection of membership subscription fees as a priority for continuity of the Institute when other activities are not possible. We are looking at various training initiatives and other ways to thank our members for their ongoing support.

Obituary

With Covid-19 taking an additional toll, we have had to say sad farewells to several IMESA stalwarts in this last year.

The sudden loss of Pieter Myburgh in January 2021 has been keenly felt. After joining IMESA in 1992, he became an active member of the Southern Cape/Karoo Branch and served as Branch Chair. He was elected to Council and then to the Executive Committee in 2010, which culminated in serving as Vice President: Technical from 2018. He held the position of Senior Manager: Streets and Stormwater at Mossel Bay Local Municipality and was highly regarded for his contribution to municipal engineering in the Southern Cape.

Professor Schoeman, mentioned earlier, joined in 1985 and his involvement over many years in various IMESA projects related to town planning has been invaluable.

Mathys Vermeulen was a member from 1981 onwards and sadly passed away in June this year. He was IMESA President from 1993 to 1994 and an Honorary Fellow.

The IMESA Annual Report has a full list of deceased members who will all be remembered for their individual contributions to IMESA.

In Summary

The unprecedented rate of change in every aspect of life over this last 20 months has truly tested us all in unthinkable ways. I am sure every one of you, or someone close to you, has experienced loss of some sort in this last year and many have lost everything that was their 'normal'.

The post-Covid-19 recovery of our nation will depend on how we empathise and address the emotional issues at all levels of interaction to build the resilience needed to carry us forward. In local government especially, I can see that it will be crucial for employees to be provided with the resources and skills to manage stress and conflict, as well as a good support network to help them deal with the pressures of a rapidly changing work environment.

As engineers, we have already had to become more resilient, forward-thinking and innovative in finding ways to get essential work done. I personally have found that the change to online meetings and teleconferencing has enabled me to multitask and to allocate more time to projects and people at less cost because of reduced travel.

It might be a good thing that we cannot go back to the old 'normal'. Let's embrace the changes we can influence as engineers and find visionary ways to solve the challenges that lie ahead. I close with advice from the former US president Theodore Roosevelt:

> ***"Whenever you are asked if you can do a job, tell 'em 'Certainly I can!' Then get busy and find out how to do it."***

Technical Advisory Committee

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Welcome from the Local Organising Committee

The last 18 months have been extraordinary, and forced us into a new type of reality. Not only have our perspectives on family, friendship and health changed, but so have the ways in which we communicate, do business and secure our future.

Most of us have lost someone or something along the line – from close family members, friends and colleagues to valuable time, business opportunities and income as a direct impact of the pandemic on our lives, livelihoods and the economy.

Our annual IMESA Conference scheduled for 2020 also took a back seat to the pandemic, as we were compelled to cancel the event for the first time in our history.

We have, however, evolved and adapted – and are now ready to welcome all our sponsors, local and international delegates, special and invited guests to our first Virtual Joint International Conference. This event is hosted in collaboration with the International Association of Water, Environment, Energy and Society (IAWEES) and endorsed by the South African Local Government Association (SALGA).

The conference will kick off with our Opening Function and bi-annual Excellence Awards on Thursday, 11 November 2021 at the beautiful Cape Town Marriot Hotel, Crystal Towers, Century City. A total of 24 projects were entered in the three categories: Engineering Excellence in Structure Civils, Community Upliftment & Job Creation, and Environment & Climate Change. In compliance with Covid protocols, this event will be open to invited guests only.

Our Virtual Conference proceedings will start on Wednesday, 17 November 2021. Staying true to this year's theme of 'Synergy Through Engineering', you will enjoy a variety of papers presented by local and international colleagues on various municipal-oriented disciplines.

The opening day will be a historical event, with the first ever IMESA Presidential Address done by a woman – Mrs Bhavna Soni, IMESA President Elect 2020. This will be followed by the IAWEES Presidential Address by Professor Vijay Singh, as well as the Executive Keynote Address by Mr Michael Webster, Executive Director: Water and Waste, City of Cape Town.

Although virtual, ample opportunity will be made available to sustain the platform where questions can be asked, opinions raised and discussions held. To ensure a technically sound and interactive conference, specialised audio and virtual experts will run the system, while MC (and commercial pop DJ) David Yapp will ensure continued interaction and a lively atmosphere. As delegates will not be able to rub shoulders with colleagues, enjoy our notorious Social Evening, Technical Tours and/or Golf Day, we will make up with generous spot prizes and lucky draws to keep the momentum going.

As the Local Organising Committee (LOC) and IMESA Western Cape branch, we wish to recognise the IMESA Conference staff – Debbie Anderson and Melanie Stemmer – for their dedication and forward-thinking in making this event happen.

May this conference be an inspiring event where new professional friendships are made and revolutionary ideas are formulated.

Jeanine du Preez
2021 LOC Chair, IMESA Western Cape branch

LOC Team:

Johan Basson
(Finance)

Kobus du Plessis
(International liaison and technical advisor)

Emmarentia Stipp
(Technical advisor)

Christo Swart
(Technical advisor)

DAY 1: Wednesday, 17 November 2021	
08h00 – 09h00	Registration Online Open
SESSION 1 - MC Sponsored by UMGENI WATER	
09h00	MC opens 1st day of Conference (all admin + how people can navigate through the virtual platform)
09h10	**OPENING OF CONFERENCE BY IMESA PRESIDENT: Mrs Bhavna Soni**
09h20	**WELCOME BY IAWEES PRESIDENT: Distinguished Professor Vijay P. Singh**
09h30	**ADDRESS BY SALGA**
09h40 – 10h00	**Executive Keynote Speaker: Mr Michael Killick** *(City of Cape Town - Director Bulk Services)*
10h00	**2022 IMESA Conference Promotional Video**
10h10	**MC closes Session 1** (basic admin + how break times will work on virtual platform)
10h20	**TEA BREAK** (30 minutes – delegates will be able to log-out and log back in)
SESSION 2 - Sponsored by MARISWE	
10h50	MC welcomes delegates to Session 2 (basic admin + intro to what can be expected in Session 2)
11h00 – 11h30	**Keynote Speaker: Mr Werner Jerling** *Deliver infrastructure to a rapidly changing and impatient world now!* *A Call to Action.*
11h30 – 12h00	**PAPER 1: Dr James Cullis** *Water Security and Climate Change Risks for Municipalities across South Africa*
12h00 – 12h30	**PAPER 2: Kerry Fair** *Financial feasibility and bankability of city-wide water loss intervention program - City of Tshwane*
12h30 – 13h00	**PAPER 3: Frank Stevens** *Deep Tunnel Sewerage Systems: Singapore's Success Story*
13h00	**Questions from the audience (online)** SPEAKER GIFTING Sponsored by ZUTARI
13h10	**LUNCH BREAK** (40 minutes – delegates will be able to log-out and log back in)
SESSION 3 - Sponsored by MNA ASSOCIATES	
13h50	MC welcomes delegates to Session 3 (basic admin + intro to what can be expected in Session 3)
14h00 – 14h30	**Keynote Speaker: Dr Weicheng Wu** *Big Geodata Management for Sustainable Development*
14h30 – 15h00	**PAPER 4: Leisel Bowes** *Illuminating a Social Development Program – Focus on the eZimbokodweni Pipe and Pedestrian Bridge*
15h00 – 15h30	**PAPER 5: Peter Fenton** *Emergency Rehabilitation of Seaward Road Bridge over the Umhlatuzana River*
15h30 – 16h00	**PAPER 6: Claus Rabe & Brendon van Niekerk** *Estimating the capital and operating costs of development proposals in discouraged growth areas*
16h00	**Questions from the audience (online)** SPEAKER GIFTING Sponsored by ZUTARI
16h10	**MC closes DAY 1 of Conference** (basic admin + intro to what can be expected for DAY 2 of Conference)
DAY 2: Thursday, 18 November 2021	
07h00 – 08h15	Registration Online
08h15	MC opens 2nd day of Conference (all admin + how people can navigate through the virtual platform)
SESSION 4 - Sponsored by SMARTLOCK	
08h30 – 09h00	**Keynote Speaker: Dr Kevin Wall** *Infrastructure Service Delivery Institutions for less functional areas*
09h00 – 09h30	**PAPER 7: Dr Danél van Tonder** *Re-watering of West Rand Dolomitic Compartments: Implications for JB Marks Local Municipality*
09h30 – 10h00	**PAPER 8: Stephan Kleynhans** *Planning and implementing large-scale groundwater supply schemes*
10h00 – 10h30	**PAPER 9: Thabang Mafokoane** *A Review of Acoustic Pipeline Monitoring Systems Used to Detect Bursts and Blockages*
10h30	**Questions from the audience (online)** SPEAKER GIFTING Sponsored by ZUTARI
10h40	**TEA BREAK** (20 minutes – delegates will be able to log-out and log back in)

SESSION 5 - Sponsored by HERRENKNECHT AG	
11h00	MC welcomes delegates to Session 5 (basic admin + intro to what can be expected in Session 5)
11h10 – 11h40	**Keynote Speaker: Dr Galkate** *Assessment of meteorological drought in Bundelkhand region of MP (India) using Standardized Precipitation.*
11h40 – 12h10	**PAPER 10: Matt Braune** *Proactive and prioritised stormwater maintenance & management system*
12h10 – 12h40	**PAPER 11: Prof JA Du Plessis & Dr Adèle Bosman** *Hydrological study and hydrodynamic modelling on Horlosiekloof, De Doorns, Western Cape*
12h40	**Questions from the audience (online)** SPEAKER GIFTING Sponsored by ZUTARI
12h50	**LUNCH BREAK** (40 minutes – delegates will be able to log-out and log back in)
SESSION 6 - Sponsored by PGA CONSULTING	
13h30	MC welcomes delegates to Session 6 (basic admin + intro to Session 6)
13h50 – 14h20	**Keynote Speaker: Dr Gerald Corzo Perez** *Machine Learning forecasting droughts and floods with open source global data sets*
14h20 – 14h50	**PAPER 12: Kennedy Wekesa Murunga** *Spatio-temporal analysis of land-use/land-cover changes in transboundary Mara river basin*
14h50 – 15h20	**PAPER 13: Erika Braune & Dr Verno Jonker** *Developing geo-information based selection algorithms to identify water resource interventions*
15h20 – 15h50	**PAPER 14: Ayanda Mthombeni** *Impact of climate change on Spatial Planning and Stormwater Management for Greenfield Sites Development*
15h50 – 16h20	**PAPER 15: Maronel Steyn & Dr Chavon Walters** *Bulk Scale Industrial Effluent Reuse Potential in South Africa*
16h20	**Questions from the audience (online)** SPEAKER GIFTING Sponsored by ZUTARI
16h30	**MC closes DAY 2 of Conference** (basic admin + intro to what can be expected for DAY 3 of Conference)
DAY 3: Friday, 19 November 2021	
SESSION 7 - Sponsored by CIDB	
08h15	MC welcomes delegates to Session 7 (basic admin + intro to what can be expected in Session 7)
08h30 – 09h00	**Keynote Speaker: Dr Abdelazim Negm** *A Novel Standalone Solar-Driven Agriculture Greenhouse-Desalination System: That Grows its Energy and Irrigation Water*
09h00 – 09h30	**PAPER 16: Shireen Sayed** *Distributed Clean Energy: Advocating for Micro-Grids As A Solution For South African Municipalities*
09h30 – 10h00	**PAPER 17: Holiday Kadada & Jacobus Kriegler** *Leliefontein Pump As Turbine Station*
10h00	**Questions from the audience (online)** SPEAKER GIFTING Sponsored by ZUTARI
10h10	**TEA BREAK** (20 minutes – delegates will be able to log-out and log back in)
SESSION 8 - Sponsored by UMGENI WATER	
10h30	MC welcomes delegates to Session 8 (basic admin + intro to what can be expected in Session 8)
11h40 – 12h00	**PANEL DISCUSSION** *"Can alternative energy resources result in independent municipal power supply?"* **Prof JL (Wikus) van Niekerk - Panel Chair** *Mr Deon Louw – Stellenbosch Municipality* *Mr Keith Bowen – ESKOM* *Mr V Padayachee – Strategic advisor to AMED*
12h00 – 12h30	**Questions from the audience (online)** SPEAKER GIFTING Sponsored by ZUTARI
12h30	**CLOSE-OFF FORMALITIES : LOC Chair & IMESA President**
12h40	FINAL Lucky Draw
12h50	**CONFERENCE CLOSE**

In a recent project, Bosch Projects and Bosch Capital completed conceptual wastewater feasibility studies and financial modelling for the eThekwini Water and Sanitation Department. This involved engineering design, financial modelling and cost-benefit analysis

60 YEARS OF SUCCESS

Bosch Projects forms part of the Bosch Holdings group of multi-disciplinary consulting engineering companies, which celebrates 60 years of business this year.

The Bosch Projects team provides consulting engineering and project management services to diverse sectors, including industrial plants, water and wastewater, roads, urban developments and buildings, as well as ports and terminals, the sugar sector and agriculture.

These services include detail engineering design, project and construction management; programme management – management of multiple linked projects; procurement and contract services; risk management; quality assurance; and projects control, including cost and schedule management. The company also designs and supplies a unique range of process production equipment to the global sugar industry.

Recent work in eThekwini

In a recent project, Bosch Projects and Bosch Capital completed conceptual wastewater feasibility studies and financial modelling for the eThekwini Water and Sanitation Department (EWS).

The scope of services included a conceptual-level infrastructure planning exercise for the Umlazi and Umhlatuzana catchment areas within eThekwini Municipality. The planning reports will serve as a 'Master Plan' for the municipality, providing a strategic motivation for bulk sanitation augmentation and infrastructure investment within these catchments over the short, medium and longer term.

According to Jason Holder, divisional manager: KZN Wastewater for Bosch Projects, the purpose and objectives of the bulk sanitation/wastewater catchment studies were to present the most favourable options to best serve key areas in the short to long term. "We also needed to assess the impact on existing and future bulk sanitation infrastructure and considered human settlement housing plans, sanitation backlog areas and future developable areas. These wastewater feasibility design studies – which involved engineering, financial, social and environmental factors – were based on a high-level approach incorporating infrastructure designed for fully developed catchments."

This project – with an anticipated value of over R1 billion – spans 43 000 ha and will benefit a population of 1.2 million, which comprises a backlog of approximately 280 000 people currently without sanitation services.

As part of the financial modelling and cost-benefit analysis components for this project, capital costs were calculated for the new infrastructure and operational costs were based on actual information provided by EWS. A life-cycle costing approach was applied over a 20-year period and the project returns for each of the possible scenarios were compared through the use of indicators such as net present value, internal rate of return, payback and discounted payback period.

The team conceptualised a multicriteria decision matrix, incorporating weighted scoring where applicable, to critically and transparently evaluate each of the potential scenarios. Parameters within the scoring matrix included environmental, capex, opex, life-cycle costing, social benefit (backlog eradication) and alignment with eThekwini Municipality's strategic planning.

The Bosch Projects and Bosch Capital teams worked closely with key stakeholders within the municipality to obtain relevant information for future developments, guidance and approval, where necessary. They also ensured the delivery of a successful project that was well designed to meet the client's requirements.

Global footprint

The Bosch Holdings Group – with its head office in Durban – is supported by a strong regional presence, with highly qualified professionals at more than 10 office locations across South Africa, Kenya, Brazil and the UK.

The Group comprises eight companies – Bosch Projects, Bosch Munitech, Bosch Ulwazi, Bosch Capital, Bosch Engenharia, Booker Tate, Bosch East Africa and Bosch Trading – all offering specialist services.

Sponsors

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Umgeni Water is one of Africa's most successful bulk potable water services providers. Its core business is the abstraction of raw water, storage of raw water, treatment of it and its conveyance as drinking water to seven municipal customers and a private sector customer that provides reticulation services as a concessionaire for a municipality. The potable water Umgeni Water supplies meets the standards specified in (SANS 241:2015) for drinking water quality.

As the largest bulk potable water provider in the province of KwaZulu-Natal, Umgeni Water supplies, on average, 450 cubic metres of drinking water per annum. The water it treats and supplies ultimately reaches an estimated 7 million consumers in KwaZulu-Natal. The gazetted supply area of Umgeni Water is the entire province of KwaZulu-Natal, which covers an area of 94 359 square kilometres. At this stage, Umgeni Water covers 55% of the province of KwaZulu-Natal, ultimately reaching 75% of the population of 11.3 million people, or 2.9 million households.

Umgeni Water has a total asset value of R9.1 billion, and it manages 15 storage dams, 20 waterworks, 31 newly acquired waterworks from KCDM, and 12 wastewater works. Some of the storage dams are managed on behalf of the Department of Water and Sanitation and municipalities. Other infrastructure owned by Umgeni Water, in order to effectively conduct its core business, includes 1 260 kilometres of pipelines, 53 kilometres of tunnels, reservoirs and pump stations.

Umgeni Water is financially sustainable as a result of profits/surpluses it has consistently posted over at least a decade. This means it does not require government funding to conduct its activities in a sustainable way. Ratings reaffirmed by Fitch Ratings Agency are: long-term and unsecured ratings at AA+zaf; and short-term at F1+zaf. Ratings from S&P were: long-term zaAAA, while the short-term rating was at zaA-1.

Umgeni Water has a total staff complement of 1 298, including highly trained and experienced scientists, engineers and water management experts.

In support of the organisation's operations, Umgeni Water's Laboratory Services provides quality services that comply with internationally recognised standards. Water sampling programmes at Umgeni Water are ISO 9001 certified, and the analytical competence of the laboratory is demonstrated by consistent accreditation with the ISO/IEC 17025 standards.

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ZUTARI (PTY) LTD

Zutari co-creates an engineered impact that enables environments, communities and economies to thrive. Few can match our local capacity, long-standing presence and understanding of the challenges required to operate successfully across various regions, namely Africa and the Middle East.

Our ongoing commitment to co-create an impact makes us the perfect partner to those less familiar with working in these regions. We are experienced in complex international projects and proudly bring world-class solutions to our clients.

We blend the old and the new. We have moved beyond traditional engineering and work collaboratively to integrate technical and creative thinking. This process of co-creation allows us to unearth new opportunities with our clients and partners.

Our technical eminence is complemented by digital technology to solve problems where human ability alone is not enough. What took days now takes moments. We also deliver outcomes that help clients stay and thrive in business by co-creating solutions that consider the impact on the environment and communities.

Zutari's broad collective of in-house, industry-recognised engineering consultants and trusted advisors provide seamless and integrated delivery. This unique ability to offer scaled engagement allows Zutari to solve complex challenges more efficiently.

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CIDB (CONSTRUCTION INDUSTRY DEVELOPMENT BOARD)

DEVELOPMENT THROUGH PARTNERSHIP

The Construction Industry Development Board is a Schedule3a public entity established to lead construction industry stakeholders in construction development. It is established in terms of the CIDB Act (No. 38 of 2000).

Construction plays a pivotal role in South Africa's economic and social development. It provides the physical infrastructure that is the backbone of economic activity. It is also a large-scale provider of employment opportunities. The role of the CIDB is to facilitate and promote the improved contribution of the construction industry to SA's economy and society.

Amongst others, the CIDB must promote:
- Uniformity in construction procurement
- Efficient and effective infrastructure delivery
- Construction industry performance improvement
- Development of the emerging sector, including industry transformation
- Skills development.

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HERRENKNECHT AG

With the experience of more than 5 300 projects, Herrenknecht is a technology and market leader in the area of mechanized tunnelling technology. Herrenknecht is the only company worldwide to deliver cutting-edge tunnel boring machines for all ground conditions and in all diameters – ranging from 0.10 to 19 metres.

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MARISWE (PTY) LTD

Mariswe (Pty) Ltd is a South African company offering comprehensive project management, infrastructure planning and civil engineering services, as well as complete life-cycle management for strategic projects. This approach harnesses the multi-disciplinary skills of our teams in South Africa and on the African continent to offer innovative and diverse project packages under a single umbrella.

The company has built a proud tradition of excellence in providing engineering solutions with integrity across sub-Saharan Africa over the past 49 years, driven by our core focus on improving lives.

Mariswe is committed to providing consistent, high-quality services to its clients and has continuously held an ISO 9001 certification for its quality management system since 2007.

Mariswe is 100% employee-owned and 60.34% of its employees either own shares or are direct shareholding beneficiaries. Black employees own 51.57% of the firm, while 28.26% is owned by women and 20.39% by black women.

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MAKHAOTSE, NARASIMULU & ASSOCIATES (PTY) LTD

Makhaotse, Narasimulu & Associates (MNA) is an affirmable professional service provider offering expert consulting services in the fields of civil engineering and project management.

Currently in its 20th year of operation, MNA has exponentially grown from a single office in Pietermaritzburg to having a national footprint with subsidiary offices in Durban, Theunissen, East London and Johannesburg.

The company's successes over the last 20 years are attributed to the commitment of the firm to the continual development and training of staff, provision of quality services to clients, growing of relationships and integration of sound management mechanisms in all business operations.

As a proud Level 1 B-BBEE contributor with an ISO 9001:2015 accredited Quality Management System, MNA is dedicated to the vision of being a market leader in the civil engineering industry, putting the communities and clients served first while practising the highest ethical standards and contributing to the economy of South Africa.

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PGA CONSULTING

A cutting-edge consulting company, PGA was established in 2005. It has enjoyed a steep trajectory in growth and is a market leader in the SA private and public sector.

Not only has PGA been involved in consulting but it has evolved for the past 16 years, with extensive work in civil engineering infrastructure and associated services.

PGA has broken new ground within the housing sector by providing support to the private sector. This role focuses on structural design with strategic piling (as a geotechnical input). This has positioned PGA with a strategic partner who is a major player in the built environment space to unlock estate developments that were previously closed off to previously disadvantaged individuals.

In positioning PGA for the Fourth Industrial Revolution, the company has acknowledged advancements in the technological sphere. This has brought opportunities for PGA to start a functional robotics academy for youth development for the advancement to 5.0.

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SMARTLOCK

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3S Media is owned by Novus Print, a group company of Novus Holdings – one of Southern Africa's largest print production and manufacturing operations.

IMIESA magazine is 1 of 6 publications owned and published by 3S Media – a content marketing and specialist media company providing targeted B2B solutions across print, digital and streaming platforms.

IMIESA is the official magazine of the Institute of Municipal Engineering of Southern Africa (IMESA) – giving you access to a wide range of experts (and decision-makers) in the construction sector.

3S Media has three industry websites with weekly newsletters offering breaking news, in-depth analyses, upcoming events, and the latest industry developments. With a strong social media presence, 3S Media is entrenched in and engaged with its communities.

As a media house, we know that there is only one clear way to grow and thrive in a fast-paced digital age, and that is with a multiplatform approach.

IMIESA

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and service delivery

Speaker PROFILES

KEYNOTE SPEAKER – SESSION 2

WERNER JERLING

MSc (International Construction Management)
ASLA

Werner Jerling is an experienced construction professional with a particular interest in design and construct, as well as collaborative contracting models. He spent a short period the consulting engineering field and the majority of his career in the civil engineering construction environment, during which time he gained experience in the field of designing and constructing large reinforced concrete structures for a multitude of South African and foreign clients in a multitude of different industries. He has gained valuable experience on-site and has in a number of senior management and board positions.

Jerling is a registered Professional Engineer and Construction Project Manager holding a BEng (Civil) degree from Stellenbosch University, a BCom from the University of South Africa, and an MSc in International Construction Management from Bath University.

He has a passion for sharing his knowledge and experiences, and regularly presents talks and lectures at conferences, universities and industry programmes such as the Construction Management Programme (CMP).

Jerling's speciality attributes include: strategic management in construction, leadership and mentorship in construction, international construction management, design and construct project management, bridge construction, construction labour relations, collaborative contracting models, construction marketing, construction education, public speaking with a bent toward motivational speaking from a construction perspective, etc.

KEYNOTE SPEAKER – SESSION 3

DR WEICHENG WU

PhD (Geography)
East China University of Technology

Dr Weicheng Wu has a PhD in Geography from the University of Paris 1 Pantheon-Sorbonne, as well as 33 years of professional experiences – of which 21 were spent in European institutions (France, Belgium and Italy) and at international organization ICARDA.

Wu has been actively involved in and partially led more than 20 international R&D projects located in China, Central, Southern and Western Asia, Northern Africa and the European Mediterranean region funded by different international consortia such as ESA, EU, UNDP, FAO, WFP, AusAID/ACIAR and ADB. His projects were focused on environmental monitoring, land resource mapping, land degradation assessment and land-use-related carbon emission analysis using geospatial big data and machine learning techniques. He joined East China University of Technology in 2018 as a full-time professor and is currently leading three projects in the sustainable use of environmental resources with big data mining.

Wu is a board member of IAWEES, chair of the International Conference on Geo-Information and its Applications (ICGITA 2019), and guest editor for several ISI refereed journals – inter alia *Remote Sensing* and the *International Journal of Geo-Information*. He serves as reviewer for a number of top journals in remote sensing, geography, geology and environmental science.

KEYNOTE SPEAKER – SESSION 4

DR KEVIN WALL

PhD (Engineering)
University of Pretoria

Professor Kevin Wall, until 2014 a built environment fellow of the CSIR, is a civil engineer and town planner. He is a long-time fellow of IMESA.

An extraordinary professor at the University of Pretoria and a fellow of the South African Academy of Engineering, he is also a non-executive board member of the City of Ekurhuleni's wastewater treatment entity ERWAT.

A past president of the South African Institution of Civil Engineering (SAICE), within the last few years, he has received both the Gold Medal of SAICE – the highest honour that can be bestowed by the civil engineering profession in South Africa – and the Lifetime Award of the National Science and Technology Forum – the highest honour that can be bestowed by the science, engineering and technology community.

Much of his work over the last two decades has been on the effectiveness of government spending on infrastructure, and ways to improve the quality, reliability and sustainability of that infrastructure. In this respect, he led the CSIR research team for, and co-authored the main report of, the three SAICE Infrastructure Report Cards on the condition of infrastructure in South Africa that have been published so far, in 2006, 2011 and 2017.

Wall's biggest recent project appointments have been as research leader of the fourth SAICE Infrastructure Condition Report Card scheduled for 2022 release, and work on capital programme and project appraisal – in East Africa for GIZ and Nepad, and for the City of Cape Town.

KEYNOTE SPEAKER – SESSION 5

DR RAVI GALKATE

MTech (Soil and Water Engineering)
National Institute of Hydrology

Ravi Galkate has obtained his BTech (Agricultural Engineering) from the College of Agriculture Engineering and Technology, Akola, India, after which he obtained his MTech in Soil & Water Engineering from IIT Kharagpur, India.

He is presently working as a scientist at the National Institute of Hydrology, a premier research organisation under the Ministry of Jal Shakti, Govt. of India. He has more than 25 years of research experience in the fields of hydrology, drought, climate change, water resource management, hydrological modelling, watershed hydrology, irrigation project benchmarking, etc.

Galkate has published more than 80 papers in international and national journals, and has delivered numerous conference presentations. He has organised more than 30 national and international training programmes for water resource managers and has provided guidance to more than 20 postgraduate students. He is an expert lecturer on all aspects of hydrology and water resource management.

KEYNOTE SPEAKER – SESSION 6

DR GERALD CORZO PEREZ

PhD (Floor Forecasting and Data Driven Models)
IHE Delft Institute for Water Education

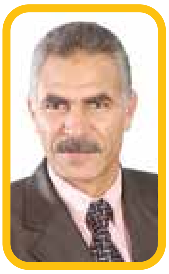
Dr Gerald Corzo has extensive experience in modelling water resources using advanced ICT technology. He is an expert in programming mathematical models and online hydroinformatics management systems. Over the last four years he has been working on integrated global hydrological models and their utilisation in climate change analysis.

In 2012, he won the Tison Award as the young scientist from the IAHS association. He has worked for international institutions such as Wageningen University in the Netherlands and the Tecnológico de Monterrey in Mexico. He has coordinated the statistics of the climate change inventory of adaptation and mitigation actions for Latin America, presented at the WWF in 2012.

Corzo is a civil engineer by training, with a strong background in computational science and a specialisation in telecommunications. He has researched methods for integrating computational intelligent algorithms and hydrological conceptual models for hydrological forecasting. He has worked on the integration of the Delft-FEWS flood forecasting system and has developed scripts for areas of computational intelligence, the optimisation of water resources, online modelling and fluid dynamics simulation.

One of his recent projects focuses on exploring the use of mobile phone antennas in Colombia for measuring precipitation. He has participated in research projects in countries that include China, Colombia, Norway, the UK and others. From 2011 to 2012, he created and led the Latin Aqua network for water research scientists in Latin America and he has served as chair of the session on geostatistics at the European Geoscience Union over the last two years.

KEYNOTE SPEAKER – SESSION 7



DR ABDELAZIM NEGM

PhD (Hydraulics)
Zagazig University

Professor Abdelazim Negm is a professor of hydraulics in Zagazig University (ZU) and is very interested in sustainable water resources management. He is a member of IAHR, ICWEES and the head of the Egyptian permanent scientific committee for water resources to promote associate and professorship positions.

He is a member of the editorial board of several scientific journals, including *IJESD, AJES, JEST, JHGGM, ENRRJ*, etc. and a member of the scientific committee and organising committee of several international conferences. Additionally, he was the secretary-general of the IWTC from 2013 until the year 2017.

He was the head of the ZU committee for assessing the scientific publications of ZU faculties until December 2018. He published more than 350 papers, 100 book chapters, and published 34 contributed volumes during 2017-2021 through Springer International Publishing House.

Professor Negm was the editor-in-chief of *EIJEST* (2016-2020), associate editor of *IWTJ* and *EMJEI*, and guest editor of *AJGS*. He has led several international projects and participated in some others. He has also been nominated for many awards by IBC and ABI, and is listed by Marquis Who's Who? and in IBC's *2000 Outstanding Intellectuals of the 21st Century*.

PAPER 1

DR JAMES CULLIS

PhD (Civil and Environmental Engineering)
Zutari

Dr James Cullis is a technical director in Zutari's office in Cape Town, South Africa. He is a specialist in the field of water resources engineering, integrated water resources management, the water-energy-food nexus, resilience, sustainability, hydro-economics, and climate change impacts and adaptation.

He has a broad range of experience, including technical engineering, hydrology and design, as well as social, political, environmental and economic aspects of water resources. Cullis has over 16 years of experience in the water sector in Africa and has an interest in sustainable water resources development, investments in ecological infrastructure, environmental flows and climate change impacts and adaptation.

He is also an honorary research associate at the African Climate and Development Initiative at the University of Cape Town and a fellow of the South African Academy of Engineers (SAAE). Until recently, he was also the global service leader: Water at Aurecon before it became Zutari.

PAPER 2

KERRY FAIR

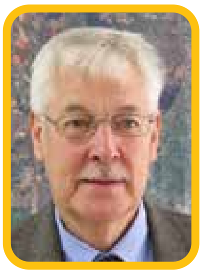
MSc (Civil Engineering)
GLS

Kerry Fair first started analysing municipal meter readings and consumption data over 21 years ago, when she joined GLS and became the lead developer and product specialist for Swift, the geospatial software application used to analyse consumption, perform water and energy balances, identify unbilled and unmetered consumption, and report on related statistics and trends.

She has been involved in projects in four international cities and in approximately 30 municipalities in South Africa, including seven metros. She has presented on these topics at several conferences and has been an integral part of the GLS teams that have trained stakeholders to make optimal use of their billing data. Fair also gained experience in water and sanitation hydraulic modelling and master planning at GLS and has been an integral part of the GLS Software development team.

Prior to joining GLS, she gained experience in water resource modelling and river modelling at BKS. Fair obtained her MSc (Civil Engineering) from the University of Kwa-Zulu Natal and her BEng (Civil) (cum laude) from Stellenbosch University.

PAPER 3



FRANK STEVENS

BSc (Civil Engineering)
Herrenknecht

Frank Stevens matriculated in Germiston and obtained his BSc (Civil Engineering) from the University of Natal. After graduating, he spent his early formative years with consultants Campbell, Bernstein and Irving and contractors Murray and Roberts. During this time, he was involved with projects as far afield as Richards Bay, Bloemfontein, Eshowe and Swaziland.

He served on IMESA's Exco for many years and as the IMESA President for 2014 to 2016. After 30 years of municipal service, Steven retired, some six years ago, as deputy head of eThekwini Water and Sanitation. Since retirement, he has been employed, on a part-time basis, as the South African representative for Herrenknecht Utility Tunnelling. Tunnels on which he has recently been involved include several bulk sewer tunnels in Cape Town and two sea-outfalls in Ghana. He has also spent much of his post-retirement time assisting and guiding candidate engineers, technicians and technologists on their journey towards ECSA registration. He has delivered several papers and lectures, focused on municipal service delivery, both nationally and internationally.

Stevens presently lives in Queensland, Australia (close to the Great Barrier Reef), and he still tries to jog with his wife a few times a week (slowly). He completed 21 Comrades Marathons on the trot (a long time ago) and enjoys collecting old Hornby model trains and Meccano.

PAPER 4

LEISEL BOWES

BTech (Civil Engineering)
eThekwini Municipality

Leisel Bowes started worked as bursary student with Grinaker LTA, obtaining her National Diploma in Civil Engineering through Natal Technikon in 2002. Through Grinaker LTA, she worked on several bridge projects in KwaZulu-Natal, including the iconic Millennium Bridge in Umhlanga as a well as SANRAL's Nandi Drive Interchange project.

Bowes then joined eThekwini Municipality, first working on the replacement of the aged water infrastructure within the municipality with the Water Construction Division and subsequently with the Water and Sanitation Design Division as a senior civil technician where she was involved in the design and implementation of sewer reticulation and bulk water infrastructure projects. She is currently the acting area project manager for the Western and Southern Regions of the municipality in the Water Design Division.

Bowes obtained her BTech: Civil Engineering specialising in structures in 2013 and acquired her professional registration earlier this year. As the mother of three boys, this experience has influenced her approach to her career – being soft and firm, yet granting respect and acknowledging all perspectives – a stance that has contributed to the successful community facilitation which she wrote about in her paper.

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PETER FENTON

BTech (Civil Engineering)
eThekwini Municipality

Peter Fenton joined eThekwini Municipality in 1985 as a learner technician, qualified as a technician in 1988 and joined the Roads Department's Bridge Office.

He studied computer science with Unisa (Dip Data) and then completed his BTech (cum laude) at DUT in 1995, with a structures major. During this period and under some solid mentorship, his love and respect for bridge engineering was born. In 1999, he was appointed as the manager of the Structures Branch where the bridge design is carried out 'in-house'. He was fortunate enough to be involved in several high-profile projects such as the Southern Freeway ramps at the Durban Market, the Umhlanga Pier, Queen Nandi Drive over several phases, and the Warwick Triangle Flyovers for the 2010 FIFA World Cup. In recent times, he has mentored young engineers to assist with their professional registration and foster their interest in bridge engineering and bridge management.

Over the past decade or so, Fenton has been involved with the COTO Structures Subcommittee and is currently the chairperson, along with leading the COTO Structures Inspector Accreditation Committee for certifying suitably trained and experienced engineers to carry out culvert and bridge inspections in South Africa. He also lectures on prestressed concrete part-time at DUT to the BTech students, has contributed to the SAICE publication, and led several winning teams in bridge structures award categories for IMESA, SAICE and Fulton.

PAPER 6

BRENDON VAN NIEKERK

MSc (Urban Development Planning), MBA
Palmer Development Group (PDG)

Brendon van Niekerk is a consultant at PDG and leads the Urban Systems practice area. His work is centred on the interactions between municipal services, land, transport and housing, and he has a keen interest in the sustainable financing of cities. He is a qualified civil engineer, with a Master's in Urban Development Planning and an MBA.

Van Niekerk has performed quantitative and qualitative analysis to provide an evidence base for policy decisions in South Africa, Rwanda, and several other African countries. He has published academic articles on how the impact of location of low-income housing affects the municipality's financial position, and how the use of public-private partnerships in the provision of municipal services could potentially lead to better service delivery.

PAPER 6

CLAUS RABE

MCRP
Palmer Development Group (PDG)

Claus Rabe is a director at Palmer Development Group, leading its Urban Economies practice area and responsible for implementing data transition at the 31-year-old niche consulting firm. As consultant and (formerly) principal planner at the City of Cape Town, he has led teams of engineers, data scientists, economists, and municipal finance experts across a wide range of development and institutional contexts.

Rabe equips decision-makers with the right tools to design, prioritise and spatially target interventions aimed at particularly complex multi-scalar problems: housing affordability and access, the viability and impact of large infrastructure investments, neighbourhood liveability, the management of the public environment, the retention and growth of businesses, and the financial sustainability of local government.

He holds majors in economics and decision-making from Stellenbosch, a Master's in City and Regional Planning from the University of Cape Town, and – as an Ernest Oppenheimer scholar – a distinction from the Berlin University of Technology for his work on urban safety. Rabe is academically engaged, having authored numerous papers on data-driven approaches to urban policy and delivering guest lectures on urban economics and public sector innovation at the University of Cape Town.

PAPER 7

DR DANÉL VAN TONDER

DTech (Water Science)
North-West University (NWU)

Danél van Tonder received her BSc in Geology in 1992 and her Honours in Geology in 1993 from Potchefstroom University for CHE (now North-West University). She completed her MSc in Geology with research interest in geochemistry in 2010 at the University of Pretoria. Her DTech research focused on the development of a solar desalination system for small-scale water supply and was completed in 2017 through Tshwane University of Technology.

Van Tonder worked at the Council for Geoscience, Pretoria from 1994 until 2011 and has done comprehensive environmental impact studies mainly related to mining in parts of the Witwatersrand gold mining basin, as well as the Mpumalanga coalfields. She moved to North West-University, Potchefstroom in 2012 where she is a senior lecturer and head of the Geology, Soil Science and Agriculture Department. Her research interests include impact assessments related to water, mining and agriculture; geotourism; geoconservation; and agrogeology.

PAPER 8

STEPHAN KLEYNHANS

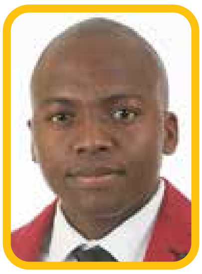
MSc (Civil Engineering)
Zutari

Stephan Kleynhans holds an MSc in Civil Engineering from Stellenbosch University. He started his career in 1996 with Ninham Shand (now Zutari) and became a technical director in 2010. Currently, he is Zutari's expertise leader: Bulk Conveyance and Distribution.

He specialises in the design and management of bulk water and sewerage infrastructure projects. Over the years, he has worked on a number of large projects within South Africa, including the Berg Water Project, the Vaal River Eastern Subsystem Augmentation Project and, more recently, the Lower Thukela Bulk Water Supply Scheme – as well as projects in Namibia, Angola, Algeria, Tanzania, Kenya and Mozambique.

Stephan is a fellow of SAICE and is also involved as an external examiner at Stellenbosch University.

PAPER 9



THABANG MAFOKOANE

BEng (Civil)
University of Johannesburg

Thabang Mafokoane matriculated at Ga Matlala in Limpopo province and obtained his BEng (Civil Engineering) from the University of Johannesburg (UJ). He is a lecturer at UJ in the Department of Civil Engineering Science. He has more than six years of experience in teaching and research.

Mafokoane is a registered Candidate Civil Engineer with the Engineering Council of South Africa (ECSA) and an associate member of the South African Institution of Civil Engineering (SAICE). He a member of HELTASA's Professional Learning Project Team as a scholarly practitioner. He has supervised more than 10 final-year students.

In December 2019, he chaired a session titled '4IR - opportunities, challenges and inequality' at the Science Forum South Africa. His research interests lie in the fields of water engineering (open channel discharge and computational fluid dynamics), education (use of technology for teaching and learning), and the fourth industrial revolution (impact on society and industry).

PAPER 10

MATT BRAUNE

BSc (Civil Engineering)
Bio Engineering Africa Consulting and Training Academy

Starting his career over 35 years ago in the construction industry at Concor Construction in 1983, Matt Braune went into the consulting industry in 1985 at SRK Consulting, where he worked until 2016. That same year he founded Bio Engineering Africa Consulting and Training Academy.

He became a registered Professional Engineer in 1988 and a director of SRK in 1995. He joined IMESA during 1988 and became a registered ECSA Mentor in 2016.

Specialising in urban stormwater management and municipal engineering, Braune has worked on projects that include:

- compiling integrated stormwater master plans for all major metropolitan councils within Southern Africa
- carrying out several river upgrading projects throughout South Africa
- initiating the application of best management practices within most local municipalities
- carrying out several dam safety studies, as well as flood risk and floodline studies
- carrying out several asset management projects, including detailed field surveys, visual inspections and asset registers.

PAPER 11

PROFESSOR KOBUS DU PLESSIS

PhD (Water Governance)
Stellenbosch University

Kobus du Plessis has more than 32 years of experience in the field of water engineering in South Africa.

He worked for the Department of Water Affairs, the City of Cape Town and the West Coast District Municipality before he joined Stellenbosch University in 2003, where he is presently a professor in hydrology and environmental engineering in the Civil Engineering Department.

Du Plessis specialises in water resource evaluations and flood hydrology, and he provides institutional support to various local authorities. He obtained his PhD (Water Governance), MEng (Water Resource Management) and BEng (Civil) from Stellenbosch University.

He serves as a member of the executive committee on the board of the Institute of Municipal Engineering of Southern Africa (IMESA), where he is the director: Training and Skills Development. He also serves on the Education and Training Committee of the South African Institute of Civil Engineers (SAICE), and serves on the Editorial Panel of the *SAICE Journal*.

PAPER 11

DR ADÈLE BOSMAN

PhD (Civil Engineering)
Stellenbosch University

Adèle Bosman has more than 12 years of experience in the water engineering field in South Africa. She is currently a lecturer in hydraulics at Stellenbosch University.

She has experience mainly in stormwater, river hydraulics, rock scour and the design of large hydraulic structures. She obtained a PhD from Stellenbosch University in 2021. Bosman was awarded the Best Presentation by a YPF member at the 2019 SANCOLD Conference held in Benoni, Gauteng.

PAPER 12

KENNEDY MURUNGA

PhD Fellow (Civil Engineering)
PAUSTI

Kennedy Wekesa Murunga graduated with a BSc in Water Engineering from Kenyatta University in 2011. After graduating, he worked as a part-time lecturer at the Kenya Water Institute before he left to serve African Mission in Somalia in 2015 as a field design engineer specialising in grey, black and clean water systems design.

In 2015, he won the Nuffic scholarship to study a Master's in Water Science and Engineering (Hydrology & Water Resources) at the UNESCO-Institute for Water Education in Delft. After graduation, he worked at Upande Limited as a non-revenue water, GIS and remote sensing specialist, before joining GIBB Africa in March 2018 as a senior graduate water systems engineer with a focus on hydrology, remote sensing and flow hydraulics.

From April 2019 to March 2020, Murunga worked with Save the Children International in Afghanistan as a lead ecosystem-based disaster risk reduction hydrologist under the Afghanistan Resilience Consortium while maintaining a close relationship with GIBB Africa as an associate hydrologist. Kennedy has worked on projects in Kenya, Uganda, the DRC, Somalia and Afghanistan.

He recently won a full-time African Union PhD Scholarship and Rambøll Innovative Idea Acceleration Scholarship. He loves coding and badminton. Murunga is a member of the Hydrological Society of Kenya, Engineers Board of Kenya, British Hydrological Society, International Association of Hydrological Sciences, and International Society of Photogrammetry and Remote Sensing. He is currently a PhD Civil Engineering fellow at the Pan African University Institute for Basic Sciences, Technology and Innovation, Kenya.

PAPER 13

ERIKA BRAUNE

MEng (Civil)
Zutari

Erika Braune is a civil engineer working at Zutari within the Water Resource Management Unit. She has experience in dam safety investigations, performing flood frequency analysis and compiling municipal water resources management plans. She has also gained experience in international water resource management as well as data processing skills while working at Zutari.

In 2017, Braune obtained her BEng from Stellenbosch University, while being exposed to hydrological and geotechnical projects during her vacation work. In 2018, she pursued a Master's in Hydrology and Water Resources Management at Stellenbosch University while performing part-time work on dam safety investigations. Her master's thesis presented a daily conjunctive use model that incorporated links between surface water and groundwater, as well as reuse and desalination as municipal planning tool. In 2020, she obtained her MEng (cum laude) and was awarded the best civil engineering thesis. She is a registered as a candidate engineer with the Engineering Council of South Africa (ECSA), is a graduate member of the Institute of Municipal Engineering of South Africa, and is a member of the South African Institute of Civil Engineers (SAICE).

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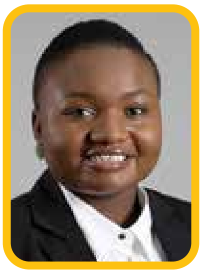


AYANDA CAROLINE MTHOMBENI

BTech (Civil Engineering)
Zutari

Ayanda Caroline Mthombeni is a master's candidate at Tshwane University of Technology (TUT) in the Civil Engineering Department. Her master's dissertation aims to analyse the impact of climate change on spatial planning and stormwater infrastructure, to predict future flood events that would likely be attributed to climate change. These predictions can then be used in the consideration for new developments on greenfield sites for spatial planning and the conceptual design of stormwater infrastructure. Various hydrological simulation techniques have been incorporated into her research, which has broadened her knowledge base of flood hydrology and its impact on engineering design.

She holds a BTech in Civil Engineering, which focused on urban engineering, from the same institution. Mthombeni currently works for Zutari as a civil technologist within the built environment and is also a research assistant for the Department of Civil Engineering at TUT. Her career has mainly been within the engineering consulting industry where she has been exposed to the design and site supervision of municipal infastructure in both the building and land infrastructure development sectors. Her passion involves community upliftment and development, and her projects have allowed her to further this passion.

PAPER 13

DR VERNO JONKER

PhD (Civil Engineering)
Zutari

Verno Jonker is an experienced water resources engineer with 25 years' experience in the consulting environment. He started his career with Van Wyk and Louw, where he was involved with potable water treatment design and master planning studies. Following a research position at Stellenbosch University during his PhD research, he joined Ninham Shand where he had the privilege of working with eminent dam engineers and hydrologists. After spending three years with Mott MacDonald in Cambridge, UK, he returned to Ninham Shand and now leads the Water Resources Management Group in Zutari.

Jonker has comprehensive experience with international development funded projects in Africa and has worked on some of the major river basins on the continent. His philosophy is that a fulfilling and rewarding career is only possible if you truly believe that what you do makes a difference.

PAPER 15

DR CHAVON WALTERS

PhD (Medical Biosciences)
CSIR

Chavon Walters began her career in 2007 when she was employed as a researcher at the CSIR in the Water Ecosystems and Human Health Research Group. She obtained her MSc in Environmental Sciences from the University of the Western Cape in 2010, and her PhD in Medical Biosciences in 2016.

Walters is currently a senior researcher in the Integrated Water Assessments and Solutions research group within the Water Centre at the CSIR. She has experience in the implementation and management of several multidisciplinary research projects. Her current job purpose includes the implementation and management of several research projects, project management and the attraction of funding through the preparation of proposals and networking. Her project portfolio includes projects relating to water quality, wastewater quality, ecotoxicology and water reuse potential. In addition, she has experience in mentoring junior staff and interns, and in the supervision of postgraduate students. Walters has developed a significant track record (as measured by a basket of publications and presentations.

Actively involved in the scientific community, she is a SETAC and RCS member. She serves on the exco and LOC of both the 2022 and 2024 ICMGP Conferences.

PAPER 15

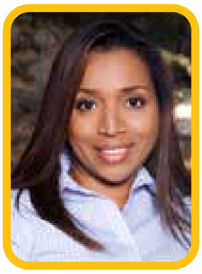
MARONEL STEYN

MTech (Environmental Health)
CSIR

Maronel Steyn obtained her Master's in Environmental Health from Central University of Technology, Free State, in 2002. Her competencies lie in environmental management and seeking causes or solutions driven to improve the quality of ecosystems and human health specifically related to water. She has worked at the CSIR in Stellenbosch for the last 16 years and currently forms part of the Integrated Water Analytics and Solutions Research Group within the Smart Places Cluster.

Steyn has experience in water-related and environmental health research projects and has worked on large international projects funded by the European Union, African Union, the African Development Bank and USAID. She currently leads a multicountry project on phycoremediation in SADC. She is the secretary for the IWA Metals and Related Substances specialist group and a board member for the IWA Health Related Water Microbiology specialist group. Steyn is an active WISA member and was the YWP Chapter Chair for the Western Cape a few years ago. She has several publications in international journals that span social and natural sciences.

PAPER 16



SHIREEN SAYED

MSc (Renewable Energy Engineering), MSc (Project Management)
SSIMM Energy

Shireen Sayed has been involved in the built environment for over 20 years and has performed various technical, project management and executive management roles. She was born in Durban, South Africa. After completing her engineering studies and working in South Africa, she relocated to Ireland where she spent 11 years working on various infrastructure projects.

Sayed returned to South Africa in 2012 as the Managing Director of Aspire Project Management, delivering infrastructure projects for the public and private sector. She has recently taken up the reins as CEO for SSIMM Energy, which specializes in micro-grid and energy storage.

The experience gained in South Africa and Ireland, together with a naturally affinity to deliver projects, provided a sound foundation for specializing in project management. She gained extensive experience in the implementation of various, complex projects. This experience has given her the opportunity to work on projects funded by the European Union and National Treasury, and therefore reporting to both these entities on technical progress and financials for the respective projects. She is now focusing on renewable energy projects and the deployment of micro-grids and energy storage for various applications across South Africa.

Shireen holds an MSc in Renewable Energy Engineering (University of Aberdeen, Scotland), an MSc in Project Management (University of Limerick, Ireland), and a BTech in Civil Engineering (Technikon Natal). For more information on micro-grids and energy storage technology, connect with ssimmenergy on LinkedIn and Facebook.

PAPER 17

HOLIDAY KADADA

MSc (Electrical Engineering)
Zutari

Holiday Kadada, a Zimbabwean national, obtained her BSc and MSc in Electrical Engineering from the University of Cape Town. She has nine years of experience in industrial and control engineering, working predominantly in the water industry. She works on water and wastewater treatment projects, as well as pump stations – designing electrical, control, instrumentation and monitoring systems for these installations. She is registered as a Professional Engineer with the Engineering Council of South Africa (ECSA) and is a project lead and line manager at Zutari (formerly Aurecon).

Kadada's favourite engineering victory is when the highly electrical and mechanical project Leliefontein Pump-As-Turbine Station won a National SAICE Award. She now feels like an honorary civil engineer and is still waiting on invitations to all the SAICE events.

As much as she enjoys working on poo farms, her career driving force is training and mentoring young engineers to gain confidence and equipping them with the tools to be competent, ethical, independent and empowered engineers.

PAPER 17

JACOBUS KRIEGLER

MSc (Civil Engineering)
Zutari

Jacobus Kriegler obtained his BEng (Civil) and MSc Eng (Civil) from Stellenbosch University. He started his career at Zutari (then Africon) in 2001 in their Cape Town office, where he is currently an associate in the Water Unit.

His area of specialisation is in the design of bulk water conveyance systems, which includes system optimisation, hydraulic design and surge analysis. He has experience in the hydraulic design and layout of water and wastewater pump stations, including the compilation of contract documentation, contract administration, and the commissioning of pump systems. In recent years, he has also gained experience in the condition assessment and rehabilitation – using trenchless technologies – of bulk sewer systems.

He is a registered Professional Engineer with the Engineering Council of South Africa (ECSA) and is a member of the South African Institution of Civil Engineering (SAICE). He currently serves on the board of the South African Society for Trenchless Technologies (SASTT). In his free time, Kriegler likes cooking and is also a keen homebrewer.

Abstracts

KEYNOTE SPEAKER – Session 2

Werner Jerling

Deliver infrastructure to a rapidly changing and impatient world now! A call to action

So called 'service delivery protests' have become commonplace in South Africa, yet the factors giving rise to an increasingly disgruntled populace are not unique to South Africa and the need for improved access to critical infrastructure is widespread in both developing and underdeveloped countries. South Africa provides an excellent case study that would resonate in many countries.

The engineering community plays a pivotal role in planning for, designing and constructing critical infrastructure and stand central in the process finding synergy between those needing infrastructure, decision-makers, funders, designers, constructors, and maintainers of infrastructure. The nexus between these parties may be argued as the point where synergies between parties must be found, at local and provincial government level.

There is no end to the writing of papers, undertaking expensive studies and compiling reports to investigate problems and propose solutions, yet, when words need to turn to action, we are failing with ample criticism in hindsight and very little urgency in solving looming crises in foresight. The ability of the engineering fraternity to influence policy and decisions with foresight and wisdom may very well be questioned when we, in the profession, lament slow and poor decision-making. Time is not the friend of planning for and delivering infrastructure. As the sands of time run out, we will not forever have the luxury of cogitating and procrastinating. We will be driven to urgent and drastic action!

Our actions need to be driven by realities we face, such as continued rapid population growth, urbanisation, climate change, disparity in education and income, lawlessness and gangsterism, unemployment, and the rights and expectations of citizens.

This keynote address will aim to stimulate debate and thinking as it investigates the rapid changes influencing the call for an urgent and drastically revised approach to delivering infrastructure. It considers the status quo and identifies some barriers toward the delivery of infrastructure in pace with the growing demand. In contribution to the debate, some suggestions as to potential courses of action will be presented to support a drive toward getting much needed infrastructure projects across the line to be productively and cost-effectively delivered with the associated benefits of creating much needed employment improving the lives of millions.

KEYNOTE SPEAKER – Session 3

Dr Weicheng Wu

Big geodata management for sustainable development

The term 'Big data' was proposed by J.R. Mashey (SGI) in 1998 but it did not become popular until 2013 when Mayer-Schönberger and Cukie published a book *Big Data: A Revolution That Will Transform How We Live, Work, and Think*. Big data is now a hot-spotted term and used in all different domains with '5V' characteristics – i.e. Volume, Velocity, Variety, Value, Veracity, and now with three more, Variability, Validity and Visualization (8V). The purpose of this paper is to introduce the big geodata and its applications in natural resource exploitation, and socioenvironmental interactive analysis for sustainable development.

Big geodata are the huge volume of variety of Earth-related information with geographic coordinates including geographic data, geological data, different spherical data (lithosphere, biosphere and atmosphere), and all types of spatial data including landform (elevation, slope and aspect), meteorological data, and land use and land cover data, etc. With integration of the human dimension data (e.g. socioeconomic data, policy and strategy) after spatialization, it is possible to constitute an integrated Man-Earth System big dataset. The strategic significance does not lie in its huge volume but in its new added values after thematic processing and extraction using artificial intelligence (AI) tools, which allow us to obtain key knowledge and achieve more profound understanding about the integrated system and determine the optimal utilization of the natural resources and sustainable ways of development.

The traditional processing and statistics are not suitable for such big data mining and analysis. We have to apply new approaches such as machine learning, including deep learning and 3D visualization, to extract the useful and necessary information or to visualize the complex, abstract Earth and Man-Earth Systems in 3D and 4D to achieve our goal. The study will be unfurled in the following steps: 1) Integration of multisource big geodata and human socioeconomic data; 2) Machine learning-based thematic analyses; 3) Simulation to define the sustainability thresholds; and 4) Development of the sustainable interaction system.

KEYNOTE SPEAKER – Session 4

Dr Kevin Wall

Infrastructure service delivery institutions for less functional areas

Municipalities that serve SA's small towns and rural areas usually suffer service delivery problems, which can be ascribed to inadequate management, skills and budgets. The reasons for these in turn invariably include weak economic base, unwise spending of available funds, and difficulty of recruiting and retaining skilled staff.

The municipal model South Africa uses was evolved for industrialising 19th-century Britain, then transplanted to its colonies. Is it not time to review if it is still appropriate to delivering services in the non-metropolitan areas of SA? Alternative institutional models have been proposed. Examples: (i) The attempt many years ago to set up 'regional electricity distributors' to address electricity distribution infrastructure's deterioration. (ii) The periodically revived proposal for 'regional water utilities'. These two concepts had in common that responsibility for specific infrastructure and its service delivery function would be removed from municipalities and given instead to regional bodies.

During the second half of 2019, two departments published somewhat divergent views on institutional reform: (i) CoGTA diagnosed 'the pattern of operating in silos' as leading to 'non-optimal delivery of services'. Its proposed solution is an 'integrated district-based approach'. (ii) The National Water and Sanitation Master Plan identified 'several challenges associated with the current institutional arrangements'. To address this, DWS reiterated its preference for regional water (and sanitation) utilities 'where necessary'.

Will one of these be the saviour of failing service delivery? Alternatively, would some communities not be better served by a regional utility – maybe a multipurpose regional utility, rather than one for water and sanitation only, as DWS is proposing? If either Minister (of Cooperative Governance or Water and Sanitation) gets their way, municipalities, especially those covering rural areas, will undergo changes to their powers and functions on a scale not seen since the late 1990s.

At the end of 2020, the National School of Government published 'A national implementation framework towards the professionalisation of the public service'. Of particular interest to municipal service delivery practitioners is the intention 'to create a capable, ethical and developmental public service', and that the public service 'be merit-based and insulated from party politics'. How it would be thus insulated is not described – perhaps an institutional form is in mind?

Discussion at an IMESA conference of alternative service delivery models is long overdue. The proposed paper will offer a starting point for this discussion.

KEYNOTE SPEAKER – Session 5

Dr Ravi Galkate

Assessment of meteorological drought in Bundelkhand region of MP (India) using Standardized Precipitation Index (SPI) and remote sensing derived Vegetation Condition Index (VCI)

Drought is a natural, temporary, random, and regional climatic phenomenon caused due to a lack of precipitation leading to a water deficit. Many drought indices are being used worldwide to assess drought duration, magnitude and severity, which are helpful in the formulation of drought mitigation strategies. The satellite-based data, information and indices have been found very efficient and useful for the quick assessment of a drought situation and can be proved to be more effective if tested using suitable similar physically observed climatic data-based indicators.

In the present study, the MODIS NDVI data has been used for vegetation health and drought monitoring through NDVI based Vegetation Condition Index (VCI) (Kogan, 1990; 1995) and results were compared with the Standardized Precipitation Index (SPI; McKee et al., 1993) in the Bundelkhand region in Central India, covering five districts of Madhya Pradesh namely, Sagar, Damoh, Tikamgarh, Chattarpur and Panna. The VCI is computed as the pixel-wise normalization of the NDVI and its values can be averaged spatially and temporally to facilitate comparison with the meteorological drought indices.

The Bundelkhand region of India has been experiencing recurrent droughts, causing adverse impacts on water resources, agriculture, rural livelihood and economy (Pandey et al., 2010 and Kundu et al., 2015). The monthly rainfall data of five stations for 29 years from 1990 to 2018 was used to analyse the extent of meteorological drought and identify the driest years using rainfall departure analysis and three-month time scale SPI. The VCI was analysed for the NDVI data from 2000 to 2020. From the departure and SPI analysis, the years 2007, 2015 and 2017 were observed as the driest years, with the larger spatial extent in the study area. The spatial variabilities of droughts in 2007, 2015 and 2017 were also assessed on the basis of the satellite-based indices. The VCI shows that about 49%, 87% and 40% of the area of Bundelkhand region was under drought in the month of October, while 18%, 7% and 10% area was under drought in the month of August in the years 2007, 2015 and 2017, respectively. The drought severity was observed to be very high during October 2015; however, in the years 2007 and 2017, the whole monsoon seasons have experienced drought. The satellite-based indicator VCI has interpreted results in agreement with the SPI results.

KEYNOTE SPEAKER – Session 6

Dr Gerald Corzo Perez

Machine learning and information systems for spatiotemporal analysis of hydrometeorological extremes from global data sets

Technological advances in the world have an important contribution in the areas of models, data and data-driven models (machine learning and AI). Climate change is a concern around the world, and this is one of the most important areas nowadays in which large data sets must be shared and used. In this work, the information system from the past and future hydrometeorological extremes has been implemented on an online platform.

The data was analysed through a series of non-linear thresholds to assess extreme hydrological events. Spatial and temporal variations of extremes are presented using combinations of simple patterns of anomalies and various techniques for visualization. Masks that filter data have been applied to analyse from a continental scale and climatic regions to river basins. A comparison of two large data sets at a global scale – namely ERA5 and IMERG – are compared by patterns of extremes and analysis of temporal variations of spatial aggregated information of extremes. For this, thresholds and spatiotemporal analysis of clusters of events have been grouped using a standardized index for precipitation (SPI). Overall trends and dynamics of the extremes show clear similarities, and are also in agreement with in-situ measurements and coherent with all models. Clearly, it is possible to see that the data available can capture the relation between El Niño and La Niña years, and the occurrence of worldwide changes in the water balance.

An online platform to visualize the extremes has been prepared and the results are shared in this presentation.

KEYNOTE SPEAKER – Session 7

Dr Abdelazim Negm

A novel standalone solar-driven agriculture greenhouse-desalination system: that grows its energy and irrigation water

Food security is an essential issue for many countries around the world. It is of particular concern in Egypt, where the hot climate, high solar radiation, and lack of water resources for irrigation continue to pose an obstacle in increasing the amount of farmland and making growing crops an expensive and resource-intensive endeavour. As Egypt and many regional countries enjoy a relatively high intensity of solar energy, utilizing the surplus solar energy to overcome these drawbacks, produce irrigation water, and generate the power required for the system's sustainable operation presents a real challenge focus of our novel developed system.

The system developed, designed and implemented a pilot-tested innovative solar-driven agricultural greenhouse (GH) integrated with desalination system that grows its energy and irrigation water (i.e. self-sufficient in energy and irrigating water). The developed system utilizes the excess GH solar energy (above that needed for the plant photosynthetic process) for producing the irrigating water (via desalination processes) to provide the suitable GH partial shading to reduce the cooling load and generate thermal energy (via a semi-transparent roof), and provide the GH plants with the required cooling and controlled microclimatic environment via a solar-driven cooling system. Numerical models will be developed to simulate the physical phenomena in the new solar GH desalination system. The validated numerical models and experimental results of the pilot system were used to develop the conceptual design of the large-scale system that suits different operating conditions in Egypt and other regions of similar climate conditions worldwide. The new system will provide the basic food needs for small communities living in remote areas and act as a means of creating jobs and business opportunities. Also, severe saltwater (desalination residue) will be used in agricultural production and to produce seafood. The system could be operated remotely by mobile application utilizing IoT. The project idea was originally developed by a team presented at the website www.smart-gh.net.

It worth mentioning that this work was supported by the British Council (BC) of UK (No. 332435306) and Science and Technology Development Fund (STDF) of Egypt (No. 30771), through the project titled 'A Novel Standalone Solar-Driven Agriculture Greenhouse-Desalination System: That Grows its Energy and Irrigation Water' via the Newton-Musharafa funding scheme call 4.

PAPER 1

Dr James Cullis

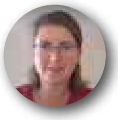
Water security and climate change risks for municipalities across South Africa

Recent events, including the Cape Town water crisis, continuing drought conditions in large parts of South Africa and an increase in recent flooding events, particularly in urban areas, have highlighted the increasing water security risks for towns and cities in South Africa as a result. Climate change is considered to be a significant factor in this increasing risk that needs to be urgently taken into account in terms of both water resource planning and infrastructure planning and design.

In this paper, we present the results of a study that looked at current and future water security risks for all municipalities as a result of both expected climate change impacts as well as future population growth scenarios up to 2050. The study was done in support of the development for the CSIR Greenbook for assisting municipalities with evaluating their climate change risks and giving consideration to appropriate adaptation and mitigation options. The study, however, also builds on work done for previous projects, including contributing to the Long Term Adaptation Scenarios (LTAS) research programme, DWS climate change strategy and a study of the economic impacts of climate change for South Africa for National Treasury. These studies, as well as recent work done in support of update estimates of climate change risk for water supply to the City of Cape Town, will be presented and recommendations made for appropriate adaptation and response options.

We also consider the potential impact of climate change on increasing flood risks across South Africa, particularly for critical infrastructure such as cities, dams, bridges, roads and power lines, and describe how supporting a transition to becoming a Water Sensitive City (WSC) in particular is crucial in managing both increasing water security and urban flood risks, as well as additional co-benefits necessary to create resilient, sustainable and liveable infrastructure and urban areas in South Africa, but also relevant for the rest of the SADC region and for other cities across Africa. In particular, we advocate for a better understanding of the specific risks associated with climate change and developing bottom-up solutions that address the underlying risks and vulnerabilities and allow for an adaptive pathways solution to increasing resilience. Investing in ecological infrastructure (EI) such as rehabilitation of catchments and water sensitive urban design (WSUD) is also critical.

PAPER 2



Kerry Fair

Financial feasibility and bankability of city-wide water loss intervention programme – City of Tshwane

The study described in this paper designed a programme for reducing water losses in City of Tshwane (CoT) and improving revenue and financial viability based on risk principles, proving the bankability of such a programme with a view to attracting potential funders.

Water security is one of the key challenges facing South Africa and the reduction of water losses forms an integral part of ensuring sustainable water supply. Few studies have been undertaken where the potential for water loss reduction and potential savings have been analysed separately and in detail for each water distribution management zone (DMZ).

The CoT system is being operated in 240 primary DMZs, all of which are either supplied by a reservoir, a water tower, or a direct connection to a bulk pipeline. These DMZs were the core subjects of this water loss reduction feasibility study. A DMZ database was compiled and populated with all the requisite water use/billing, water loss, water pressure, customer debt and water system condition information. This database was used to develop a set of rules-based decision trees to determine first order optimal water loss interventions and costs for each DMZ.

Each DMZ was then considered a "sub-project" and a detailed Terms of Reference and capex and recurring opex costing for the indicated interventions in each DMZ were done. The potential benefits (decrease in SIV, decrease in AADD, increase in billed/metered AADD) for each intervention were calculated.

A financial model was developed for each of the 240 DMZs to evaluate the impact of the capital and operating costs of the proposed water loss interventions against the potential achievable savings. The capex and opex associated with each intervention selected per DMZ were formulated in a 20-year cash flow model against the incremental benefits in bulk purchases and increased. These incremental cash flows were then discounted to NPV terms. Each DMZ model considered the unique characteristics of the particular DMZ, including average tariff earned, collection rate and water balance.

City-wide modelling was performed to evaluate the impact of four DMZ-based intervention implementation strategies. The evaluation was based on the projected cash flows of CoT Water Services as a whole, considering its ability to service the resultant debt and ability to generate future excess cash to allow future interventions to be implemented without the need for external funding.

The results revealed positive city-wide NPVs achieved both pre- and post-funding, with all debt covenants met.

PAPER 3

Frank Stevens

Deep tunnel sewerage systems: Singapore's success story

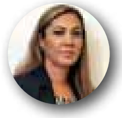
With a growing world population and increasing urbanization, volumes of sewage are rising, especially in large cities, which require larger capacities in sewage transport and treatment. The systems built decades ago need to be modernized, extended or replaced to ensure efficient and sustainable wastewater management.

A Deep Tunnel Sewerage System is – especially from an operation cost point of view – a very cost-efficient solution to meet long-term needs for wastewater collection, treatment and disposal. Deep sewer systems involve large diameter main tunnels that convey wastewater by gravity to centralized treatment plants, mostly located outside the cities. Smaller diameter, often pipe jacked, link sewer networks and deep shafts are further parts of these schemes. Due to the length and the required slope towards the treatment plant, tunnels and access shafts are installed in increasing depths, which represents a challenge for tunnelling and shaft sinking, especially if high ground water tables are present. In addition, cities demand the construction of such large-scale schemes to be quick and safe, with minimal impact on population and environment. One of the benefits of deep tunnelling is the activity takes place well below other existing and future municipal services.

The first large-scale Deep Tunnel Sewerage System (DTSS Phase 1) has been completed in Singapore. Due to a high population density and a continually developing economy, Singapore faces a lack of land space for development and is therefore a leading innovator in sustainable planning and managing its underground space. Singapore has already moved other municipal infrastructure and utilities below ground, including metro lines, retail, parking and pedestrian walkways. The next major milestone is the construction of the DTSS Phase 2. Fourty kilometres of deep tunnels – average depth 30 m – (ID 3 m to 6 m) and sixty kilometres of link sewers (ID up to 3 m) are currently under construction for the new wastewater infrastructure system. The deep tunnels will connect with the existing used water infrastructure to create one seamless and integrated system; the link sewers will create an interconnected network to channel used water from the existing sewerage pipelines to the deep tunnels. Numerous tunnelling and mechanized shaft sinking machines are deployed to ensure a reliable and cost-effective construction of the high-quality structure.

This paper will present the concept of the Deep Tunnel Sewerage Systems and Singapore's pioneering role as an example of what could be replicated by South African cities. Furthermore, it will discuss the application of mechanized tunnelling and shaft sinking technologies to realize deep sewer projects to the benefit of all parties involved.

PAPER 4



Leisel Bowes &
Devan Govender

Illuminating a social development program – focus on the eZimbokodweni pipe and pedestrian bridge

The eZimbokodweni Pipe and Pedestrian Bridge, located in the Philani Valley (Umlazi Y Section) and the New City Area of eZimbokodweni in KwaZulu-Natal, entailed raising an encased sewer pipe as well as the development of a pedestrian bridge over the eZimbokodweni River. The bridge provided a much needed, safe pedestrian crossing in this largely rural area, and considering South Africa's rolling blackouts through load-shedding, as well as continuous electricity cable theft, innovative technology through the use of photo-luminescent concrete (glow-in-the dark) was used to ensure that residents could safely utilise the bridge at night in the absence of electrical lighting. The innovation was realised through partnership between the client, the contractor and the consultant with technical support from the material supplier and research undertaken by the University of KwaZulu-Natal.

Whilst this has garnered much positive technical interest, the implementation of infrastructure projects in South Africa at large has been hindered by work stoppages through worker unrest and, more recently, local contractor organisations demanding that a percentage of projects be awarded to emerging contractors, citing government's transformation policies. To prevent the derailing of this project, extensive effort was made to allow early engagement and manage stakeholder expectations. Social facilitation was undertaken with numerous key stakeholders within this community through an Institutional and Social Development (ISD) process.

The ISD element enabled stakeholders to incorporate social upliftment components into the project without compromising the project output (construction of the bridge). Whilst some 12 sub-contractors were engaged on the project, stakeholder engagement platforms were established that created an environment where social challenges could be promptly raised and resolved. As a result of the introduction of these important social facilitation processes, the risk for work stoppages was mitigated, allowing completion of the project two months ahead of programme and within budget.

This paper reviews the methods employed by the project team to engage with the numerous relevant stakeholders in the project, in such a manner as to prevent any work stoppages or work disruptions throughout the project. The paper aims to draw a comparison between the methods employed in the case study against theoretical best practice procedures, providing recommendations for further roll-out in future projects.

PAPER 5

Peter Fenton

Emergency rehabilitation of Seaward Road Bridge over the Umhlatuzana River

A portion of the five-span, 150 m long Seaward Road Bridge over the Umhlatuzana River collapsed during Durban's April 2019 floods, cutting off an important regional transport link and hampering the local economy. In solving this problem, municipality-employed structural engineers demonstrated how careful risk management and close cooperation with an experienced contractor can unlock synergies that save time, money and the environment.

It would have been relatively quick and easy to demolish the whole structure and rebuild it 'from scratch', especially under emergency provisions with a budget ready. The alternative of taking apart and reconstituting the bridge required negotiating many levels of uncertainty and risk. As a multispan, continuously prestressed concrete bridge, it was specifically designed to only be able to stay up as an integrated structural arrangement, and never supposed to be tampered with once complete. Moreover, the bridge had an unusually unstable design that made supporting it in its damaged state particularly difficult. But a straightforward replacement would have come at the expense of riverside ecosystems, and wastefully discarded the portion of the bridge that was still intact. Environmental sustainability considerations determined decisions all the way through the project, which involved numerous unusual challenges, some very unexpected.

The salvaged spans had to be stabilised through extreme and ongoing variations in loading and displacement, as the damaged spans were cut away, then blasted with explosives, then replaced, while suffering renewed flooding. Prestress couplers buried deep in existing reinforced concrete had to be meticulously quarried out and exposed, so they could be safely reused to connect the replacement spans. When it was discovered that those couplers weren't compatible with modern components, the components had to be custom-modified and then brutally tested. A precisely limited prestress force had to be applied to the new deck spans, to account for the age-related differences in concrete behaviour, and increase in length, of the reconfigured bridge.

The success of this project clearly demonstrates the flexibility of prestressed concrete as a construction system. Prestressed elements can be reused if a structure is damaged or when major modifications are required, making it much more modular than is usually assumed. In particular, it establishes that decision-makers should consider modifying the length of continuous multispan bridges rather than rebuilding them, particularly when adding additional lanes below. This is in the interests of both economy and environmental sustainability.

PAPER 6

Claus Rabe &
Brendon van Niekerk

Estimating the capital and operating costs of development proposals in discouraged growth areas

Urban land markets tend to drive outward expansion to where land is cheaper. However, it is argued that, since the true cost of peripheral development is not fully internalised into the developer's location decision, land markets are inherently distorted. By imposing significant long-term costs and risks on the providers of municipal services, an unregulated land market results in sub-optimal fiscal outcomes for the municipality, and the corollary budgetary constraints that could impact the delivery of municipal services citywide. Accordingly, growth management instruments are justified in order to correct these distortions.

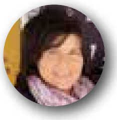
The so-called 'urban edge', widely adopted in South Africa, is a simple growth management tool that has achieved varying levels of success. In replacing the urban edge with 'Discouraged Growth Areas', the City of Cape Town has opted for a smart instrument that requires developers to cover the full cost of peripheral development as accrued over 20 years.

However, such an instrument requires the development of a credible method of estimating the long-term capital and operating costs of yet-unknown future development proposals based on their scale, land-use configuration and spatial location.

In this paper, we will establish both the business case and describe the methodology of a spatial costing tool adapted to geographically remote contexts where no master planning exists, and the potential engineering solution is not yet known. By applying a first principles approach to a given set of development parameters located within a cost surface per service, the spatial costing tool is able to quantify the capital and operating costs apportioned to the City, the State, the developer and the end-user. The cost surface was developing using a range of spatial analytical techniques, including terrain and network analysis applied to City infrastructure and elevation data. Municipal service arrangements particular to each service were described by City engineers and applied via a set of calculation rules and assumptions.

These costs may then be compared to equivalent developments located elsewhere in the city. This process provides an evidence base to inform and guide decision-making concerning urban development in the Discouraged Growth Areas. The assessment of the long-term costs of developments provides nuance to the perceived desirability of land-use applications that deviate from Council-approved policy.

PAPER 7



Dr Danél van Tonder &
Professor Carel Schoeman

Re-watering of West Rand dolomitic compartments: Implications for JB Marks Local Municipality

The Far West Rand goldfield represents one of the richest gold mining areas in the world overlain by one of the largest dolomitic aquifers in the world. This posed unique challenges to underground mining development as well as the surface municipal development. During the peak of gold mining in the Far West Rand, a decision was made to reduce the large influx of dolomitic groundwater into the underlying mine void by dewatering the >1.2 km thick dolomitic compartments.

By dewatering the dolomitic compartments, significant sinkhole formation and widespread ground instability was initiated, a situation that still poses challenges for development in this area. Mining is not a sustainable practice and many gold mines are closing down operations. Mining adversely affects not only water quality but also quantity, posing a significant risk to water resources in the Mooiriver catchment. Although various scenarios predicting the post-mine closure consequences have been modeled, the uncertainty remains.

However, all modeled scenarios are in agreement on three important aspects:

1) The water quality for downstream users (including J.B. Marks Local Municipality) will be compromised.
2) The quantity of water reaching the downstream users, during the period after pumping ceases and the time the mine void and overlying dolomitic compartments have naturally filled up and contribute to the water resource, will be compromised.
3) Renewed surface instability due to sinkhole formation and potential re-activation of existing sinkholes will pose a threat to infrastructure, built environment and socio-economic development in the catchment.

Unless the complexities of the long-term risks associated with post-mine closure are addressed in a coordinated manner as a matter of urgency through a rational and integrated spatial planning process and strategy formulation, a socio-economic disaster in the not-too-distant future is a certainty. Additionally, environmental pollution, dysfunctionality of infrastructure (transport, roads, water and sanitation) and compromised sustainability of the built environment will impact negatively on economic growth in the region.

PAPER 8

Stephen Kleynhans

Planning and implementing large-scale groundwater supply schemes

Abstracting groundwater from the TMG (Table Mountain Group) Aquifer was initially proposed as a potential source of water supply to the Cape Town metropolitan area in the 1990s during the initiation of a comprehensive water resource planning study for Cape Town and the surrounding metropolitan areas. This resulted in a process of research, investigation and consultation, during which an extensive list of potential water supply schemes was generated. A TMG Aquifer groundwater development scheme was envisaged to be one of the schemes that would be called into service.

The City of Cape Town (CCT) initiated the TMG Aquifer Feasibility Study and Pilot Project in 2001 and continued until 2013, to determine the potential yield from three main groundwater target areas (namely Theewaterskloof [Nuweberg/Eikenhof], Wemmershoek and Kogelberg-Steenbras). From 2013 onwards, the study continued in the form of an extended Exploratory Phase to also investigate the potential yield from the Groenlandberg/Klipfontein area near Theewaterskloof Dam and to undertake yield tests in the three previously identified main target areas.

The implementation process of the scheme was disrupted during a severe drought in 2017 as 'Day Zero' loomed for the CCT. A National Disaster was declared and the CCT initiated an emergency initiative, called the New Water Programme (NWP), to fast-track the implementation of alternative water supply schemes to the City. The CCT aimed to implement initiatives for water supply which would contribute to the drought resilience of the City in future. One of these potential water supply sources was the TMG Aquifer.

The project involves the development of boreholes in the TMG Aquifer in three geographic areas to augment the water supply to Cape Town as part of their water resilience strategy. It includes the drilling of production boreholes with depths greater than 800 m, the mechanical and electrical equipping thereof, as well as the pipelines required to connect to existing dams. The estimated yield from the three wellfields is 50 Mℓ/day in total. The construction of the Steenbras Wellfield is well underway and will be commissioned by the time the paper is presented in December 2021.

The project provided valuable opportunities to test, model and adapt environmental protection measures and aquifer management principles, and some useful lessons were learnt. The unusual circumstances of this project resulted in a situation where stakeholders, engineers, contractors and specialists were required to work together to achieve a successful outcome.

PAPER 9

Thabang Mafokoane

A review of acoustic pipeline monitoring systems used to detect bursts and blockages

Pipeline leakages, bursts, and blockages are issues that are experienced by numerous urban communities globally and locally. These issues emerge from numerous variables such as pipe deterioration and human-instigated assembly faults. Leakages and bursts of pipelines are some of the major causes of the increased scarcity of drinking water. These pipeline issues not only affect society but also apply pressure on the economy and the environment. As such, this issue needs our undivided attention to prevent it from escalating. This study shows a project design done on the review and a proposed design of acoustic monitoring system for pipeline leakages, bursts, and blockages.

To achieve this, a review of the existing methods and models for pipeline monitoring was conducted. A comparison of existing methods was based on system characteristics – i.e., operation efficiency, maintenance efficiency, ease of installation, cost efficiency, energy efficiency, and overall reliability. These characteristics form part of the most vital characteristics of a system concerning its reliability. To better propose the best solution, the social, environmental, and economic influences of the above-mentioned pipeline issues are just as important to consider.

A comparative analysis on the performance of the existing models and systems was performed to provide the best guide in determining the best model in pipeline monitoring for leakages, bursts, and blockages. These systems include: a) Conventional and visual method, b) Wireless sensor network systems, c) Acoustic monitoring systems based on WSNs, d) Sound variation vibration sensor systems, e) SmartPipe based on WSNs approach, f) ADIGE method, g) SPAMMS system, h) EARNPIPE Systems, and i) Magnetic induction based WSNs (MISE-PIPE). Comparisons made were based on other works by different authors, hence no empirical measurements were taken. A framework was then proposed and executed to examine the best design for monitoring pipelines.

Based on available methods and models, the model proposed in this paper is a hybrid one that combines the best of what the existing models can offer to monitor a pipeline under and above ground. Many existing models can only manage a single job with a lot of drawbacks on other features such as burst detection. The combination of the most efficient models to a single model comes with a lot of benefits and less drawbacks. As with any system in existence, a maintenance plan was discussed to ensure the best operation of the system.

PAPER 10

Matt Braune

Proactive and prioritised stormwater maintenance & management system

South African municipalities have been criticised for insufficient service delivery, causing strikes and unrest by the public. At the same time, municipalities are challenged with increasing maintenance costs and budget constraints for the upgrading of municipal services such as roads and stormwater. This has again been highlighted by several flood events during the rainy season causing significant damages to roads, property, as well as loss of life. A further aggravating factor is climate change, which is causing more sporadic as well as intensive storm events.

The lack of maintaining existing stormwater drainage systems has a significant effect on the drainage system capacity due to blockages and siltation causing excessive run-off on roads that are severely damaged by erosion of the road surface. Furthermore, the increased urbanisation and densification causes a significant increase in surface run-off, which existing drainage systems can no longer accommodate.

A recent project involving a stormwater master plan for Alexandra in the City of Johannesburg has highlighted the need for planned and regular maintenance of stormwater systems, as well as upgrading of under-capacity drainage systems to prevent excessive and uncontrolled flooding. The stormwater master plan included the visual condition assessment and survey of the existing stormwater drainage system, as well as hydrological modelling and developed a unique and practical approach using a prioritisation algorithm in identifying and prioritising the flooding problems, as well as required maintenance activities and schedules. The study also included a cost comparison of regular maintenance that would be required to clean the drainage system and the capital cost now needed to repair and replace the blocked drainage system.

This paper presents a case study that highlights the implications of not maintaining stormwater drainage systems, as well as the excessive capital cost required to now replace and upgrade the drainage system – which could have been prevented by carrying out regular maintenance. The paper also gives a practical approach to prioritising flooding problems, upgrading under-capacity systems and maintenance activities for improved forward planning, budgeting and service delivery.

PAPER 11


Prof JA du Plessis &
Dr Adèle Bosman

Hydrological study and hydrodynamic modelling on Horlosiekloof, De Doorns, Western Cape

Municipalities frequently need to deal with unique stormwater design problems. In the case study presented in this paper, the unique approach to resolve a stormwater design problem is presented and illustrates how smart engineering can be used to create synergy between different design components. An investigation on the flood hydrology and river hydraulics of the Horlosiekloof catchment area (De Doorns in the Western Cape) was carried out after agricultural development resulted in significant changes to the lower section of the catchment.

The primary objectives of the research were to:

- Determine the expected flood peaks and hydrographs from the Horlosiekloof catchment area.
- Ascertain the impact that the agricultural development has on the flood regime.
- Perform 2D modelling of the current development of the study area to determine the extent of the flooding that can be expected by using the HecRAS software program.
- Determine possible mitigation measures to decrease the flood risk.

Three methods were used in calculating the flood peaks. The rational method proved to be the more appropriate approach to be used. The flood analysis of the pre- and post-development of the lower catchment concluded that developments had a marginal impact on the expected flood peaks. However, human interaction resulted in altering the flow path, and presently most of the run-off is diverted into/concentrated in a well-defined stone pitched channel.

A detailed 2D hydrodynamic modelling (HecRAS 5.0.3) simulation was conducted on the catchment. The modelling indicated that, while the combined capacity of the culverts may be adequate to deal with the 1:2-year flow, supercritical flow conditions exist upstream of the N1. It was found that upgrading the discharge capacity of the existing culverts near to the channel, and that additional culverts might reduce the flood risk. The lowering of the ground level upstream of all culverts will result in the formation of a hydraulic jump upstream of the N1, which will create subcritical flow conditions.

A flood attenuation dam was evaluated as an alternative to upgrading the capacities of the culverts but was found to more costly than the proposed solution. Moreover, an attenuation dam may lead to fluvial morphological impacts upstream and downstream of the dam.

PAPER 12

Kennedy Murunga

Spatio-temporal analysis of land-use/land-cover changes in transboundary Mara River Basin

Limited water availability during the dry season in the Mara River Basin has been a major problem to sustain ecosystems, domestic demands and other socio-economic requirements. Currently, there is not enough water allocated to meet these demands and its management is also inefficient. The problem is directly linked to land-use/land-cover and landscape pattern changes. The conversion of land poses risks of reduction in infiltration rates, groundwater recharge or short-circuiting of vital hydrological process such as evapotranspiration.

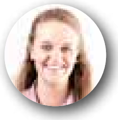
The objective of this study was to use open-source GIS tools and remote-sensing techniques to analyse spatio-temporal land-use and land-cover changes in the Mara River Basin for the period 1961-2016. The study focused on three selected areas. Area 1 comprised the upper Mara Nyangores and Amala tributaries. Area 2 included the Nyangores and Amala confluence at Emarti Bridge, while area 3 included the meandering section on the mainstream Mara River, and the Mara national reserve. These areas were purposely selected since they cover sites where environmental flow surveys were undertaken in 2015 and 2016. In this study, multi-temporal satellite images (1973, 1984, 2002, 2009, 2014 and 2016) and aerial photographs of 1961 were used.

For the satellite image time series, a supervised image classification was applied. Reference data for the classification was derived from high-resolution imagery provided by Google Earth. For the aerial photographs, manual digitisation of land-use/land-cover classes was performed. Prior to digitisation, aerial photographs were pre-processed. Image Composite Editor (ICE) was used for stitching, while ImageJ was used to enhance contrast. Statistics derived from classification of the time series were analysed.

Results indicated that in study area 1, forests decreased from 7 473.7 ha (1961) to 2 270.8 ha (2016), while grasslands reduced from 5 208.8 ha to 120.9 ha over the same period. In study area 2, forests reduced from 1 041.9 ha (1961) to 126.0 ha (2016) and grasslands from 640.7 ha (1961) to 481.6 ha (2016). In study area 3, the forest cover decreased from 1 572 ha (1961) to 198.5 ha (2016), while grassland cover increased from 5 192.9 ha (1961) to 14 017.8 ha (2016).

The study found that agriculture is the main driver of land-cover change in the basin. The study further demonstrated that remote-sensing data from satellite sensors and aerial photographs used in combination with open-source GIS tools is important for land-cover change detection in basins with poor in situ data.

PAPER 13




Erika Braune & Dr Verno Jonker

Developing geo-information based selection algorithms to identify water resource interventions

The Southern African region is subject to frequent droughts, which contribute to crop failures, famines and epidemics, often coupled with devastating socio-economic impacts. To encourage proactive planning in securing water for drought-prone areas, the Southern African Development Community Groundwater Management Institute (SADC-GMI) implemented the project: Assessment of Groundwater Resources Development Priority Intervention Areas in the Southern African Development Community Region.

As part of the analyses undertaken to identify drought-prone areas, existing geospatial, hydrological and hydrogeological global datasets were researched and analysed according to their validity and applicability to the region. Time series global data sets were interrogated to produce several statistical climate risk indices, which were weighted and used to produce three maps (groundwater and surface water drought risk and population vulnerability).

Through a weighted overlay process, the three maps were combined to identify hotspot areas that are most vulnerable to drought. To mitigate the potential impacts of drought, different types of interventions were conceptualised and evaluated in each hotspot area. These include boreholes, sand dams, managed aquifer recharge, new dams, rainwater harvesting, stormwater harvesting, as well as desalination and water reuse. Selection criteria were developed for each intervention by using a typology matrix. The matrix took various physical characteristics into consideration that would have to be satisfied for the intervention to be feasible. The criteria were further refined in workflow diagrams to aid incorporation of algorithms and decision-making methodologies in a GIS environment. By using these geo-information-based selection algorithms, a suite of technically feasible interventions was identified, on a grid-by-grid basis, for each hotspot area through spatial analyses.

The identified interventions were further refined by performing high-level cost analyses, taking into account the reliability of supply, population served, level of technical skills required for maintenance and operation, energy requirements, and associated capital and operational costs associated with every intervention.

Furthermore, institutional and environmental factors were also considered before presenting a list of targeted interventions per hotspot area. The targeted interventions were a combination of large-scale and local-scale interventions aiming to strengthen water resources diversity and improving water resilience in communities within the SADC region. The targeted suite of interventions was presented at stakeholder workshops and supported relevant organisations in motivating sustainable water supply investments in drought-susceptible regions.

PAPER 14

Ayanda Mthombeni

Impact of climate change on spatial planning and stormwater management for greenfield sites development

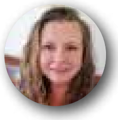
Climate change is indisputably recognised as one of the major global concerns that has multiple negative impacts. Projected climate change impacts such as increased incidence of droughts, more intense precipitation and rising sea levels suggest that human goods and lives will be adversely impacted through the increased flood risk among other impacts. In view of this, this study aimed to evaluate the current spatial planning principles in order to address and mitigate the impact of climate change in an urban setting by integrating stormwater management practices.

Statistical methods were used to extend the available historical rainfall data to predict the likely frequency of occurrence of future rainfall events. The Autodesk Civil 3D Storm and Sanitary application enabled the simulation of the impact of future rainfall over greenfield site development. Flood frequency analysis was also conducted as a direct method of estimation of flood frequency, which indicated that a 21% increase would be expected between the 2020 and 2069 period, with the intensity of the two-year return period expected to increase by 40%. The simulated changes in precipitation were incorporated into spatial planning by using the catchment characteristics to derive key land-use zoning factors for future consideration when designing urban areas.

The analysis of the study revealed that the amount of greenfield area that is available for stormwater management should be identified at an early stage during the project planning. This will largely dictate the extent to which different stormwater design elements are incorporated that are also feasible in any development to ensure that climate change impacts are considered.

This study provided a methodology to determine the impact of climate change on future rainfall events over greenfield sites for pre-development and post-development conditions. Outcomes of this study may aid in understanding the increasing frequency and intensity of extreme rainfall events that will have a significant impact on existing stormwater infrastructure. The study may aid provincial and local municipalities to adapt to changing rainfall regimes to ensure that adequate levels of spatial planning for greenfield sites are effectively integrated with stormwater management to ensure that climate impacts are accounted for prior to any development.

PAPER 15




Maronel Steyn &
Dr Chavon Walters

Bulk scale industrial effluent reuse potential in South Africa

Water scarcity, increased pollution, unprecedented population growth and climate change are collectively driving the need to reuse water with the aim to enhance water security, sustainability, and resilience. It is clear that South Africa's already strained water resources will become even more stressed in the near future. The Department of Water and Sanitation (DWS, 2017) predicted that by 2030 water demand will reach 17.7 billion m^3, far more than what is available to allocate. Globally, responsible and efficient water management is fast becoming a pressing reality for domestic users, agriculture and industry alike.

The challenge is therefore to capitalise on the limited water we currently have. Bulk-scale reuse of industrial water effluent can play a significant role in water security in a water-scarce country, such as South Africa, as it can augment or partially substitute freshwater resources needed for domestic purposes and future development. Water reuse in South Africa is however lagging behind. An atlas for potential industrial bulk-scale water reuse was produced from publicly available Natsurv and WARMS data. It highlights the urgent need for water reuse to form an integral part of an integrated water management supply approach in South Africa.

While South Africa has progressive legislation to support the implementation of wastewater reuse, it can also be regarded as a barrier in implementing reuse projects, as water reuse standards and guidelines are often far too stringent to allow for cost-effective reuse options to be developed and implemented. Currently, very little to no data exists regarding wastewater reuse options, treatment options and capabilities, or costs that can be used for decision-making, and much more directed research and information is needed in order to identify wastewater and industrial effluent volume availability, quality and fitness for use in South Africa.

A web-based Decision Support System (DSS) tool is being developed to enable municipal and industry partners, and water quality managers to make informed decisions for possible reuse options. The tool aims to directly assist by linking industrial effluent volumes and quality to fitness for use, and linking it with specific industries in the geographical vicinity based on industry-specific water quality and quantity requirements. In addition, the tool will enable engineers and industry partners to collaborate to identify and employ treatment technologies and capabilities to link industrial effluent quality and volumes available to that of potential user requirements in a geographical area.

PAPER 16

Shireen Sayed

Micro-grids with energy storage – a solution for generating energy for municipalities

Reliable, clean energy is critical for today and into the future. While various leaders across the world grapple to meet greenhouse gas emission targets as well as 'keep the lights on', private industry is moving full steam ahead to find solutions to what is deemed an energy crisis for some countries such as South Africa. Steady, reliable and cost-effective electricity production and supply is the backbone of any first-world country. It is hard to imagine how society would function without electricity, yet in this day there still exist communities located on the periphery of cities as well as remote areas with no connection to the transmission grid. In addition, the Eskom grid is under strain due to high demand and ageing infrastructure, and 'blackouts' have become a common daily occurrence. Considering the current constraints to generate reliable energy at a national level, it makes sense for municipalities to have the autonomy at a local level to explore and implement clean energy technologies as an affordable, reliable option to serving communities and businesses in their jurisdiction.

The reality is that there is a drive across the globe to cleaner, more sustainable way of generating electricity for various applications, and renewable energy is now more prominent and prevalent in many countries. Microgrids underpinned by advanced storage systems have been used extensively for various applications including serving large industries as well as remote rural communities. In addition, they insulate the municipality against load-shedding of the national grid, therefore doing away with rolling blackouts. South Africa's energy crisis, together with the current recession, creates a perfect storm for the exploration of generating electricity from clean nature sources into connected microgrids.

PAPER 17


Holiday Kadada & Jacobus Kriegler

Leliefontein Pump-As-Turbine Station

The Leliefontein Pump-As-Turbine (PAT) Station is deemed to be a first of its kind in South Africa. Originally intended as a booster station to supply water to Wellington during peak summer, Leliefontein has evolved into a practical, easily maintainable and exciting green energy solution that can be utilised by various municipalities.

As per its original intention, the booster pump station, along with the local reservoirs, would operate as a back-up water supply to Wellington when the Wemmershoek Water Treatment Works supply is unavailable during planned and unplanned maintenance. This occurs for about one week per year, which meant the booster pump station's mechanical equipment would be severely underutilised, leading to premature equipment failure.

To address this problem of underutilisation, Zutari, together with the Drakenstein Municipality, identified Leliefontein's location within the municipality's bulk water network as a prime opportunity for a productive mini hydropower station. This led to the idea to convert the booster pump station to a pump-as-turbine station – an installation with the dual functionality of pumping water and generating electricity. While using pumps as turbines is not a new technology, Leliefontein uses the same set of pumps to pump water and generate electricity, which ensures that the PATs are active for the majority of the year, solving the problem of underutilisation. This dual functionality is accomplished by reversing flow through the pumps and controlling the speed of the PATs to generate electricity at the available flow rates.

This is achieved through the innovative use of active front-end variable-speed drives to lower the speed of the PATs, a series of actuated valves, a centralised control system, off-the-shelf pumps and some creative pipe work.

The estimated annual generation for Leliefontein is 320 MWh, translating to 44 days of free pumping for the Drakenstein Municipality. The power generated at Leliefontein is distributed into the municipality's electrical grid, offsetting the power consumed during pumping with the remaining balance of the generated power, reducing the municipality's electrical consumption bill. The municipality can utilise the savings, due to these reduced power purchase costs, to reinvest into the community through avenues such as service delivery.

Leliefontein is a true marriage between the civil, mechanical and electrical engineering disciplines, and serves as an example of how municipalities can use low-cost, off-the-shelf equipment like centrifugal pumps and induction motors to generate clean power using potential energy in their existing infrastructure.

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KEYNOTE SPEAKER – SESSION 4

Infrastructure Service Delivery Institutions for Less Functional Areas

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ABSTRACT

Many South African municipalities usually suffer service delivery problems which can be ascribed to inadequate management, skills and budgets. The reasons for these in turn invariably include weak economic base, unwise spending of available funds, and difficulty of recruiting and retaining skilled staff. The municipal model which South Africa uses was evolved for industrialising 19th-century Britain, then transplanted to its colonies. Is it not time to review if it is still appropriate to delivering services in the non-metropolitan areas of SA?

Alternative institutional models have been proposed. Examples: (i) The attempt many years ago to set up "regional electricity distributors" to address electricity distribution infrastructure's deterioration. (ii) The periodically revived proposal for "regional water utilities". These two concepts had in common that responsibility for specific infrastructure and its service delivery function would be removed from municipalities and given instead to regional bodies.

During the second half of 2019, two departments published somewhat divergent views on institutional reform:

- CoGTA diagnosed 'the pattern of operating in silos' as leading to 'non-optimal delivery of services'. Its proposed solution is an 'integrated district based approach'.
- The 'National Water and Sanitation Master Plan' identified 'several challenges associated with the current institutional arrangements'. To address this, DWS reiterated its preference for regional water (and sanitation) utilities 'where necessary'.

The debate needs to be opened: will one of these be the saviour of failing service delivery by many municipalities? Moreover, is a single model for the whole country an appropriate response – or might a variety of responses be most appropriate and, if so, how could this be accommodated? Should the entire concept and scope of what constitutes 'municipal services' be reconsidered? If either Minister (Cooperative Governance or Water and Sanitation) gets her way, many municipalities will undergo change to their powers and functions on a scale not seen since the late 1990s.

Discussion at an IMESA conference of alternative service delivery models is long overdue.

INTRODUCTION

In the 1990s, the designers of South Africa's new local government system applied the municipal model long established in the urban areas, with its attendant responsibilities, to the whole country, in the process creating a series of wall-to-wall municipalities. At the same time, an extensive set of support measures – subsequently much modified and enhanced – was put in place.

The independence of local government was emphasised by it, and provincial and national government, being referred to as 'spheres of governance', rather than as 'tiers'.

After more than two decades of experience, there can no longer be any doubt that many municipalities have failed in their primary duty of delivering services. This paper presents evidence of this, and refers to the wide variety of interventions which have been proposed or attempted. But the paper goes further, asking fundamental questions about the current municipal model. It also argues that IMESA, as the body representative of those responsible for delivering municipal services, needs to consider what its views are.

THE PURPOSE OF MUNICIPALITIES

Clause 152 of the Constitution states that:

> "The objects of local government are — (a) to provide democratic and accountable government for local communities; (b) to ensure the provision of services to communities in a sustainable manner[1]; (c) to promote social and economic development; (d) to promote a safe and healthy environment; and (e) to encourage the involvement of communities and community organisations in the matters of local government."
> *(South Africa 1996)*

Some South African municipalities do at least a fairly good job of ensuring the provision of services to their communities in a sustainable manner. A sizeable number, however, do not – for the purposes of this paper, these are collectively referred to as the 'less functional' municipalities.

THE ORIGINS OF MUNICIPALITIES – SET UP TO DELIVER SERVICES.

Prior to the start of the 19th century, the only settlement of any size in South Africa, Cape Town, was administered by the Dutch East India Company. The Company did not provide more than rudimentary municipal services as we know them today, but when the British arrived a few years after the turn of the century, it was not as if they brought with them a tried and tested service delivery system which could quickly be adopted. Their own existing system, historically based on parish responsibility for basic services, was already unable to cope with rapid changes to the social and demographic face of Britain, in particular the Industrial Revolution then gathering speed.

In Britain, from 1832 onwards, a series of laws to radically restructure local government was crafted. These defined which services should be the responsibility of municipalities, how revenue should be raised, and how these institutions should be governed (generally, by councillors periodically voted into power by all adult persons). Changes continued for the rest of the century, driven by the need to provide more services for a rapidly increasing urbanised population. Change was also driven by, or enabled by, rapid advances in the theory of engineering, science and medicine, and the industrial capacity to manufacture the pipes and pumps and the engineering works for service delivery, of types and on a scale not seen before. At the same time, rising educational standards and rising democracy levels, requiring a quantum jump in how local service delivery (with unprecedented representation of the users would be implemented), had to be thought about.

Cape Town, then the only South African urban centre of any consequence, became a municipality along the latest British lines in 1840. Its powers, and those of the municipalities subsequently created, were initially very limited, but evolved over more than a century in step with those in Britain, until the stage was reached that municipal government in both countries enjoyed a wide, albeit by no means identical, range of service delivery responsibilities.[2]

The current local model is, more or less, single or two-tier local government throughout South Africa, with each tier responsible for specific services, and governed by locally-elected council members. Revenue is raised from within the area of jurisdiction, supplemented by operating subsidies from national government. Capital funding is similarly raised from a mixture of local sources and national transfers.

Is it time to ask: how well is this model delivering the required services and, if not, why not?

THE PERFORMANCE OF LOCAL GOVERNMENT: A BRIEF OVERVIEW

It can't be said that many South African municipalities have, by and large, performed well at delivering the services expected of them in terms of the Constitution. A sample – just a sample – of indicators of this include:

- Service delivery protests (e.g. as measured by Municipal IQ).[3]
- The findings of the 'report cards' prepared by the South African Institution of Civil Engineering (SAICE) on the condition of public sector infrastructure.[4]
- The 'strategic overviews of the water sector' produced each year by the Department of Water and Sanitation (DWS).[5, 6]
- The litigation, occasioned by repeated service delivery failure, brought by citizens or business groups against individual municipalities.[7]

The financial state of many municipalities is a cause of the greatest concern. For example, as the Deputy Minister of Finance recently expressed it:

'There are ….163 municipalities in financial distress and 108 municipalities that have passed an unfunded budget in 2020/21 financial year, Masondo said.' (Staff Writer 2021)

But the most recent, and the most comprehensive, assessment of the state of South Africa's local government, and the consequences for service delivery, was that which appeared just as this paper was being finalised: the Auditor General's annual report on municipalities in terms of the Municipal Finance Management Act (MFMA).

'Audit results under the outgoing administration have demonstrated little sign of improvement and we have observed the deteriorating state of local government. When it took over, the administration inherited 33 clean audits. Unfortunately, it is now regressed to only 27 clean audits'. (AG Media release, page 1)

'Moreover, it is not surprising that citizens experienced poor service delivery from municipalities if less than a quarter of them could provide us with quality performance reports to audit' (Media release page 4).

The Auditor General gloomily observed that recommendations made in the past, e.g. 'effecting consequences for accountability failures', 'investing in preventative controls', and 'using our reports briefings and engagements to identify key areas that need attention', have largely been ignored or have been ineffectual (Media release page 2).

Most deplorable, she pointed out that: 'the most jarring revelations concern the impact of service delivery failures upon the most vulnerable of our citizens – the poor.' (Media release, page 7). Which is a conclusion reached some years before by SAICE which, in the 2011 report card stated that 'the quality and reliability of basic infrastructure serving the majority of our citizens is poor and, in many places, getting worse' (2011, page 5).

None of this comes as any surprise, as some of the same municipalities have for a decade or more been identified as problematic. Media reports or court judgements name the same issues year after year. Each year, too, promises are made as to how improvements will be affected – very seldom can this improvement be observed.

WHERE DO WE STAND?

A perusal of the literature indicates that the biggest contributors to municipal service delivery failure are (in random order):

1. financial: the municipality overspends;
2. skills shortfall;
3. leadership is wanting.

A fourth possibility is that the current municipal model is simply no longer able to perform the service delivery functions expected of a municipality in South Africa.

1.

'Overspend' by definition is in terms of a funded and balanced budget – which, as the Deputy Minister of Finance has pointed out above, municipalities do not necessarily start the year with. Then income might not be raised where it could be. Or the municipality overspends on providing services or on overheads, or both.

The Auditor General reports year after year describe many areas where the funding available to municipalities can be spent to better effect. The reports on each municipality outline recommended improvement, which would sometimes save tens of millions of rand. Much of this is related to more appropriate purchasing or hiring choices, and also to supply chain management to obtain better value for money, and taking life-cycle costing into account when making capital purchases. But much of it is also related to money wasted in various other ways, particularly wasteful or even corrupt spending.

The reports also identify areas where opportunities to raise revenue – even where a municipality had the right to raise revenue, but did not – have been forgone.

That said, the weak state of much of the economy, weakened still further by the arrival of COVID-19 and the effect of the lockdowns, has undoubtedly hit municipal finances hard, as businesses and householders have found it increasingly difficult to pay what they owe municipalities.

2.

SAICE has consistently identified that insufficient skills – and systems (as for example systems for collection and analysis of performance data, and systems for identifying the long-term least-cost alternatives when initiating capital improvements) have hampered the operation and maintenance of infrastructure, and directly led to the deterioration of its condition. The same point – about low skills – has made by others, including SALGA and the Auditor General. For years, the solution has been sought in 'capacity building', but recently, and justifiably, scepticism has grown as to the efficacy of this capacity building.[8]

Provision for the outsourcing of selected services has long been on the statute book. The injudicious use of this has, however, attracted heavy criticism: e.g. from the Auditor General, commenting, not for the first time, on the widespread but apparently ineffective use of consultants to prepare the financial statements (Auditor General 2021a;3).

Apart from 'capacity building', ways in which skills shortfall can sustainably be addressed are seldom explored to any effect, despite the difficulties which lack of capacity presents to many municipalities. For example, the smaller more remote municipalities would be unlikely to be places where staff with the required, often post-school, qualifications would ordinarily reside – or would even be willing to live for months at a time. Another aspect is the reported unwillingness of many competent staff to join the staff of municipalities because of their perception that municipal employ is too politicised.[9] Ways must, and surely can, be found where it can be arranged that the low-level skills in the small remote towns are complemented by higher-level skills located elsewhere, rather than a search for these skills being confined to the municipality where the skills are needed. For example, it is worth investigating if the framework procurement contract concept, designed with infrastructure purchases in mind, can be adapted and extended to assist municipalities with other duties.

That obtaining skills from outside can be undermined, unless carefully designed and managed, is shown by the response to the use of consultants, reported above, to assist the municipal staff with preparation of financial statements.

Continuity of service can underpin the improvement of staff performance, as individual staff members over the years gain more and more understanding of the municipality for which they work.[10] 'Job-hopping' is, however, all too prevalent.

3.

Poor leadership at underperforming municipalities is widely reported – not least by the Auditor General – as a prime suspect for the 'less functionality' of these municipalities. 'Poor' is variously defined, including leadership being unethical and corrupt, lacking accountability, and less than competent. While this applies to all levels of leadership in the municipality, for good reason – because it is the top leadership which has the greatest effect on the futures of a municipality – the heaviest criticism can be made of the political leadership and the level of the municipal manager.

One does not necessarily expect the leadership of a municipality to always be collegial, but the rivalries – inter-personal, inter-party and even intra-party – reported by the media almost daily can only be harmful to service delivery, as councillors attempt to influence service delivery decisions for sectarian gain or their own political gain rather than in the interests of all the citizens.

AUDITOR GENERAL 2019/2020 – AND RESPONSES

On the day that this paper was due to be completed and sent to the conference organisers – also the last day of the 2020/2021 municipal financial year – the Auditor General released her report on the local government audit outcomes for the 2019/2020 financial year. This prompted a flood of commentary, including a formal response from SALGA.

The Auditor General report, while an authoritative and most valuable snapshot of the status of municipal finances, reveals nothing unexpected, much of it deplorable, as in previous years. No fault can be found with its proposals for reform and the SALGA list of 'what must be done' – together with many of the proposals in the commentaries, this year and on previous occasions (more or less the same lists that appear each year). But it must be asked: why is there little progress?

For example, SALGA advocates that: 'Councils must employ competent people and take appropriate steps where officials fail to carry out their responsibilities'. Then again, 'Mayors and Speakers must hold the administration accountable and act decisively to implement consequence management'.

The ratepaying public hears year after year of the need for municipalities to employ only competent people. But it is rare to hear of a senior official being ousted for incompetence.

MODIFYING THE MUNICIPAL SERVICE DELIVERY MODEL

As mooted above, a fourth possibility is that the current municipal model is no longer able to perform the service delivery functions expected of a municipality in South Africa, and needs modification. Alternatively, that some municipal service delivery functions would be better performed by other institutions.

The municipal model for service delivery which South Africa uses was evolved for industrialising 19th-century Britain, then transplanted to its colonies. Is it not time to review if it is still appropriate to delivering services in the non-metropolitan areas here?

The possibility of significant institutional change, to improve municipal service delivery, was touched on above. Would some form of institutional change be an appropriate response? Not across the board, surely, because not all municipalities can be described as 'less functional'. Which suggests that it is possibly not the model at fault, but the way it so often operates.

Again, the Minister of Finance:

'We can't speak of economic recovery and prosperity when municipalities, as agents responsible for helping government achieve these objectives, find themselves in a perpetual crisis.

'… decisive action is needed to restore the integrity of the municipal sector.'

(Ministry of Finance 2021, pages 11 and 12.)

What is this 'decisive action'? He does not say.

We now consider, firstly, ad hoc, on a small scale, bypassing the municipal model. And then some proposals

already made for a larger-scale, more nation-wide, move of specific services to alternative institutions.

AD HOC BYPASSING OF THE MUNICIPAL MODEL

Consider the possibility of ad hoc arrangements to accommodate a particular need – arrangements suitable for a particular municipality over a particular period of time. For example, that, to assist with skills deficiencies, a section of responsibility is outsourced for, say, five years.

As noted above, how well this would work would depend on the contract between the municipality and the organisation outsourced to, and how well this is managed on both sides.

There are limited precedents for management contracts in South Africa. Some of them, e.g. to stiffen the water and sanitation department leadership at a municipality (e.g. Johannesburg), have been for a fixed period with gradual handover of responsibilities until the end of the contract. It has been reported these have generally been a success. However they have only been put in place in municipalities, already well capacitated, that needed new strategic direction and innovative methods.

A number of other contracts, such as the framework procurement contract, and the multi-year series of social franchising model contracts for outsourcing infrastructure operation and maintenance, all, to the author's knowledge, in water and sanitation, have been successful. But the total number of these remains low. Why this is so is unknown, but a strong possibility is that the municipalities concerned have been reluctant to let go of responsibilities. Moreover, once appointed, some contractors find their municipalities unable to pay in full and on time, so the contractors themselves walk away.

There have been many programmes for the private sector to second qualified staff, especially technical and financial staff, to municipalities, some of them of several years duration. These also have had varied success, for different reasons, including that the seconded staff report that they are not accepted, and their work is not valued.

Nonetheless it is evident that a number of measures – not a full package, by any means – are currently available to assist municipalities with their service delivery tasks. But these are not as fully utilised as they could be.

Interest in local place-and-time-specific initiatives has risen during the last 12 months, where communities, or entities (e.g. Gift of the Givers), on a variety of bases, have intervened, specifically in the water and sanitation sector. Those with long memories will recall that, three decades ago, there were many functioning community-based water and sanitation schemes successfully operating, particularly in the former homelands. Once the initial capital cost of infrastructure had been covered, often with donor funding, these were generally financially self-sustaining. Post-1994, however, these were 'blocked because the priority was to establish municipalities that would be responsible for service provision' (Muller 2021: 1). Nonetheless, Section 51 of the 1997 Water Services Act remains on the statute books, allowing communities in smaller towns and rural areas to establish local water committees to take responsibility for their own water supply and sanitation services, and it would seem that the courts appear increasingly willing to brush aside objections that dysfunctional municipalities might have. However for such committees to be viable they would have to get access to that portion of equitable share funding intended for these same services (Ibid, pages 2-5).

A SAICE platform during June 2021 aired some of the related debate, and it became evident that ways do exist, difficult they might be, for a variety of community-based initiatives. For a small financially sound local group to take the lead would be a big asset.

Two further options could go some way to addressing the concerns of local businesses which pay their municipalities for water and/or electricity, intending that these funds be paid to Eskom and/or a water board, only for the municipality to retain the money and, as a consequence, for the utility to cut supplies. In June, a court ordered the Maluti a Phogung municipality to hand over for five years its revenue stream for electricity distribution. In May 2021 Sakeliga approached the courts for support of the establishment of so-called 'special masters' – such as independent auditors – to take control of water and electricity payments. Ratepayers and users of the services would then see their service tariff payments forwarded to the providers of the services, and not retained by the municipalities (Sakeliga 2021).

ALREADY TABLED FORMAL ALTERNATIVE INSTITUTIONAL MODELS FOR SERVICE DELIVERY

Alternative institutional models have been proposed in the past. Two examples:

- The best part of 20 years ago, government attempted to set up 'regional electricity distributors' to address the deterioration of electricity distribution infrastructure which is in the care of municipalities.
- Round about the same time, in response to repeated municipal water and sanitation delivery failures, government proposed the formation of 'regional water utilities'.

These two concepts had in common that responsibility for specific infrastructure and the associated service delivery function would be removed from multi-function municipalities and given instead to regional single-purpose bodies.

The six wall-to-wall regional electricity distributors (REDS) originated in proposals to Cabinet as far back as the 1990s but it was only in 2005 that the first RED, for the Western Cape including Cape Town, was established. Unfortunately, despite the merits of the proposal, government was unable to address the concerns of those municipalities which depended on surpluses from their electricity undertakings – if these were taken away, what substituting revenue stream would they receive? This, together with political opposition from Cape Town, killed the proposal, and the only RED was dissolved (Eberhard 2013).

The regional water utilities proposal has been revived a number of times, notably in the Water Master Plan (see below).

A dozen years ago, the Department of Cooperative Governance (CoGTA) evolved the Local Government Turnaround Strategy (LGTAS), a hugely ambitious programme to 'improve the organisational and political performance of municipalities and in turn the delivery of services' (CoGTA 2009: 25).

No confirmation could be received as to why, after a number of years, the initiative fizzled out, but it is suspected that it tried to do too much too soon, and the effort could not be sustained.

Incidentally, considering the importance of improving the top leadership of municipalities, this, and other initiatives, have in common that relatively little attention is given to this vital aspect. This is despite acknowledgement of its importance: e.g. in the LGTAS that 'there are serious leadership and governance challenges in municipalities' (Ibid, page 18).

During the second decade, the Municipal Infrastructure Support Agent (MISA), with the financial support of national Treasury, evolved the Regional Management Services Support model. The intention was that a small high-powered multidisciplinary team would be appointed to support each of three district municipalities in a change management process that would see a radical improvement in the leadership, service delivery, financial management, human relations practice, and supply chain management. If this succeeded on a pilot basis over several years, it would be rolled out to further municipalities (Wall 2016).

According to the latest annual report of MISA, the project is continuing, still in the three original municipalities, with no thought (yet) of it being extended to other municipalities.

More recently, during the second half of 2019, two national government departments published somewhat divergent views on local government institutional reform:

- CoGTA diagnosed as a 'challenge' the pattern of government operating in silos, contributing to non-optimal delivery of services. Its proposed solution is a district- based process by which joint and collaborative planning is undertaken at local, district and metropolitan by all three spheres of governance resulting in a single strategically focussed 'One Plan and One Budget' for each of the 44 districts and 8 Metros (CoGTA 2020: 8).

- Three months later, DWS launched its 'National Water and Sanitation Master Plan', which identified 'several challenges associated with the current institutional arrangements'. To address this, DWS reiterated its preference for regional water (and sanitation) utilities 'to deliver some local government services on an agency basis where local or district municipalities lack capacity' (DWS 2019b: 2-5).

If either Minister (Cooperative Governance or Water and Sanitation) gets her way, municipalities, especially those covering the less functional areas, will undergo change to their powers and functions on a scale not seen since the late 1990s.

The regional water utility concept still features in the latest version of the National Water Master Plan on the Department's website, although no information of current activities could readily be seen.

In contrast, the district development model is reported to have been working well in its three pilot municipalities (CoGTA 2020), while it is known that workshops are being held in preparation for the model rollout elsewhere in the country.

At the end of 2020, the National School of Government (NSG) published 'A national implementation framework towards the professionalisation of the public service'. During February 2021 it hosted consultation hearings for specific stakeholder groups. One of these was targeted at 'Professional bodies and institutions in local government', and indeed local government is frequently mentioned in the document. Of particular interest to municipal service delivery practitioners is the intention 'to create a capable, ethical and developmental public service', and that the public service 'be merit-based and insulated from party politics'. How it would be thus insulated is unfortunately not described.

Most recently of all, as noted above, the Minister of Finance stated that:

'… decisive action is needed to restore the integrity of the municipal sector.'

He, too, did not indicate what he had in mind – what type of 'decisive action'!

WHERE CHANGE MIGHT NEED TO BEGIN

There is some evidence that the service delivery problems of some municipalities originate in, or are greatly exacerbated by leaderships' politics and personalities. This would suggest that resolving, or neutralising, these politics and personalities would likely go a long way to improving the service track record of many municipalities.

After all, it is at the level of political leadership that the major decisions are taken: for example budget priorities, and key staff appointments. Once these are in place, the ability of even senior staff below management level to influence bad decisions (for example, a decision that the operation and repair budget will be cut to the bone) is very limited.

When 'resolving or neutralising' these is referred to here, it is so that the leadership will as a result only make decisions in the best interests of the municipality as a whole, and no longer be influenced by personal or political agendas.[11]

It is here at this top level, also, that the moral tone of the municipality is best set – e.g. a stance against corruption and nepotism.

Perhaps the Deputy Minister of Finance, in his comments on the Lekwa ruling, has put his finger on a key factor in rebuilding infrastructure service delivery where it is broken:

'The case also shows that political and administrative leadership is fundamental to creating a viable municipal sector, he said. "It is also perpetuated by a failure to deal decisively with disruptive management and leadership issues. If we are serious about fixing a financial and service delivery crisis, we need to first fix the political and administrative leadership crisis".'

There is a lot of merit in this suggestion that change might need to begin here, with the political and administrative leadership.

Reinforcing this, the Auditor General deplored that, 'while the support of mayors and councils is crucial when it comes to resolving material irregularities', 'this is an area where we have not yet observed any significant uptake or commitments' – the only area she thus highlighted (Auditor General 2021a: 5).

So: what can be done to moderate the 'political landscape' in municipalities, in the interest of service delivery?

Would institutional change assist this process?

CONCLUSIONS: WHERE IMESA COMES IN – OR SHOULD COME IN

The above discussion has (briefly) aired issues of vital importance to the sustainability of municipalities – and therefore to the sustainability of the service delivery ambitions of municipalities. Some randomly selected and sorted points to ponder (without taking a stance on any of them), which go to the heart of the reasons for the existence of municipal government:[12]

- Are the service delivery ambitions of many municipalities too ambitious to possibly succeed? That is, ambitious in the range of services (should some municipalities simply give up trying to provide specific services) or quality of services (for example, given the operation and maintenance costs that will be incurred, should some municipalities – specifically rural municipalities – cease attempts to provide reticulated water and sanitation to any households not close to existing urban areas, and rather encourage much less expensive and more sustainable decentralised solutions)?
- Of the expenses that municipalities incur, which category of substantial expenses could be drastically reduced with the least harm to service delivery? (One thinks of the costs of administration – e.g. of the council leadership – as opposed to the costs of water supply, or road repair.)
- Certainly, to still be, after 20 years, persevering in some parts of the country with the colonial municipal model despite the huge efforts that each year have to be invested in trying to assist those municipalities, no longer makes any sense whatsoever.

The debate needs to be opened: will one of models described in this paper – or some other model – be the saviour of failing service delivery by many municipalities – the "less functional areas"? Alternatively, would some communities not be better served by a regional utility – maybe a multipurpose regional utility, rather than one for water and sanitation only, as DWS is proposing? And what about the "district development model", which appears at the time of writing (June 2021) to be government's current favourite?

IMESA, as the body which is representative of those responsible for a primary "object" of local government, namely implementing infrastructure service delivery, needs to consider what its views are. If change in powers and functions at municipal level, and/or change to the institutional model for service delivery, are proposed, IMESA needs to be ready to respond. Better still, IMESA should be formulating its own ideas on the matter, proactively ready to present them when appropriate.

What alternatives will moderate the "political landscape" in municipalities, in the interest of service delivery? And what can be done to assist under-capacitated municipalities in respect of the skills and other resources, especially finance, which they need?

TO SUM UP:

- It must seriously be considered if municipalities which chronically fail at delivering services should not rather be relieved of some responsibilities.
- National government seems to be swinging towards recognition of the need to address this.
- Alternative institutions have been proposed from time to time. The merits of these and other possibilities need to be investigated systematically.

And, certainly:

- One model will not be suitable for all of our municipalities, so enormously varied are they in terms of factors such as population, resources, and urbanisation. A variety of arrangements for service delivery will be needed. But how could this diversity be accommodated?
- The imported model, working so well in parts of this country, can, if governance issues are resolved, also work in others – but demonstrably not throughout the country.
- For much of the country, what constitutes a municipality, and which institution delivers what are currently regarded as 'municipal services', needs to be rethought.

Whereas discussion at an IMESA conference of service delivery models is long overdue, it is trusted that this paper will offer a starting point for the discussion.

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Emphasis added by the author.

[1] It is acknowledged that these few paragraphs are a gross over-simplification of a complex history. For example, the many changes to franchise arrangements, involving gender, racial and property-

owning qualifications – also the skewing effect of the period of homeland government – are acknowledged, but not described here.

[2] Its most recent annual summary, that of the year 2020, notes the 'downward dip' in that year compared to the several years preceding it, but adds that this dip is 'not necessarily an endorsement of municipalities'. Rather, it ascribes the dip to COVID-19 lockdown measures which for most of the year placed restrictions on public gatherings. (Municipal IQ 2021: 1)

Nonetheless, 2020 witnessed 102 service delivery protests – an order of magnitude not seen since 2011, whereafter the numbers grew annually, reaching a peak of 237 in 2018 – during which 'protesters raise issues that are the responsibility or perceived responsibility of local government (such as councillor accountability, the quality and pace of basic service delivery, and, in metro areas, housing).' (Ibid)

[3] That this exercise concluded in 2017, the most recent year available, with awarding South Africa's public infrastructure an overall average (i.e. across all sectors) grade of only 'D+', of a range from 'A+' through 'E-',, indicates a worrying incidence of infrastructure failure, or propensity to fail, with consequences for service delivery. (SAICE 2017: 11)

[4] Using inter-alia information from the annual Statistics South Africa General Household Survey, DWS in its "2019 Strategic Overview of the Water Sector in South Africa" (DWS 2019a: 35) stated that, in that year:

[5] "88.0% of households had been provided with a basic level of water supply infrastructure. However, not all of the infrastructure was able to meet the level of assurance (reliability) of supply requirements, defined for a basic water supply as interruptions of less than 48 hours at any one time and a cumulative interruption time of less than 15 days every three months. If this reliability requirement is taken into consideration, then the 88.0% value reduces to 74.36%."

[6] For example, Emfuleni LM, in Gauteng; Koster, in Kgetlengrivier LM, North West Province; Lichtenburg, in Ditsobotla LM, also in North West Province; Standerton, in Lekwa LM, Mpumalanga; Mafube LM, in Free State; Maluti-A-Phofung LM, also in Free State; Enoch Mgijima LM, in Eastern Cape; Makhanda LM, also in Eastern Cape; Msunduzi LM, in KwaZulu-Natal.

[7] The Minister of Finance, no less, has queried the efficacy of government programmes to build capacity in municipalities:

[8] "National and provincial government have to date spent billions of rands in local government capacity building programmes. The poor performance of many municipalities shows that there was almost a zero return on that investment." (Ministry of Finance 2021: 11)

[9] "The most important factor for attracting those with experience back into the system are, however, the need for more autonomy and authority for delivery departments, and uncoupling the business of local government from the politics of local government.' (Lawless 2016: 61):

[10] SALGA gives instances of this. (SALGA 2021: 8)

[11] As envisaged by the CEO of the South African National Roads Agency Ltd some years ago. When talking about the difficulty of obtaining funding for maintenance and repair, he stated that:

While underbudgeting for maintenance and repair is not justifiable and makes no sense in the long run, it is nonetheless understandable that it happens 'in a political landscape dealing with a tight budget and a scarcity of skills'. 'The critical question', he went on to say, was how much does engineering (read 'infrastructure', or 'service delivery') inform needs and priorities in that political landscape. (Quoted in: Frankson, 2018, page 25)

[12] Raising these questions might be heresy to some, within and outside of IMESA – but they must be asked.

KEYNOTE SPEAKER – SESSION 5

Assessment of Meteorological Drought in Bundelkhand Region of MP (India) Using Standardized Precipitation Index (SPI) and Remote Sensing Derived Vegetation Condition Index (VCI)

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ABSTRACT

Drought is a natural, unpredictable, temporary, and regional climatic phenomenon that occurs when there is a lack of precipitation, resulting in a water shortage. Many drought indices are being used worldwide to assess drought duration, magnitude and severity which are helpful in the formulation of drought mitigation strategies. The satellite-based data, information and indices have been found very efficient and useful for quick assessment of drought situations and can be proved more effective if tested using suitable similar physically observed climatic data-based indicators. In this study, the MODIS NDVI data has been used for vegetation health and drought monitoring through NDVI based Vegetation Condition Index (VCI) and results were compared with the Standardized Precipitation Index (SPI) in the Bundelkhand region in Central India covering five districts of Madhya Pradesh namely, Sagar, Damoh, Tikamgarh, Chhatarpur and Panna. The VCI is a pixel-wise normalisation of the NDVI whose values can be averaged spatially and temporally to make comparisons with meteorological drought indicators.

The Bundelkhand region of India has been experiencing recurrent droughts and causing adverse impacts on water resources, agriculture, rural livelihood and economy. The monthly rainfall data of five stations for 38 years from 1980-2017 was used to analyse the extent of meteorological drought and identifying the driest years using rainfall departure analysis and 3 Month time scale SPI. The VCI was analysed for the NDVI data from 2000 to 2020. From the Annual rainfall Departure and SPI analysis, the years 2007, 2015 and 2017 were observed as the severe drought years with the larger spatial extent in the study area. The spatial variabilities of droughts in 2007, 2015 and 2017 were also assessed based on the satellite-based indices. The VCI shows that about 49, 87 and 40% area of the Bundelkhand region was under drought in October while 18, 7 and 10% area was under drought in August in the years 2007, 2015 and 2017 respectively. The drought severity was observed very high during October 2015 however in the years 2007 and 2017, the whole monsoon seasons have experienced drought. Both SPI and VCI indicated very high drought severity during October 2015. The satellite-based indicator VCI has been found interpreting results in agreement with the SPI results.

INTRODUCTION

Droughts are one of the most dangerous environmental disasters, causing adverse impacts on the natural ecosystem, hydrological and agricultural systems (Bond et al., 2008). Drought arises due to lack of precipitation and availability of variation in rainfall patterns. Generally, it occurs in almost all climatic regions. Droughts seem like a situation of below-normal rainfall and evolve into a dangerous climatic event with significant consequences for the environment. Drought has affected about half of the world's population (Kogan et al., 2019). It is one of the serious phenomena and always ranks on top among all the natural hazards concerning the number of people gets affected globally (Dunn et al., 2018). Drought risks build up gradually, which often accumulate over a long period, and might last for years after the drought is over (Mishra and Singh, 2010). The drought severity, their onset as well as withdrawal, are not only difficult to identify but quantify also. According to a recent Intergovernmental Panel on Climate Change (IPCC) report, maize, wheat, and rice output has decreased in various regions of Asia during the last several decades owing to rising temperatures, water stress, a decrease in the number of rainy days, and the frequency of El Nino occurrences (Change, 2014). In the last five decades, India has been one of the most vulnerable and drought-prone countries, with drought occurring at least once every three years (Miyan, 2015).

Drought is a common natural hazard in India and was seen prominently in the years 1877, 1899, 1918, 1972, 1987 and 2002 (Yadav, 2009). The total geographical area of India is 3.38 million km^2, out of that about 1.08 million km^2 of land is subjected to various degrees of drought and water stress (Jain et al., 2009). Drought areas are mainly confined to the peninsular western and central parts of the country. The recurrent droughts in the Bundelkhand region of Madhya Pradesh state in Central India are causing adverse impacts on water resources, agriculture, rural livelihood and economy (Pandey et al. 2010 and Kundu et al. 2015). Due to uncertainty in the monsoon season, high temperatures and unfavourable meteorological conditions, the incidence of drought are frequent in these regions. The National Commission on Agriculture in India classify droughts into three types i.e. meteorological, hydrological and agricultural (Mirdha, 1973). A meteorological drought is an event that occurs when an area receives precipitation less than 25% of its normal. Hydrological drought is the outcome of long-term meteorological droughts resulting in the drying up of rivers, streams, lakes, reservoirs, and a decrease in groundwater level. Agricultural drought occurs when soil moisture is insufficient due to continuous meteorological drought to support healthy crop growth during the growing season, resulting in crop stress and wilting.

Drought must be assessed and monitored using scientific techniques to reduce future risk and potential dangers. Traditional drought monitoring relies on ground-based observations of meteorological and hydrological data including precipitation, temperature, evapotranspiration, soil moisture, surface runoff, and groundwater levels. Several drought indicators have been developed in recent years based on this single location data such as the Standardized Precipitation Index (SPI) (Guttman, 1999), Crop Moisture Index (Palmer, 1968), Palmer Drought Severity Index (Palmer, 1965), Soil Moisture Drought Index and Streamflow Drought Severity Index, Groundwater Drought Index and many more. Many studies have successfully applied the SPI, which is related to the probability of occurrence of wet and dry events, by many researchers efficiently for monitoring the spatial extension and intensity of droughts, at different time scales of 3, 6, 12, and 24 months (Khan et al., 2008; Belayneh and Adamowski, 2012; Thomas et al., 2015). It takes longer for deficiency precipitation to affect the streamflow, soil moisture, reservoir and groundwater levels. SPI on 1 and 3-month time scales are associated with soil moisture and precipitation deficit however the hydrological drought is associated with the SPI-6 which indicates precipitation deficit for more than 6 months (Van Loon, 2015). Although meteorological data from ground-based stations have a high level of accuracy and is widely utilised across the world, the density and distribution of meteorological stations are insufficient for spatial data extraction. Without an optimal network of meteorological stations throughout the study region, the geographical extent of drought cannot be accurately assessed (Vicente-Serrano and López-Moreno, 2005). Even yet, the time and cost of data preparation, as well as the risk of errors, may cause a delay in drought mitigation operations. In this context, drought monitoring using satellite-based data has gained widespread acceptance in recent decades because of its low cost, ease of data acquisition, synoptic perspective and reliability.

Remote sensing is a state of the art and useful technique for monitoring drought. Many drought indices are developed based on remote sensing data such as the normalized difference vegetation index (NDVI) (Tucker, 1979), Land Surface Temperature (LST), Temperature Vegetation Drought Index (TVDI), Vegetation Condition Index (VCI) (Kogan, 1990) and many others. VCI is more significant in drought monitoring when compared to NDVI and TVDI. VCI distinguishes between climatic and long-term biological signals, making it more diagnostic of moisture deficit. As a result, when compared to other remote sensing-based indices, VCI can provide more exact findings for monitoring and quantifying droughts in non-homogeneous areas. Therefore, VCI is widely utilised in drought monitoring and analysis, with several studies confirming its accuracy (Unganai and Kogan, 1998; Jain et al., 2009; Du et al., 2013; Liu et al., 2020). Thus, the present study focuses on evaluating drought indicators based on the integration of meteorological and satellite-based indices in the Bundelkhand region of Madhya Pradesh, which experiences very frequent droughts of higher intensities in India. Rainfall based departure analyses were used to identify the dry periods using long term rainfall data of five stations. The monthly rainfall based index, 3 Month SPI is estimated for the monsoon season of the identified severe drought years. Furthermore, satellite-based data index VCI is calculated over the area using long-term MODIS based NDVI for the monsoon season of the same classified drought years.

STUDY AREA

Madhya Pradesh is a centrally located state in India. The present study has been carried out in the Bundelkhand region located in the northern part of Madhya Pradesh state comprising 5 districts Sagar, Damoh, Chhatarpur, Tikamgarh and Panna as shown in Figure 1. The Bundelkhand region is located between 23.14 and 25.55 latitude and 78.05 and 80.67 longitude covering an area of 37 479 km^2. The Bundelkhand region of Madhya Pradesh state faces the problems of recurrent droughts that are unpredictable both in their occurrence and duration; hence predictions and preparedness against droughts would be key elements for minimizing their impacts (Galkate et al., 2015). The Bundelkhand region has long been regarded as a drought-prone region of the country, but drought frequency and severity have increased in recent decades. (Gupta et al., 2014). The region receives an annual rainfall of more than 1 100 mm. Around 80% of the population are directly dependent on agriculture which is mostly rainfed and susceptible to drought. The major rivers flowing through the study area includes Betwa, Sindh, Tons and Chambal and all are tributaries to the Ganga river. The topography of the region is undulating, with boulder-strewn plains and rocky outcrops and in a rocky landscape. Wheat and Soybeans are the major crops grown in the rabi and Kharif season, respectively. The major soils in this region include alluvial, black soils and mixed red soil.

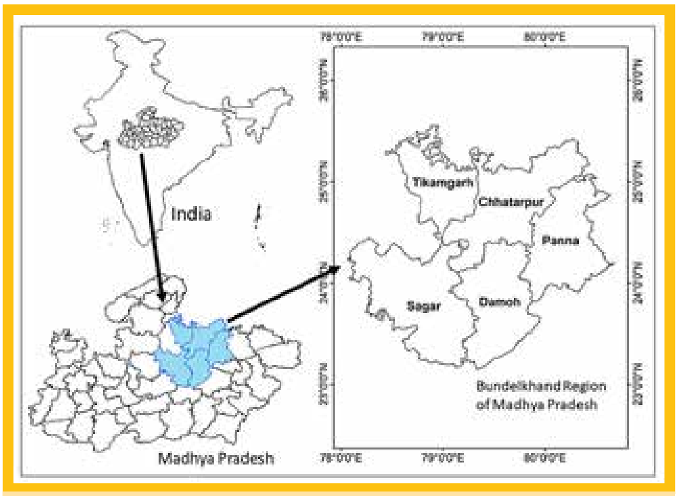

FIGURE 1: Location of Study Area (Bundelkhand region of Madhya Pradesh)

MATERIALS AND METHODOLOGY

Statistical analysis

The rainfall statistics of five rain gauge stations Sagar, Damoh, Panna, Tikamgarh and Chhatarpur of Bundelkhand region has been worked out using 38 years of rainfall data from the year 1980 to 2017. The rainfall data has been collected from India Meteorological Department and State Data Centre, Madhya Pradesh Water Resources Department, Bhopal. The statistical analysis of annual, monsoon, non-monsoon and monthly rainfall have been carried out to estimate average rainfall, standard deviation and coefficient of variation of five stations and Bundelkhand region to understand rainfall pattern and its variability.

Rainfall Departure Analysis

The annual rainfall departure analysis was performed for the determination of drought years, frequency Return period and severity in the study area. As suggested by India Meteorological Department, a year can be considered as a drought year when the annual rainfall deficit is more than 25% of its long term normal rainfall (Appa Rao, 1986). Further, the meteorological drought can be classified according to its severity level. It is considered as a Moderate drought when the annual rainfall deficit is between 25% to 50%, Severe drought when the annual rainfall deficit is between 50% to

75% and Extreme drought when the annual rainfall deficit is more than 75%. The percentage departure of the annual rainfall time series has been calculated using equation 1.

$$\text{Percentage of Departure} = \frac{Annual\ Rainfall - Average\ Annual\ Rainfall}{Average\ Annual\ Rainfall} \times 100 \qquad \textit{Equation 1}$$

Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) assigns a numeric value to the precipitation based on the deficit severity and it can be associated across regions with a different environment. In brief, SPI is the number that represents the standard deviation of precipitation data from its long-term average for a normally distributed series. As the precipitation data is not normally distributed, a transformation technique is used in the first stage of SPI to convert the data series to a normal distribution. The SPI determines the probability of occurrence of wet and dry events at different time scales i.e. 1 month to 24 months which are associated with different droughts such as soil moisture drought, agricultural drought, meteorological drought and hydrological drought. The 3 Month SPI values are indicative of soil moisture condition as well as meteorological drought, hence in this study, analysis has been carried out to assess drought severity in the study area using 3-month SPI values and its comparison with satellite-derived index. For this analysis monthly rainfall time series of 38 years from the year, 1980 to 2017 was used for five stations of the Bundelkhand region.

Drought characteristics based on their severity can be assessed using an analytic method to determine the cumulative probability (McKee et al., 1993). The cumulative probability, H(x), is then converted into the standard normal random variable 'Z,' which has a mean of zero and a variance of one and is the SPI value. The Z or SPI values are more easily estimated using an approximation that converts cumulative probability to the standard normal random variable Z (Abramowitz and Stegun, 1965). The SPI computation for each place is based on the long-term precipitation data of the selected period. This long-term data fitted to a probability distribution, which is then converted into a normal distribution, resulting in a mean SPI of zero for the chosen place and duration (Edwards, 1997). The SPI values and their classification indicating severity range are shown in Table-1.

TABLE 1: SPI classification and their values

2.0 +	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-.99 to .99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 and less	Extremely Dry

In the derived SPI series, when continuous negative values of SPI reach an intensity of -1.0 or less and then SPI remains constantly negative, a drought event has begun, which will terminate when the SPI becomes positive. As a result, each drought event has a duration that is determined by its start and end dates, as well as its intensity and severity.

Satellite Data

Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data provides a new generation of land resources products to support natural resource management and global change research (Didan, Kamel, 2015). Drought monitoring is one of the many environmental concerns for which these products are used. (Gu et al., 2008; Bajgain et al., 2015, 2017). In this study, the MODIS data were accessed using Google Earth Engine (GEE), which is a cloud-based remote sensing platform. The 16-Day composite (MOD13Q1) MODIS Terra Vegetation Indices product was used to estimate NDVI based VCI. The datasets are available for global coverage at a 250 m spatial resolution from the year 2000 onwards.

Vegetation Condition Index (VCI)

Normalized Difference Vegetation Index (NDVI) is a widely used remote sensing index that gives quantification of quantitative estimation of vegetation growth based on surface reflectance. NDVI is calculated as the ratio between the reflectance of a red band (0.6-0.7 µm) and a near-infrared (NIR) band (>0.7 µm). The NDVI values range from -1 to 1, the responses of healthy vegetation in this range are towards one while water and the built-up area will be represented as negative and near-zero values. The NDVI can be estimated using equation 2.

$$NDVI = \frac{NIR - Red}{NIR + Red} \qquad \textit{Equation 2}$$

To normalised current NDVI w.r.t maximum and minimum NDVI over a single pixel, Kogan proposed Vegetation Condition Index (VCI). VCI compares the current vegetation index to the values observed in a similar period over a specific pixel. VCI can be estimated with equation 3

$$VCI_{ijk} = \frac{NDVI_{ijk} - NDVI_{ij\,min}}{NDVI_{ij\,max} + NDVI_{ij\,min}} \qquad \textit{Equation 3}$$

Whereas VCIijk is the VCI value for the pixel i during the month j for year k, NDVIijk is the VCI value for the pixel i during the month j for year k, NDVIijk min is the multiyear minimum NDVI for i pixel during the month i and NDVIijk max is the multiyear maximum NDVI for i pixel during the month j. The VCI values less than 0.4 indicates mild to extreme drought conditions while VCI above 0.4 shows normal conditions as shown in Table 2. When compared to NDVI, this VCI normalises NDVI responses and removes the long-term ecological indication from the short-term climatic signal, proving to be a better index for monitoring water stress conditions.

TABLE 2: VCI Classification

VCI Values	Category
0.0 - 0.1	Extreme Drought
0.1 - 0.2	Severe Drought
0.2 - 0.3	Moderate Drought
0.3 - 0.4	Mild Drought
0.4 - 1.0	No Drought

RESULTS AND DISCUSSION

The long term rainfall data of 38 years from 1980 to 2017 were analyzed to assess the average rainfall pattern and variability for five stations Sagar, Damoh, Panna, Tikamgarh and Chhatarpur of the Bundelkhand region of Madhya Pradesh. Rainfall statistics of these stations is summarized in Table 3. The Distribution of monthly rainfall of all five stations is shown in Figure 2.

From Table 3, the average annual rainfall in the Bundelkhand region was observed varying between 1 202 (Sagar) to 960 (Chhatarpur) with an average of 1 105 mm. The average annual monsoon and non-monsoon rainfall in the region were observed as 1 008 mm and 97 mm respectively. The region receives a major portion of rainfall during the monsoon season as shown in Figure 2. The rainfall pattern in Bundelkhand has a very high temporal variation, the average standard deviation annual, monsoon and non-monsoon rainfall has been estimated as 336, 320 and 97 mm. The high values of coefficient of variation for annual and monsoon rainfall 0.31 and 0.32 indicate high rainfall variation and non-monsoon rainfall seems to be

TABLE 3: Rainfall statistics of five stations of Bundelkhand region (data used 1980-2017)										
No	Station Name	Annual			Monsoon			Non-Monsoon		
		Avg.(mm)	Std Dev	CV	Avg. (mm)	Std Dev	CV	Avg. (mm)	Std Dev	CV
1	Sagar	1 202	390	0.32	1 092	365	0.33	110	76	0.69
2	Damoh	1 207	333	0.28	1 114	325	0.29	92	75	0.81
3	Panna	1 174	331	0.28	1 074	333	0.31	100	72	0.72
4	Tikamgarh	960	309	0.32	876	295	0.34	84	84	1.00
5	Chhatarpur	984	318	0.32	884	282	0.32	100	140	1.40
	Average	**1 105**	**336**	**0.31**	**1 008**	**320**	**0.32**	**97**	**89**	**0.92**

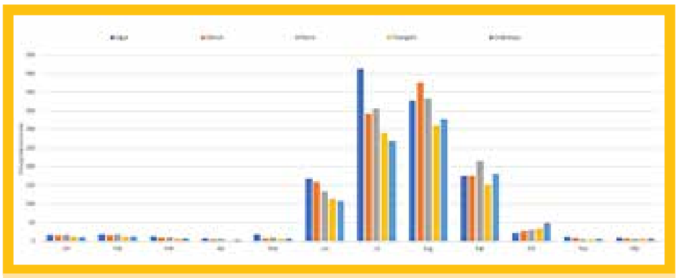

FIGURE 2: Distribution of Monthly Rainfall of all stations

very erratic with a very high coefficient of variation value of 0.92. Very high temporal variation has been seen in the non-monsoon rainfall time series at Chhatarpur and Tikamgarh stations. High variation in rainfall is one of the causes of frequent and severe droughts in the Bundelkhand region.

Rainfall Departure Analysis

Departure analyses were performed using 38 years of annual rainfall data from the year 1981 to 2017. Drought years were identified based on annual rainfall deficit and drought years were classified based on their severity. Drought years of rainfall deficit between 25 to 50% were grouped as moderate drought years and deficit more than 50% were considered as severe drought years as shown in Table 4.

TABLE 4: Rainfall Departure Analysis using annual rainfall time series (data used 1980-2017)					
Sr No	**Station Name**	**Frequency (%)**	**Return Period**	**Drought Years (Deficit less than 25 to 50%)**	**Severe Drought Years (Deficit greater than 50%)**
1	Sagar	28.94	1 in 3-4 years	1986, 1988, 1989, 2002, **2007**, 2010, 2012, **2015**, **2017**	1981, 2004
2	Damoh	21.05	1 in 4-5 years	1989, 1998, 2002, 2006, **2007**, 2014, **2015**, **2017**	--
3	Panna	18.42	1 in 5-6 years	1981, 1985, 2000, 2006, 2010, **2015**	**2007**
4	Tikamgarh	23.68	1 in 4-5 years	1986, 1991, 2000, 2006, **2007**, 2010, **2015**, **2017**	1989
5	Chhatarpur	23.68	1 in 4-5 years	1995, 1998, 2000, 2006, **2007**, 2012, 2014, **2015**	**2017**

From Table 4, it has been observed that the drought frequency is very high at all five stations however drought frequency was observed highest at Sagar (29.34%), Tikamgarh (23.68%) and Chhatarpur (23.68%). Thus the drought return period is very low at these three stations. Most of the stations in Bundelkhand experience a very low drought return period i.e. one drought after every 4 to 5 years. Sagar station has a chance of occurring drought year after every 3 to 4 years. From the analysis, it can predominantly be seen that the years 2007, 2015 and 2017 were the most common and severe drought years at almost all stations in the Bundelkhand region. Thus the dry event probability was typically examined for these widespread and severe drought years 2007, 2015 and 2017 for comparison of SPI and VCI.

Standardized Precipitation Index (SPI)

As 3 month time step SPI i.e. SPI-3 is indicative of meteorological drought situation, it has been used as a seasonal drought index to characterize the short-term drought and its impact on vegetation. The probability of occurrence of dry events of SPI-3 indicates the severity of drought as shown in Table 5.

TABLE 5: Probability of occurrence of 3 Month SPI in Bundelkhand						
Sr No	**Severity**	**Probability of occurrence of 3 Month SPI (%)**				
		Chhatarpur	**Damoh**	**Panna**	**Sagar**	**Tikamgarh**
1	Extremely Wet	1.77	2.65	3.03	4.00	2.56
2	Severely Wet	5.96	4.87	4.55	3.06	5.12
3	Moderately Wet	9.05	11.50	8.44	8.71	7.68
4	Near Normal	74.61	71.46	70.35	70.12	78.25
5	Moderate Dry	5.74	7.52	10.17	8.94	2.77
6	Severely Dry	1.99	1.33	2.60	4.00	2.13
7	Extremely Dry	0.88	0.66	0.87	1.18	1.49

The analysis of Table 5 shows the probability of occurrence of dry events of SPI-3 at all five stations of the Bundelkhand region. It is broadly seen that the probability of occurrence of moderate dry situation is very high at Panna, Sagar and Damoh with the probability of occurrence 10.17, 8.94 and 7.52% respectively. The probability of occurrence of severe drought events has been observed high at Sagar, Panna and Tikamgarh. The probability of extremely dry events was also seen high at Tikamgarh and Sagar with the probability of occurrence 1.49 and 1.18% respectively. From the overall analysis, it can be seen that the probability of occurrence of severely and extremely dry events is very high at Sagar and Tikamgarh stations. Though the Sagar station receives a good amount of rainfall as compared to other stations, the probability of severely and extremely dry events has been observed very high at this station. Tikamgarh station has also shown a high probability of severe and extreme events. In the Bundelkhand region, the rainfall season comprises four to five rainy months i.e. June, July, August, September and October, and rainfall deficit during these months will have cumulative impacts during later monsoon months i.e. August, September and October. Thus for the 3-month SPI, analysis was especially focused on the drought severity during the August, September and October months. From the rainfall departure analysis, years 2007, 2015 and 2017 were identified as severe dry years for which further analysis of SPI and VCI has been performed. The SPI-3 severity values of the monsoon months for severe and widespread drought years 2007, 2015 and 2017 in the Bundelkhand region are given in Table 6.

TABLE 6: SPI-3 values for monsoon months of drought years 2007, 2015 and 2017

Months	Sagar	Damoh	Panna	Tikamgarh	Chhatarpur
Aug-07	-1.26	-0.79	-2.05	**-2.18**	-2.01
Sep-07	-2.22	-0.87	-2.04	**-2.28**	-1.77
Oct-07	-1.31	-0.65	-1.61	-1.44	**-1.15**
Aug-15	-0.64	-0.78	-1.29	**-0.73**	-0.58
Sep-15	-0.89	-1.34	-1.69	**-1.12**	**-1.46**
Oct-15		-1.12	-1.45	**-0.79**	**-1.79**
Aug-17	-0.80	-1.41	0.15	**-0.69**	**-1.45**
Sep-17	-0.57	-1.47	-0.05	**-1.43**	**-1.64**
Oct-17	-0.78	-2.09	-0.93	**-1.87**	**-1.80**

To monitor drought from a long-term space-based observation, the VCI index derived from NDVI is used in the study, The spatial extent and temporal change of VCI in the study area in August, September and October for the years 2007, 2015 and 2017 are shown in Figure 3. First of all the VCI is classified into five classes from extreme drought to no drought and then the percentage of the area falling in each class in the Bundelkhand region is calculated and is given in Table 7.

From the analysis of Figure 3 and Table 7, the extent and onset of drought events can be detected from the VCI maps of successive fortnights of the three driest years 2007, 2015 and 2017. Severe vegetation stress is evident all over the area during the last fortnight of October 2015. The situation was seen normal in August 2015 in Bundelkhand, where the majority of the area was under no-drought condition. The drought situation started worsening after the first fortnight of August 2015. By the end of October 2015 around 27.5, 24.7 and 13.5% area of the region were found under extreme, severe and moderate stress conditions respectively. A similar progression of drought situation from August to October has been seen in the years 2007 and 2017 in the whole region. Some exception was seen in the middle of September 2007, when more area was under drought as compared to October 2007 especially in the southern part of the Bundelkhand region. From the overlaying of VCI maps, it is observed that the Sagar and Tikamgarh district of the study area is prone to water stress and severe drought. In a comparison of the dry periods identified using SPI and water stress conditions identified using VCI, it is observed that both indices are showing droughts almost at the same period and with the same severity. VCI analysis of all the three severe drought years indicated the increase of spatial extent of drought from August to September especially in the Sagar and Tikamgarh districts which are quite relatable and in agreement with the results derived from the SPI-3. The present study justifies the advantage of satellite-based data for identifying the spatial and temporal extent of vegetation stress and prevailing drought situation in the larger area with ease.

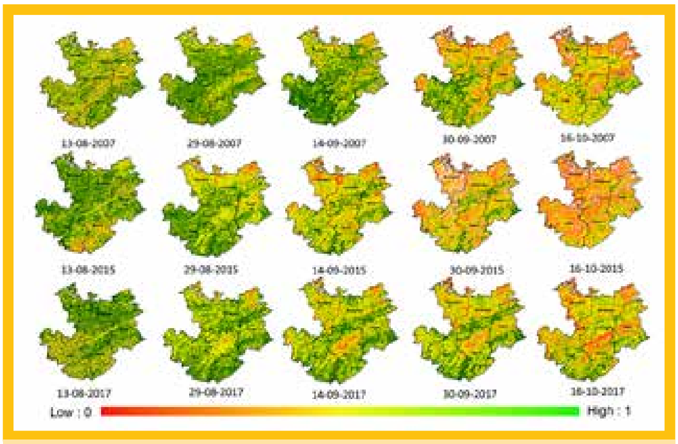

FIGURE 3: Fortnightly spatio-temporal variation of Vegetation Condition Index (VCI) for the years 2007, 2015 and 2017 (low VCI value indicates drought severity)

TABLE 7: Area in percentage under different VCI classes in Bundelkhand

Dates	Extreme Drought	Severe Drought	Moderate Drought	Mild Drought	No Drought
8/13/2007	3.63	3.41	4.92	6.72	81.32
8/29/2007	0.20	0.36	0.72	1.46	97.26
9/14/2007	0.72	0.51	1.39	2.84	94.55
9/30/2007	7.01	9.13	11.52	11.98	60.37
10/16/2007	10.16	10.12	13.44	15.34	50.95
8/13/2015	0.91	1.32	2.14	3.20	92.43
8/29/2015	0.03	0.12	0.41	1.29	98.14
9/14/2015	0.59	2.95	6.98	11.39	78.09
9/30/2015	18.66	11.92	13.85	14.63	40.95
10/16/2015	27.52	24.86	21.74	13.55	12.33
8/13/2017	1.57	1.87	2.73	3.75	90.08
8/29/2017	0.07	0.14	0.34	0.84	98.61
9/14/2017	0.20	0.70	2.18	5.19	91.74
9/30/2017	1.16	2.97	6.32	10.64	78.91
10/16/2017	5.77	8.81	11.58	13.51	60.32

CONCLUSIONS

The present study examined the spatial and temporal extent of drought over five districts, Sagar, Damoh, Panna, Tikamgarh and Chhatarpur of the Bundelkhand region in the Madhya Pradesh state of India using the annual rainfall departure analysis and combination of station-based rainfall drought severity index (SPI) and remote sensing-based index (VCI). The annual rainfall departure analysis indicated a very high drought frequency at most of the stations with an overall drought return period of 4 to 5 years in the region. Years 2007, 2015 and 2017 were identified as the severe drought years which had a wide coverage over the region and were common in all the five districts and further analysis for comparison between SPI and VCI was carried out for those years. SPI-3 values were estimated for all five stations using the long-term monthly rainfall data. Analysis of SPI-3 shown that, though the Sagar station receives a good amount of annual rainfall as compared to other stations, the probability of severely and extremely dry events is very high at this station. Tikamgarh station has also shown a high probability of severe and extreme events. The results of SPI-3 were further analyzed for the August, September and October months of dry years 2007, 2015 and 2017. VCI is estimated for August to October of dry years using the MODIS long term fortnightly NDVI data. The VCI analysis during all the three severe drought years indicated an increase in the spatial extent of drought from August to October at all stations of the region and August to September especially at Sagar and Tikamgarh. Similar temporal and spatial pattern of drought severity has also been interpreted through SPI-3. The present study justifies the advantage of satellite-based data for identifying the spatial and temporal extent of vegetation stress related drought. The study can be extended further by linking data of crop production with SPI and VCI for drought and wet years, it can be helpful to quantify the economic impact of droughts. The VCI findings may be influenced by inaccuracies in optical satellite data caused by cloud cover, which causes a shift in the real reflectance from ground objects. Conclusively, it can be said that the onset and progression of drought can be monitored with the application of station-based and satellite-based data, which will certainly help the various stakeholders to take necessary disaster management decisions.

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PAPER 1

Water Security and Climate Change Risks for Municipalities and Critical Infrastructure Across South Africa

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ABSTRACT

South Africa is a water scarce country with many towns and cities already experiencing sever water security challenges. Recent events, including the Cape Town water crisis, the current water supply crisis for Gqeberha, continuing drought conditions in large parts of South Africa and an increase in recent flooding events, particularly in urban areas, have highlighted the increasing water security risks for towns and cities in South Africa. Climate change is considered to be a significant factor in this increasing risk that needs to be urgently taken into account in terms of both water resource planning and infrastructure planning and design. Population growth and economic development, however, are also contributing to the increasing water security challenge.

In this paper we present the results of a study that looked at current and future water security risks for all municipalities as a result of both expected climate change impacts as well as future population growth scenarios up to 2050. The study was done in support of the development for the CSIR Greenbook for assisting municipalities with evaluating their climate change risks and giving consideration to appropriate adaptation and mitigation options. The study, however, also builds on work done for previous projects including contributing to the Long-Term Adaptation Scenarios (LTAS) research program, DWS climate change strategy and a study of the economic impacts of climate change for South Africa for National Treasury. These studies, as well as recent work done in support of update estimates of climate change risk for water supply to the city of Cape Town will be presented and recommendations made for appropriate adaptation and response options.

We also consider the impact of climate change on increasing flood risks across South Africa, particularly for critical infrastructure such as dams, bridges and power lines, and describe how supporting a transition to becoming a Water Sensitive City (WSC) in particular is crucial in managing both increasing water security and urban flood risks, as well as additional co-benefits necessary to create resilient, sustainable and liveable infrastructure and urban areas in South Africa, but also relevant for the rest of the SADC region and for other cities across Africa. In particular, we advocate for a better understanding of the specific risks associated with climate change and developing bottom-up solutions that address the underlying risks and vulnerabilities and allow for an adaptive pathways solution to increasing resilience. Investing in Ecological Infrastructure (EI) such as rehabilitation of catchments and promoting the transition to a Water Sensitive City (WSC) are critical.

INTRODUCTION

With an average rainfall of only 450 mm/year and significant annual and seasonal variability, South Africa is a water-scarce country. Rainfall also varies from over 1 900 mm in the east of the country and in the mountainous areas, to almost zero in the west and northwest of the country. Conversion of rainfall to runoff is also low with an average mean annual runoff (MAR) of only 40 mm, one seventh of the global average of 260 mm per year (DWA, 2013). Despite the low levels of water availability, South Africa has however been able to provide the bulk of its population with a secure water supply and to support the largest economy in Africa.

This would not have been possible without the development of a highly integrated and well-developed bulk water supply systems that has been continually adapting to the changing needs of the country. Many towns and cities within South Africa however are already starting to experience increasing water security risks and without further development of the bulk water supply system it is likely that many parts of South Africa will start to experience sever water shortages which will impact both on people's livelihoods, but also economic development. South Africa already has the greatest number of large dams in Africa, and the sixth greatest number of large dams globally (ICOLD) and there is limited potential for new dams or additional surface water supply, hence it will be necessary to consider alternative supply options as well as improved water use efficiency. The likely impacts of climate change must also be taken into consideration for future planning.

According to Poff et al (2015) "securing the supply and equitable allocation of fresh water to support human well-being while sustaining healthy, functioning ecosystems is one of the grand environmental challenges of the twenty-first century, particularly in light of accelerating stressors from climate change, population growth and economic development". Increasingly climate change is being incorporated into water resources and infrastructure planning across Africa. See for example the World Bank's initiatives on Enhancing the Climate Resilience of Africa's Infrastructure (ECRAI) including the water and energy sectors (Cervigni et al, 2015).

Water supply is considered to be one of the principal mechanisms for the realization of climate change impacts on society (UN Water, 2010). A review of the impacts of climate change on the water sector in South Africa (Schulze, 2011) concluded that it was not all "doom and gloom". Due to variability in the impacts of climate change some areas of South Africa would most likely be "winners" while other areas and other sectors would be "losers". Particular "hotspots" of concern, primarily due to decreasing rainfall, are the southwest of the country, the West Coast and to a lesser extent the extreme north of the country. Even in areas considered to be "winners" due to increasing precipitation, there are potential increases in risks due to increased intensity of rainfall events and associated water logging and flooding (Schulze, 2011).

A study of the potential economic impacts of climate change in South Africa, (Cullis et al, 2015) showed that the existing integrated bulk water supply system, however, provides some resilience to the potential impacts of climate change by being able to manage water supply from different parts of the country, and the efficient utilisation of dam storage. The benefits of this, however, will vary significantly between different towns dependent on their current and future water supply sources. For example, several towns are already highly dependent on groundwater, while other towns, particularly in the coastal region, are already starting to implement desalination and re-use. The town of Beaufort West for example has already implemented a direct potable re-use (DPR) plant. The integration of alternative supply sources is a key part of transition to becoming a Water Sensitive City (Brown et al, 2016).

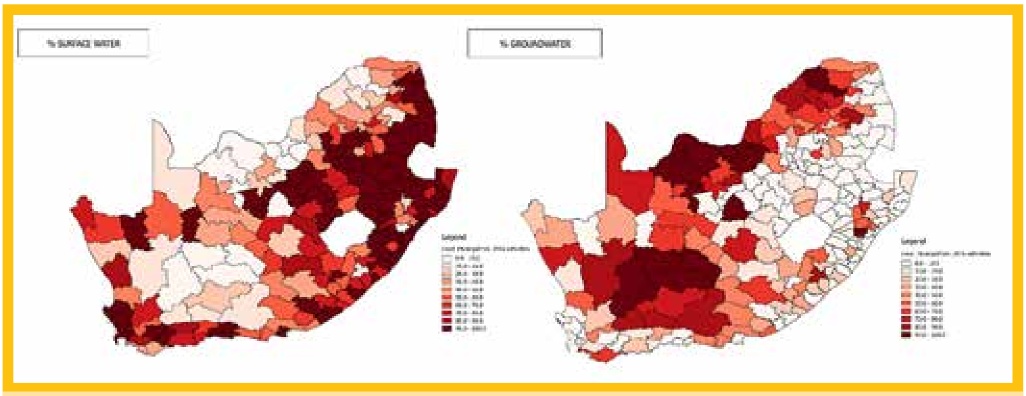

FIGURE 1: Percentage of municipal water supply provided from surface water (left) and groundwater (right)

Climate change is also likely to impact on the frequency and intensity of flood events across South Africa (Engelbrecht, et al, 2019). This presents a significant increasing risk to both towns and cities, particularly in areas where informal development has taken place within existing flood plains (Le Roux, et al, 2019), but also in terms of critical infrastructure such as bridges, roads, dams, and power line crossings (DEA, 2013). Adapting to these increasing risks, particularly in urban areas and for critical infrastructure, will be critical in terms of supporting social and economic development in South Africa, and the post COVID economic recovery plan.

APROACH AND METHODOLOGY

Water Security Risks for South Africa Municipalities

In order to get a high-level first order assessment of the relative climate change risks for water supply to municipalities across South Africa, a general risk equation was developed to determine the current and future surface water supply vulnerability that combines both climate change and development risks (i.e. due to an increase in population and associated increase in water demand). The general risk equation recognizes that risk is not just based on the direct exposure to a climate change (e.g. the change in precipitation or temperature) but is also dependent on the vulnerability of each town in terms of its current and future water demand and water availability.

Future water supply risk could therefore be affected either by reduced availability of surface water or by an increase in demand and it is important to consider that these factors will be different for different towns. The basic risk equation used in this study is given and is consistent with the general approach recommended by the IPCC for understanding climate change risks.

It is also consistent with the development of bottom-up solutions to climate change impacts through a better understanding of the drivers of risk.

$$Risk = \frac{Vulnerability \times Exposure}{Adaptive\ Capacity}$$

Vulnerability is determined as the ratio of available water supply and estimated total water demand.

$$Vulnerability = \frac{Demand}{Supply}$$

The overall exposure to future climate change risks for water supply is calculated in two ways:

$$Exposure\ (E_1) = \frac{\Delta MAE}{(\Delta MAR \times \%SW) + (\Delta MAP \times \%GW)}$$

$$Exposure\ (E_2) = \frac{\Delta MAE}{(\Delta RWS \times \%SW) + (\Delta MAP \times \%GW)}$$

Where: ΔMAR = the change in the Mean Annual Runoff for the catchment in which the town is located (i.e. indicating a the potential impact on local surface water supply options)

ΔRWS = the change in Regional Water Supply derived from the study used to calculate the impact of climate change on average water supply at a WMA scale (from Cullis et al, 2015).

ΔMAP = change in the mean annual precipitation

ΔMAE = change in the mean annual evaporation

RWS = change in regional water supply availability

%SW = percentage of total supply that is from surface water

%GW = percentage of total supply that is from groundwater

The current water demands, current water supply, percentage of supply from surface water and from groundwater and the future augmentation options were taken from a synthesis of the DWS All Towns study of 2011 and supplemented from various DWS reconciliation studies for the major metropolitan areas that was compiled by Cole et al, (2017). Future projects of population growth for local municipalities across South Africa were provided by the CSIR. These were used to estimate future water demands for all local municipalities assuming that increasing water demand was proportional to the increase in population.[1]

Climate Change Impacts on Future Water Supply and Demand

Settlements in South Africa get water primarily from either surface water sources, or groundwater sources, or some combination of both (Figure 1). Climate change will impact on these two water sources differently. In order to determine the overall exposure to climate change risks for water supply we have determined the overall exposure based on an estimated change in surface water availability multiplied by the percentage of the town's water supply that is provided from surface water plus an estimated change in groundwater availability multiplied by the percentage of the town's water supply that is provided from groundwater.

Climate change is also anticipated to impact on demand with higher temperatures leading to increasing demands for water unless specific mitigation actions are taken to manage demand and improve water use efficiency. While there has been some research to indicate how climate change will impact on increased irrigation water requirements (see for example Cullis et al, 2015 and Schultze 2010) as well as evaporation losses from dams and reservoirs there has been only limited research into the impact that this will have on urban water demand. As a first order estimate we have assumed that the increase in urban water demand is proportional to the increase in potential evaporation demand as a result of increasing average temperature.

Determining the impact of climate change on water supply is almost impossible without a detailed analysis of the specific water supply system of each individual town and settlement. This needs to consider the source of the water, the unique spatial and temporal variability in runoff, the specific characteristics of the catchment (which could be far from the actual location of the settlement), the volume of storage available and the nature of the demand. Requirements for environmental flow releases and the impacts of upstream demands, future developments and augmentation options are also critical. The ability to manage the system and to utilize a diversity of water supply options (including inter-basin transfers), the potential for conjunctive use from groundwater, access to desalination or re-use of treated effluent, the acceptable levels of risk (i.e. the degree to which demand can be managed), and any water quality constraints, also need to be taken into consideration.

In order to highlight the importance of having access to a regional integrated bulk water supply option, we have adopted two separate approaches to estimating the impact of climate change on the availability of surface water supply. The first (E1) assumes that changes in water supply are directly proportional to changes in the Mean Annual Runoff (MAR) of the catchment in which the settlement or municipality is located. This would be the case for example of a town with access to run-of-river supply only from local sources, with limited or no storage. The second (E2) is based on the results of a study that modelled the overall impacts of climate change on water supply to each of the original 19 Water Management Areas (WMA). This study made use of a national configuration of the Water Resources Yield Model (WRYM) that accounts for the interconnectedness of systems through inter-basin transfers and the main national and local water supply systems. Each of these approaches to determine the provisional impact on surface water are described below.

The likely impact of climate change on the proportion of water supply that comes from groundwater is assumed to be directly proportional to the impact on Mean Annual Precipitation (MAP). This is assumed because groundwater yield is a function of precipitation and recharge. Recharge potential does vary across the country, however for this initial assessment we have assumed the climate change impact is directly proportional to likely changes in MAP. Further work should consider these regional differences. As with the comment above in terms of the specific impacts on surface water yield, further research should also consider the potential for increased resilience through conjunctive use of both surface and groundwater sources.

Future Population and Climate Change Scenarios

A set of climate change scenarios for South Africa was provided by the CSIR. These included a 10th, 50th and 90th percentile scenario for the two of the IPCC global climate scenarios representing Relative Concentration Pathway (RCP) 4.5 and RCP 8.5. For this study only the RCP 8.5 results were used. The precipitation and temperature impacts for the different scenarios by 2050 where then aggregated at quaternary catchment scale and presented as a time series of average monthly precipitation values as well as maximum and minimum daily temperatures. These were then used to estimate average monthly evaporation based on the Hargreaves equation (Hargreaves, 1994). Similar scenarios were also used in a national climate change study (Cullis et al, 2017) and were used to determine the impact on the average annual water supply to different water management areas incorporating the regional bulk water supply systems.

Population growth scenarios were provided by the CSIR (Le Roux et al, 2019b) including a medium and high growth scenario. These scenarios were produced at the level of individual settlements and taking into account migration impacts but were then aggregated up to municipality scale for estimating future water demands which were assumed to be directly proportional to the change in population numbers at municipal level.

Impact of Climate Change on Surface Water Runoff

The impact of the different climate change scenarios on surface water runoff, used in the E1 definition of exposure as described above, was determined using the Pitman model (Pitman, 1973) at quaternary catchment scale across South Africa using existing calibrated Pitman parameters contained in Water Resources 2012 (WR2012). The Pitman model is a monthly rainfall-runoff model that is the standard for water resources planning in South Africa (Pitman, 2006; DWA, 2012) and has become one of the most widely used monthly time step rainfall-runoff models within southern Africa (Hughes et al, 2006). As a first order assumption we have consider the climate change impact on local water supply sources as directly proportional to the change in mean annual runoff (MAR). This will, however very significantly, particularly in terms of the amount of storage available, and also as a result of any impact on both seasonal and inter-annual variability which could result in the impact on "yield" being very different from the impact on average surface water availability.

Impact of Climate Change on Regional Bulk Water Supply Systems

For this study it was not possible to model the water supply system to each individual town or local municipality. As a first order estimate of the impact of climate change on water supply (and not just on surface water runoff) for urban areas across South Africa, we made us of a national configuration of the Water Resources Yield Model (WRYM) that had been developed for the Long-Term Adaptation Scenarios (LTAS) flagship research programme (DEA, 2015a) and UNU-WIDER report (Cullis et al, 2017).

The national WRYM was based on secondary catchment scale modelling units and aggregated results at the level of Water Management Area (WMA). The WRYM was selected as it is still the primary water resources modelling tool used by the DWS for bulk water resources systems analysis in South Africa. Although the national model was a simplification of much more detailed WRYM models configured for individual water supply systems in South Africa, it was still adequately detailed for the purposes of this study.

The outputs from the model include the impact of climate change scenarios on the water supplied to agriculture, urban and bulk industry and these were aggregated to Water Management Area (WMA). Without modelling the individual towns or bulk water supply systems it was not possible to determine the specific impacts for individual towns or cities, but the results of the study for the WMA in which the town or city was located were used to adjust the current water supply volumes to get a first order estimate of the impacts of climate change.

RESULTS AND DISCUSSION

Current and Futrure Water Supply Vulnerability due to Population Growth

The current water supply vulnerability of a municipality has been calculated as being the ratio of the total demand to the total supply and is shown in Figure 24. These results are based on estimate by the Department of Water and Sanitation (DWS) and aggregated by Cole et al (2017). A value of 1 implies that the demand and supply of the municipality are equal while a value of less than 1 means that there is surplus of supply. A value of more than 1 means that either the demand is too high, or the supply is too low or both. The region with the highest vulnerability is the eastern portion of the Eastern Cape which has a vulnerability of more than 2. This is largely due to historic under-investment in bulk water supply systems for the province and reflects the fact that many towns and municipalities are highly dependent on local and often unprotected surface water sources.

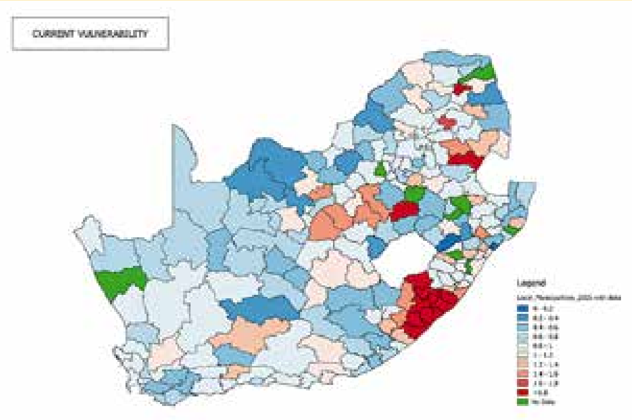

FIGURE 2: Current water supply vulnerability (estimated demand/ supply) for municipalities in South Africa

The estimated future water supply vulnerability (excluding climate change) is shown in Figure 3.These results show an increasing number of municipalities where water demand will increase current supply. In general, the water supply vulnerability in the Eastern Cape remains high, but there are increasing number of local municipalities across the country, particularly in the western and southern cape, Gauteng, Limpopo and Mpumulanga. The municipalities on the border are expected to see significant population growth as a result of migration from other countries, while there might even be a reduction in water supply vulnerability for some more rural municipalities as these experience population declines due to internal rural- urban migration.

Overall Exposure to Future Climate Change Impacts on Municipal Water Supply

The level of exposure to the 10th (dry), 50th (median), and 90th (wet) climate scenario for local municipalities based on the two different approaches are given in the figures below. When looking at the climate change exposure for both the impacts on surface water runoff (scenario E1) and the impacts on the regional water supply system (scenario E2) for the 10th, 50th and 90th percentiles, the West Coast of South Africa seems to be more exposed than the eastern portions of South Africa. This is because there is a decrease in runoff and regional water supply and precipitation in the west when compared to the increases that are to be experienced in the east. While there may be only a limited difference in the impact on the median scenario, the benefits of being connected to a regional bulk water supply system are shown by the smaller impacts under the E2 scenario particularly for the dry (10th percentile) scenario. The fact that the impact/benefit is also less in the wet (90th percentile) scenarios indicates the importance of taking into consideration up-stream demands, particularly when these are competing demands, or have first access to water.

Combined Water Security Risks of Population and Climate Change

The overall water supply vulnerability (demand/supply) by 2050 under the 10% percentile (dry) and 90th percentile (wet) future climate change scenario and medium and high population growth scenario are shown in Figure 5. These results indicate the Eastern Cape remains the greatest area of concern, but that this is largely as a result of the current lack of basic water supply infrastructure. In terms of future impacts, there are an increasing number of municipalities are risk, but these vary depending on the specific climate change scenario and also the impacts of population growth.

Even under the "wet' scenario, there are a number of municipalities, particularly in the Western Cape that will experience increasing water security risks, while in some cases any increase in water security risk due to climate change is matched by a reduction in demand.

In order to compare the relative impacts of climate change versus population growth on the overall water supply vulnerability, the results of the study for both exposure to climate change and also the anticipated population growth (high scenario) are plotted in Figure 5. This plot shows the relative importance of the two drivers of increasing water supply risk, but also the benefits of considering the impacts of a regional, integrated bulk water supply system that mitigates the potential future risks due to climate change and population growth. Overall, the impacts of population growth appear to be greater than due to climate change.

For future water resource planning, however, is critical to take both factors into account, and to undertake a more detailed analysis of the impacts on individual water supply systems and also in terms of estimating the level of risk by determining the impacts on system yield, rather than just average supply.

CONCLUSIONS

This is a first order estimate of the relative future water security risks for all local municipalities across South Africa due to future climate change impacts and population growth. Given the high-level nature several assumptions have been made that would differ from more focused analysis of individual water supply systems. As a result, it should not be taken as the final climate change risk profile for any specific individual local municipality, but rather as an indication of overall trends and highlighting key issues to be investigated further. Additional analysis is required specifically with regards the unique nature of the water supply system to each individual municipality, particularly when integrated with a regional or bulk water supply system.

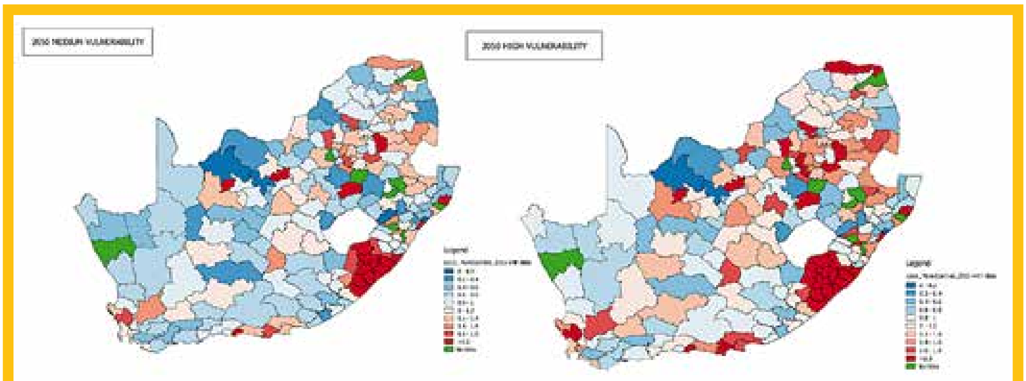

FIGURE 3: Water supply vulnerability (i.e. demand/supply) for local municipalities by 2050 as a result of the medium (left) and high (right) population growth scenarios, excluding the impacts of climate change

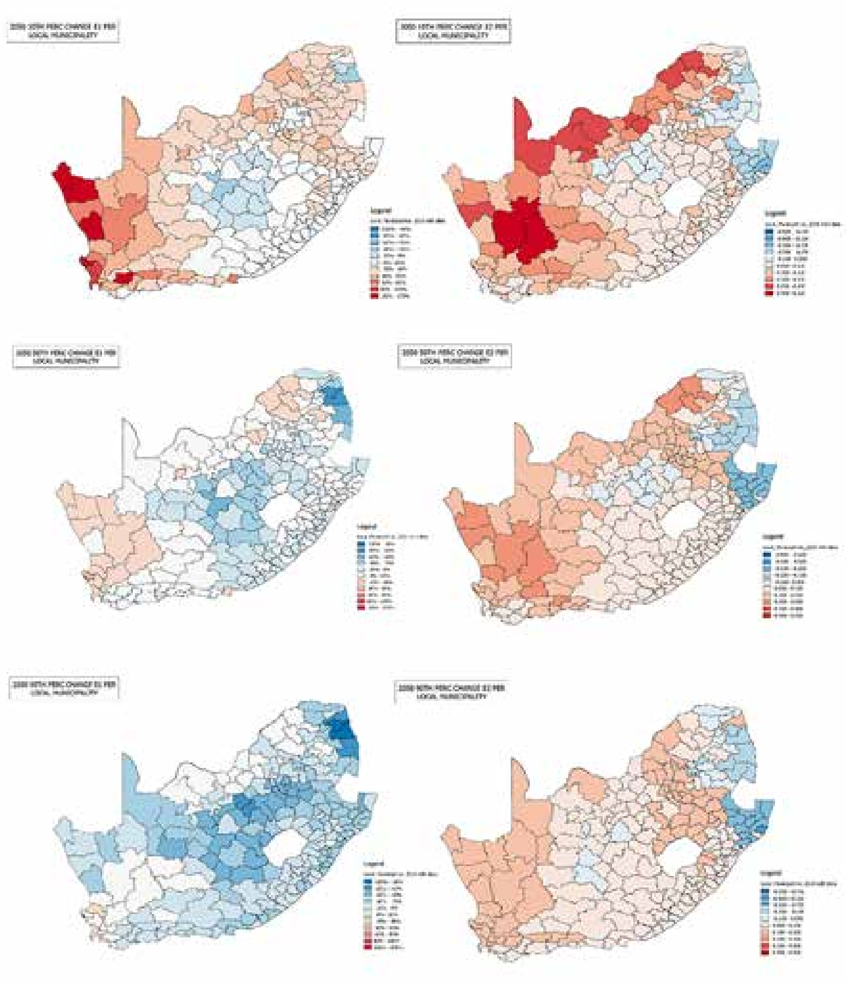

FIGURE 4: Overall exposure of municipal water supply to climate change impacts for the 10th (top), 50th (middle) and 90th (bottom) climate change scenarios for 2050 and also in terms of exposure (E1) based on local surface water impacts only (left) and exposure (E2) based on regional water supply impacts (right)

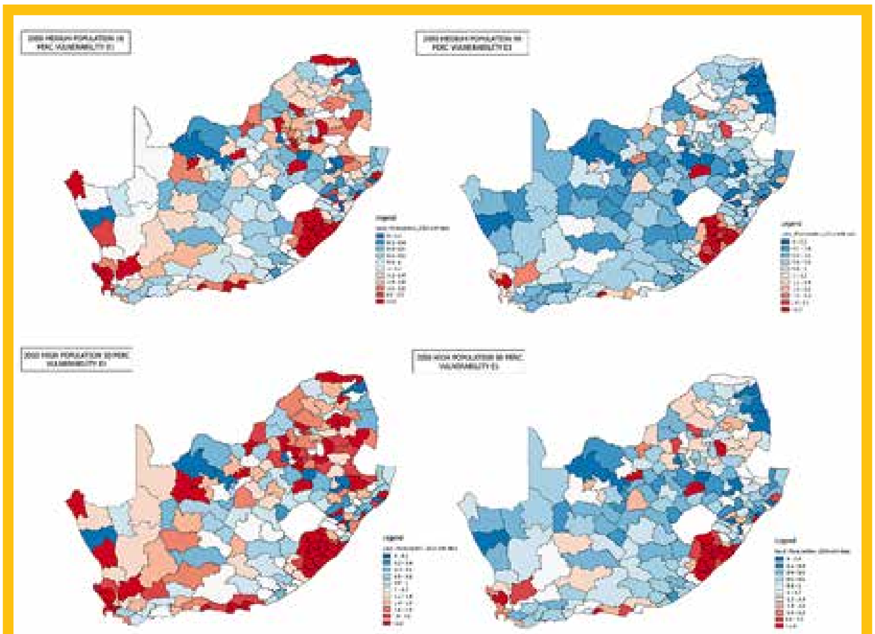

FIGURE 5: Water supply vulnerability (estimated demand/supply) by 2050 with 10% (left) and 90% (right) climate change exposure (E1) scenario and medium (top) and high (bottom) population growth scenarios

The climate change risk for water supply to municipalities is calculated based on the water supply vulnerability (i.e. demand/supply) multiplied by the exposure either as a function of the change in the local MAR or as a function of the likely change in the percentage of water supply that can be met at a regional or WMA scale combined with the exposure to impacts on groundwater and the possible impact of increasing evaporation on urban water demands. The results show the importance of taking into account both the impacts of climate change as well as population growth on future water demands and the associated changes in vulnerability (i.e. demand/supply). Overall, the results of this study indicate that the local municipalities with the highest water supply vulnerability, both current and future, are located in the Eastern Cape. This can be ascribed primarily to the fact that these places have limited existing supply capacity. In future, most municipalities will see an increase in water supply risk either as a function of increasing population growth or exposure to potential climate change impacts for both supply and demand (evaporation), or both. There are, however, one or two municipalities that could experience a reduction in water supply risk, either a result of a declining population, or due to the positive impacts of increasing precipitation and surface water availability due to climate change. These areas might, however, also experience an increase in flood risk.

The results of the study highlight the importance and potential benefits of being connected to a diverse and more integrated bulk water supply system. In this scenario the major economic hubs of Johannesburg, Durban and Cape Town, which are also the major centres for urban water demand are the most likely to benefit from the mitigating impacts of being connected to a highly integrated bulk water supply system.

It is, however, important to note that this is a first order estimate only and that a number of critical assumptions have been made. In order to understand the true climate change risks for water supply to settlements, it will be necessary to consider each individual settlement in more detail taking into account the unique nature of its current and future water supply infrastructure. Further work is required, particular for high-risk municipalities.

RECOMMENDATIONS

Adapting South African settlements to increasing water supply risks includes not only adapting to climate change impacts, but also to future growth and development requirements as

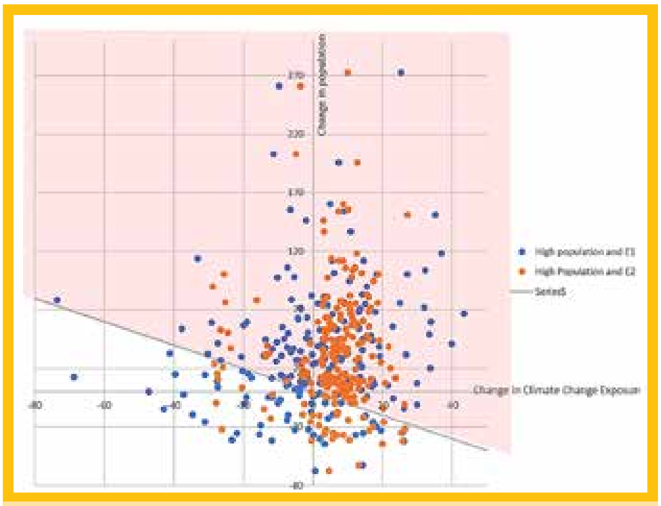

FIGURE 6: Estimated percentage change in water supply risk for municipalities by 2050 as a result of population growth (High Scenario) and exposure to climate change estimated based on impacts on local surface water runoff (E1) and taking into account the potential impacts due to regional water supply systems (E2). The shaded areas show overall increase in water supply risk, while the unshaded area shows a potential overall reduction in water supply risk. Each point represents an individual municipality

well as other factors that impact on water security such as continued catchment degradation and water quality risks.

Some recommendations for climate change adaptation for improved water security include the following:

- Improved operation, maintenance and management of existing water supply infrastructure is critical in terms of managing future water supply requirements and improving current water use efficiency.
- Investments must be made in more diverse water supply options including conjunctive use (e.g. surface and groundwater), alternative supply options such as desalination and re-use, increased integration between supply options and long term investments in ecological infrastructure (EI).
- Better catchment protection and investing in ecological infrastructure (EI) is required such as the removal of invasive alien plants and the rehabilitation and protection of wetlands.
- Compliance with ecological water requirements, as required by the National Water Act, will become even more critical in the face of increasing demands from population growth and climate change.
- More detailed assessment of climate change risk for individual towns and water supply systems including bottom-up assessment of climate change risk, vulnerabilities, and adaptation potential.
- Increased investments in monitoring particularly of surface and groundwater resources is required.
- Improved co-operative governance between local, national, and provincial departments, and different water users, is critical for the efficient operation of complex and integrated bulk water supply systems.
- Continuous monitoring and communication with stakeholders are important, particularly during periods of drought where users are critical in terms managing demands, and also in investing in future schemes.
- Improved water use efficiency and reduced unaccounted for water is important, but it must be noted that the more efficient users become, the harder it is to manage demand during periods of drought.

With the urban areas being the focus for most of the future population growth, particularly in developing countries, it is critical that urban water security is a priority focus area for all national and local governments.

As these results have shown, the specific impact of climate change and population growth will vary significantly between different municipalities based on their location and economic growth trajectories. Each municipality also has a unique water supply system and unique challenges for managing demand.

While a national study like this one can provide general insights and highlight key priorities, it is critical that each municipality be considered from a bottom-up perspective. Increasingly it is important to adopt a bottom-up approach founded on the principles of co-exploration and co-discovery of solutions to challenges such as climate change and future water security (Ilunga, 2017). Such an approach also requires supporting the transition to becoming a Water Sensitive City. The principles of a Water Sensitive City include embracing a diversity of water supply options, introducing ecological infrastructure and catchment interventions to both manage the increasing urban flood risk as well as improved water security and providing recreation and cultural spaces that also help in cooling cities. Better incorporating indigenous knowledge into the water planning process is also becoming more critical and increasingly important for improved water security.

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[1] For this study we have made the simple assumption that water demand will increase proportional to the increase in population. There are however many factors that impact on urban water requirements including economic development which tends to result in an increase in per capita urban water demand, as well as other urban demands associated with the growth of industries within the urban area. Similarly, efforts to improve water use efficiency, conservation and demand management will result in an increase in water demand that is lower than the estimated population growth.

PAPER 2

Financial Feasibility and Bankability of City-wide Water Loss Intervention Programme – City of Tshwane

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ABSTRACT

The study described in this paper designed a programme for reducing water losses in City of Tshwane (CoT) and improving revenue and financial viability based on risk principles, proving the bankability of such a program with a view to attracting potential funders.

Water security is one of the key challenges facing South Africa and the reduction of water losses forms an integral part of ensuring sustainable water supply. Few studies have been undertaken where the potential for water loss reduction and potential savings have been analysed separately and in detail for each water Distribution Management Zone (DMZ).

The CoT system is being operated in 240 primary DMZ's, all of which are either supplied by a reservoir, a water tower, or a direct connection to a bulk pipeline. These DMZ's were the core subjects of this water loss reduction feasibility study. A DMZ database was compiled and populated with all the requisite water use/billing-, water loss-, water pressure-, customer debt- and water system condition information. This database was used to develop a set of rules-based decision-trees to determine first order optimal water loss interventions and costs for each DMZ.

Each DMZ was then considered a "sub-project" and a detailed Terms of Reference and capex and recurring opex costing for the indicated interventions in each DMZ were done. The potential benefits (decrease in System Input Volume, decrease in Annual Average Daily Demand, increase in billed/metered demand) for each intervention were calculated.

A financial model was developed for each of the 240 DMZ's to evaluate the impact of the capital and operating costs of the proposed water loss interventions against the potential achievable savings. The capex and opex associated with each intervention selected per DMZ were formulated in a 20-year cash flow model against the incremental benefits in bulk purchases and increases. These incremental cash flows were then discounted to Net Present Value (NPV) terms. Each DMZ model considered the unique characteristics of the particular DMZ including average tariff earned, collection rate and water balance.

City-wide modelling was performed to evaluate the impact of four DMZ-based intervention implementation strategies. The evaluation was based on the projected cash flows of CoT Water Services as a whole, considering its ability to service the resultant debt and ability to generate future excess cash to allow future interventions to be implemented without the need for external funding. The results revealed positive city-wide NPV's achieved both pre- and post-funding, with all debt covenants met.

INTRODUCTION

The City of Tshwane (CoT), located in Gauteng, South Africa, was established through the amalgamation of various municipalities. It is currently the third largest city in the world by area (CoT, 2021) with over 3 million residents. As a legacy of the amalgamations, the CoT has a vast and complex water distribution system with integration between various bulk facilities and water resources.

As water security within this complex and water scarce environment is a key challenge for the CoT, the reduction of water losses has been identified by the CoT as an integral part of ensuring sustainable water supply. The purpose of the study was to design a programme for reducing water losses and improving revenue and financial viability based on risk principles, and to prove the bankability of such a program with a view to attracting a potential funder such as the Development Bank of South Africa (DBSA). In addition to updating the water resources master plan, the project followed the recommendations made by Bruinette and Claasens (Bruitnette & Claasens, 2016) for an integrated and holistic approach to turn around a municipal supply system and re-establish financial viability and sustainability.

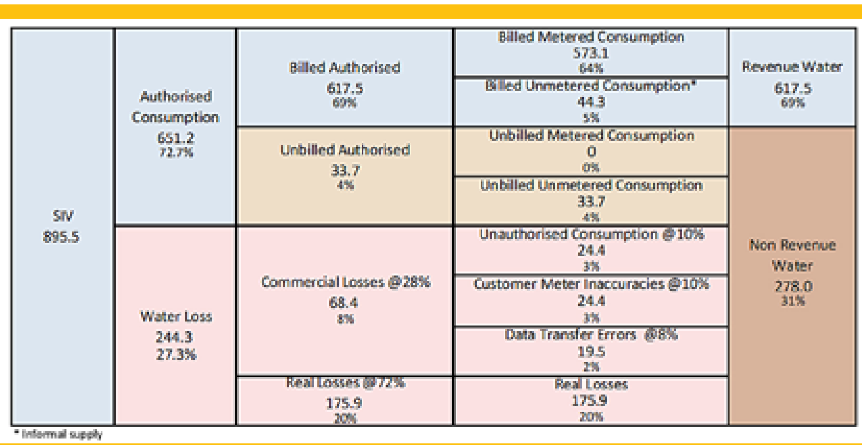

FIGURE 1: CoT FY 2017/18 Water Balance

WATER RESOURCES

The city has 13 Water Treatment Plants (WTPs) and various fountains and boreholes. Water purchases are made from Magalies Water from the Crocodile River, but most water is purchased from Rand Water and is supplied from the Vaal River System. The Vaal River System is under pressure and municipal customers are required to limit their demand from the system. However, in an interesting conundrum, increases in CoT's sewer return flows are required to generate sufficient yield in the downstream Crocodile River System which supplies several strategic power stations. This is compounded by the fact that augmenting CoT's own resources will reduce the load on the Vaal River System, but will also decrease the return flows to the Crocodile River System. To ensure holistic consideration of any proposed interventions the CoT Water Resource Master Plan (WRMP) (Mouton et al. 2015) was updated in this study.

The WRMP indicated that there is sufficient surplus yield available in the Crocodile River basin for CoT to increase both the capacities of the Temba WTP and to increase the capacities and supply areas of the CoT's Rietvlei and Roodeplaat WTPs. Despite significant capital expenditure the latter can be achieved at a unit cost for water which is lower than the RW tariff.

There is no surplus yield available in the Olifants River basin for expansion of the Cullinan, Bronkhorstspruit and Bronkhorstbaai WTP's. Sufficient water resource availability can only be ensured through additional augmentation from RW to Cullinan and Bronkhorstspruit in combination with successful Water Conservation and Water Demand Management (WCWDM) initiatives.

WATER INFRASTRUCTURE

The water distribution system comprises inter alia of 658 km of bulk pipeline, 9 943 km of reticulation pipes, 183 pumping stations, 151 reservoirs and 31 water towers. The construction value of the system is estimated at more than R20bn. The CoT system is being operated in 240 primary Distribution Management Zones (DMZ's), all of which are either supplied by a reservoir, a water tower, or a direct connection to a bulk pipeline. These were the core subjects of this water loss reduction feasibility study and are shown on Figure 09 at the back of the paper.

The CoT has a system of dynamic master planning (Loubser et al, 2012) in which the relevant water information systems and master plans are updated regularly. The database of all 240 primary DMZ's was extracted from this information along with the requisite water use/billing-, water loss-, water pressure-, customer debt- and water system condition information for further analysis in the study.

CURRENT WATER DEMAND, WATER BALANCE AND RECOVERABLE REAL LOSSES

The current water demand and water balance was determined which included an analysis of the consumer base to establish the different consumption components, calculation of the unavoidable real losses and determination of the potential recoverable real losses for the city as a whole and for each DMZ. Data from the 2017/18 financial year (FY) was available as the basis for this study. The actual water balance for the CoT is in Figure 01. The invoices from RW and MW, bulk meter data and billing data (extracted from the SAP financial system) were input and spatially referenced within the Swift program (Jacobs & Fair, 2012). Stands with water consumption were mapped in Swift against aerial photographs to identify and quantify unbilled unmetered authorized consumption. It was assumed that informal water supply, being 5% of SIV, although free to the customers, is "billed" to National Treasury and paid in the form of the equitable share grant.

The total water loss for CoT is fairly accurately determined at 27.3%, or on average 244.3 ML/d (for 2017/18). The ratio of apparent loss to real loss was agreed with the CoT and was based on the typical parameters impacting apparent losses within the city: meter accuracy, meter reading errors, data transfer errors. The Unavoidable Real Loss (URL) for CoT is estimated per industry-standard formula as 35 ML/d, meaning that the estimated Recoverable real Loss (RRL) is: RRL = Total Loss – URL – Apparent loss = 244.3 ML/d – 35 ML/d – 68.4 ML/d = 140.9 ML/d.

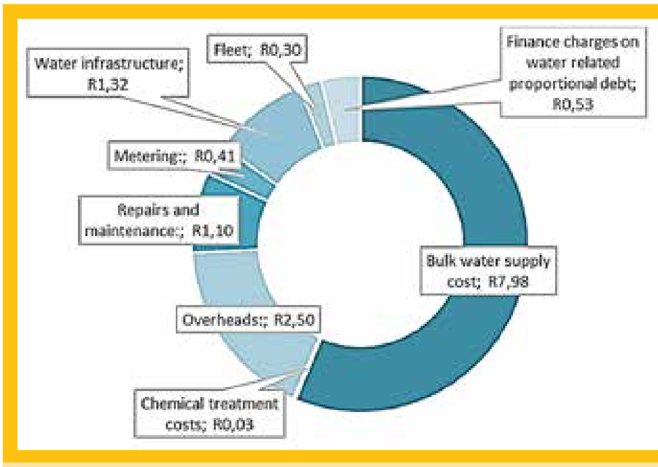

FIGURE 2: Breakdown of CoT unit water cost

COST OF WATER SUPPLY

Before financial modelling could be performed, the cost of water supply needed to be determined. This included determining the economic cost of water and the zero-based cost of water.

Water economic cost

An analysis of the costs of water input by the City was conducted and revealed the actual current cost of water input to be R12.73/kL. The breakdown of this cost is shown in Figure 02. If this is adjusted to account for water losses (27.3%) and collection rate (86.3%) the total cost of water per kL billed and collected amounts to R20.39/kL. The CoT's actual cost (R12.73/kL), before adjusting for Non-Revenue Water (NRW) and collection risk, align with those of other South African metros', such as Cape Town, Johannesburg and Nelson Mandela Bay.

Water zero based cost

The zero-based cost of water (R14.17/kL) is the best practice costing for the CoT's water supply, taking into consideration the current network demands and operating landscape for CoT. The zero-based economic cost calculated (R22.70/kL = R14.17/kL when adjusted for 27.3% NRW and 86% collection risk) is 11% (or R2.31/kL) higher than the CoT's actual cost per kilolitre of

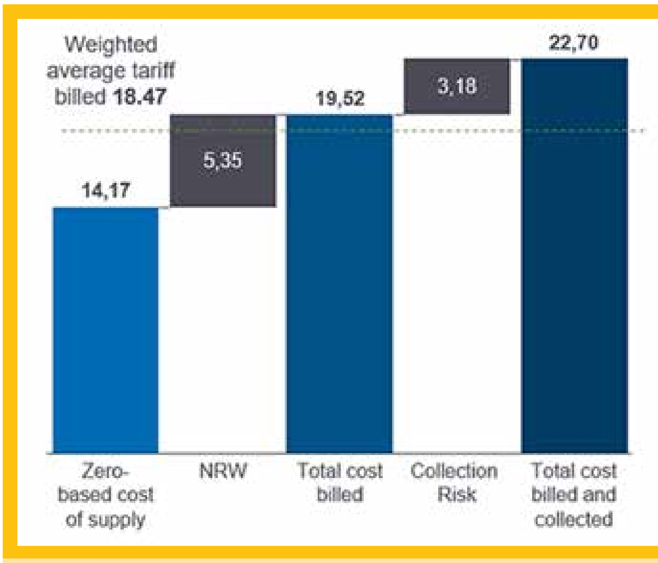

FIGURE 3: Zero-based cost of water supply vs. FY 2019 weighted average tariff (WAT) billed (R/kL)

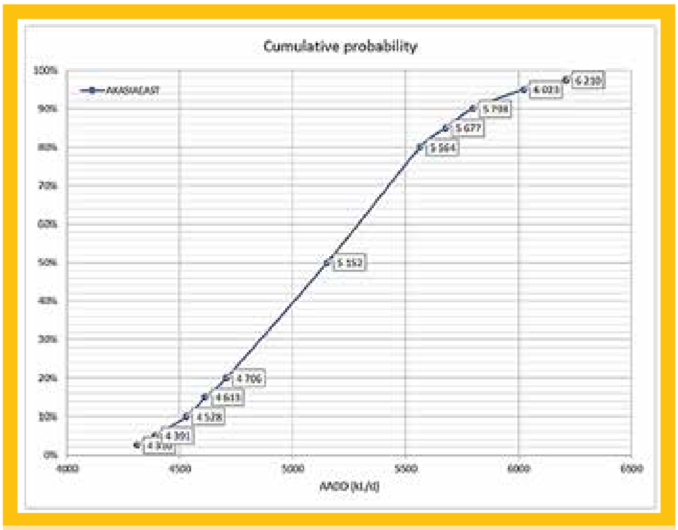

FIGURE 4: Cumulative empirical probability function for AADD in an example DMZ for total CoT

R20.39/kL and 22.9% (or R4.23/kL) higher than the equivalent weighted average tariff billed. As such, tariffs would need to be increased by 22.9% to cover zero-based costs unless the CoT's proportion of non-revenue water can be reduced, and collection rates improved.

Price elasticity and over consumption

A price elasticity analysis including stepped tariffs (similar to Hoffman & Du Plessis 2013) showed that the billed water consumption in CoT is likely to reduce to 476.5 ML/d should the water tariffs be increased by 40%. This represents the zero based demand "break-even" point where the zero based cost for water is covered by the billed and collected income. The current over consumption is therefore estimated at 98.9 ML/d which is 11% of the SIV. (Over consumptions are the difference between the actual billed water use and the water use at zero based prices.)

WATER DEMAND AND COST RECOVERY RISK

Using bootstrap techniques on the empirical data, rather than fitted probability density functions, the actual empirical distribution of demand in each DMZ was determined, with confidence bands for Annual Average Daily Demand (AADD) and billed income for stress-testing the financial modelling of the Net Present Value (NPV) of water loss interventions in each DMZ.

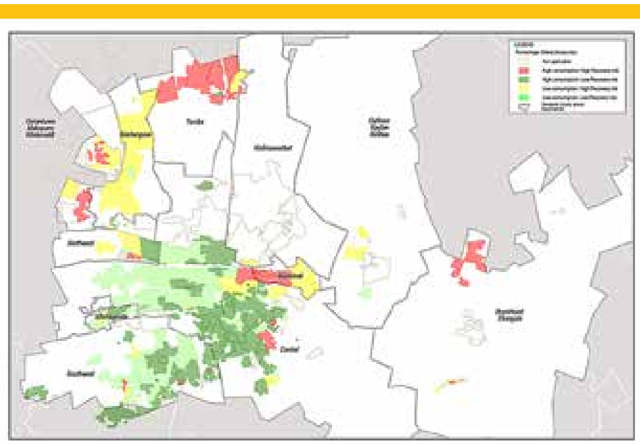

FIGURE 5: DMZ recovery risk categorization

Cost recovery and recovery risk

Using bootstrap techniques on the empirical data, rather than fitted probability density functions, the actual empirical probability density function (PDF) of current billed income was determined, with confidence bands for billed income for stress-testing the financial modelling of the NPV of water loss interventions in each zone.

The various DMZ's were categorized into a cost recovery risk matrix shown in Figure 05 as High Consumption/Low Recovery Risk (Green); Low Consumption/Low Recovery Risk (Light Green); Low Consumption/High Recovery Risk (Yellow); and High Consumption/High Recovery Risk (Red).

Future water demand and risk

The available CoT Spatial Development Framework (SDF) at the time of this study represents more than a doubling of the City over ±45 years at a rate of ±2% p.a. For this study a 20y horizon was considered. Using assumptions about the probabilities of developments occurring over time, a 95% confidence band for the additional future anticipated 20y AADD was established as between 304 ML/d and 612 ML/d as shown n Figure 06. This information was requisite input into the stress testing of the financial viability of proposed water loss reduction interventions in each DMZ, and was also aggregated input to a city-wide analysis.

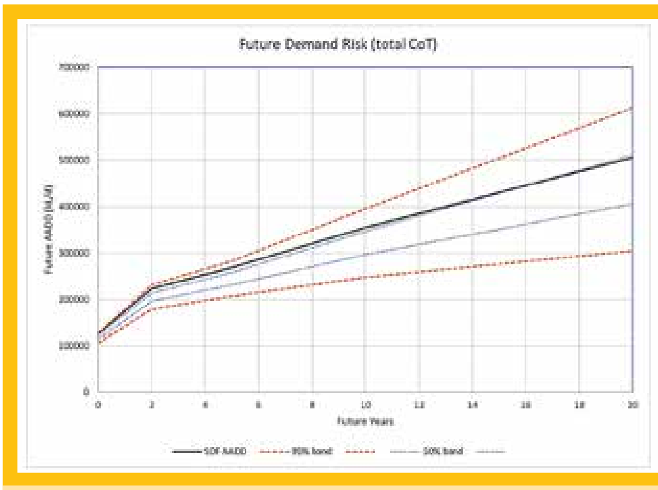

FIGURE 6: Additional future demand timeline and confidence bands for total CoT

INTERVENTION PROGRAMME

DMZ database and decision tree analysis

A comprehensive geo-database was developed for all ± 240 "Level 4" DMZ's in CoT, with requisite fields to allow in-depth analysis of the water losses and potential remedies in each. This database was used to develop a set of rules-based decision-trees to determine first order optimal water loss interventions for each zone, and a first order associated cost.

Possible interventions

The possible interventions considered in this feasibility study are listed in Table 1 and the workflow to use the decision trees in order to determine the first order interventions is shown in Figure 8.

Potential benefits per DMZ

In order to evaluate the bankability of each intervention sub-project, an estimation of the benefits of the intervention was required (McKenzie et al. 2002) (Wegelin et al. 2009) (WRC, 2020).

Potential benefits considered were:

POSSIBLE WATER LOSS INTERVENTION	WHEN APPROPRIATE
Install bulk meter(s) for SIV/Water Loss calculation	No bulk meter / for loss calculation
Log bulk meter	No logging / determine MNF / calibrate AADD
Pressure management	High static and/or dynamic pressures
Leak detection and fixing	Indication of high real losses / high MNF
Pipe replacement	Indication of deteriorating pipe condition
Meter audit/replacement	Indication of old an/or improperly sized meters
Connection replacement	Indication of old and/or deteriorating connections
Retrofitting	Indication of high MNF/UWD's and cost recovery risk
Water management devices	Indication of excessive UWD's
Billing data cleanup	Indication of many unbilled stands/areas
Check DMZ boundary discreteness	Indication of cross-boundary flows
Rezoning/Sectorization	Large zone or potential PRV sub-zone
Punitive tariffs	Indication of excessive UWD's

TABLE 1: Possible water loss interventionsfor total CoT

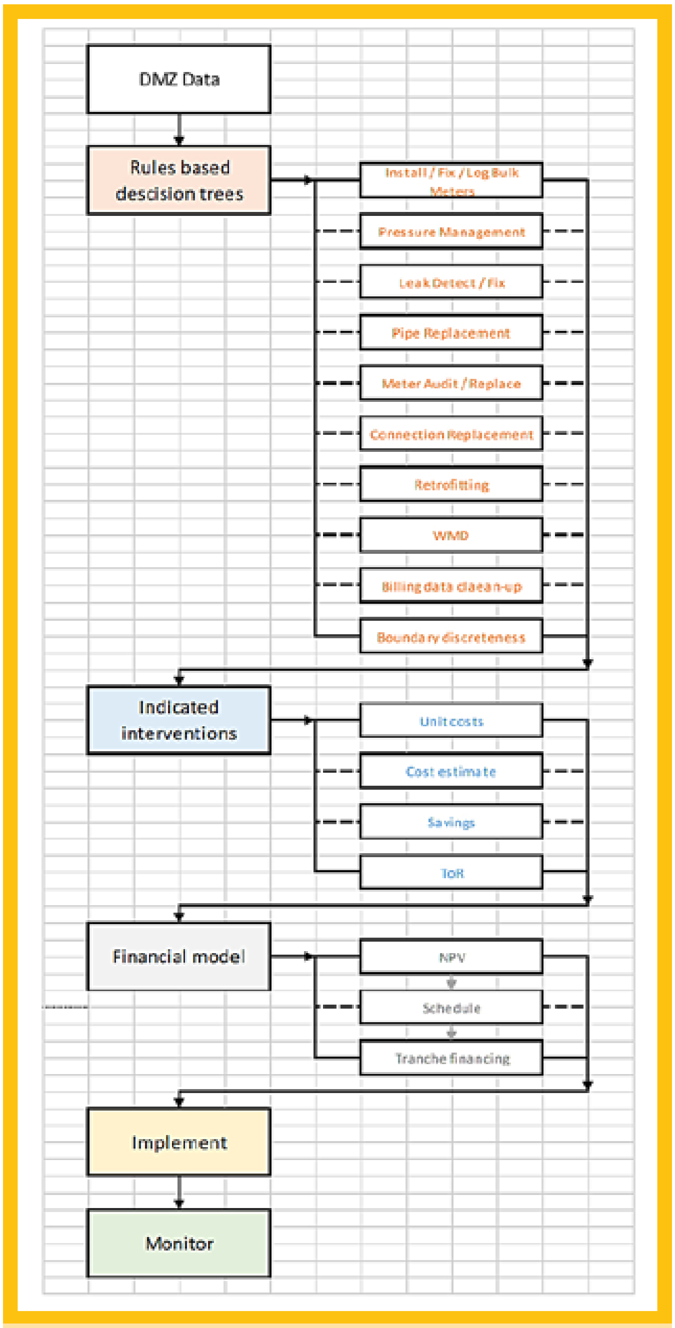

FIGURE 7: Workflow for decision-tree based first order interventions

- Reduction in SIV
- Reduction in water demand
- Increase in metered/billable water consumption

Table 2 lists the (high level view) potential benefits of each water loss intervention, together with notes on the quantification thereof. Most of the formulae use data which was readily available from the fully populated DMZ database. In all cases a range (min/max) of potential benefits was calculated, in order to allow "stress-testing" of the NPV of each intervention.

These potential benefits (decrease in SIV, decrease in AADD, increase in billed/metered AADD) for each intervention in each DMZ were calculated on a detailed level.

Summary of interventions and benefits

Table 3 summarises the indicated interventions and potential range of benefits determined in this manner for all the DMZ's. The full details with Scope of Work (SoW) maps, Bill of Quantities (BoQ) tables, and cost summaries were provided in electronic media with the project report.

The ToR, costing and benefits were used as inputs into a financial model, which determined the NPV for each DMZ sub-project. This allowed for the sub-projects to be ranked in accordance with their "bankability" (i.e. their NPV).

FINANCIAL MODELLING

DMZ level financial modelling

A financial model was developed in order to evaluate the impact of the capital and operating expenditure cost of the proposed water loss interventions against the savings envisaged to be achieved on each of the 240 DMZ's included in this study.

The DMZ level intervention financial modelling was conducted on an incremental cash flow approach. Therefore, the capital and annual operating expenditure associated with each intervention selected per DMZ was formulated in a 20-year cash flow forecasting model against the incremental savings in bulk water purchases and increased billing potential. These incremental cash flows were then discounted at an assumed weighted average cost of capital for CoT to NPV terms. Each DMZ model considered the unique characteristics of the particular DMZ including average tariff earned, collection rate and water balance.

The DMZ level financial model calculates both a project and equity NPV based on the net incremental cash flows. Project NPV is based on only the present value of incremental cash flows between costs and revenue potential of the interventions, i.e. project cash flows. The equity NPV is based on project cash flows after indicative funding terms for the capital expenditure required for interventions per DMZ. All interventions were assumed to be implemented in project year 1 for comparability across the results of the 240 DMZ's evaluated. These project NPV results were used to rank the financial preference of each DMZ for implementation of the technical suite of interventions.

The results of the 240 DMZ's with all the technical interventions, as recommended based on the technical decision-trees explained earlier, revealed an aggregate funding requirement of R3 422 million. The majority of the DMZ's however do not achieve a financial viable cash flow profile that can be expected to settle the debt required to fund its interventions. This

POSSIBLE WATER LOSS INTERVENTION	POTENTIAL BENEFIT	BENEFIT ESTIMATION
Install bulk meter(s) for SIV/Water Loss calculation	Knowledge of water loss and MNF w/o which sensible interventions cannot be determined	Not applicable
Log bulk meter	Knowledge of MNF w/o which sensible interventions cannot be determined	Not applicable
Pressure management	Reduction in SIV and unit water demands due to drop in pressure	Dependent on land use, SIV and UWD are reduced as a funtion of the % reduction in ave.pressure
Leak detection and fixing	Reduction in real losses due to minimisation of leakage	Real loss will reduce with 5% to 10%
Pipe replacement	Reduction in real losses due to improved reticulation condition	Based on reduced number of leaks, and the ave. leak report time, leak run/fix time, and leak flow rates
Rezoning/Sectorization	Improved information on water losses	Not applicable
Check DMZ boundary discreteness	Improved information on water losses since cross-boundary flows prevented	Not applicable
Meter audit/replacement	Increase in metered and billable water consumption	Bus/Comm customers increase = 25 kL/m (or 1255 kL/m if previously audited); Residential customers increase = 19%
Connection replacement	Reduction in real losses due to minimisation of leakage	Based on reduced number of leaks, and the ave. leak report time, leak run/fix time, and leak flow rates
Retrofitting	Reduction in on-site wastage will lead to reduction in SIV and concomitant reduction in AADD	Based on observed values retrofitting results in reduction of between 2.9 and 10.5 kL/month per household
Billing data clean-up	Increased billed income	Estimated demand for all identified unbilled/unmetered users will increase billing income accordingly
Punitive tariffs	Decrease in water consumption whilst not compromising revenue	Over-consumption is reduced in accordance with assumed price elasticity
Water management devices	Limit indigent users to FBW amount	If WMD is set to 0.4 kL/d then all excess consumption by indigent and non-paying customers is reduced to this level

TABLE 2: Potential benefits from water loss interventions

funding requirement is significantly reduced with the exclusion of the pipe replacement intervention. The number of DMZ's with a positive project NPV increased and ability to settle debt funding is also improved as a result. Table 04 below shows a summarised comparison of the key results of the DMZ modelling including and excluding the pipe replacement intervention.

Programme-wide financial modelling

The programme-wide modelling aimed to evaluate the impact of four DMZ-based intervention implementation strategies. The evaluation was based on the projected cash flows of CoT Water Services as a whole, considering its ability to service the resultant debt and ability to generate future excess cash to allow future interventions to be implemented without the need for external funding. These four implementation strategies considered the roll-out of the suite of technical interventions in DMZ's that either only revealed a positive project NPV or to all DMZ's identified, and whether the suite of interventions should include pipe replacement or not.

POSSIBLE WATER LOSS INTERVENTION	Number of DMZ's	Estimated capex (R million)	Estimated PV of opex (R million)	Potential SIV saving (kL/d)		Potential AADD saving (kL/d)		Potential increase in AADD (kL/d)		Potential Billing clean-up (kL/d)	
				Min	Max	Min	Max	Min	Max	Min	Max
Install bulk meter(s) for SIV/Water Loss calculation	129	R39.68	R7.32	0	0	0	0	0	0	0	0
Log bulk meter	55	R6.205	R11.337	0	0	0	0	0	0	0	0
Pressure management	111	R96.259	R37.202	11970	23156	4781	9270	0	0	0	0
Leak detection and fixing	15	R6.373	R10.042	2810	5619	0	0	0	0	0	0
Pipe replacement	36	R3 006.325	R0.000	6208	15219	0	0	0	0	0	0
Meter audit/replacement	97	R63.439	R0.000	0	0	0	0	8912	11691	0	0
Connection replacement	41	R139.729	R0.000	2789	5578	0	0	0	0	0	0
Retrofitting	13	R23.531	R70.594	3250	11766	3250	11765	0	0	0	0
Water management devices	13	R33.616	R53.786	7165	10236	7165	10236	0	0	0	0
Billing data cleanup	71	Internal	Internal	0	0	0	0	0	0	9890	24514
Check DMZ boundary discreteness	21	R7.409	R0.000	0	0	0	0	0	0	0	0
Rezoning/Sectorization	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Punitive tariffs	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		R3 422.57	R190.28	34177	71549	15197	31271	8913	11689	9890	24514

TABLE 3: Summary of interventions and benefits (with costs)

TABLE 4: Comparison in NPV and funding requirement between including and excluding pipe replacement

	Incl. PRP	Excl. PRP	Comment
Full funding requirement	R 3 435 mil	R 416 mil	88% reduction funding requirement
DMZ's with project NPV>=0	106	143	29% increase in DMZ's with pos. NPV
DMZ's with Project NPV<0	134	97	25% reduction in DMZ's with neg. NPV

TABLE 5: Recommended feasibility scenario – key outputs

Key outputs	
Total funding draw-down	R471 391 413
Number of active DMZ's	240
Active DMZ's with project NPV – positive	143
Active DMZ's with project NPV - negative	97
NPV: Consolidated cash flows	R2 311 164 320
NPV: Interventions (pre-funding)	R780 144 319
NPV: Interventions (post funding)	R778 857 708
Project IRR: Active DMZ's	36%
Equity IRR: Active DMZ's funded	N/A
Debt Service Cover Ratio	12.58
Loan Life Cover Ratio	5.86
Project Life Cover Ratio	10.49
Debt repayment period met?	Yes

A recommended feasibility scenario was developed after rigorous financial analysis and consultation on these four strategies with CoT officials, engagement with the technical work stream members on the practical roll-out recommendations of interventions and consideration of the funding implications of staggered implementation over a 5-year period. This final selected scenario is based on the roll-out of interventions, excluding pipe replacement, to all 240 identified DMZ's in CoT. The aggregate capital expenditure requirement of this scenario amounts to R471.4 million.

Table 05 sets out the key outputs of the recommended feasibility scenario. These results reveal positive NPV's achieved both pre- and post-funding, with all assumed debt covenants met. It is worth noting that the deferral in project cash flows to accommodate a 5-year staggered roll-out period results in one DMZ which held a positive project NPV (without staggered roll-out) to turn negative over the fixed 20-year evaluation period. The recommended scenario therefore has 143 DMZ's with a project NPV of zero and greater cross subsidising the project cash flows of the 97 DMZ's with a negative project NPV.

The profile for the five consecutive tranches of project finance to fund the capital expenditure requirements of the suite of recommended interventions shows a funding peak of R404.4 million in 2024/25 (see Figure 08). Once all the facilities have been drawn, the maximum required repayment per annum occurs in 2026/27 at R95.2 million. All funding tranches are projected to be repaid by the close of 2033/34.

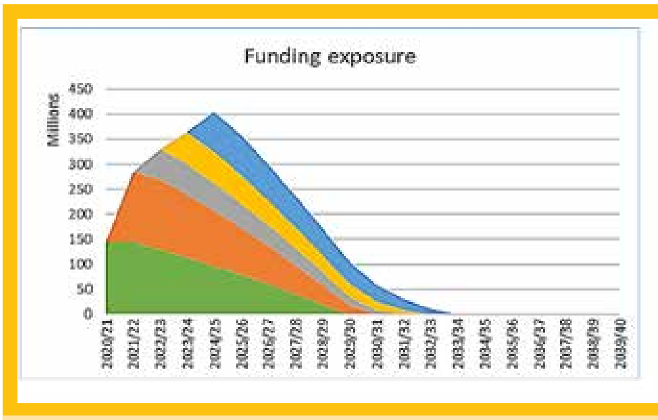

FIGURE 8: Recommended feasibility scenario – Funding exposure

Whilst pipe replacement has been excluded from the financial packaging of the recommended scenario, CoT is encouraged to consider the recommended pipe replacements in each of the DMZ's indicated should other sources of funding be available. The same applies to implementation of master plan items where required to eliminate capacity backlogs in parallel with the water loss interventions.

Stress tests have been performed on key assumptions to evaluate the financial implications of the roll-out of interventions for CoT Water Services should actual conditions differ to those projected in the base case. These stress tests indicate financial resilience to flexes on key economic assumptions, but with critical monitoring required on the balance between bulk water cost escalations and water tariff increases. Continued misalignment in the annual escalations of bulk water costs and that of the average water tariff charged, by as little as 0.5% will curtail long-term viability. Further, stress tests confirm that the average billing collection rate is a sensitive lever to the financial sustainability of quality water services in CoT. An average collection rate of less than 75% is likely to result in a financial inability to operate and maintain water services, even with the realisation of savings achieved through the suite of interventions.

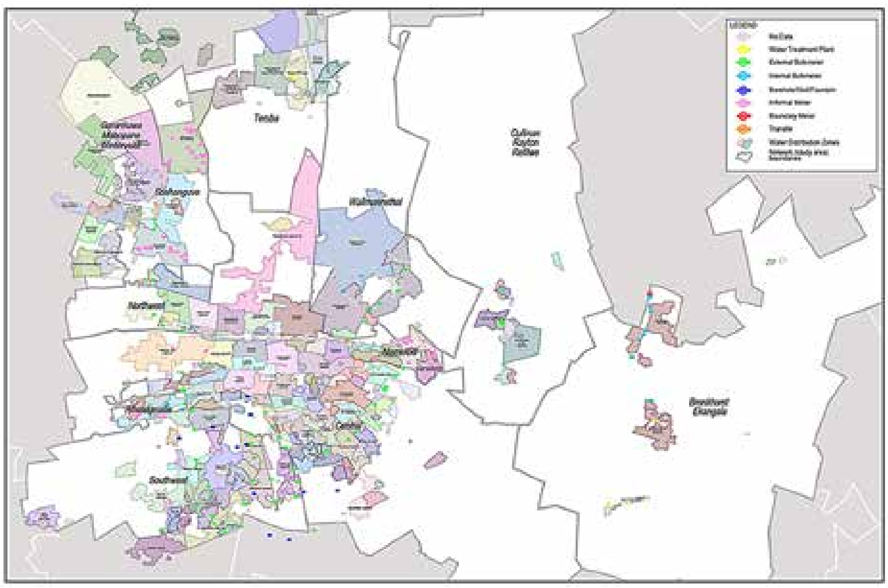

FIGURE 9: Study area and primary distribution management zones (DMZ's)

The financial viable realisation of this proposed project under the set of assumptions as set out in this study is therefore dependent on CoT's ability to roll-out the technical (and non-technical) interventions in accordance with the recommended DMZ prioritisation, monitoring and aligning the escalation of bulk water costs versus what is passed onto consumers, and ensuring improved collection of water tariffs charged.

MONITORING AND EVALUATION OF RESULTS

In November 2020 the CoT (CoT 2020) issued a press release approving the implementation of the water loss reduction strategy. This includes monitoring the success (or not) of the interventions in a database containing key performance indicators (KPIs) for each DMA, date stamped to monitor trends using the 2017/18 values collected from this study as the baseline. These will be added to the existing web-based platform on which all water and sanitation related information is stored, including models of existing systems, master planning of systems (based on SDF), and all billing and water balance related data.

The primary KPI's in this regard include the SIV, Authorised AADD (Billed, Unbilled), Minimum Night Flow (MNF), Water loss (Volume, %), SIV saving (kL/d, ZAR/a), Total billed amount (ZAR/a), Customers with 60d+ debt (%), Total collected revenue (ZAR/a), PRV / CP /Average pressures.

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PAPER 3

Deep Tunnel Sewerage Systems: Singapore's Success Story

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ABSTRACT

With a growing world population and increasing urbanization, volumes of sewage are rising especially in large cities which require larger capacities in sewage transport and treatment. The systems built decades ago need to be modernized, extended or replaced to ensure efficient and sustainable wastewater management.

A Deep Tunnel Sewerage System is – especially from an operation cost point of view – a very cost-efficient solution to meet long-term needs for wastewater collection, treatment and disposal. Deep sewer systems involve large diameter main tunnels that convey wastewater by gravity to centralized treatment plants, mostly located outside the cities. Smaller diameter, often pipe jacked, link sewer networks and deep shafts are further parts of these schemes.

Due to the length and the required slope towards the treatment plant, tunnels and access shafts are installed in increasing depths, which represents a challenge for tunnelling and shaft sinking, especially if high ground water tables are present. In addition, cities demand the construction of such large-scale schemes to be quick and safe, with minimal impact on population and environment. One of the benefits of deep tunnelling is the activity takes place well below other existing and future municipal services.

The first large-scale Deep Tunnel Sewerage System (DTSS Phase 1) has been completed in Singapore. Due to a high population density and a continually developing economy, Singapore faces a lack of land space for development and is therefore a leading innovator in sustainable planning and managing its underground space. Singapore has already moved other municipal infrastructure and utilities below ground, including metro lines, retail, parking and pedestrian walkways. The next major milestone is the construction of the DTSS Phase 2. Fourty kilometers of deep tunnels – average depth 30m - (ID 3m to 6m) and sixty kilometers of link sewers (ID up to 3m) are currently under construction for the new wastewater infrastructure system.

The deep tunnels will connect with the existing used water infrastructure to create one seamless and integrated system; the link sewers will create an interconnected network to channel used water from the existing sewerage pipelines to the deep tunnels. Numerous tunnelling and mechanized shaft sinking machines are deployed to ensure a reliable and cost-effective construction of the high-quality structure.

INTRODUCTION

Challenges for urban wastewater systems

Metropolises around the world are all facing the same challenges when it comes to sewage: The systems that were built decades ago are just not effective enough for the future. Capacity constraints outdated existing infrastructure and space constraints in cities demand new solutions.

According to the UN, 9.8 billion people will be living on the planet by 2050 with growth particularly coming from Africa and Asia (Figure 1). A total of 70% of that population will be urban, a 1.7-fold increase compared to 2015. Cities will have to invest massively in sewage capacity to serve this growing population. In addition, climate change will further stress capacity. Extreme weather is confronting cities with high amounts of rainwater to be collected, discharged and -at least partly- treated within a short period. Diminishing surfaces for infiltration add to the problem by leaving fewer opportunities for rainwater to drain naturally.

This paper will present the concept of the Deep Tunnel Sewerage Systems and Singapore´s pioneering role as an example of what could be replicated by South African cities. Furthermore, it will discuss the application of mechanized tunnelling and shaft sinking technologies to realize deep sewer projects to the benefit of all parties involved.

The body of the paper will be structured as per the following headings:

1) The City of Singapore in a nutshell.
2) Description of Singapore's deep tunnel sewerage system.
3) The equipment used to execute the project:

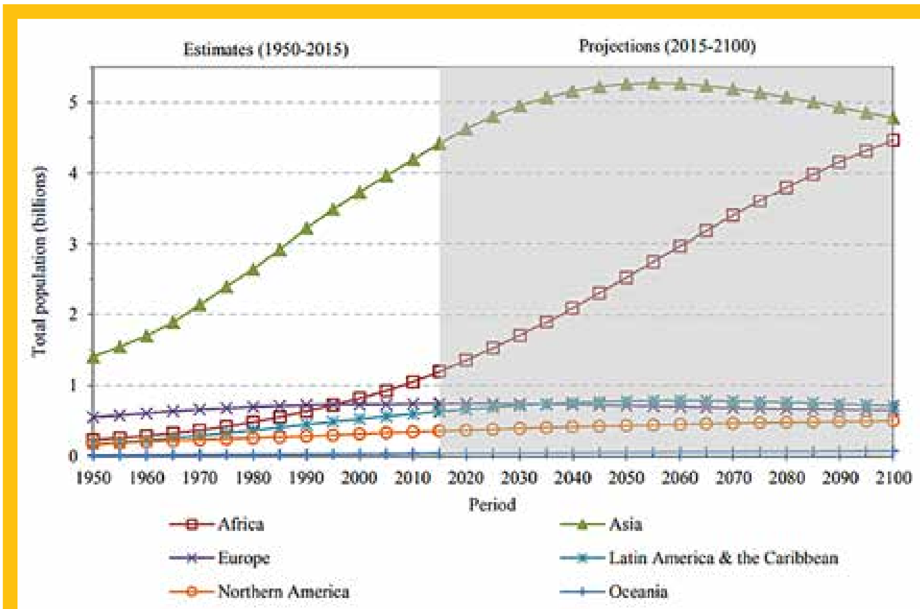

FIGURE 1: World Population predictions.
(Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision. New York: United Nations)

FIGURE 2: The City of Singapore

3.1) Mixshield TBM

3.2) Verticle Shaftsinking Machine (VSM)

4) The Taus Wastewater Recycling Plant.

1. THE CITY OF SINGAPORE IN A NUTSHELL

The Republic of Singapore is a sovereign island city-state, has an area of 730 square km and a population of 5,7 million people. Despite having the second highest population density in the world this country boasts of the second highest GDP per capita in the world and Singaporians enjoy one of the world's longest life expectencies.

One of the challenges facing Singapore is to ensure the security of its water supply which is derived from three sources:

- **Imported Water**

  40% of Singapore's water is imported from the Johor catchment in Malaysia via a 1km causeway. Singapore has an obligation to supply 2% of this water back to Malaysia once treated and the agreement with expires in 2061.

- **Reclaimed Water**

  30% of Singapore's supply is presently obtained from 5 state-of-the art treatment works. This ultra-clean water known as "NEWater" is used for both domestic and industrial consumption.

- **Desalinated Water**

  30% of its need is obtained from Singapore's 4 desalination plants. Each uses the energy intensive reverse osmosis process.

2. DESCRIPTION OF SINGAPORE'S DEEP TUNNEL SEWERAGE SYSTEM (DTSS)

The first sewage systems date back to the early Mesopotamian Empire in Iraq, around 5 000 years ago. While these systems focused on efficient collection and conveyance, treatment and discharge only gained importance in the 19th century due to the cholera outbreak in Europe (de Feo; et. al 2014). Although the basic logic of collection, conveyance, treatment and discharge has remained the same ever since, today, sewage systems are put under scrutiny once again: Rapid population growth, increasing urbanization as well as climate change demand for larger sewage capacities and a thorough treatment of the disposal, often located outside the city. In addition, cities want to re-use sewage instead of discharging it into nearby waters.

FIGURE 3: Underground view of the deep sewer system

Expanding capacity however is not enough. Ageing infrastructure needs replacing and health and environmental requirements have changed. Booze Allen Hamilton estimated in 2007 that some US$41 trillion would have to be spent on this replacement by 2030. Of this US$22 trillion would be for water and sanitation services.

In the past years, more and more cities utilized mechanized tunnelling technology to build large-scale sewage systems. Doing so does not only ensure fast and reliable construction times with minimum surface disruption but also -more importantly- overcomes constraints in terms of tunnelling distance and depths. So-called Deep Sewer Systems involve large diameter main tunnels that convey wastewater by gravity over large distances to centralized treatment plants, where the sewage is pumped to the surface and treated. In addition, smaller diameter, often pipe jacked, link sewer networks and deep shafts are parts of these schemes. The following paper will explore the need and concept of deep sewers, give an overview of the technologies available and finish with Singapore´s deep sewer project, one of the most famous examples for sustainable wastewater management.

Singapore's National Water Agency, known as PUB, has coined this project as "Singapore's Sanitary Superhighway". Consisting of two phases once complete it will convey wastewater to three centralized treatment plants. The DSTT will finally consist of 200km of new sewers at depths of up to 60m.

Phase 1 is already complete and the body of this paper will focus mainly on Phase 2 which is presently underway.

DTSS Phase 1

Refer to Figure 4. This phase was completed in 2008. Built in the Eastern part of Singapore this phase effluent conveyance system consists of deep tunnels and link sewers which conveys effluent to the Changi water reclaimation plant and sea outfall situated on the south east of the island.

DTSS Phase 2

Refer to Figure 4. This deep tunnel system extends to the South Western part of the island and will feed effluent to the new Taus water reclaimation plant. It will consist of 40 km of deep tunnels, 60 km of link sewers and a specialised industrial sewer network. The main South Tunnel will vary in depths ranging from 35m to 55m.

FIGURE 4: Plan showing the extent of Phase 1 and Phase 2

The client chose to break Phase 2 into 5 tunnelling contracts as described below:

- **Contract T-07**
  Four Mixedshield TBMs constructing 12 km of tunnels and odour control shafts. (Diameters 7,56m and 4,86m).

- **Contract T-08**
  Four Mixedshield TBMs constructing 10 km of tunnels serving the industrial area and two undersea tunnels. (Diameters 7,46m and 4,35m).

- **Contract T-09**
  Three Mixedshield TBMs constructing 8 km of tunnels (Diameter 7,51m).

- **Contract T-10**
  Two Mixedshield TBM and one EPBM Shield machine constructing 8km of tunnels.

- **Contract T-11**
  Five AVN Machines and specialised Veertical Shaft Sinking (VSM) equipment.

Many benefits are to be gained by using an entirely gravity fed deep sewer system. The need for constructing new intermediate pump stations is eliminated and a number of old existing pump stations will be removed thus releasing valuable land for housing development and reducing energy costs. Obstacles at shallower depths are easily avoided – e.g. the South Tunnel passes well below busy freeways, large buildings, a section of sea-bed and many existing services.

FIGURE 5: TBM with cutter head removed

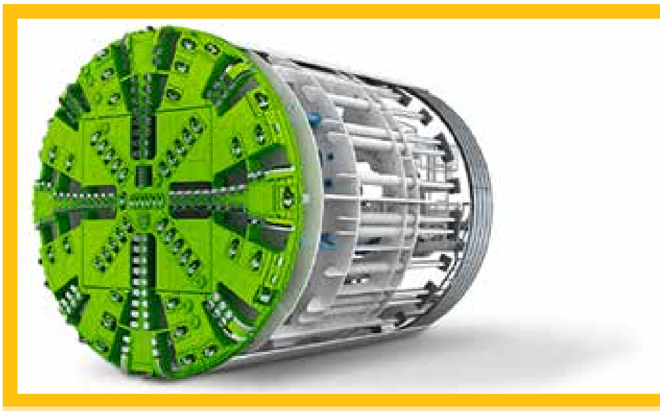

FIGURE 6: Front view of a Mixshield TBM machine

The tunnels will be concrete segment lined with a secondary inner HDPE lining which will eliminate the threat of corrosion. Tunnel conditional monitoring will be undertaken via a system of fibre optics within the tunnel lining and the need for human entry for inspection will be drastically reduced.

Odour control will be achieved by using forced ventilation shafts.

3. THE EQUIPMENT USED TO EXECUTE THIS PROJECT

3.1 Mixshield TBM

Two of the many issues that must be considered when deciding on the best machine to use for a particular job are the geological conditions and the ground water conditions. It is vital that the soil properties (i.e, grain size, compactness and consistency) and the rock properties (i.e., compressive strength, tensile strength and R.Q.D. index) are accurately determined and catered for.

Complex geological conditions were encountered for this project. The tunnels pass through the Jurong Formation which is made up of a mix of limestone, sandstone and argillite which is a sedimentary rock with a high clay and silt content.

The Mixshield machine was chosen as the best option due to its ability to handle heterogeneous ground conditions and its ability to withstand very high water pressures (up to 15 bar). Figure 6 shows a typical Mixshield TBM and Figure 7 shows an internal view thereof. Safe working conditions are achieved using a hydraulic support system of slurry suspension together with a controlled air cushion system.

Excavated material is removed through a closed slurry circuit and hydraulic thrust cylinders within the shield area push the machine forward. The cutting wheel is made up of both knives and disc cutters and boulders and stones are crushed and screened to a manageable grain size for conveying to the surface.

3.2 Vertical shaft Sinking Machine. (VSM)

This is the first time that VSM technology has been used in Asia. This equipment has made it possible to sink 5 shafts with an ID of 10,0m (depths up to 60m) and 2 shafts with an ID of 12,0m (depth of 52m).

Challenges which had to be overcome include fines with clogging potential, areas of highly abrasive rock, varying geology and ground water which was, at times, 2m from the surface and the lowering of the water table was not permissible. Two of the shafts were situated less than 2m apart.

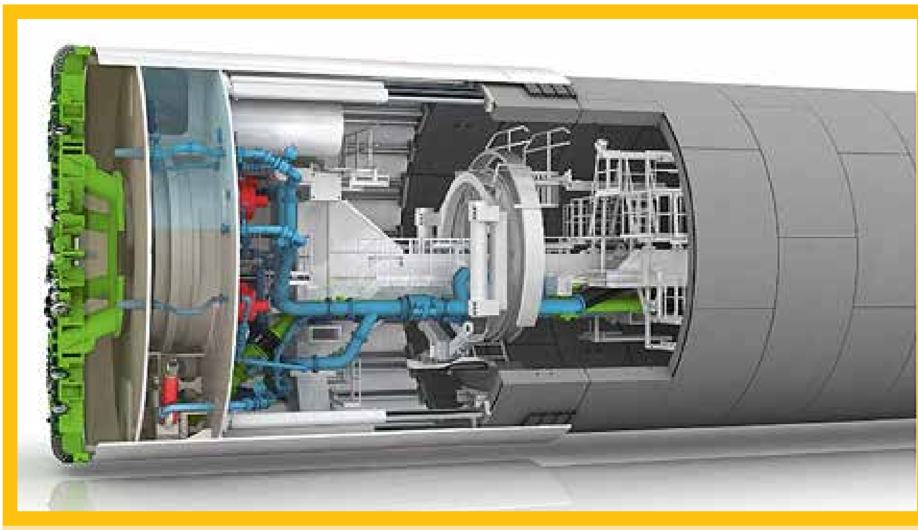

FIGURE 7: Internal view of a Mixshield TBM machine

Some of the benefits derived from VSM technology include safe working conditions, a continual construction process with sinking rates of up to 2,4 m per day.

Shafts for odor control, air jumpers and drop shafts which lead to the main tunnels are required.

A hydraulically powered cutting drum equipped with excavation tools controlled by a telescopic boom loosens the soil on the shaft bottom. The excavated material is removed to the surface using a submersible pump. Typical advance rates of up to 5m per shift can be achieved in soft and stable soils and excavation can be undertaken below the water table. The operation is controlled from the surface.

The completed shafts are protected by pre-cast concrete segments. The shaft lining is installed at the surface and is in most cases made up with precast concrete segments. Alternatively, in-situ concrete casting of the shaft walls can also be implemented. In this case, the slower progress of shaft construction works is compensated to some extent by having a "continuous" structure without joints and by the possibility of integrating entire entry and exit structures for Microtunnelling activities in the walls of the shaft.

4. THE TUAS WATER RECLAMATION PLANT

The layout of the Tuas Wastewater Reclamation Plant is shown in figure 10. Effluent will be fed via the Southern Tunnel and then treated at the new plant. Once fully operational its output will increase the amount of reclaimed water use in Singapore from 30% to 55% of its total. The plant's output will be 800 ML per day. This purified water will be sold as potable NEWater and to industry. Any excess treated water will be discharged into sea outfalls. Thanks to this project the older Jurong and Ulu Panda recycling plants will eventually be phased out.

State-of-the-art design ensures higher energy efficiencies and features such as the use of membrane reactors (which replace the need for primary sedimentary tanks, bioreactors and secondary sedimentation tanks) and this will result in a smaller footprint of the plant. Reverse Osmosis and UV Disinfection will form part of the treatment process. Biogas will be used to reduce energy dependency.

CONCLUSION

Around the world, there is an increasing demand for sophisticated water and wastewater management. That holds true especially for cities where population is growing but space is restricted. The paper shows that deep sewers offer an effective solution for cities to collect and centrally treat their wastewaters thus adding capacity to their systems and at the same time freeing up valuable space for development.

Tunnel boring machines and vertical shaft sinking machines help to execute such projects quickly, safely and with a minimum impact on the population and environment. They offer solutions for the prevailing geological and hydrogeological conditions and can excavate at the extreme depths required in a deep sewer system. Especially, shaft-sinking machines offer an alternative state-of-the-art solution to excavate deep shafts in difficult ground conditions without lowering the ground water table and risk for involved personnel and settlements.

RECOMMENDATIONS

In South Africa, and Africa as a whole, client Government and Local Authorities and Consultants should explore and consider the benefits of employing deep tunnelling solutions for projects with similar demands and conditions as those encountered in Singapore.

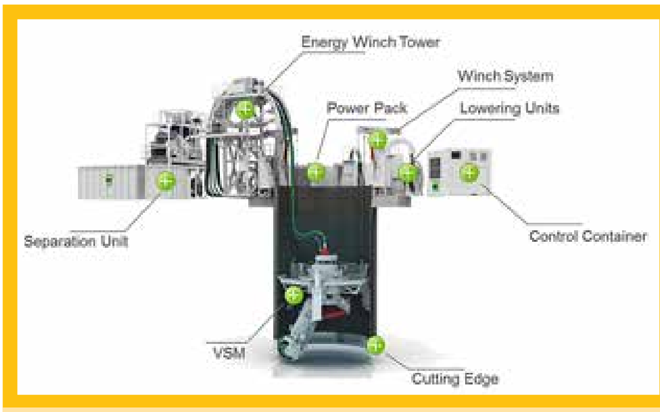

FIGURE 8: Vertical Shaft Sinking Machine (VSM). DTSS11

FIGURE 9: Aerial view of shaft sinking site

FIGURE 10: Tuas Water Reclamation Plant

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PAPER 4

Illuminating a Social Development Program – Focus on the eZimbokodweni Pipe and Pedestrian Bridge

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ABSTRACT

The eZimbokodweni Pipe and Pedestrian Bridge, located in the Philani Valley (Umlazi Y Section) and the New City Area of eZimbokodweni in KwaZulu-Natal entailed raising an encased sewer pipe as well as the development of a pedestrian bridge over the eZimbokodweni River. The bridge provided a much needed, safe pedestrian crossing in this largely rural area, and considering South Africa's rolling black-outs through load shedding, as well as continuous electricity cable theft, innovative technology through the use of photo-luminescent concrete (glow-in-the dark) was used to ensure that residents could safely utilise the bridge at night in the absence of electrical lighting. The innovation was realised through partnership between the client, the contractor and the consultant with technical support from the material supplier and research undertaken by the University of KwaZulu-Natal.

Whilst this has garnered much positive technical interest, the implementation of infrastructure projects in South Africa at large, has been hindered by work stoppages through worker unrest and more recently, local contractor organisations demanding that a percentage of projects be awarded to emerging contractors, citing government's transformation policies. To prevent the derailing of this project, extensive effort was made to allow early engagement and manage stakeholder expectations. Social facilitation was undertaken with numerous key stakeholders within this community through an Institutional and Social Development (ISD) process.

The ISD element enabled stakeholders to incorporate social upliftment components into the project without compromising the project output (construction of the bridge). Whilst some 12 sub-contractors were engaged on the project, stakeholder engagement platforms were established that created an environment where social challenges could be promptly raised and resolved. As a result of the introduction of these important social facilitation processes, the risk for work stoppages was mitigated, allowing completion of the project two months ahead of programme and within budget.

This paper reviews the methods employed by the project team to engage with the numerous relevant stakeholders in the project, in such a manner as to prevent any work stoppages or work disruptions throughout the project. The paper aims to draw a comparison between the methods employed in the case study against theoretical best practice procedures, providing recommendations for further roll-out in future projects.

1 INTRODUCTION

Sand mining activity along the river banks of the eZimbokodweni River, located in the Philani Valley (Umlazi Y Section) and the New City Area of eZimbokodweni in Kwazulu-Natal caused a drop in the water level of the river, undermining a sewer pipe crossing whilst increasing the risk to members of the local community who had to cross the river. To circumvent further risk, the project entailed the raising of the encased sewer pipe including the provision of access onto the bridge for pedestrians to cross. The 160m long proposed prestressed concrete bridge was 10 meters high and 2 meters wide.

A unique feature of this is bridge is the use of photo-luminescent concrete (glow-in-the dark) which allows residents to safely utilise the bridge at night even in the absence of electrical lighting. Whilst the application of technology has garnered much interest another key strength of this project is the successful method of engagement with the community – success which has allowed the project to finish ahead of time without work stoppages. Not only has this project become a light in the dark for pedestrians that are crossing but it has also become a beacon of hope for project implementers. This paper sets out to explore these community engagement methods to understand why such success may have been achieved.

2 TECHNICAL ELEMENTS OF THIS PROJECT

The eZimbokodweni River flows divides the distinct communities of Umlazi

FIGURE 1a: An aerial view of the site prior to construction showing the old bridge

FIGURE 1b: The existing bridge prior to re-construction

FIGURE 2: An aerial view of the site post-construction. The picture depicts the newly built bridge and the wards serviced

Y section in Ward 86 and Ezimbokodweni in Ward 93. The community of eZimbokodweni comprises a population of 12 882 people, with some 50.8% being female. Prompted by the high number of drownings and crime incident. In 2016, ward 86 councillor Sindisiwe Dlamini-Shange approached the Municipality to propose the reconstruction of the existing bridge in order to provide a safe crossing for the community. Her concern emanates from reports of several drownings in a 10-year period during times when the low-lying bridge became submerged during heavy rains. She also noted the heightened criminal activity that occurred at night whilst people crossed the unlit pipe crossing. It was also reported that the construction of the existing syphon which were undertaken in 2000 was marred by hijacking of the stakeholders that were involved in the construction.

The existing infrastructure across the river consisted of a siphon encased in a reinforced concrete structure buried approximately 4m deep in the riverbed. Due to illegal sand mining, the water level of the river dropped, causing further riverbank erosion, exposing the encasement leaving it susceptible to vandalism, undermining during floods and a potential structural risk through heavy trucks driving over it.

The client, along with designers Naidu Consulting, therefore looked for a solution which considered the protection of the pipe and the pedestrians who frequently use the pipe crossing to traverse the river. The solution comprised the raising of the pipe and provision of access onto the bridge for pedestrians. The 160 meters long prestressed concrete bridge was 10 meters high and 2 meters wide with handrails constructed using photo-luminescent concrete (glow-in-the dark) which allowed residents to safely utilise the bridge at night even in the absence of electrical lighting – technology introduced after extensive research undertaken by Resocrete, the consultant and the University of Kwazulu-Natal.

3 THE CLIENT - ETHEKWINI METRO

The client on this project was eThekwini Metro. EThekwini is located on the east coast of South Africa in the Province of KwaZulu-Natal (KZN). The Municipality spans an area of approximately 2 297km^2 and is home to some 3.5 million people. It consists of a diverse society which faces various social, economic, environmental and governance challenges. As a result, it strives to address these challenges which mean meeting the needs of an ever-increasing population.

The metro has been faced with a scourge of project stoppages due to community needs to participate in such projects. Various stakeholders express different needs to participate in the contract one of which being business forums such as the Delangokubona Business Forum who, having considered the PPPFA and the contract participation goals, hope to gain access to the up to 30% of the project value subcontracted to them for supply of materials or service delivery. Where inappropriately consulted, the intervention from such groups have had varied impacts and, in some instances, even turned violent where the municipal officials have been forcibly removed from their offices and municipal assets set on fire – destroying such assets and potentially resulting in injuries and trauma. Historically, the cost of these interruptions has amounted to millions of Rands. One such project was the Northern Aqueduct Augmentation bulk water pipeline project where eThekwini Mayor Mxolisi Kaunda indicated that the council has had to approve a further R13.9 million funding due to delays that were propelled by the business forums who violently threatened the contractor.

To this end, it was imperative that the municipality look at avenues to reduce the risk of project interruptions caused by Business Forums or the community at large.

4 THE CHALLENGES WORKING WITH COMMUNITIES

A simple definition of the Institutional and Social Development (ISD) services is that it deals with community participation in ensuring that communities are part of the development process (decision making). The ISD thus refers to both what needs to be done as well as an approach of how things should be done within a context of community participation in order to achieve sustainable development. Development refers to a process of social, economic and human empowerment through which ordinary people gain greater control over factors which control their lives. It is a process where people are at the centre of their own development with the necessary support of others.

Social facilitation is similar to Stakeholder engagement which is defined by Wikipedia as the process by which an organization involves people who may be affected by the decisions it makes or can influence the implementation of its decisions. They may support or oppose the decisions, be influential in the organization or within the community in which it operates, hold relevant official positions or be affected in the long term.

An underlying principle of social facilitation is that stakeholders have the chance to influence the decision-making process – a key part of this is multistakeholder governance. This differentiates stakeholder engagement from communications processes that seek to issue a message or influence groups to agree with a decision that is already made. Social facilitation provides the opportunity to further align project practices with societal needs and expectations, helping to drive long term sustainability and stakeholder values.

Jeffrey (2009) in "Stakeholder Engagement: A Roadmap to meaningful engagement" describes seven core values for the practices of gaining meaningful participation of which perhaps the three most critical are:

- Stakeholders should have a say in decisions about actions that could affect their lives or essential environment for life.
- Stakeholder participation includes the promise that stakeholder's contribution will influence the decision.
- Stakeholder participation seeks input from participants in designing how they participate.

The practitioners in stakeholder engagement are often businesses,

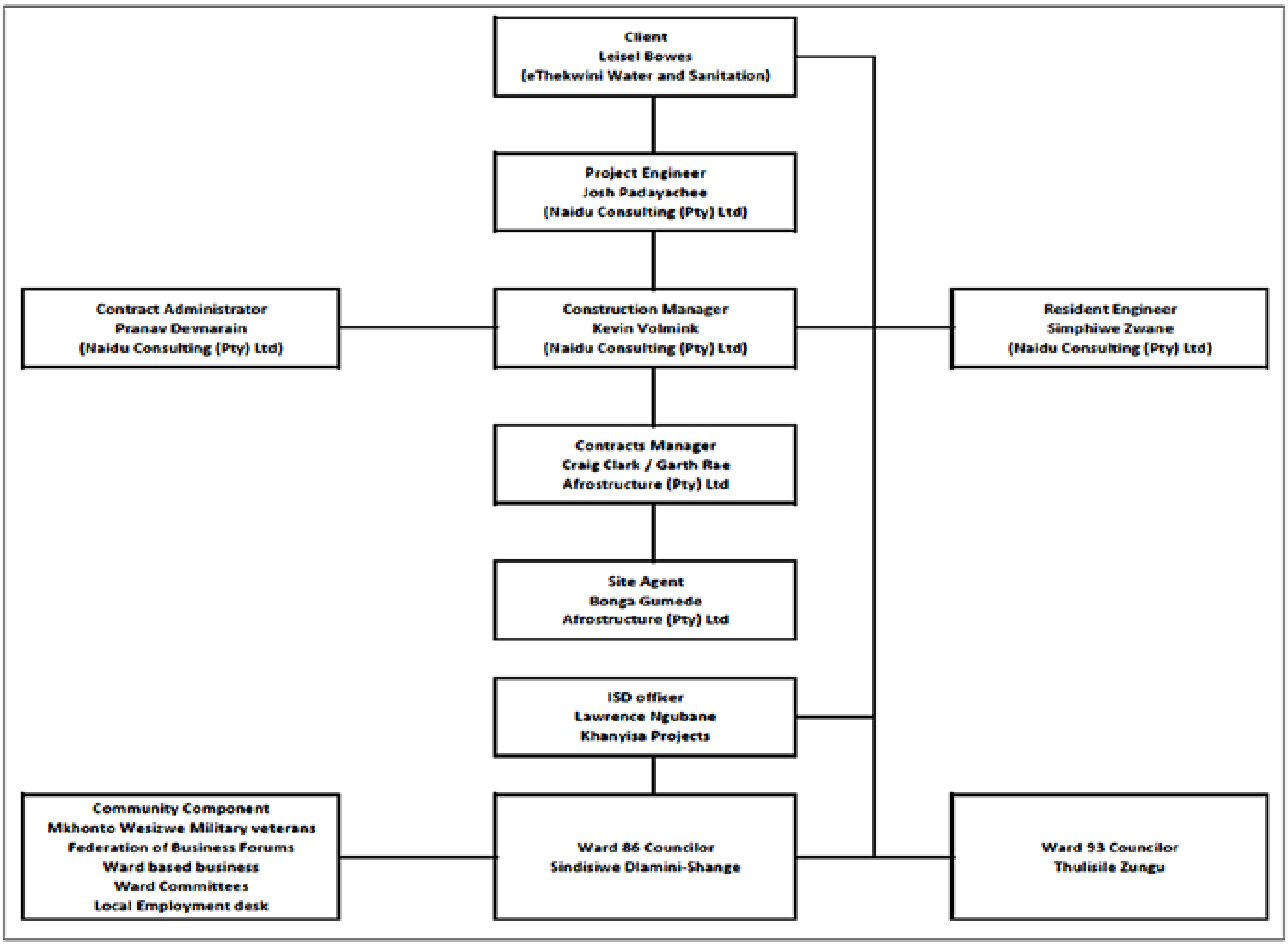

FIGURE 3: Project team organogram

non-governmental organizations (NGOs), labour organizations, trade and industry organizations, governments, and financial institutions.

The main goals for social facilitation are as listed below:

- To provide balanced, objective, accurate and consistent information to assist stakeholders to understand the Project and how they will be affected.
- To obtain feedback from stakeholders on analysis, alternative solutions and/or outcomes
- To work directly with stakeholders throughout the process to ensure that their concerns and interests are consistently understood and considered.
- To partner with the stakeholder including the development of alternatives, making decisions and the identification of preferred solutions.
- Stakeholders are enabled/equipped to actively contribute to the achievement of outcomes.

The social facilitation remains a binding factor between the community that is receiving the service (project) and the project team that is delivering the project.

5 THE CLIENT'S VIEW ON SOCIAL FACILITATION

The eThekwini Municipality recognises the importance of social facilitation and includes clauses in their project tender documents to allow for a community liaison officer as well as the establishment of a Project Steering Committee. Whilst this is standardized on most projects, an ISD Specialist is not always specified placing responsibility for community engagement with the construction monitoring team and the client themselves. Whilst this has worked on many projects, there is an increased resistance to this method of working with increased resistance from communities as their voices are not heard. The client has historically engaged the community to inform of the impacts of the work and hear their response toward it rather than allowing the stakeholders to participate in decisions. Further to this, it must be noted, that even when ISD consultants have been engaged, that the ISD consultant is not effective with problems still arising. Finally, where ISD consultants are engaged, the results realised may not be consistent or do not achieve the desired outcomes. Notably, the Northern Aqueduct project which was undertaken in the near vicinity of the project utilised the services of an ISD Consultant however, despite the intervention, the project was severely delayed with delay costs amounting to some R13.9million.

6 HOW SOCIAL FACILITATION WAS IMPLEMENTED ON THE EZIMBOKODWENI PROJECT

6.1 The ISD Team

Ethekwini Metro appointed Khanyisa Projects to provide Institutional and Social Development (ISD) services on eZimbokodweni Pipe and Pedestrian Bridge project. Amongst other responsibilities, the ISD was appointed to:

- Contribute to project risk identification with respect to the community and plan appropriate mitigation thereof;
- Manage the community stakeholder interests;

FIGURE 4: Installation of bridge decking

- Attend project team and Project Steering Committee meetings; and
- Act as and interface between the project team and the community stakeholders.

The appointment of the ISD was made at the Preconstruction stage after the contractor had been appointed but before the contractor had established on site. An ISD team was established and comprised representatives from:

- eThekwini Water and Sanitation (Project Sponsor)
- Naidu Consulting (Engineering consultant)
- Afrostructures (Contractor)
- Khanyisa Projects (ISD Consultants).

6.2 The ISD

Team's approach to engagement with the community

Whilst the project team had formulated a technical viable response to the engineering problem, the ISD recognised the importance of the Voice of the Stakeholders and their contribution to the success of the project. The ISD Team resolved to build credibility and trust, develop supporters and champions for the project and ensure that the needs and wishes of the stakeholders were taken into consideration in decision-making. Rather than doing the minimum to keep the community at bay, the ISD Team elected to apply a stance of mobilisation and inclusion – not fighting the community but working with them.

As such the ISD team developed a stakeholder management strategy. The strategy was based on:

- Engaging the correct stakeholders
- Applying appropriate communicating techniques to allow the stakeholders to understand the message

FIGURE 5: The project team after a site visit

- Not applying a "need to know" approach to information sharing but rather an "information-sharing-for-empowering" approach – providing the community with as much information as possible to allow them to participate
- Being transparent
- Applying a stakeholder participation approach rather than a stakeholder informing approach.

Fundamentally, the ISD team agreed that the approach to the community would be to have them participate in decision making – empowering them through open and appropriate communication.

6.3 Initial engagements

Whilst the project team identified wards 86, 89 and 93 as being the impacted wards for this project, the initial meeting called with ward councillors was attended by just one councillor. Whilst the meeting allowed a streamlining of the stakeholders to those in wards 86 and 93, the ISD team elected to delay the commencement of the project until adequate stakeholder engagement was undertaken. (as opposed to a tick box for completion with the stakeholders who did not attend deemed disinterested) The ISD team therefore planned and held a subsequent meeting using further means to ensure representation from all affected stakeholders. The stakeholder participating in the subsequent meeting included representation from both wards. During this engagement, the ISD explained:

- The project scope including the numerous features and benefits of the proposed structure
- Explaining the benefits that the community would derive outside of the project output of a bridge. Having carefully considered the technical complexity of solution, the ISD consultant relayed the skill required to achieve the already embraced end-product and the lack of such skill within the pool of contractors within the project area. Given this limitation, the ward councillors still iterated the need for the project to add value to the community through other mechanisms such as educational programmes at schools and learnerships contributing toward the Contract Participation Goal.

6.4 Mobilised the community

As a result of the approach, the ward councillors embraced the project and aided the execution of the works in many aspects. To this end, the councillors assisted the project team to identify available resources within the community and support the identification of potential threats such as individuals or organisations that might have concerns about the projects or other external issues that may hinder the project's success. Clear guidelines on how to appoint the PSC were shared with both the councillors. To this end, the councillors provided guidance on how to formulate the PSC in order to mitigate the risks of negative inputs from such stakeholders providing guidance on the recommended composition of the members of the PSC from the community. The PSC ultimately comprised project representatives from the client, consultant, contractor and ISD Consultant with community representatives:

- Mkhonto Wesizwe Military veterans
- Federation of Business Forums
- Ward based business
- Ward Committees
- Local Employment desk.

PSC members were inducted explaining roles and responsibilities in the project. The resulting PSC then aided the identification of a pool of subcontractors which were available within the community to utilise where opportunities for such services arose through the project.

FIGURE 6: Completed bridge structure during the day

The advantage of this representation became clear. It allowed community members to voice ideas and concerns and gain an understanding of alternate views and the rationale for decisions. The project team maintained their stakeholder strategy to remain transparent through the project particularly the subcontractor procurement processes including appropriate rates in alignment with the baseline project budget.

6.5 Construction

Whilst traditional ISD focuses on the management of local labour employment and business opportunities expectations during construction, several components were strategically incorporated during the construction stage to promote inclusion of the community through the construction process. The community was consistently allowed to participate throughout the construction of the project. Two meetings were held each month namely the technical meeting and the PSC meeting. The PSC members were also allowed to attend the Technical meeting and even though this was optional, the members elected to attend these regularly with both meetings being avenues to raise any social facilitation issues. The PSC members were provided with stipends when attending the PSC meetings which affirmed the value that the client had for the voice of the community – enhancing the probability of the full complement of the community representation for issues to be fully addressed. The project team allowed the community to participate in finding solutions to the problems identified.

To further emphasise the belief of their importance of the voice of the community, the client provided the PSC Community representatives with project branded Personal Protective Equipment. The project team applied an inclusive approach as opposed to a need-to-know approach basis where the community is kept in the dark on the proceedings of the projects. This presented an inclusive environment, where the community representatives could ask questions regarding technical matters and adequate responses provided to aid capacitation. This was taken further through the involvement of the interested community representatives in the traditional celebration of the achievement of specific project milestones such as the installation of the bridge decking.

A business desk was established on the project. In conjunction with the Business Forums, the ISD facilitated the creation of a database of service providers in the project wards. This database was used to source sub-contractors from the community.

6.6 Impact of the community participation

The impact of the effective Social facilitation was evident throughout the contract period. Numerous benefits were realised including the following:

- Whilst the initial engagement took longer than anticipated, the mobilised community aided the execution of the works, so much so that the project was completed earlier than anticipated. This was realised through the community supporting the process of the identification of local materials and suppliers and, due to the inclusion of all stakeholders – no work stoppages associated with community unrest, occurred.
- Despite investing in bursaries, partnerships in education programmes, utilising local labour and local contractors for the works, the effort resulted in the project finishing within budget. The site establishment was let after the contract for usage as a block precast yard for a local business within the community.
- The project was historically prone to crime and, in previous projects, several hi-jackings had taken this place. During the project an incident occurred where a battery was stolen from the site. As part of the commitment to transparency, the incident was communicated at the PSC. Subsequently, the stolen goods were returned to the site.
- The ownership exhibited by the community for the works, resulted in a reduced cost for security measures for the project.
- The community understood the key features and benefits of the assets being created and continue to ensure that their "asset" is well taken care of.

7 THE CONTRIBUTION OF THE PROJECT TEAM STAKEHOLDERS ON THE FACILITATION SUCCESS

A stakeholder is either an individual, group or organization who is impacted by the outcome of a project. They have an interest in the success of the project and can be within or outside the organization that is sponsoring the project. Whilst community facilitation may follow a series of steps to ensure specific results, the response from the community in this project is testimony of a perhaps untapped resource in a project – the community. This response was triggered by a common thread which has been identified in each of the stakeholders.

7.1 Client Representative

Whilst the client body endorsed an element of social facilitation, this has not always yielded similar results. The client representative was a professionally registered technologist with 21 years of experience in the construction industry. Acting as the Area Project Manager in the Water Design Branch for the Western and Southern Region of the eThekwini Municipality, the resource had extensive experience in construction with experience in understanding the dynamics of working with projects sensitive to community impact.

The client representative appreciated that:

- The roll out of CPG in projects has generated interest in communities, and when not adequately addressed, could result in negative feedback from the community including unrest and potentially loss of lives.
- Not dealing with the issue could impact progress and the budget of the project.

As a mother of three boys, the client representative likened her work on the project to her parenting – firm yet granting respect and acknowledging each of them without leaving any behind. In context, this inspired her to lead the project team in such a way as to create a positive engaging environment in the project. Whilst she trusted her consultant and contractor to execute facilitation, she emphasised the need for effective facilitation and therefore requested an outsourced specialist social facilitator to support the project through approval of a variation order.

7.2 The consultant

Whilst the consultant had a proven technical ability to undertake the works, the consultant has committed to making a difference through their work, consistently seeking avenues to enhance socio-economic benefits through their numerous projects. This commitment is affirmed through staff KPIs which include socio economic initiatives infused into traditional projects with or without mandatory client requirements. Not seeing this as a burden, staff have in fact been inspired by the initiates and have rallied other staff to personally compliment such efforts in order to optimise the benefits. Historically, this has included the staff arranging book drops for newly built libraries and offering maths and physics tuitions in their own time to uplift a community. Their culture has seen them win numerous national community-based project awards for their efforts.

To this end, the consultant designed the structure with the community in mind, not limited to the structural and sewage works but considering the community impacted by it. Whilst their research on glow in the dark concrete with suppliers Resocrete and the University of Kwazulu-Natal for this project has garnered significant interest in the country and won national awards, the biggest winners still remain the community who can cross the bridge at night on a better lit structure, without the need for electrical lighting. The consultant devised a clear strategy for CPG spend through the project. Considering this and having seen the value of social facilitation on their KZN Department of Transport Projects, the clients request in the project for additional support, was therefore welcomed by the consultant.

7.3 The contractor

The contractor on the project was a well-developed contractor who has been in operation since 1980 and specialises in Structural Concrete & Water Retaining Structures, Building & Developments and Pipelines. The company's mission statement includes instilling a "culture of respect". This site agent, although experienced, was not closed to new ideas or set on traditional approaches. The contractor emanated respect – towards his peers to ensure that roles and responsibilities were effectively enacted and the community, where he was open to comments and suggestions from the different stakeholders. To this end, the site agent ensures that labour and subcontractor requirements were communicated via the ISD officer – reaffirming commitment to the social facilitation process.

7.4 The social facilitator

The ISD consultant appointed on the project has approximately 30 years of working experience, holding a qualification in Public and Development Management and beginning his career as a Community Liaison Officer. He then developed an affection for the Development theory and practice as opposed to pursuing a career as a public administrator for a government entity. Whilst his education and experience make him a competent social facilitator, his ability to understand the community and respond to their needs make him an excellent, well sought-after resource. In the project, he was instrumental in identifying the correct stakeholders, soliciting their needs and, in the process averting several potential project threats throughout the project. Whilst he developed a clear facilitation strategy, he remained flexible to read, the sometimes-changing needs of the community whilst also acting as a filter to outlandish requests. He played a vital role in bridging the gap between the project team and the members of the community. A key strength of the ISD consultant was his ability to solve many problems before they even escalated to a PSC meeting or the project. He developed strong relationships with members the community who keep in contact with him up to today.

7.5 The ward councillors

The ward councillors in the project were committed to their roles in their respective wards. They understood their responsibilities as could easily identify the relevant stakeholders in their wards. They contributed to rapidly identifying the resources available in the respective wards – displaying their extensive knowledge of their respective wards. Whilst both possess the necessary qualifications to fulfil the roll, their persistence and hands on approach have enhanced the probability of achieving success in their targeted areas of work. The 49-year-old and 52-year-old councillors from ward 86 and 93 respectively, have mobilised the community through their efforts.

7.6 The business forum

The project allowed for Contract Participation Goals (CPG). Several business forums existed through the project area however, through the ward councillors, a representative from each ward was nominated to represent all the forums within this project. The representatives, through the business forums, played a crucial role in compiling a list of available contractors in the community – carefully aligning the expertise of the service provider with the project requirements. To this end, the appointment of sub-contractors was facilitated through the business forums with the main contractor informing the ISD officer of their requirements and the ISD officer along with the business desk identifying potential subcontractors from the database that was initially created.

Lindelani Zungu, a local small business and a nominated representative on the PSC members, highlighted how the PSC became a bridge between the community and the project team. He proactively assisted, along with the other members, to solve problems within the community well before they got to a stage where they could affect the project. He commended the project team for the spirit of inclusion that was established in the project as well as the transparency that existed. He indicated, that as members of the community, they were aware of the progress of the project and that they could also share their own ideas and opinions about the projects. He noted that these were taken into consideration by the team instead of being kept on a need to know basis.

A key role that the members of the PSC played was to invoke accountability amongst subcontractors. In the PSC meetings, the subcontractors were rated according to their performance and the contractor got to express the challenges with them if there was any. The affected subcontractor would then be called to account and advised to improve as underperformance would subsequently affect the timelines of the project.

8 FIVE KEY TAKE-AWAY POINTS

The social facilitation has been effective in not just alleviating the risk of community interference but capitalising on the benefit of community input in a project. The intervention worked, and whilst many textbook activities were undertaken, many lessons could be learned through the process. Of these, 5 are discussed in the sections below.

8.1 CPG is not a burden

Consultants and contractors have historically grappled with CPG. There is uncertainty as to how to package it – with specifiers at times struggling to identify suitable work packages or activities which may be undertaken through such work. Many designers at times include work not suitable for the community or specify training or unrealistic employment or local content targets which simply set projects up for failure. CPG is perceived as being counter-productive with "money being given away" from the contract.

The project has proven that CPG can be effectively implemented without compromising the scope, time, cost or quality when planned and implemented correctly. The social facilitation on the project has aided the

FIGURE 7: Illuminating bridge in the evening

FIGURE 8: Illuminating sidewalks leading to the bridge

identification of avenues of spend which are not random but carefully crafted to enhance the benefits to the community without compromising the technical outputs of the project. In this instance, the community aided the realisation of the CPG benefits by contributing to the planning, implementation and ongoing monitoring. The success of the project through social facilitation has proven that CPG can be successful and beneficial.

8.2 Business Forums don't have to spell disaster

The several business forums in the project had the potential to threaten the progress of the project. Some project teams hope that such threats don't arise whilst others make plans to avoid them as best possible. In this instance, the project team chose the direct approach: to involve them. They welcomed inputs, from a representative of all forums, averted unrealistic expectations, contributed to weeding out poor performance and aided matching the available pool of resources with the scope of works. The approach has mitigated the negative risk and capitalised on the positive influence. When involved, business forums may offer value to your project. The response from the forums and the potential gain realised through this begs the question as to whether more should be done with Business Forums – supporting them and their members rather than fearing them and trying to work around them.

8.3 Don't underestimate the community

The community stakeholders should never be underestimated. They can contribute, may make valuable input and can greatly influence the success of your project. Each community is not the same with further differences between the individuals of that community. Despite these differences, one should never underestimate the ability to contribute to a project. What started off as an attempt to limit losses in the project, resulted in significant benefits to the community and the project – even to the extent of stolen items being returned to the project site. Never underestimate the community and its stakeholders!

8.4 Plan to include, not to appease

It must be remembered that the purpose of any infrastructure project is to create a service or an asset for people. People who don't understand the value of a project may respond very differently to those who do. The project team deliberately created opportunities for the community to be engaged, to understand the project and contribute towards it. The community responded and not just appreciated the gesture but reciprocated through lending ideas and thoughts which could address the challenges in the project resulting in unplanned benefits that saved cost and time in the project.

8.5 Attitude determines altitude

The attitude and approach of each member of the team contributed significantly toward the success of this project. Each member of the project team exhibited a commitment to making a difference in the community through this project. The service to community was not reduced to a mere asset created. This resonated through the various components within the project from the inclusion of the glow in the dark concrete for the community to the decisions to continually engage the community. The client, consultant, contractor and ISD had various fundamental drivers to support the community through their work. There appeared to be a genuine belief that this was their core mandate as Practitioners in the built environment. This belief may have arisen from the role as parents, a company culture, company vision or experience. Whatever it was, this belief guided their decision making – whether approving variation orders for the ISD consultant or making the bold move to invite "traditional problematic stakeholders" to sit in the PSC – and genuinely allow them to contribute to steering the project. It guided their transparency and allowed for healthy partnerships to be established to effectively implement the project. It allowed the flexibility to respond to the community's ever-changing requirements whilst it caused balance so as not to be side-tracked by sometimes unrealistic community requests.

The success of the project should cause the built environment practitioner to perhaps re-evaluate why they do what they do to bring humanity into every that we do. This belief may go a lot further than preventing unrest on a project.

9 CONCLUSION

Since the dawn of South Africa's rainbow nation, policy makers have penned many thoughts and plans to rebuild the nation including the National Development Plan, Contract Participation Goal and Labour-Intensive Construction. Whilst many practitioners have been critical of these policies and procedures, citing additional effort with more hurdles, even calling it "castles in the sky", the project highlighted the possible socio economic and project benefits that policies such CPG could have when embraced with genuine intention to support its success. Built environment practitioners play a pivotal role in enacting the National Development Plan as well as other infrastructure policies to support transformation in the country and the industry. This requires a change in mindset, where experience must be used to support change rather than to resist it. The practitioner must realise the objective of this people centred profession – with a need to provide services to people. There must be a mindset change in the approach to any infrastructure change – one which much emanate through all members of the project team and fostered in any PSC through strong, clear, ongoing social facilitation. The project has proven that effective social facilitation can lead to highly effective projects which realise many projects and socio-economic benefits.

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PAPER 5

Partial Reconstruction and Lengthening of a Continuous Post-tensioned Concrete Bridge Deck: Case Study of Emergency Rehabilitation of the Seaward Road Bridge

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ABSTRACT

Major modification or partial reconstruction of continuous post-tensioned concrete bridges is rarely undertaken. Instead, these structures are typically demolished and rebuilt in situations where a bridge is damaged or unable to meet new requirements. However, the option of re-using structural elements is much more environmentally sustainable and creates opportunities for large cost-savings and time-savings. This case study demonstrates how, in certain situations, it may be possible for a large, continuous, post-tensioned concrete bridge to be taken apart, modified from the original design and rebuilt.

The Seaward Road Bridge over the Umhlatuzana River underwent a partial collapse during flooding and municipal engineers successfully salvaged the three undamaged spans rather than demolish the entire structure. This required splitting the continuous prestress system at a construction joint between the damaged and undamaged portions of the bridge, then using the original prestress couplers to connect the new replacement spans to the salvaged existing spans. The length of the new portion of bridge was also increased.

This case study demonstrates how modification of existing structures is fraught with risks and technical challenges, some of which may be difficult to anticipate. Major challenges in this particular case included: (1) supporting a structure with an unusually high global instability through extreme and ongoing variations in loading and displacement, (2) demolishing deck spans of a concrete bridge suspended over a sensitive waterway through ongoing flood events, (3) meticulously quarrying out and exposing prestress couplers buried deep in existing reinforced concrete, so they could be safely reused, (4) modifying and testing bespoke prestress coupler components, (5) applying a precisely limited prestress force to the new deck spans, to account for the age-related differences in concrete behaviour, and increase in length, of the reconfigured bridge.

More broadly, the project emphasises how close coordination between the client, technical design team and contractor are critical to effectively managing the complex risks and challenges associated with modification of existing structures. The project provides a particular demonstration of how technical staff employed by the municipality may be best placed to achieve this technical cooperation if competent design, management, and construction supervision capacity is available in-house.

FIGURE 1: The collapsed eastern abutment and end span of the Seaward Road bridge over the Umhlatuzana River

INTRODUCTION

The rehabilitation and upgrading of ageing public infrastructure is an ever increasing part of the work of local authorities all over the world, including in South Africa.

Where structural elements have deteriorated beyond repair, or been damaged, they may need to be replaced. But ideally the replacement of one element in poor condition should not require the replacement of other elements that are still serviceable. Partial reconstruction of infrastructure may offer considerable benefits over full reconstruction. Similarly, where a piece of infrastructure no longer provides sufficient capacity for what is required, it may be possible to modify it to increase its capacity, rather than rebuilding it completely.

In practise, a partial compromise solution is often more technically advanced and complex to implement than wholesale replacement, because there are high levels of risk that must be managed, and unique problems to overcome. And so these projects require more technical and organisational competence to implement. But municipal officials and engineers cannot avoid the increasing prominence of these kinds of projects.

In many cases it may not be clear whether it is possible or practical to modify or repair existing infrastructure, rather than simply replacing it. This paper describes a case study of one such scenario involving a continuous, post-tensioned concrete bridge deck.

LITERATURE REVIEW

A careful review of the published literature makes it clear that both the lengthening and partial reconstruction of continuous bridge decks are distinctly unusual solutions.

Where significant modification of span configurations is undertaken, it invariably involves steel girder bridges (Warren et al. 2014), for which splicing beams together is relatively simple, as is balancing the load capacity of existing spans by attaching additional steel plates to girder flanges. There is also no need to deal with prestress cables in these structures.

When individual spans of a continuous bridge are damaged, the chosen solution is invariably to demolish the entire structure, or to go to whatever lengths may be necessary to repair the damaged members. The heroic rehabilitation of severely damaged bridge decks is a major field of ingenuity and ongoing innovation for suppliers, engineers and contractors, with published case studies showcasing numerous unique problems and

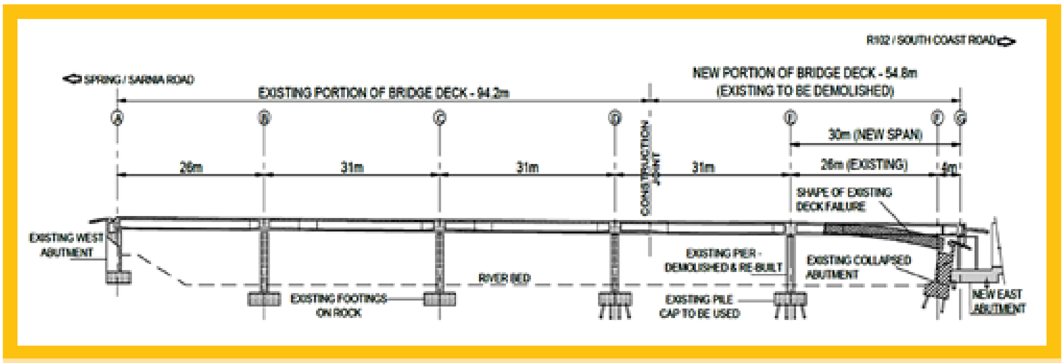

FIGURE 2: Long section through the entire 150m 5-span bridge

solutions. But if repair is not feasible or not possible, then the entire structure is usually demolished. A large research project into rapid bridge replacement techniques was initiated in the United States in response to the September 11 2001 terrorist attacks, and in the 26 case studies that were examined, the continuous decks were all repaired or replaced in their entirety (Bai et al. 2006).

The only other case study that this literature review found to compare with the case study under consideration was the reconstruction of a four-span continuous post-tensioned concrete bridge in Iraq that had two of its four spans damaged in a bomb blast. The demolished spans were replaced in a straightforward way with simply-supported steel plate-girders, but before these could be installed, a very complicated partial demolition had to be undertaken. The demolition was notable for the design and installation of special clamps for securing the prestress cables at an intermediate point between the anchors. These clamps then functioned as new prestress anchors at the location where the continuous prestress cables were cut (Oukaili 2019). It appears to have been a highly risky approach, with no obvious way to verify the clamp connections, and a reliance on a well-grouted cable duct to deal with any failure in the clamps. As such, it clearly demonstrates why significant tampering with continuous post-tensioned concrete bridges is unusual.

There thus appears to be a significant gap in the research regarding options for lengthening or partially reconstructing continuous post-tensioned concrete bridges, which this case study contributes to filling.

BACKGROUND: THE FLOOD AND THE FALL

The Seaward Road Bridge was constructed in 1979 as a five-span, prestressed, post-tensioned single-cell concrete box girder, continuous over a total length of 150m. It supports the only direct access between the Umhlatuzana Industrial Park and major road, rail and sea connections in the direction of the Port of Durban.

The April 2019 floods in the southern regions of Durban claimed at least 85 human lives and caused over R650 million in municipal infrastructure damage, including to the Seaward Road Bridge over the Umhlatuzana River.

The bridge crosses a complex curve in the river, which was originally intended to be canalised. The flooding first eroded the river's eastern embankment immediately upstream of the bridge, redirecting the flow directly at the face of the eastern abutment, where the piles were exposed, and the abutment wingwall dislodged. The saturated abutment fill pushed the precast piles out of position, then sheared them off. Without the piles, the abutment collapsed. The remainder of the deck was not strong enough to perform without the abutment's support, and the deck stresses were transmitted far beyond the end span, straining the prestress and reinforcing steel beyond serviceability and cracking the concrete. The deck was twisted over sideways on its bearings and the end span slumped down (Figure 1).

Fortunately, no persons were harmed in the vicinity during or after the collapse.

Access to the industrial park now required an additional 5km detour over a nearby hill along steep, narrow, winding suburban roads, where trucks had previously been completely forbidden. This was a hazard for both the large trucks carrying shipping containers and heavy machinery, and the local residents, including children walking to school. Congestion from trucks queuing to navigate difficult portions of road could introduce long delays in accessing the industrial park, holding up work and reducing productivity. Political pressure to replace the bridge as soon as possible came from both the residential and industrial areas.

THE PROBLEM: ENGINEERING FREEDOM

A rudimentary environmental impact assessment for the bridge reconstruction was quickly approved as part of a package of emergency flood repairs on the river, and funding was made available through a Municipal Finance Management Act Section 36(1)(a)(i) emergency procurement process with a shortened tender duration. But despite pressure to prioritise speed and reliability above cost-considerations, the project team still felt a responsibility to look at both the human and environmental impacts of their plans. Trying and failing to salvage the remaining deck might waste time. But success would instead save time, and also bring large benefits in terms of sustainability and cost-reduction.

A careful inspection was carried out to map the extent of the strain damage and the original as-built drawings were successfully tracked down. The conclusion was that the excessive strain stopped just short of a point where a cluster of prestressing couplers connected the prestress cables from intermediate construction stages together.

A key advantage was that the prestress cable layout in the bridge deck was extremely simple, with all of the prestress cables terminating in couplers between the construction stages. This is a typical arrangement in the 'span-by-span construction method', where "construction joints with couplers for the tendons are generally placed close to the theoretical point of inflection for dead load to minimize reinforcement requirements in the construction joint" (Seible 1985). Fortunately, the original designers ignored the recommendation that, "a balance between coupled and uncoupled tendons in each construction joint should be provided" (Seible 1985), since all of the prestress tendons were coupled at each construction joint.

In principle, a replacement deck was only needed in two of the bridge's original five spans (Figure 2). The original prestress couplers at the construction joint could be used to connect the new deck to the salvaged deck and share its loads. But first the team would need to dismantle a structure that was specifically designed to only be able to stay up as an integrated structural arrangement, and never supposed to be tampered with once complete.

THE SOLUTION: SEWING A PRE-STRESSED BRIDGE DECK BACK TOGETHER

The existing deck was first completely remodelled and analysed using modern design codes and software. The prestress analysis and design was made complicated by two factors. Firstly, because the original bridge is

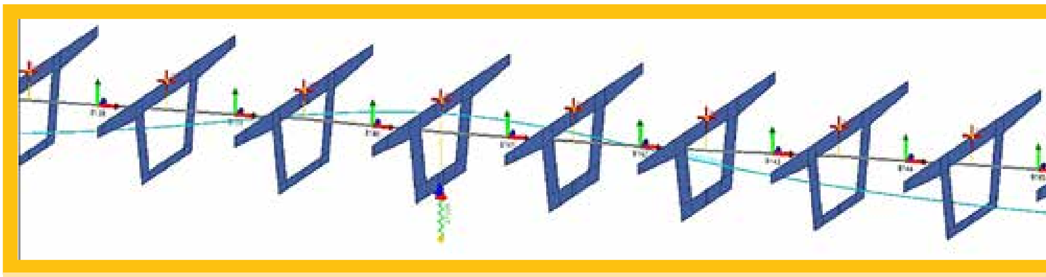

FIGURE 3: Typical extract from RM Bridge FEM Model – the entire bridge had to be modelled due to the increase in jack (end) span length and accurately account for time-related effects on the structure

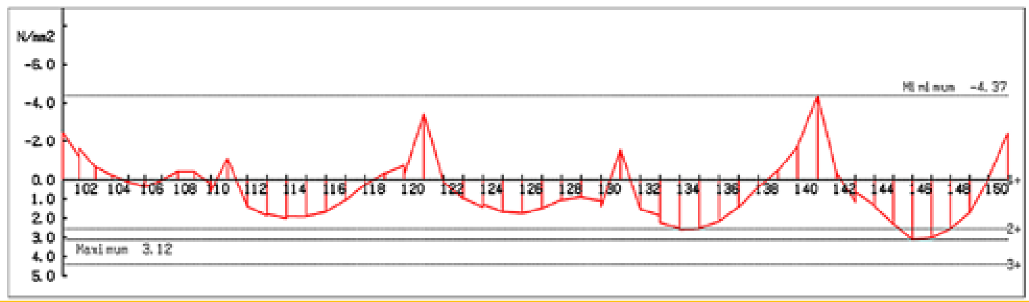

FIGURE 4: Maximum stresses at bottom fibre of structure for NA Loading – the end span showed, stresses slightly above the allowable limits for class 2 and as a result the modifications were designed as a class 3 structure (stresses shown are at full NA loading)

40 years old, its concrete behaves very differently to new concrete when tensioned. Secondly, the bridge had to be lengthened by 4m so the piles for the new abutment would not clash with the original driven piles, which remained in the ground. The increased length changed the loading and stiffness of the end span.

Careful modelling of the various stages of the bridge's construction, lifespan, demolition, reconstruction and future lifespan was done using advanced Bentley RM-Bridge software (Figure 3). The long-term prestress losses in the 40 year old portion of the deck are substantially complete, while the losses would only just be starting for the new portion. The designers needed to be confident that despite the future variability in prestress losses over time, the residual force at the prestress coupler would remain balanced and the connection would not be overstressed, which could have extremely serious consequences. The prestress in the new portion of the bridge is thus 64% of ultimate tensile strength, not 70% as per the as-built design.

It was reassuring that when modern NA and NB36 loadings were applied, it was close to a perfect fit, almost on the limit of the confines of a class 2 prestress structure (Figure 4). The effect of lengthening the bridge was for the end span to move from a class 2 prestress condition to a class 3 partially prestressed condition under full traffic loading, and it was designed with this in mind. The end span is thus still very capable of carrying NA and NB loads as per design codes

CHALLENGES

An unusually unstable old bridge

However, a number of complications were also confirmed, particularly relating to torsional stiffness and global stability. The bridge is completely straight in its horizontal alignment so has no intrinsic stability. The piers cannot help as each has just one bearing, so cannot provide any torsional restraint. The exclusive use of single-column piers gives a pleasingly sleek, minimalistic visual impression. But this means stability is only introduced at the abutments, which each have a pair of bearings. With the east abutment gone, the stability of the entire deck depended on that single additional bearing at the west abutment, 150m away.

Delicate demolition

The collapsed portion of bridge deck needed to be removed without causing the remaining portion to collapse and become unsalvageable or pose a safety risk for workers. Temporary stability was achieved with the urgent installation of ultra-heavy-duty 1 000kN props (Figure 5) on either side of each pier. The props had to be monitored and adjusted throughout the demolition and reconstruction phases, to balance the torsional forces

FIGURE 5: The remainder of the existing structure had negligible stability and needed to be carefully propped until construction was complete

FIGURE 6: Buried coupler being carefully exposed with sharpened chisels and no power tools

FIGURE 7: Sacrificial props maintained stability until demolition

FIGURE 8: The demolition process was designed to minimise environmental effects

released as the collapsed spans were removed and then replaced. They also had to be able to handle ongoing flooding that occurred during the course of the project.

Once a reliable stabilising system was in place, the deck was cut all the way through with a wire saw at a position 2m away from the ten critical prestress couplers.

The latest South African specifications state that "Water jet removal of concrete is preferred wherever possible" (Committee of Transport Officials 2020). However, on making enquiries it was found that it is still true that "techniques for cutting the concrete and exposing tendons are highly specialised and expensive. Water jetting with a grit additive will cut the prestressing tendons. To avoid damage to the steel, water jetting without an abrasive additive must be specified." (Telford, 1995). Due to high cost and lack of suitable options, couplers were instead carefully exposed by hand, with sharpened chisels to minimise any microcracking (Figure 6). The existing steel reinforcement was also treated with care, so new rebar could be spliced onto it.

Demolition of prestressed, post-tensioned concrete structures carries high risks in all situations, as high stresses are suddenly released or transferred by the severing of cables. Grouted cables may present less risk than unbonded cables, because the stress is distributed through the grout into the surrounding concrete along the length of the deck. However even so, it is still recommended to undertake "debonding trials", since even when bonded, "a tendon is likely to slip on each side of a cut position, causing longitudinal cracks along the line of the ducts until it re-anchors by bond action" (Pritchard, 1995). More critically, the International Federation for Structural Concrete (FIB) emphatically warns in extra-bold text that "During the initial stages of any demolition it must be ascertained that the grouting is effective." (Fédération Internationale Du Béton, 1982)

The FIB guidance was relevant, since when prestress ducts and cables were examined, none had been successfully grouted during the original construction, and the cables could not be treated as homogenous with the surrounding material. Grout had been introduced into the prestress anchors and couplers but had not travelled into the ducts. Fortunately, there was no indication of corrosion in the unbonded strands, and no violent effects were noted when the cables were cut, presumably due to constrictions and contortions of the ducts during the original collapse, which prevented the prestress energy being released.

Rather than push the damaged deck off its support and demolish it on the ground, it was decided to break it up in situ using chemical explosives, simultaneously with its original supports. Despite the latest South African guidelines being that "Demolition by explosive means shall generally not be permitted," (Committee of Transport Officials, 2020), it is still generally accepted that "all structures and heavy bridge decks can be most effectively brought to the ground with explosives" (Pritchard, 1995). Using explosives to demolish the bridge directly over its supports also reduced the environmental impact of having a much larger platform in the river alongside the existing footprint, and reduced the time spent breaking up the material for recycling.

The portion to be demolished was stabilised with lightweight, sacrificial falsework props (Figure 7), which needed to be accurately designed. If the props were too strong, they would be a large, unnecessarily wasteful expense, and might delay the collapse and cause it to happen in an unpredictable, dangerous way. If the props were too weak, the deck could collapse prematurely, in a similarly dangerous, unpredictable way.

With the deck wrapped in geofabric to prevent flying debris, a carefully designed sequence of closely timed blasts created a safe, predictable collapse (Figure 8). The blasts were also designed to ensure that their vibrations would not destabilise the remaining portion of the deck, or affect nearby railway lines.

Customised coupler components

A major setback was discovered when the prestress couplers were exposed: the VSL fittings from 1979 are not compatible with the prestress systems available today. Extensive enquiries were made among South African prestress suppliers, but only one of them, OVM, could supply coupling components for 12.9mm strand. Unfortunately, the swage thickenings supplied by OVM would still not fit into the grooves of the old couplers (Figure 9). The only option was to modify the modern swages to fit and test the results in a laboratory empirically.

Five 500mm long sample strands were tested. A 70mm long swage was crimped onto the end of

FIGURE 9: Comparing the existing couplers with the closest available match on the contemporary market

FIGURE 10: Temporary supports had to withstand repeated flooding

FIGURE 11: The new abutment is unusually heavy and sits behind extensive protection works

each, and then either 10mm or 15mm of the crimped swage was ground off. Loading was applied using a single strand, twin ram stressing jack.

The first tests aimed to apply 85% of the ultimate load capacity of the strand, for a period of several hours. However, because of difficulties with maintaining the tension in the samples, the samples were then also tested to failure. In all cases the swages were unaffected, and the strands snapped at a load of around 195kN. This was about 5% more than their theoretical load capacity of 186kN.

Since the modified swages showed no sign of failure or distress at 195kN, it was concluded that they could safely carry the tendon design force of 119kN/strand.

Furthermore, as has been described, the prestress force was reduced in the new portion of the bridge to balance time-related effects across the new and the old portions. This also reduced the likelihood of the custom-trimmed swages failing. There were nevertheless still risks, because stress flow in concrete around prestress couplers is very complex, and this would be accentuated by the difference in material behaviour between the new and old concrete. In 1980, a comprehensive study of 2431 German bridges found that 66% of German bridges with coupling joints had visible cracks in the region of the coupler (Seible, 1985). But careful monitoring under loading indicates that in this case the connection performs adequately, with none of the visible cracks that Sieble warns against.

Future-proofing

During construction the site suffered significant additional flooding (Figure 10). The irregular bend and susceptibility to flooding of the Umhlatuzana river make it hard to predict its behaviour, and ongoing development upstream will produce stronger flows in the future. To safeguard the City's asset and public safety, an exceptionally robust new abutment and wingwall were designed. A mass abutment with encapsulated fill material provides the stability to withstand high loads and is protected by very long wingwalls. It sits atop a large, monolithic, three-tier pile cap, which required careful design, detailing and construction monitoring to ensure no thermal or shrinkage cracks occurred in the complex arrangement. The 39 piles of 500mm diameter were installed with a specialised 'overburden drilling eccentric' method, otherwise known as an 'Odex pile' or 'Rota-pile'. This uses 'down the hole' percussion impacting to penetrate boulders, and pull down permanent casings, which prevent river scour effects. Extensive gabion protection works were added upstream on the east bank to prevent a reoccurrence of the flood-related erosion of the riverbank that had initiated the collapse of the original abutment.

RESULTS

Environmental Excellence

As discussed, the chosen solution was complex, but left the existing footprint of the bridge in the watercourse unchanged, saved 850m^3 of concrete in the existing bridge, and avoided a larger demolition that would have destroyed nearby trees with nesting birds.

All 620m^3 of demolished reinforced concrete was recycled. The concrete recycling was done on site – it was crushed to a maximum particle size of 75mm and mixed in a 50/50 ratio with excavated material to create G7 material for use in layerworks and abutment fill. Additional environmental measures included adding debris filters to nearby stormwater outlets and clearing all alien vegetation in the site vicinity. A specialist aviologist was appointed to reposition birds' nests adjacent to the collapsed deck, prior to the nesting season.

Close coordination

The unusual nature of the project and its many unknowns required extremely close coordination between all construction stakeholders. The design, project management and contract administration were all done by municipality-employed engineers, who could also take major decisions as representatives of the client and engage with risk management in a knowledgeable way with the experienced contractor, Icon Construction. Despite the emergency conditions, 30% of the contract needed to be given to an emerging community subcontractor, and the absence of typical work stoppages from strikes or business forums demonstrates this arrangement's success. Despite more flooding, and Covid-related delays, the entire project, including design, procurement, and construction, was completed in eighteen months, from May 2019 to September 2020, and within its budget of R36 848 530,00.

CONCLUSION

This case study establishes that partial reconstruction and lengthening of continuous post-tensioned concrete bridges is possible, most particularly in the case where prestress couplers are all clustered together at construction joints. However, it also highlights many of the risks involved in modifying existing structures. In addition to an experienced contractor and skilled design team, this project relied on a lot of good luck – particularly the availability of as-built drawings, the particular arrangement of the original prestress couplers, and the precise limit of the strains in the bridge deck during its collapse. If any of these things had not been in place, the bridge could not have been salvaged so effectively.

Modifying bridges with more complex prestress cable arrangements may be possible but would require additional research into retrofit mechanisms for anchoring prestress cables, such as the clamps described by Oukaili 2019.

RECOMMENDATIONS

The success of the project should inspire structural engineers to attempt similarly substantial restoration or modification of large concrete structures, even when elements are connected together in a unified structural system with prestressing tendons. In particular it establishes that decision-makers should consider modifying the length of continuous multi-span bridges rather than rebuilding them. This may provide opportunities to expand jack spans on other bridges to enable more lanes below or allow ramps for a loop interchange under the jack span. Reconfiguring the spans may be a more sustainable alternative to demolishing and rebuilding bridges where capacity is constrained.

Most importantly, the project demonstrates the value of in-house technical capacity for municipalities in the undertaking of complex projects where time, cost and safety risks need to be dealt with on an ongoing basis through the course of the project. An in-house project team can be particularly agile in dealing with these unpredictable scenarios and taking advantage of fortunate coincidences that may appear. Choosing to manage risk rather than avoid it has the potential to unlock significant benefits in terms of sustainability, and time and cost efficiency, which can have direct benefits for affected communities.

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PAPER 6

Estimating the Capital and Operating Costs of Development Proposals in Discouraged Growth Areas

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ABSTRACT

South African city governments bear the lifecycle cost of providing municipal services to customers in outlying locations and expect to recover these costs through rates and tariffs to cover the operating costs, and development charges to cover the capital costs of bulk and connector infrastructure. Significant variation in actual costs across geographic space suggests a distortion in the urban land market and an allocatively inefficient spatial outcome. This paper explores the policy and regulatory instruments available to metropolitan municipalities to mitigate against such distortions. It introduces a spatial costing method to enable municipal decision-makers to evaluate the capital and operating cost of a given property development proposed in a peripheral location; that is, beyond the reach of existing infrastructure master plans. By applying this method to Cape Town's Discouraged Growth Area, we find that it is possible to estimate actual costs accruing to the municipality in a rational, defensible and administratively simple way, using the city's own spatial and expenditure data.

INTRODUCTION

Urban scholars describe the persistence of dispersive residential growth as symptomatic of an underlying market failure in the urban land market; that is, the actual cost of peripheral development is not fully internalised into its pricing (Brueckner 2000). The 'hidden cost' of peripheral development frequently invoked by 'compact city' advocates are generally expressed in normative-ideological rather than quantitative terms (Davies and Imbroscio 2010), with a focus on environmental and social-, rather than fiscal-, impacts. Consequently, the semantic distance between, on the one hand, the widely accepted normative argument against peripheral growth, and, on the other, the circumscribed and sector-specific set of factors considered by city engineers and budget officials, has to date inhibited metros' ability to quantify and remedy these distortions dispassionately by means of credible quantitative methods.

Having adopted a fiscal lens to the question of the true cost of peripheral growth in South African cities, we firstly observe that tariffs and development charges intended to recover the cost of providing infrastructure and services are fixed, irrespective of the actual cost of providing services to the customer. Planners tasked with adjudicating development applications in conflict with long term spatial plans are precluded from considering lifecycle infrastructure costs in their determination of the desirability of the development. Were it possible to credibly show significant variation in actual costs of providing municipal services across geographic space, it stands to reason that fixed (i.e., spatially neutral) tariffs and development charges necessarily distort the efficient operation of the urban land market. Spatially variable actual costs are not being internalised in the location decision of developers, and ultimately, the purchase and tariffs born by homebuyers.

If geographic variation of costs is shown to be significant, it would imply that landowners in high-cost areas are effectively being subsidised by those in low-cost areas. The cost advantage enjoyed by users of land in high-cost area stimulates peripheral development beyond an allocatively efficient spatial outcome: that is, where the full marginal cost of a housing unit borne by the homebuyer, the developer and the municipal pool of landowners exceeds the marginal benefit of that unit to the homebuyer.

Introducing a systematic and data-driven spatial tool to estimate geographic variation in the cost of providing municipal services on explicitly fiscal grounds, using readily available spatial and financial data, may be a first step towards closing the distance between spatial planners, budget officials and engineers.

POSITIONING THE INSTRUMENT

Before introducing a spatial costing method, we first take stock of the legislative and regulatory instruments available to metro governments to remedy such land market distortions, were they shown to be significant. In this section we do a brief review of (1) the legislative imperative for cities to promote spatial sustainability and efficiency, (2) issues of a technical and practical nature to consider, and (3) identifying three instrument options accommodated within existing legal and policy frameworks.

1.1 Legislative rationale

The Spatial Planning and Land Use Management Act (Republic of South Africa 2013) establishes a number of principles governing land use management in South African municipalities: first, the principle of spatial sustainability (s7[b]), (iv) requires the promotion of effective and equitable land markets, and (v) the consideration of all current and future costs to all parties for the provision of infrastructure and social services in land developments, and (vi) the promotion of land development in locations that are sustainable and limit urban sprawl. Second, the principle of efficiency (s7[c]), whereby (i) land development optimises existing infrastructure, (ii) and decision-making procedures are designed to minimise negative financial, social, economic or environmental impacts.

FIGURE 1: Growth management instruments

To enact the principle of spatial sustainability, South African cities have generally relied on the urban edge as a relatively simple growth management tool to protect high potential agricultural land, raise the effective cost of peripheral development through constraining the supply of land, and create certainty for technical planning. However, in her survey of three South African metros, Horn finds evidence of disregard for urban edge policies, with the spatial logic of urban development directed by ad hoc public and private housing development applications rather than formally adopted planning policy (2019). The implied shift from a regional to a case-by-case approach to land use decision making tilts the emphasis from regional environmental and social factors towards development-specific and developer-calculated economic benefits and the number of housing units provided (Horn 2019).

This shift in approach culminated in Cape Town replacing its urban edge with a new instrument in 2017; such that all unprotected developable land beyond its erstwhile urban growth is designated as a "Discouraged Growth Area" (City of Cape Town 2018:6), where both capital and operating costs associated with the development will be borne directly by the developer, in the form of on-site provision and maintenance, or through administered fees which are reflective of actual development costs given the type and location of a given development. These administered fees may include, inter alia, development contributions or spatially differentiated tariffs and rates. Whilst these provisions are available to reduce fiscal impacts associated with unplanned growth, the municipality had not developed a method or tool to quantify fiscal implications of development proposals.

1.2 Technical considerations

The key technical question which arose is how to correctly estimate actual costs and incorporate this evidence into the initial development decision.

Simple instruments (e.g. an urban edge) are cheaper and less burdensome to administer, easier to 'explain to a judge', and creates certainty for both city officials and developers. An urban edge serves to trigger a number of additional controls by virtue of a proposed development's application, placing the onus of the applicant to demonstrate desirability in terms of site-specific circumstances. Judiciously implemented, an urban edge in principle and by design should achieve cost efficiencies by preventing unplanned, leapfrog development.

However, the strength of its rationale begins to falter at site-level. It becomes assailable for being arbitrarily delineated and out-of-touch with the demands of the property market and the economy more broadly. When assessed as a remedy for land market failure, an urban edge is an untargeted, undifferentiated binary instrument.

When intervening in complex systems such as cities, instruments designed on the basis of stylised 'rules of thumb' rather than nuanced and evidence-based understanding of the causal processes driving urban development are much more likely to generate unintended consequences and perverse incentives.

On the other end of the spectrum, actual costs associated with a given development can be estimated on a case-by-case basis by engineers using a range of sector-specific models. However, this will impose significant costs on either the developer or the local authority where a degree of preliminary or detailed design is needed to properly calculate the costs of service provision. If conducted by the developer, the city official will have little control over the underlying assumptions informing the cost estimation, or the range of factors being considered. Unless the city official can provide a template for such calculations which cover all municipal services and include both capital and operating costs, developer-driven estimates may result incorrect or inconsistent results.

The middle ground between the aforementioned simple instrument, and a detailed case-by-case costing study, is a multi-sector, spatially-sensitive cost estimation method which relies on a set of explicit assumptions and calculation techniques. An overly sophisticated method requires significant and ongoing technical capacity and data to set up and maintain, can be prone to estimation error and thus vulnerable to legal challenges and may generate ambiguous signals to officials and property markets. Thus, striking the balance between accuracy and practicality should be informed by (1) the threshold of accuracy required by law and policy, (2) the availability and reliability of spatially disaggregated expenditure data, and (3) the extent to which costs can be reliably estimated given the nature of bulk engineering service provision and the operations and maintenance of the infrastructure.

1.3 Legal mechanisms

A second important dimension in positioning the instrument is its interface with the land use decision making process. There is more than one possible point of entry with regards to applying the outputs of an envisaged spatial costing tool to the land use decision-making and condition-setting process. These may be broadly categorised into 'direct' and 'indirect' mechanisms:

1. <u>Direct application of the spatial costing tool as a fee-setting mechanism</u>, including (1) setting development contributions on the basis of anticipated actual capital costs, directly influencing the developer decision; (2) applying surcharges to rates and/or tariffs on an ongoing basis to recover the actual operating cost of providing services to end-users;
2. <u>Indirect application of the spatial costing tool as a guide to planning decisions</u>, including (1) as a source of evidence to inform the assessment of desirability, specifically to strengthen to argument for refusal; and (2) as the basis upon which to specify conditions for approval, including but not limited to maintenance guarantees and the establishment of homeowners' associations.

1.3.1 Spatial costing tool as a capital cost recovery mechanism

'Impact fees' are a common means to recover capital costs associated with development. Development charges ('DCs') is a local variant of impact fees. In South Africa, city policy typically provides that DCs can be increased on a geographical scale to recover costs more accurately within specific impact zones, although this is not currently being applied.

Actual costs can be calculated on a case-by-case basis where exceptional circumstances exist, such as an unprecedented scale of a development and where there is exceptional dependence or independence from municipal engineering services. However, DCs cannot be used for the purpose of achieving spatial planning or economic development objectives, and DCs should be administratively simple and transparent (City of Cape Town 2014).

1.3.2 Spatial costing tool as an operating cost recovery mechanism

Spatially differentiated tariffs internalise the true cost of providing services to prospective end users, thus enhancing citywide economic and resource efficiency by depressing the demand for development in higher cost areas. They are also more equitable and aligned to the cost of service principle, as they better account for variation in customer contributions, and reduce cross subsidies to high-cost customers. However, arguments against spatially differentiated tariffs are that they (1) raise administrative costs, (2) reduce the affordability of services for customers in some areas, (3) encourage off-grid options, and (4) undermine customer equity on a regional basis.

In South Africa, operating costs are nominally recovered through two mechanisms, property rates and tariffs. Property rates are governed by the Municipal Property Rates Act ('MPRA'), which states categorically that it is impermissible to differentiate rates on any criteria except land use categories and market value (S19), with the exception of Special Ratings Areas ('SRAs'), that allow for the levying of additional rates for the purpose of improving that area, and are thus are not suited to be applied as a mechanism for recovery of operating costs through differentiated property rates.

Tariffs are governed by the Municipal Systems Act (Republic of South Africa 2000), which empowers municipalities to establish internal municipal service districts ('IMSDs'), (S85) where municipalities may set tariffs, levies, special surcharges or increase tariffs (S85[3]). However, IMSDs must balance development needs, promote the citywide economy, contribute to integration and not entrench disparity. It may therefore be argued that the establishment of IMSDs, in furtherance of spatially differentiated operating cost recovery, is ostensibly reconcilable with governing legislation.

1.3.3 Spatial costing tool as a guide to planning decisions

Municipalities may adopt guidelines to guide decision-making in respect of applications made in terms of their Municipal Planning By-Law. Of the various criteria given for determining desirability (s99), the spatial costing tool may conceivably provide information with regards to (1) socio-economic impact, (2) impact on external engineering services, (3) impact on safety, health and wellbeing, (4) biophysical environment, and (5) transport impacts (City of Cape Town 2015). These metrics may be considered alongside motivations for site specific exemptions, and all other relevant spatial informants.

TABLE 1: Measuring desirability (Source: City of Cape Town Municipal Planning By-Law 2015)

Desirability criteria	Desirability metrics
Socio-economic impact	• Bulk capital cost / service / EDU
Impact on external engineering services	• Operating cost / service / EDU
Impact on safety, health and wellbeing	• Distance to social facilities
Impact on biophysical environment	• Distance to emergency services
Transport impacts, parking, access	• Transport-related emissions

(HOW) DO COSTS VARY IN SPACE?

The motivation for developing a spatial costing tool is underpinned by three core assumptions, which will be interrogated in this section: (a) actual costs vary in space; (b) costs in peripheral locations are greater than in other areas of the city; and (c) it is technically possible to calculate actual costs with a reasonable degree of accuracy. In examining these technical questions, it is important to differentiate between capital and operating costs. This section will discuss the costing methodology that has been applied.

1.4 Capital costs

The capital cost of infrastructure varies according to the capacity of the infrastructure (such as the size of the pipeline, or the carrying capacity of the road) and the extent of the infrastructure (i.e. its length). In order to calculate capital cost factors, we applied the concept of an Equivalent Development Unit ('EDU') as a standardised unit of demand – equivalent to a low-middle income dwelling unit. The use of standardised units of demand controls for the effect of infrastructure capacity on cost, resulting in cost variation determined solely by the extension to infrastructure required to service the EDU (i.e. through connector or link infrastructure). The location of the proposed development should be known in relation to (a) the distance to the bulk water network, (b) the distance to the bulk sewer network, (c) the distance to the medium voltage electricity network, (d) the distance to the primary road network, and (e) the distance to the nearest landfill or solid waste transfer station.

The richest sources of empirical findings with regard to actual capital costs across space in Cape Town are the Cape Town Growth Options study (City of Cape Town 2012) and the Medium-Term Infrastructure Investment Framework (City of Cape Town 2017), which found that the main determinant of geographic variation in capital costs is the extent to which scale efficiencies have been realised by the magnitude of development within a given network or service district. In other words, capital cost efficiencies are chiefly realised through orderly growth within predefined catchments, because of the ability to correctly plan, size and phase, and thus fully utilise – bulk and connector infrastructure. Accordingly, ad hoc and unanticipated patterns of development are significantly more costly than incremental, contiguous and planned growth. Since the rate of development within a given catchment is central to the estimation of capital costs, the latter cannot be systematically and accurately estimated in the absence of a credible 20-year land use model and high level master plan. It may only be assumed that large out-of-sequence development is likely to have disproportionately high capital cost implications. It is therefore recommended that in these cases, capital costs are estimated on a case-by-case basis, closely guided and monitored by planning officials.

Table 2 shows the different bulk and connector factors and data sources that were considered when calculating the capital costs. Note that for the bulk systems, the DC's for these services had already been calculated.

1.5 Operating costs

The conceptual framework that was applied to the operating cost allocation assumes that only a portion of operating costs vary in space. The portion of costs that are spatially neutral are either determined by the number of customers on the service (called 'fixed costs' because these costs are spread among existing and future customers) or by the quantity of the service provided (called 'demand-driven costs' as these will vary directly with the quantity of the service delivered). Spatially variable costs are also divided into those that are determined by the location of where the service is provided (called 'unit driven costs'), or by

TABLE 2: Capital cost factors

	Connector infrastructure	Bulk infrastructure
Water	DGA broken into 6 zones. Added bulk pipelines, servitude, storage and pumping if required.	Water DC + marginal cost of additional capacity, if required
Sanitation	Spatial distance and elevation analysis to determine most efficient path for infrastructure to bulk network. Added gravity and rising main costs, servitude and pumping where necessary.	Sewer DC + marginal cost of additional capacity, if required
Electricity	Capacity and distance variable cost according to CCT calculator includes feeder bays, customer site building, site switchgear, and 11kV cabling.	Shared Network Charge depending on Eskom or City area
Roads	Distance to main road network multiplied by standard unit cost.	Roads DC
Stormwater	Not possible to determine at coarse scale + policy to detain stormwater on site.	Stormwater DC
Solid waste	Threshold used to determine transfer station requirement.	Waste DC

the quantity of the service that is provided in a particular location (called 'demand-driven costs').

The four cost groupings are therefore called:
(1) spatially variable demand-driven costs,
(2) spatially variable unit-driven costs,
(3) spatially neutral demand-driven costs, and
(4) spatially neutral fixed costs.

The spatial unit of analysis of spatial variation and output of the operating cost modelling is an EDU, which is located at a point in space and has a service demand profile associated with it. The unit of analysis of the existing cost data is the service district (the size of which varies by service). The entire service district budget is included in the analysis, as this represents the real expenditure in providing the service which is the basis that the tariffs are set on.

It is important to note that this actual expenditure does not necessarily represent the cost of providing an adequate level of service, but only the actual expenditure incurred to maintain the current level of service.

The concept and resulting methodology was applied to roads, stormwater, water, sanitation, electricity and solid waste. Public transport operating costs are inherently spatial in nature and have been calculated based on modelled modal splits and trip distances, rather than on the methodology described below. Municipal public services and provincial social services have not been included in the analysis because the impact of space on these services is unclear, given that different levels of services are provided at different spatial scales, and the operating costs are determined more by the number of each facility that is provided, rather than their spatial location.

1.5.1 Calculating spatial drivers of operating costs

The methodology to calculate the operating cost drivers is described below:

Identify operating cost drivers (step one)

The cost drivers are the factors that affect the costs of delivering a service. These are generally well known to line departments that are responsible for the delivery of the service. These costs can be spatially variable or fixed. The factors should be reduced to a single proxy indicator for which city wide spatial data could be obtained. For example, the mean slope of the area is taken as a proxy for the amount of pumping required to get wastewater and stormwater to the treatment works and stormwater outfalls respectively.

Once identified, the range of relative impact of each spatial cost driver on total cost should be estimated by officials and external professionals, which should be the starting point for the iterative analysis (step three).

The cost drivers considered for each service are shown in Table 3 below.

Analyse actual expenditure per district (step two)

The only quantitative evidence for spatial variation in operating cost is the actual expenditure incurred by line departments in different locations in the city. The only spatially referenced expenditure is that which is recorded against the various districts for each service. This data source is limited in the following ways: (a) not all expenditure is recorded against the spatially located cost centres – some cost centres are centralised, but expenditure is dispersed differentially throughout the city; (b) districts are relatively large with wide variations in spatial characteristics; and (c) expenditure is not equal to the actual cost of providing a proper level of service, as operating budgets are inevitably constrained.

The simplifying assumption is that all areas are underfunded equally, which enables the determination of spatial variation despite under funding; (d) district expenditure is determined by the budgets made available, which may be determined in a range of different ways, which may include historical reasons, or differing operating practices of the district managers, which are unrelated to spatial characteristics of the districts. While this issue is recognised, it has to be assumed that the district expenditure is generally related to the cost of providing the service in that district and has been revised over time to be equitable across the city.

While acknowledging the above limitations, district expenditure is the best data available and is used as a starting point to test the impact of each of the cost drivers. Detailed actual operating expenditure for the most recent financial year should be obtained for all the services, and each line item categorised according to the conceptual framework categorisation.

Spatially neutral fixed costs for the entire municipal service are divided by the number of customers in the city to derive a unit cost (R/unit), while spatially neutral demand-driven costs are divided by the total amount of the service provided in that financial year to obtain a unit cost (R/unit demand). Spatially variable demand-driven costs are divided by the

TABLE 3: Spatial drivers of operating costs, per service

		Water	Waste water	Electricity	Solid waste	Roads	Storm-water
Spatially neutral	Service level	X	X	X	X		
	Land use	X	X	X	X	X	X
	Density	X	X	X		X	X
Spatially variable, unit-driven	Distance to depot/landfill	X	X		X	X	X
	Age of fixed infrastructure	X	X	X		X	
	Intensity of land use	X	X	X	X	X	
	Mean slope		X				X
	Extent of infrastructure			X			X
	Bursts / blockages	X	X				
	Outsourced service provision				X		
	% Vacant erven adjacent to service			X			
Spatially variable, demand-driven	Elevation	X					
	Mean slope		X				

amount of the service consumed in each of the relevant spatial zones to obtain a unit cost (R/unit demand per area).

The calculation of the spatially variable unit-driven unit costs is the result of a further step described below.

Calibrate cost factors to match actual spatial variation in expenditure (step three)

This is the most complex of the steps in the methodology and has four sub-steps:

1. Calculate the total spatially variable unit-driven operating cost per district. Line items in operating budgets that are classified as spatially variable unit-driven costs and allocated to a district (or depot within a district) are summed to obtain a district total;
2. Gather spatial data to populate zonal attributes for each existing transport zone which encompass the existing built fabric. Spatial data can sourced from the city, or derived by performing spatial queries on the city's spatial data using GIS software;
3. Multiply the assumed spatial cost factor for each spatial cost driver by the spatial characteristics of each and the number of units in each transport zone to generate a theoretical cost per district. The initial estimates of the impact of each cost driver are used to initialise the iterative process. An assumed base unit cost (R/unit/year) is multiplied by a land use factor, and then by the product of all the spatial factors for a particular transport zone to obtain a spatially variable unit cost per land use for that zone. This is multiplied by the current number of units of each land use to obtain a total operating cost per transport zone. The operating costs of all transport zones within a district are summed to get a theoretical (modelled) cost for that district which could be compared with the actual costs;
4. Calibrate the cost factors within the permissible range to match the actual district expenditure as far as possible. Once the possible range of each of the spatial cost factors is defined, Microsoft's Solver function is used to vary each spatial cost factor to solve for the lowest variance between the modelled and actual costs per district. The Solver function uses a Generalised Reduced Gradient algorithm for this process, resulting in a regression analysis solving for a minimum sum of least squares of the difference between the modelled and actual expenditure. Once the optimum solution is obtained, variances between the modelled and actual district costs will still be observed, but these variances are deemed acceptable given the constraints to the district data methodology described above.

Using this method, we found that the extent to which operating costs vary in space depends largely on the type of service. Whereas over 90% of stormwater-related operating costs are spatially variable, over 90% of electricity-related operating costs are spatially neutral. In general, however, operating and maintenance costs per EDU may be determined in part on the basis of proximity-based and location specific (e.g. topographic) attributes. Therefore, it is technically possible to estimate operating and maintenance costs across space, even in absence of master plans, but for some services, the benefits associated with introducing spatially differentiated operating cost recovery may be too marginal to justify the costs associated with differentiated fee-setting.

Preparation of cost surface for peripheral study area (step four)

A grid cell of zonal attributes covering the peripheral study area is required in order to calibrate actual expenditure to spatial factors. The first step is the delineation of developable land beyond the city's growth boundaries into regular spatial units. In the case of Cape Town, a grid of 1x1km (100ha) cells is created using GIS software. Zonal attributes that impact on capital and operating costs are calculated, using cell centroids for spatial queries.

All spatial queries are performed using a combination of open source QGIS3 tools, including Raster Terrain Analysis, Point Sampling, QNEAT3 Pointcloud, Distance Matrix, Distance-to-Nearest-Hub and QChainage.

The table of attributes and corresponding data and methods used, are provided in Table 4 below.

Once calculated, these values are generalised to the grid cell. In other words, the entire cell assumes the attributes of the centroid of the cell. Where it is found that a connection from cell A's centroid to an adjacent cell B's centroid is less expensive than direct connection to bulk or road network, it is connected to the neighbour instead.

Apply unit costs to peripheral study area (step five)

Actual operating and capital cost factors calculated for each service within the existing urban area are transposed to the zonal attributes calculated for each grid cell in the peripheral study area, to arrive at an operating and capital cost surface. Once this has been created, it is possible to estimate the capital and operating lifecycle costs for a notional development in any developable, peripheral location.

TABLE 4: Table of spatial cost factors to be calculated per grid cell

Type	Attributes	Spatial data	Spatial method
Terrain	• Slope, ruggedness, and elevation	• Digital elevation model	• QGIS3 Raster Terrain Analysis plugin • QGIS3 Point Sampling Tool plugin (to extract elevation from DEM)
Network distance	• Depots, public transport hubs and landfills	• Facility point data • Road network (class 1-3 only)	• QGIS3 QNEAT3 Pointcloud • QGIS3 Distance Matrix
Straight line distance	• Nearest higher order roads, water treatment works, bulk water mains, electricity substation and gravity sewer	• Facility point data • Bulk water reticulation (where diameter >300mm and <1000mm).	• QGIS3 Distance-to-Nearest-Hub (Points) • QGIS3 Point Sampling Tool (to extract elevation from DEM) • QGIS3 QChainage – create vertices every 1km along line, and calculate elevation per vertex
Conditional paths	• Of which rising main, landfill or refuse transfer station	• Digital elevation model • Facility point data	
Vertical distance along path	• Bulk main or wastewater treatment works	• Digital elevation mode • Facility point data • Network line data	
Catchment data	• Electricity authority	• Electricity catchment data	• QGIS3 Join attribute by location

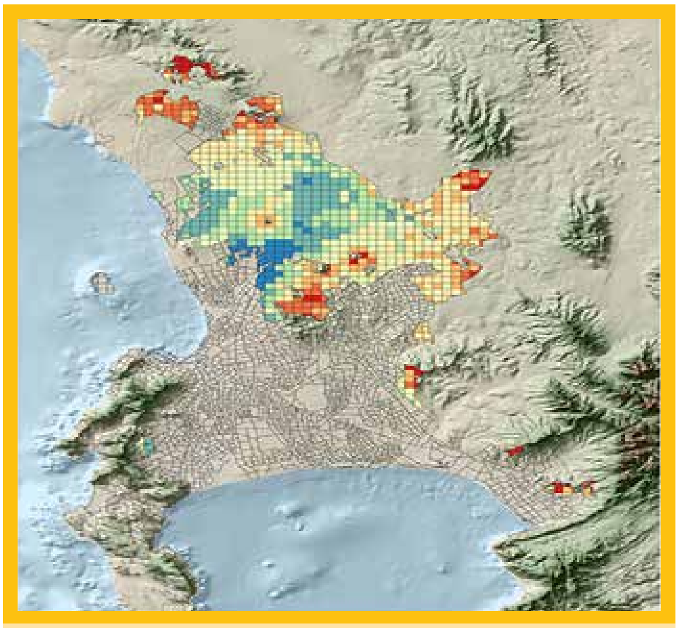

FIGURE 2: Operating cost surface (to City)

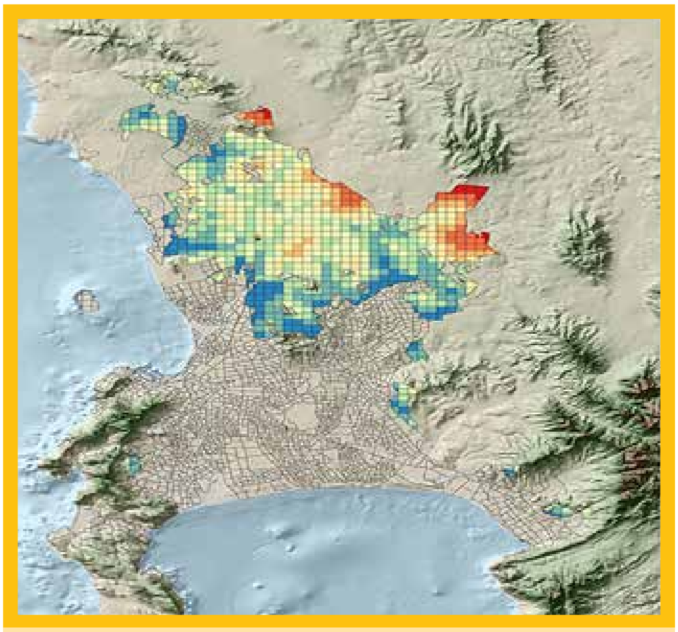

FIGURE 3: Capital cost surface (to developer)

MODEL OUTPUTS

1.6 Operating and capital cost surfaces for notional development

The map on the left shows geographic variation in operating costs for a notional development, accruing to the city. The range of operating cost differences within the Discouraged Growth Area is fairly small, varying by approximately 10% chiefly due to water pumping costs and distance to existing connector infrastructure.

On the right, the map shows geographic variation in capital costs for a notional development, accruing to the developer. The range of geographic variation within the Discouraged Growth Area is comparable to the city as a whole. The highest cost location is between five and six times more expensive than the least cost location, for an identical development. By applying a notional development (with given land use characteristics) to the cost surface, it is possible to generate the Net Present Value of (a) operating cost to the City, (b) capital cost to the City, (c) revenue to the City, (d) net financial position to the City and (e) capital cost to the Developer.

1.7 Assumptions

The spatial costing method and the corresponding results are contingent upon the following assumptions: (a) all developments are calculated in isolation (i.e. no cumulative effects are considered); (b) costs are based on the infrastructure layout as per the baseline year, (c) new bulk infrastructure are calculated at marginal cost based on development demand; (d) notional future developments are assumed to connect to the City network, except for sanitation capital costs which are capped at the equivalent cost of tankering septic tank waste to a given location. Package plants for water and sanitation are assumed to be unacceptable, and all new developments are assumed to become the City's electricity customers; and (e) public transport costs are excluded due to inadequate trip generation data.

CONCLUSION

In this article we describe a spatial costing method to estimate the capital and operating costs of a notional property development located in a peripheral area beyond the reach of infrastructure master plans. Although the method abstracts from some aspects of reality, it strikes an appropriate balance between accuracy and practicality, using spatial and expenditure data readily available in most South African cities.

The article highlights the potential for evidence-based tools to support cities' ability to evaluate land use applications in conflict with its structure plans, and as a credible evidence base to motivate for and spatially target the establishment of internal municipal service districts which reflect geographic variation of actual operating costs associated with providing municipal services. On the capital cost front, the analysis also highlights the likely gap between undifferentiated development charges unit costs and actual capital costs. Finally, the article highlights the importance of cities taking a clear policy position on the question of off-grid infrastructure.

We find that metro governments will derive efficiency benefits from coupling efforts to enhance data-driven decision-making capacity with ongoing refinements to the setting of tariffs and the adjudication of peripheral land development applications.

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PAPER 7

Re-watering of West Rand Dolomitic Compartments: Implications for JB Marks Local Municipality

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ABSTRACT

The Far West Rand goldfield represents one of the richest gold mining areas in the world overlain by one of the largest dolomitic aquifers in the world. This posed unique challenges to underground mining development as well as the surface municipal development. During the peak of gold mining in the Far West Rand a decision was made to reduce the large influx of dolomitic groundwater into the underlying mine void by dewatering the >1.2 km thick dolomitic compartments. By dewatering the dolomitic compartments significant sinkhole formation and widespread ground instability was initiated, a situation which still poses challenges for development in this area. Mining is not a sustainable practice, and many gold mines are closing down operations. Mining adversely affects not only water quality but also quantity, posing a significant risk to water resources in the Mooi River catchment.

Although various scenarios predicting the post-mine closure consequences have been modeled, the uncertainty remains. However, all modeled scenarios are in agreement on three important aspects: 1) the water quality for downstream users (including JB Marks Local Municipality) will be compromised; 2) the quantity of water reaching the downstream users, during the period after pumping ceases and the time the mine void and overlying dolomitic compartments have naturally filled-up and contribute to the water resource, will be compromised and 3) renewed surface instability due to sinkhole formation and potential re-activation of existing sinkholes will pose a threat to infrastructure, built environment and socio-economic development in the catchment. Unless the complexities of the long-term risks associated with post-mine closure are addressed in a coordinated manner as a matter of urgency through a rational and integrated spatial planning process and strategy formulation the risk of a socio-economic impact in the not-too-distant future is a certainty. Additionally, environmental pollution, dysfunctionality of infrastructure (transport, roads, water, and sanitation) and compromised sustainability of the built environment will impact negatively on economic growth in the region.

1. INTRODUCTION

South Africa is a water scarce country and already utilise 98% of its existing freshwater resources intensively (WWF 2016). Water is considered a key limiting resource for South Africa which may negatively affect social and economic development (Blignaut and van Heerden 2009). The sustainable use and management of water resources is therefore becoming vital. The situation would be further exacerbated by the effects of climate change and hydrological variability and future social and economic pressures (Mukheibir and Sparks 2003). The protection and utilisation of natural resources therefore needs to be managed in an integrated approach to achieve sustainable development as expressed in the Sustainable Development Goals (United Nations Development Program (UNDP) 2020).

Strategic surface water and groundwater source areas (SWSAs) of national importance are those considered worthy of protection because they are the only or primary source of water that sustains society and the associated economic activities in a specific area (Nel et al. 2013; Le Maitre et al. 2018a; Le Maitre et al. 2018b). Fifty-seven groundwater WSAs were identified in South Africa of which the Far West Karst region is relevant to this study (Le Maitre et al. 2018a).

In addition to the scarcity and variability of the available water resources, deterioration in the quality of South Africa's water resources, as a result of both past and current developments in addition to poor enforcement of legislation, place additional strain on safe water provision (DWS 2018). Land and water degradation, together with their subsequent impacts on land and water users, cannot easily be separated or managed independent from one another. Furthermore, catchments are often divided by provincial and other political or administrative boundaries and inter-basin transfers allow water to cross catchment boundaries. Therefore, co-ordinated and integrated planning and implementation are required at all levels, from national government through provincial authorities to individual landowners.

South Africa moved away from the traditional fragmented or supply-oriented water management to Integrated Water Resource Management (IWRM), which is a holistic approach that seeks to integrate the management of the physical environment within the broader socio-economic and political framework (UNESCO 2009, Jonker 2014).

JB Marks Local Municipality was established by the amalgamation of Ventersdorp Local Municipality and Tlokwe City Council Local Municipality on 3 August 2016 (Municipal Demarcation Board (MDB) 2018). The JB Marks Local Municipality relies on both surface- and groundwater as water resources (IDP 2019; Van der Walt et al. 2002, Nealer and Raga 2008a; Nealer and Raga 2008b). The surface water supply is via the Mooi River Catchment (a total area of 1 800 km^2) which includes the Mooi River, Wonderfontein Spruit and Loop Spruit (Figure 1). The Wonderfontein Spruit crosses the provincial boundary between North West and Gauteng Provinces as well as the municipal boundary between JB Marks Local Municipality and Merafong City Local Municipality (MLM) (Van der Walt et al. 2002) (Figure 1). JB Marks Local Municipality is both a water service authority (WSA) and water service provider (WSP) in terms of the NWA (Act no. 39 of 1998) and Water Services Act (WSA) (Act no.108 of 1997. In this regard, the municipality is responsible for ensuring access to water services (governance function) and the provision of water services to consumers, in accordance with the relevant legislation.

1.1. Hydrology

In the Far West Rand karst north–south trending dykes intrusive into the dolomite formed impermeable barriers, effectively forming separate groundwater compartments (Figure 1). Where groundwater reaches the downstream dyke barrier it breaches the surface and create springs (Enslin and Kriel 1959, 1968; Swart et al. 2003a).

Soon after deep level mining in the Far West Rand goldfield (between

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Randfontein and Carletonville) started (1960s) underground mining operations were constantly flooded by groundwater from the overlying dolomitic karst aquifer. To protect mining operations, below the karst aquifer from re-circulating and constantly pumping water from the mine void, authorities granted mines permission to partly dewater the dolomitic aquifer (Venterspost, Bank, Oberholzer compartments) in 1960 (Swart et al. 2003a). This involved extracting more water than would naturally recharge the karst aquifer and discharging it outside the boundaries of the compartment, effectively lowering the groundwater table (up to 1 000 m).

Dewatering of the dolomitic compartments however, had an unavoidable consequence of extensive ground instability in the form of sinkholes and dolines and the drying up of high-yielding karst springs and irrigation boreholes (Swart and van Schalkwyk 2001; Swart et al. 2003b; Winde and Stoch 2010; Winde & Erasmus 2011). After the extent of the ground instability due to dewatering became evident in the 1960's Government established committees such as the Far West Rand Dolomitic Water Association (FWRDWA) and the State Co-ordinating Technical Committee (SCTC) to research, monitor and manage the consequences of dewatering (Phogole and Mulaba-Bafubiandi 2013). The majority of cavities that open to surface were never rehabilitated but sinkholes which posed a threat to roads, railway lines and building infrastructure, physical danger to people in highly populated areas or warranted from an aesthetic perspective were backfilled (Swart and van Schalkwyk 2001; Swart et al. 2003; Dill et al. 2007). Materials historically used for backfilling of these cavities include soil, mine waste rock, tailings and cement or a mixture thereof (Dill et al. 2007).

In addition, water of the Lower Wonderfontein Spruit has been diverted into a pipeline (often referred to the 1 m pipeline) from the outflow of Donaldson Dam transporting water for a distance of 32 km over the dewatered dolomitic compartments (Oberholzer, Venterspos, and Bank) (Van der Walt et al. 2002). The pipeline transports water which has been impacted by anthropogenic activities (urban settlements, wastewater treatment works and defunct gold mines) from its origin on the continental divide situated between Randfontein and Krugersdorp and fissure water from operating mines to the discharge point into a cement lined channel near Oberholzer/Carletonville (Swarts et al. 2003). Mine fissure water and water from wastewater treatment works (WWTW) join the Lower Wonderfontein Spruit before the confluence with the Mooi River upstream of the Boskop Dam, the main reservoir for the water supply of some 250 000 residents of JB Marks Local Municipality (Potchefstroom). Several springs occur along the Mooi River upstream of the Boskop Dam

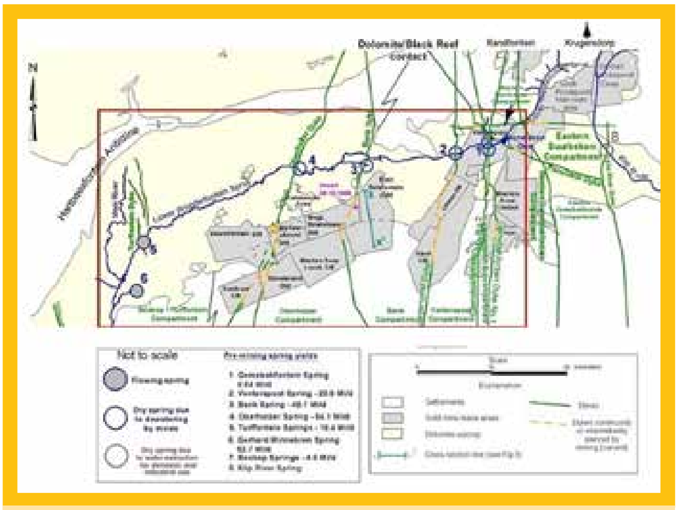

FIGURE 1: Map of the Mooi River catchment (Swart et al. 2003b)

and become part of the water supply for JB Marks Local Municipality. From the Boskop Dam, situated ±12 km north of Potchefstroom, water intended for purification and drinking purposes flows southwards, routed via an open-top cement canal on the western side of the Mooi River, from where it flows to the city's water purification plant (capacity 33.6 Mℓ/day) located to the west of the Potchefstroom Dam (Annadale and Nealer 2011). The Potchefstroom water treatment plants have been described as operating close to maximum capacity to meet consumer demand and has regular interruptions/ water shortages in some areas (Bult, Ikageng, Promosa, Dassierand, Potchindustria, CBD) (IDP 2019).

1.2. Threats to potable water resources quality

Activities upstream of the JB Marks Local Municipality treatment plant include agriculture, industrial, gold mining, urban areas, informal settlements and diamond digging in the Mooi River catchment (Barnard et al., 2013). Pressures on the Mooi River Catchment are growing amidst development and urban expansion around Potchefstroom as well as the West Rand District Municipality (WRDM) and Merafong City Local Municipality (Westonaria, Oberholzer and Carletonville and Khutsong) (Van Eeden et al. 2009; Van Eeden & Nealer 2011).

The threat from mining activities has been documented by several studies and monitoring programs between 2002 and 2017 which reported mining impacts on the surface water quality as well as sediments and wetlands (Wade et al. 2002; Coetzee et al. 2006; Barthel 2007; Winde 2010a; Winde 2010b; Winde 2011; Winde and Erasmus 2011; Barnard et al. 2013; Labuschagne 2017; Pretorius 2017). The main concern related to mining activity is the formation of acid mine drainage (AMD) and U contamination (Coetzee et al. 2006; Winde 2010, 2011; Winde and Erasmus 2011). Although the impact of mining on the water quality and sediments of the Wonderfontein Spruit has been known and studied thoroughly (Coetzee et al. 2006; Winde 2010a; Winde and Erasmus 2011; Winde 2011), water from the Upper Mooi River, before the confluence with the Wonderfontein Spruit, as well as the spring water of the Gerhard Minnebron (GMB) has always been considered to be almost pristine when compared to the Wonderfontein Spruit (Winde and Erasmus 2011; Winde 2011). However, recent studies showed a deterioration of the water quality at the springs in the un-dewatered Boskop-Turffontein compartment (Winde and Erasmus 2011; Winde 2011). Winde and Erasmus (2011) found a sharp increase in the radionuclides (U) load at the dolomitic springs which are linked to mining activities. A previously unknown linkage to the Wonderfontein Spruit via a network of underground karst channels in the un-dewatered Boskop-Turffontein compartment, which are in some way linked to deep level gold mining and/or sinkholes filled with mine tailings, were proposed (Winde and Erasmus 2011; Winde 2011).

A study by Dill et al. (2007) found that the past practice of backfilling of sinkholes with gold tailings has a high risk of causing impacts on the dolomite aquifer once mines close and dewatering of the dolomitic compartments are ceased. Dill et al. (2007) suggested that U levels of up to 300 mg/L are to be expected in leachate from tailings suggesting that tailings-filled sinkholes will be a major groundwater pollution risk. The World Health Organisation (WHO) limit for U in drinking water is 15 µg/ℓ (WHO 2006). Winde (2010a); Winde 2010b) and Winde and Erasmus (2011) reported an average U level downstream of the Wonderfontein Spruit between 55 and 79 µg/ℓ compared to the regional natural background of 0.8 µg/ℓ measured at the origin of the Mooi River at Bovenste Oog.

Pulles et al. (2005) suggested surface decanting of AMD is likely to occur to some degree in the Far West Rand after mining ceases and mine voids are flooded. In addition, the potential leaching of AMD from discard dumps such as tailings storage facilities (TSF) into the dolomitic aquifer is high (Dill et al. 2007). Although dolomite may neutralise the acidic metalliferous seepage related to mining, the armouring effect of dissolved iron in the AMD may result in a coating forming on the dolomite surfaces hindering dissolution rates and lowering the neutralisation potential (Dill et al. 2007). Modelling indicated that U would leach from tailings for 50 to 100 years (Dill et al. 2007).

Although the U load reaching the Boskop Dam is still considered relatively low compared to that in the Wonderfontein Spruit, the significant and persistent increase suggests a reason for concern. Should this trend continue significant U loads may contaminate the main water supply reservoir of JB Marks Local Municipality. Wetlands, such as that found around the springs are known to act as a passive water treatment system, removing harmful elements such as U and other contaminants from the water column by fixing it in the organic peat (Winde 2010; Winde and Erasmus 2011). However, Winde and Erasmus (2011) estimated that almost 60% of the peat in the wetland around the GMB has been extracted for potting soil and mushroom production. It is unknown to what extent the buffering function of the remaining peat deposits has been compromised.

1.3. Threats to potable water resources quantity

The post-mine closure water quality is, however, not the only concern when water security is considered. The availability of water to down-stream users (including JB Marks Local Municipality) will be influenced by the cessation of mining operations in the Far West Rand (Usher and Scott, 2001, Swart et al., 2003). Cessation of mining operations including cessation of pumping water from underground and disposing that into the Mooi River Catchment will not only have an immediate impact on the volume of surface water available to down-stream users, but it will over the long-term effectively lead to re-watering of the dolomitic compartments overlying the mine voids (Usher and Scott 2001; Swart et al. 2003).

Mining not only extensively augmented the underground storage capacity by creating voids in the rock beneath the dolomite, but mining through compartmentalising dykes effectively linked mine voids thereby changing the hydraulics of the system. This resulted in uncertainty on how the system will react once mines reach the end of their life span and pumping ceases (Usher and Scott 2001, Swart et al. 2003). Various authors attempted to model the time it will take for the mine void and de-watered dolomitic compartments to fill up naturally through infiltration from surface and estimated periods ranging from 30 years (Usher and Scott 2001, Swart et al. 2003) to 60 years (Jordaan et al. 1960; Lin and Lin 2014). However, these predictions are based on assumptions and remain largely untested. How the hydrogeologic system will react after the pumps are switched off is a topic of contention as two post mine closure scenarios have been proposed for the changed hydrogeological system: a mega-compartment scenario and a separate (pre-mining) compartment scenario.

In the mega-compartment scenario, it is proposed that mining, which pierced the dykes well below the actual karst aquifer, will hydraulically link the interconnected dewatered compartments and the downstream un-dewatered compartment resulting in a mega-compartment to form upon rewatering (Jordaan et al. 1960; Usher and Scott 2001; Swart et al. 2003). The underground connections will ultimately result in a single nearly horizontal water table which would cut across all the affected dolomitic compartments. Usher and Scott (2001) proposed that the water level in all the previously dewatered compartments will rise synchronously with a final water table in the mega-compartment remaining below its pre-mining level. This water level would be the elevation of the lowest lying springs i.e. the two Turffontein eyes, the GMB eye and possibly some smaller springs in the Boskop-Turffontein compartment, with karst springs in all upstream compartments remaining dry indefinitely despite re-watering of the karst aquifers. This scenario predicts a flow increase in the lowest lying Turffontein and GMB springs (combined pre-mining springs volume of 133 Mℓ/d) (Swart et al., 2003). However, polluted mine water would decant to surface from the mentioned springs (Usher and Scott 2001). This will therefore have implications for water quality in the JB Marks Local Municipality as water quality in the Mooi River would be compromised. Furthermore, this situation will not only have severe implications for post-mining water quality and availability but also land-use planning in the West Rand District Municipality and Merafong City Local Municipality (Jordaan et al. 1960; Usher and Scott 2001).

In the separate (pre-mining) compartment scenario the re-watering of the mine voids will be followed by a rapid rise of the water table through the fractured rock aquifer before the dewatered cavernous karst aquifer is filled (Swarts et al. 2003). The possibility that the volume of the mine void may be reduced over time due to the roof closing-in due to pressures generated by the overlying rock is considered (Winde et al. 2006; Van der Merwe & Madden 2002). This will restrict the flow of water between compartments making the formation of a mega-compartment impracticable. Swarts et al. (2003) predicted that the pre-mining differences between groundwater levels of adjacent compartments will be re-established resulting in groundwater intersecting the surface leading to the rejuvenation of the original natural springs of the Mooi River and Wonderfontein Spruit (Swarts et al. 2003). Swarts et al, (2003) also allude to the possibility that the flow at the springs may only be half of the original capacity as the void which needs to be filled is now larger as it includes the mine void and only

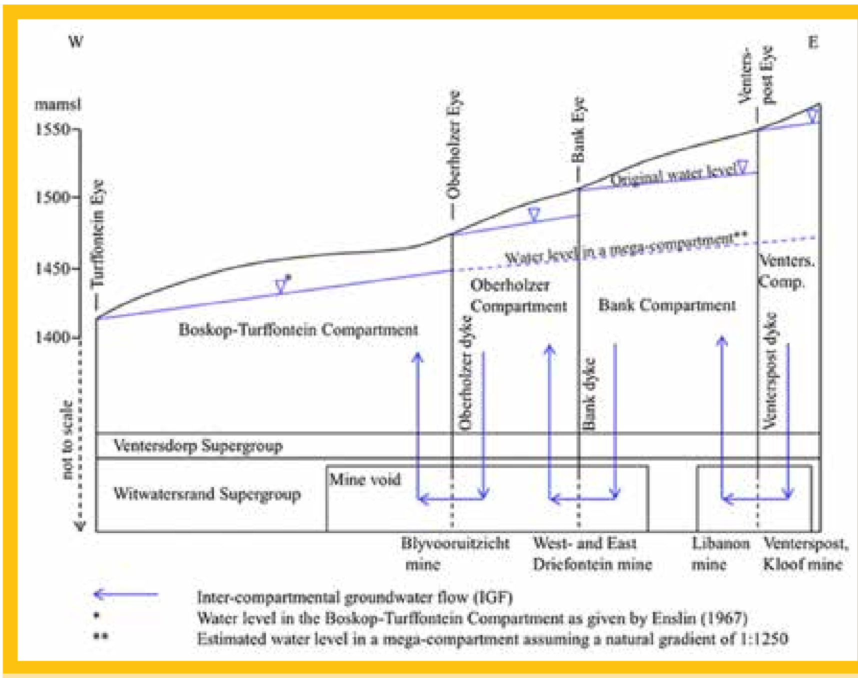

FIGURE 2: Conceptual model of the mega-compartment that could form in the FWR as a result of mining through impermeable dykes (Schrader et al. 2014)

during periods when the water level is sufficiently high will water flow from the springs.

Other impacts related to re-watering of the mine voids which might carry a risk to infrastructure and development in the area include:

Induced seismicity-

As production diminishes seismicity will decrease to background levels when mining operations ceases (Durrheim et al. 2006). However, seismicity is triggered by a rising water level in the mine void as water builds-up after cessation of pumping water to the surface (Cichowicz et al. 2016). Seismic events triggered by rising water level in mines that have been allowed to flood is likely to decrease once the water table in the mine void has stabilised (Durrheim et al. 2006; Cichowicz et al. 2016). Although further research on the link between seismicity and rising water levels are necessary, Durrheim et al. (2006) showed that it is unlikely that a seismic event triggered by a rising water table will have a greater magnitude than the events that occurred during mining. Although the damages from seismic activity around mining areas are small when compared to the damage experience in more seismic active areas around the world, damage to urban structures can be severe. Events with magnitudes exceeding 4 may cause some damage to buildings on the surface, while events with magnitudes exceeding 5 may cause serious damage (Durrheim et al. 2006). The risk of a seismic event on a mine causing damage to underground workings on a neighbouring mine depends on the distance between the focus of the event and vulnerable areas on the adjacent mines. There is some risk that a seismic event could cause movement on a fault surface transecting a water plug and/or water barrier pillar thereby opening up a fluid pathway which could cause flooding into populated mine workings (Durrheim et al. 2006).

Ground instability-

In addition to the potential threat to the water quality from sinkholes backfilled with tailings ground instability in the form of subsidence, dolines and sinkholes as a consequence of dewatering and lowering of the water table are a potential threat to infrastructure and development (Swart and van Schalkwyk 2001; Swart et al. 2003; Van Niekerk and van der Walt 2006; Richardson 2013; Schrader, Winde and Erasmus 2014; Schrader, Erasmus and Winde 2014; Constantinou and van Rooy 2018). Uncertainty regarding the potential for renewed instability exists as some studies suggest that no renewed instability will occur (Usher and Scott 2001) whereas other studies (Dill et al. 2007) propose reactivation of old sinkholes and development of new sinkholes (Swart et al., 2003; Van Niekerk and van der Walt 2006; Stoch and Winde 2010, Dill et al. 2007). Formation of dolines and sinkholes as well as re-activation of existing ones will pose a serious threat to important infrastructure such as the N12 highway and the main rail link between Pretoria and Cape Town (Dill et al. 2007; Phogole 2014).

2. CO-OPERATIVE GOVERNANCE

In the context of water security, the sustainability of the water supply from the Mooi River catchment is of concern. The Mooi River is exposed to many potential catchment related hazards that could seriously affect bulk water security of the JB Marks Local Municipality over an extended period of time. The municipality has the obligation to mitigate the impact of potential disasters within its boundaries (Disaster Management Act (Act 57 of 2002)). However, many of the impacts on the Mooi River catchment arise beyond the boundaries and control of the local municipality. This, however, does not relieve the municipality from the responsibility to develop and implement strategies to manage the risks. Effective risk management especially concerning the water quality and quantity is required.

Co-operative governance cuts across various governmental spheres. The Constitution (SA, 1996) stipulates a governance system that compels "all spheres of government and all organs of state" to co-operate with each other in "mutual trust and good faith". This should be taking place among all public sector departments, regardless of the activity and its location in the project cycle. The most important legislation, which has direct and important bearing on the environmental effects of mining, are the National Environmental Management Act NEMA of 1998 (Act, 107 of 1998), National Water Act (Act of 1998), Minerals and Petroleum Resources Development Act (MPRDA) (Act 28 of 2002). The NEMA (Act, 107 of 1998) and the National Water Act (Act 36 of 1998) support co-operative governance, for example, through the provision for arrangements such as catchment management agencies and environmental cooperation agreements.

3. REGIONAL MINE CLOSURE

Currently operating mines are required to rehabilitate any environmental damage that may occur during mining and to make financial provision for the rehabilitation of such damage (Mineral and Petroleum Resources Development Act (MPRDA) (Act 28 of 2002)). A closure certificate will be issued only if the Chief Inspector of Mines and other relevant government departments (Water and Sanitation, Environmental Affairs) are satisfied that provisions relating to health and safety and water pollution prevention/ management including the pumping and treating of water, and compliance with the conditions of the environmental authorization as part of the environmental management plan have been addressed. This requirement by legislation was put in place to hold mining companies accountable for pollution impacts and to minimize government's liability of post-mine closure acid mine drainage decant. Most mining companies comply with the minimum requirements to environmental management and rehabilitation. However, additional challenges in governing mine closure were highlighted by the cumulative pollution decanting from the West Rand goldfield where mines are hydrologically interconnected and impacted on the environment through decanting of AMD from the lowest lying mine infrastructure (Hobbs and Cobbing 2007; McCarthy 2010; Durand 2012). The cumulative impact from all the mines in a region could therefore be imposed upon the last operating mine in the region, which could be held liable for the cumulative impact of all the mines. Furthermore, a number of large underground mines are interconnected and share the responsibility to dewater the mine voids (van Tonder et al. 2009). As different mines within a region will cease operations at different times the dewatering responsibility will rest on the remaining mines with the last operating mine bearing the rewatering liability for an entire mining region. It is therefore important to coordinate the cessation of mining activities to ensure proper apportionment of liability to the contributing mines within a region and to coordinate the potential socio-economic impact of mine closure on the community.

The trend in South Africa is that mines are placed on care and maintenance due to their inability to secure a closure certificate, particularly for large-scale mines.

The concept of the regional mine closure was born from the potential risks of cumulative environmental and socio-economic impact of interconnected mines in a region (van Tonder et al. 2009; Pulles et al. 2005). Regional mine closures therefore propose a new approach away from the historical site-specific mine closure to a more integrated approach where all mines in the region have to work together to limit environmental and socio-economic impacts (van Tonder et al. 2009).

Due to the fact that most mines in the Far West Rand are hydrologically interconnected, this area is a good candidate for a coordinated plan or regional mine closure plan to be implemented as closure of one mine will impact on the remaining mines (van Tonder et al. 2009; Pulles et al. 2005). A good example is the Ezulwini operations seeking a closure certificate but was forced to continue pumping water to prevent flooding of the adjoining mining operations.

Furthermore, the regional mine closure strategy calls for the involvement of all affected local and district municipalities and national government departments to set a framework within which these mines can plan for mine closure (van Tonder et al. 2009).

The Constitution of the FWRDWA places the responsibility of reducing impacts and managing the water on all member mines until rewatering has been completed (Phogole, 2014).

4. CONCLUSION

This research highlights areas considered of utmost significance for the current and future municipal managers and officials who are tasked with the more effective, efficient and economic public management and delivery of potable water services within the demarcated municipal area of the JB Marks Local Municipality.

It is of utmost importance that the re-watering of the mine void in the FWR and the associated effects on the dolomitic compartments are well understood to avoid uncontrolled re-watering and pollution as seen in the West Rand. Where potential decant points of mining contaminated water will be and what the quality of this decanting water will be are still not confidently defined. The hypothesis that a mega-compartment will be formed that will have no impact on water security and treatment costs in the case of JB Marks Local Municipality is not the only possibility and due to geological mechanisms and forces in deep level mining should therefore not be the exclusive model used in post-rewatering impact planning. However, notwithstanding which scenario will be proven to be correct, the quality of eventual outflow will be highly contaminated, requiring additional cost in improving the quality through bulk water purification. It thus implies not only to ratepayers in terms of knock-on costs but for all governmental institutions depending on water sources in the entire Mooi River catchment, including users downstream of JB Marks Local Municipality eventually the Vaal River.

A steady deterioration of quality of water from the springs in the Boskop-Turffontein compartment as a direct consequence of mining and surface-ground water interaction is a forewarning of what can be expected over the rewatering period and for extended periods thereafter. Future generations and governmental organisations will be responsible to deal with lower quality (AMD, heavy metal and U contamination) of the bulk water supply of the JB Marks Local Municipality. The quality of raw water supply may require alternative technology processes for treatment not currently installed at the water treatment plant. The rewatering will thus result in financial implications in the delivery of bulk water services by JB Marks Local Municipality and local ratepayers.

The uncertainty regarding the re-watering of the mine void and overlying dolomitic aquifer highlights the risk of JB Marks Local Municipality losing part of its current bulk raw water supply. This uncertainty is therefore of concern as future sustainability of the municipality may be severely compromised if alternative water supply is not planned in time.

The degree to which ground stability will be affected by recovering water tables, possibly leading to the re-activation of existing sinkholes and formation of new sinkholes within the Far West Rand has not been quantified yet. Induced seismicity might have impacts on surface infrastructure not considered currently as the magnitude of potential future seismic activity has not been fixed.

Due to the trans-boundary water and instability issues cooperative governance between JB Marks Local Municipality, Merafong City Local Municipality, and the West Rand District Municipality and provincial as well as national governmental spheres are important for sustainable development in the region. As the karst aquifers are considered strategic water source areas (SWSAs) of national importance the integrated water resource management of this resource require involvement of all governmental spheres.

Although historic structures such as the FWRDWA and SCTC has the obligation to maintain control of the impacts of rewatering, the functioning of these committees is uncertain and cannot be considered as a safeguard against potential threats to water security and land stability. The proposed Regional Mine Closure strategy was not implemented leaving the question as to how mine closure is being coordinated and whether sufficient attention is paid to long-term impacts beyond the gold mining basin. The functioning of these structures along with cooperative governance on all spheres of government should be coordinated to safeguard water security of the JB Marks Local Municipality. However, no evidence could be found of prior research constructing a cooperative governance framework that could guide and assist mining companies in the Far West Rand in their decision-making and actions when dealing with the imminent mine closure and post-mining impacts on the region.

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PAPER 8

Planning and Implementing Large-Scale Groundwater Supply Schemes

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ABSTRACT

The TMG Aquifer has been under consideration as a potential water supply option for the Cape Town metropolitan area since the early 1990s. Subsequent to a comprehensive water resource planning study for Cape Town and the surrounding metropolitan areas, the TMG Aquifer was studied at feasibility level by the City of Cape Town (CCT) from 2001 to 2013 during the TMG Aquifer Feasibility Study and Pilot Project. This study focussed on determining the potential yield from three main groundwater target areas (namely Theewaterskloof (Nuweberg/Eikenhof), Wemmershoek and Kogelberg-Steenbras). From 2013 onwards, the study continued in the form of an extended Exploratory Phase to also investigate the potential yield from the Groenlandberg/Klipfontein area near Theewaterskloof Dam and to undertake yield tests in the three previously identified main target areas.

When a severe drought occurred in 2017, a National Disaster was declared and the CCT initiated an emergency initiative, called the New Water Programme (NWP), to fast-track the implementation of alternative water supply schemes. The aim was to implement water supply initiatives which would contribute to the drought resilience of the City in future. One of these potential sources was the TMG Aquifer.

The project involves the development of boreholes in the TMG Aquifer in three geographic areas to augment the water supply to Cape Town as part of their water resilience strategy. It includes the drilling of production boreholes with depths greater than 800 m, the mechanical and electrical equipping thereof, as well as the pipelines required to connect to existing dams. The estimated yield from the three wellfields is 50 ML/d in total. The construction of the Steenbras Wellfield is well underway and will be commissioned by the time the paper is presented in November 2021.

The project provided valuable opportunities to test, model and adapt environmental protection measures and aquifer management principles, and some valuable insights were gained. The unusual circumstances of this project resulted in a situation where stakeholders, engineers, contractors and specialists were required to work together to achieve a successful outcome. The authors have endeavoured to provide a roadmap to other municipalities and water services authorities on how to successfully implement and ensure the ongoing sustainability of large-scale groundwater projects.

1. INTRODUCTION

The City of Cape Town (CCT) recently began implementing a large-scale groundwater scheme, namely the Table Mountain Group (TMG) Aquifer scheme. The first part of the scheme: the Steenbras Wellfield, is under construction and will be commissioned by November 2021.

The TMG Aquifer has been under consideration as a potential water supply option for the Cape Town metropolitan area since the early 1990s. Subsequent to a comprehensive water resource planning study for Cape Town and the surrounding metropolitan areas, the TMG Aquifer was studied at feasibility level by the City of Cape Town (CCT) from 2001 to 2013 during the TMG Aquifer Feasibility Study and Pilot Project. This study focussed on determining the potential yield from three main groundwater target areas (namely Theewaterskloof (Nuweberg/Eikenhof), Wemmershoek and Kogelberg-Steenbras).

From 2013 onwards, the study continued in the form of an extended Exploratory Phase to also investigate the potential yield from the Groenlandberg/Klipfontein area near Theewaterskloof Dam and to undertake yield tests in the three previously identified main target areas.

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The project provided valuable opportunities to test, model and adapt environmental protection measures and aquifer management principles, and some useful insights were gained. This paper seeks to provide a roadmap for other Municipalities and Local Governments authorities on how to successfully implement and ensure the ongoing sustainability of large-scale groundwater projects. The steps provided below must be read against the backdrop of the severe drought faced by the CCT.

2. GETTING STARTED

A water supply scheme is developed to meet a demand for water. In the case of the TMG and the CCT, the TMG Aquifer was one of many potential future water supply schemes being investigated for implementation in the relatively 'far distant' future. The drought that took place in 2017 highlighted that the City was heavily dependent on surface water. In order to make Cape Town's water supply more resilient to the risk of drought, there was a need to bring schemes based on other water sources, such as groundwater, water reuse and desalination, into service as a matter of urgency. The City's NWP was created to make this happen, and one of the consequences was the decision to fast track the TMG Aquifer project as a drought response. Therefore the starting point for implementing the TMG Aquifer project was the drought and the need for non-surface water schemes.

The urgency created by the drought meant that there was insufficient time to go through the usual project development process, as illustrated in Figure 1. There was the need to undertake a number of tasks in parallel, while still moving the scheme forward in a responsible and sustainable manner.

2.1 A good foundation to start from

The CCT initiated the TMG Aquifer Feasibility Study and Pilot Project in 2001 and continued with this project essentially until 2017 when the drought required the fast-tracking thereof. This pro-active approach by

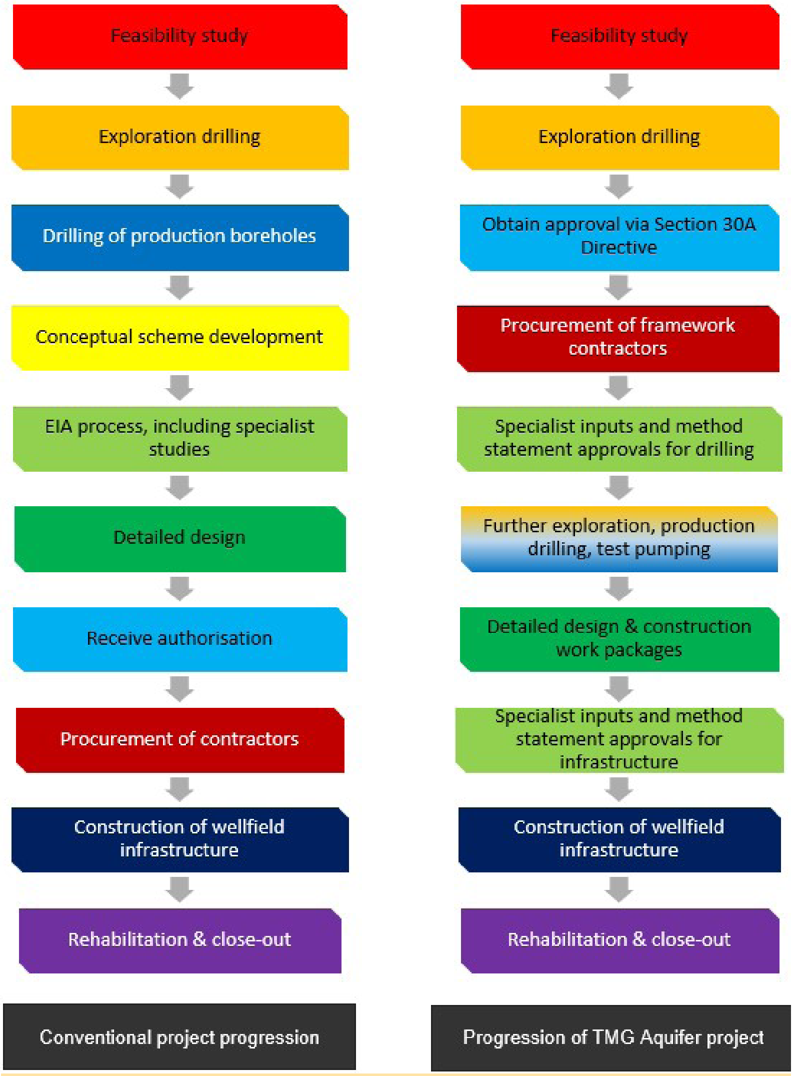

FIGURE 1: Conventional vs emergency project development process (Allpass D. & Larsen J. 2020)

the CCT to study the potential of the TMG Aquifer as a potential resource paid dividends in 2017 as potential areas for production wellfields have already been investigated. In addition, the CCT commenced with regional ecological and hydrogeological monitoring in 2006, resulting in more than 10 years' baseline monitoring data being available.

The lesson learnt was to start early with feasibility studies and investigations even when implementation is only expected to be required in the 'far distant' future. The knowledge gained from these studies and investigations is invaluable when quick decisions, linked with significant financial investment, are required in times of a crisis.

2.2 Wellfield selection

A total of eight target areas were considered for production wellfields, as shown in Table 1. First-order yield estimates were undertaken for each of these areas. Wellfields were then prioritised based on several criteria such as: expected yield per borehole (e.g. fewer high-yielding boreholes will reduce the footprint of the wellfield and be more economical), ease of integration into existing bulk water infrastructure, operational flexibility (e.g. the ability to supply multiple water treatment works), ease of operation (e.g. proximity to other infrastructure operated and maintained by the CCT to allow for potential sharing of resources and workshops), availability of power, landownership, time to implement and financial viability.

The Steenbras, Nuweberg and Groenlandberg wellfields were considered the highest priorities based on favourable hydrology and geology and their proximity to existing bulk water infrastructure. The locations of these wellfields are shown in Figure 2.

CCT elected to commence with the Steenbras wellfield, followed by Nuweberg. Nuweberg is essentially an extension to the Steenbras wellfield, as water gravitates from this wellfield towards the Steenbras pre-treatment plant before discharging into the Steenbras Upper Dam. The Groenlandberg wellfield will be developed in parallel with the Nuweberg wellfield.

2.3 Preparing to implement the project

Before construction could commence, a number of preparations had to be made, which are discussed under separate headings below.

Legislation: Environmental and Water Use Licence (WUL) approvals

The Premier of the Western Cape declared the City of Cape Town (CCT) and other areas in the Western Cape as a disaster area in terms of the Disaster Management Act (Act 57 of 2002) in May 2017 due to the severe drought. Certain legal steps were required in order to fast track the TMG Aquifer project, as described below (Wiese J et al. 2021):

- **Issuing of Section 30A Directives**

The first requirement was for the national and regional Environmental departments to issue Directives in terms of Section 30A of the National Environmental Management Act (NEMA) (Act 107 of 1998), as amended. This allowed the CCT to undertake listed activities without the need to undertake an Environmental Impact Assessment (EIA) process, thereby expediting the environmental processes to facilitate an emergency response with clearly defined checks and balances to protect the environment. The CCT applied to the Western Cape Department of Environmental Affairs and Development Planning (DEA&DP) and the National Department of Environment, Forestry and Fisheries (DEFF). These departments issued the Section 30A Directives in terms of NEMA. The conditions of the directives included, amongst others, the requirement for projects to be implemented in terms of an

TABLE 1: Yield estimates and priorities of potential TMG Aquifer production wellfields

Project/Aquifer	Initial (ML/d)	Ultimate (ML/d)	Priority (1 = highest)
Steenbras	33	144	1
Nuweberg	15	230	2
Groenlandberg	12		3
Wemmershoek	5.5	16	4
Berg River Valley	10	30	5
Voëlvlei	8	25	6
Helderberg Basin	10	30	7
Southern Planning District (SPD)	22	58	8

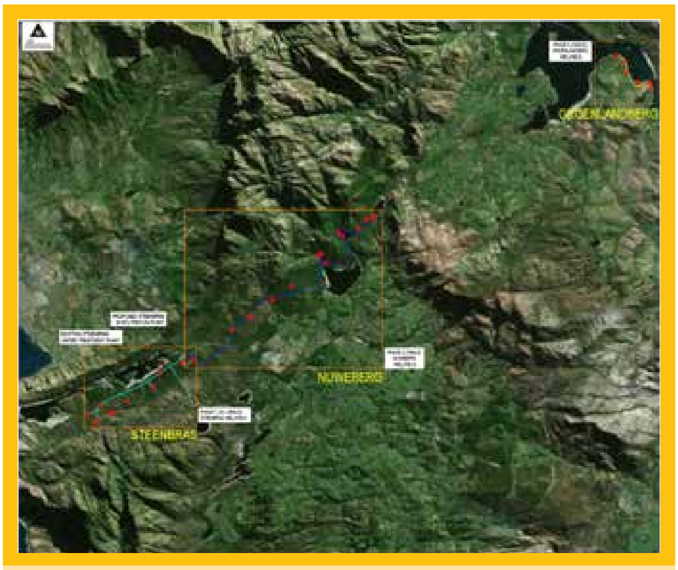

FIGURE 2: Location of the Steenbras, Nuweberg and Groenlandberg wellfields (Kleynhans et al. 2020)

approved generic Environmental Management Programme (EMPr), for approved Environmental Method Statements to be accepted by the DEA&DP or DEFF (depending on environmental competency) prior to commencement, and for regular progress reports and environmental audits to be submitted to the environmental authorities.

- **Water Use Licence in terms of the National Water Act (Act 36 of 1998) (NWA) from the Department of Water and Sanitation (DWS)**
  The DWS also expedited their Water Use Licencing process to support the CCT's groundwater development projects.

Section 21A Water Use License – abstraction

The CCT applied to secure an allocation in terms of Section 21 (a) ("taking of water") through a Water Use License Application for the Steenbras Wellfield and other proposed wellfields to abstract from the TMG Aquifer as part of the emergency response to the National Disaster declaration in 2017.

The Section 21(a) Water Use Licence was issued to the CCT on 21 December 2017 and authorised the abstraction of groundwater in three phases from the TMG Aquifer. The allocation will be reviewed after five years, thereby allowing abstraction from production boreholes up to a certain volume under emergency situations, but also ensuring that the CCT reassess the volumes required, based on monitoring data feedback during abstraction, for future long-term abstraction.

Section 21 (c) and (i) Water Use Licence – impacts on watercourses

Once exploration and production borehole drilling progressed to a point where a potential wellfield could be designed, the process of applying for the authorisation of Section 21(c) ("impeding or diverting the flow of water in a watercourse") and (i) ("altering the bed, banks, course or characteristics of a watercourse") water uses commenced in 2018. The authorisation process was preceded by workshops attended by environmental specialists who undertook sensitivity analyses of the proposed water pipeline and powerline routes, above- and below-ground water crossings and additional borehole drilling locations. This ensured that optimised solutions were presented for authorisation. A Water Use Licence was issued for Section 21(c) and (i) water uses, for the Steenbras Wellfield Project, on 23 July 2019.

FIGURE 3: Lxploratory core drilling at Steenbras
(photo credit: D Blake of Umvoto)

Stakeholder engagement

Since the abstraction of groundwater was fast-tracked as a result of the drought and national disaster declaration, stakeholder engagement was not done according to Regulation 41 of the 2014 EIA Regulations, as amended (i.e. undertaking a conventional EIA process). Stakeholder engagement on the TMG project commenced as early as March 2018 to pro-actively address concerns raised regarding the environmental impact of large-scale groundwater abstraction from the TMG Aquifer.

Stakeholder engagement included regular working groups, focus groups undertaking screening activities related to proposed infrastructure, monitoring committees focussing on WUL conditions and larger forums for sharing information from all the different projects under the NWP. Engagement also included one-on-one landowner consultations, meetings with Water User Associations, Biosphere Reserves and Municipalities and authority consultations. These consultations aided in collecting extensive local knowledge, identifying environmental sensitivities, awareness of the public's main concerns, sharing ideas, using different skills to undertake screening activities, promoting research topics and improving on-site monitoring and mitigation through information sharing.

An important outcome of the stakeholder engagement process was the refining and optimising of wellfield locations, e.g. the Steenbras wellfield was limited to the utility area, the T4 area was omitted from the Nuweberg wellfield and at the Groenlandberg wellfield, the G2 area was omitted.

Stakeholder engagement is also a critical part of compliance to the Water Use Licences issued to the CCT for the Steenbras Wellfield and other wellfields. Stakeholders have an opportunity to be appointed as members of the Environmental Monitoring Committee which is facilitated by the CCT on a six monthly basis. The aim of these meetings is to monitor compliance to water use license conditions, approve a monitoring protocol for the Steenbras Wellfield and propose additional conditions or mitigation measures, based on the outcome of monitoring data or operational feedback.

Exploration boreholes vs production boreholes

In an ideal situation, exploration drilling (see Figure 3) will be undertaken before commencing with production drilling. The drought, however, required exploration and production drilling to be undertaken at the same time.

Extensive field work and mapping was conducted by the groundwater specialists in order to site the boreholes. High yielding fractures were targeted, determined from extensive field mapping of fault structures. Aerial magnetic survey (airborne geophysics) was used to provide more information where afforestation obscured the ground level geological investigations.

FIGURE 4: The Steenbras Wellfield (Kleynhans et al. 2020)

FIGURE 5: Production borehole drilling in progress showing sumps (a series of containers) and temporary pipelines

Proposed borehole positions were screened on-site by the environmental specialists, refinements made, and mitigation measures agreed upon before finalising the positions of the exploration, monitoring and production boreholes.

Infrastructure design

Adaptive infrastructure designs were developed while awaiting borehole positions and yields. These designs were finalised once the borehole positions and yields were available, thus shortening the overall time required.

Procurement of contractors

An adaptive procurement strategy was required for drilling the boreholes and construction of the infrastructure. Groundwater projects typically follow a process whereby exploration and production boreholes are drilled, and firm borehole yields are determined. This is followed by the infrastructure design, based on confirmed borehole yields and an environmental approval process, whereafter construction commences. Due to the drought crisis, the drilling of exploration and production boreholes and the infrastructure design and construction all had to take place within the shortest possible timeframe.

In order to provide flexibility, yet abide by very tight timeframes, contractors were appointed on Framework Contracts, which allowed for the City to issue works projects as and when designs were finalised. The construction scope was handled under three Framework Contracts, i.e. drilling, civil works, and mechanical and electrical works. More than one contractor could be appointed per Framework Contract, which provided further flexibility to accelerate construction. This approach therefore ensured that construction could commence literally within a few weeks from completing the designs.

3. IMPLEMENTATION

The Steenbras wellfield (see Figure 4) comprises:

- 12 production boreholes drilled to depths of up to 1000 m and 17 monitoring boreholes
- 12 pumphouse structures housing the pumpsets, switchgear, ring main units and transformers
- 11 500 m of pipelines with diameters ranging from DN160 to DN560
- 14 300 m of medium voltage (MV) cables
- A pre-treatment works

The specific design selections made to meet the requirements detailed above are described in the sections below.

3.1 Borehole drilling methods

Water from the boreholes was high in sediment, iron and manganese and had a high pH compared to the water quality of the rivers and streams within the Steenbras catchment area. It was therefore not desirable that this water be discharged into the natural vegetation. Extensive mitigation measures were used to contain drilling water (for example sumps, berms, plastic sheeting etc.). Temporary pipelines were installed from the boreholes to discharge drilling water directly into the Steenbras dam (Figure 5).

Additional drilling methods such as flood reverse circulation and water hammer were used to supplement traditional rotary air percussion drilling. This reduced the chance of spilling drilling water and sediment while drilling.

3.2 Positive displacement pumps

Positive displacement pumps, installed at depths from 80 m to 150 m, were considered the best technical solution to deal with the varying pumping heads due to water-level fluctuation in the boreholes, which could vary by up to 100 m, and changing frictional losses in the pumping mains (e.g. depending on the number of operational boreholes, the flows in some pipelines will vary).

The groundwater also has very high concentrations of iron and manganese, which required the careful selection of equipment and instrumentation to mitigate the risk of failure or malfunctioning due to the precipitation of iron. This also limited the flow control mechanisms that could be considered should submersible centrifugal pumps be used.

A constant discharge test is undertaken for each production borehole to determine the safe yield and informs the pump duty. The safe yields, however, need to be adjusted once all boreholes are operated simultaneously, which requires flexibility to change the flow rate at each borehole to match the ultimate sustainable yield. The positive displacement pumps are belt-driven, which means that flows could be easily adjusted by strategic selection of pulley size (diameter). The motors are fitted with variable speed drives to further vary the flows to match the conjunctive use yield target set for the wellfield as well as the water level limitations within the aquifer.

3.3 Bedding / locally sourced material

The environmental specialists required that the bedding material used in the pipe installation have the same chemical composition as the natural fynbos environment. This proved challenging, because the natural pH was extremely low (i.e. a pH of 5.6) and the soil was low in nutrients. In comparison, sand available from commercial quarries had a pH of 9.0

and higher, and had much higher nutrient concentrations. A crusher dust material from a nearby commercial quarry was found to be a suitable bedding material. In addition, the need to import fill for backfilling trenches was reduced wherever possible. On-site crushing and screening of material obtained from drilling operations and trench excavations were undertaken. Road maintenance also made use of local crushed material.

3.4 Trench dewatering

Water from trench excavations could not be discharged into the natural fynbos environment due to the sediment in the water. Various dewatering options were tested (e.g. using geotextile bags to trap sediment) but ultimately a network of temporary pipelines, which also convey water from drilling operations, was installed to discharge the water to the dam.

The pipelines also intersected numerous wetland areas, which posed a risk as the wetlands could be dewatered into the pipe trenches. Impermeable walls had to be constructed in the pipe trenches to ensure that the water tables of the wetland areas are not impacted.

3.5 Choice of pipe material

Pipeline diameters vary from DN 160 to DN 560. The pipe material chosen was HDPE, based on the acidic nature of the water (a pH as low as 4.0), the very restricted working widths varying from 6 m to 10 m (i.e. HDPE pipes can be welded outside the trench and then installed), and the need to limit joints (i.e. the pipeline working width is rehabilitated with fynbos, and the risk of roots penetrating the joints and causing leaks had to be minimised). Furthermore, continuously butt-welded HDPE pipelines did not require concrete thrust and anchor blocks to be installed.

3.6 Stream crossings

A total of nine stream crossings were identified by the environmental specialists, where they recommended above-ground stream crossings to avoid disturbing the streambeds. The pipes had to be installed above the 1:100-year flood levels and no pipe supports were allowed in the flow path of the streams, requiring the pipes to span lengths up to 20 m. The spans up to 13 m were designed such that the pipes could span the entire length of the crossing, but pipe bridges had to be constructed for the longer spans. The above-ground piping was manufactured from stainless steel with a suitable coating and lining to protect it from the low pH of the groundwater. Stainless steel, however, has a much lower yield strength compared to mild steel, requiring careful design to optimise the wall thicknesses required against the distances to be spanned.

FIGURE 6: Completed pumphouse structure clad with natural stone to reduce visual impact

3.7 Pumphouse structures

The pumphouse structures comprise four rooms to house the pump motor, low voltage and control equipment, transformer and ring main units respectively. Due to the environmental sensitivity of the area, the structures were manufactured off-site as precast units and then erected on-site. This reduced the risk of environmental degradation due to concrete spills and also drastically shortened the construction time on-site. To further mitigate the visual appearance of these rather large structures, visualisation specialists were appointed to provide advice about mitigation measures. The final solution was to clad the structures in stone, as shown in Figure 6.

3.8 Buried MV cable

Due to the environmental sensitivity of the area, and the risk of damage by natural fire cycles in fynbos, the medium-voltage power cables were buried in the same trenches as the pipelines. Fibre optic cables, feeding all the data from the respective boreholes to the centralised SCADA, were also installed in the pipeline trench.

3.9 Pre-treatment works

A detailed study was carried out on the fate of the iron and manganese when discharged into the Upper Steenbras Dam. The in-lake dissolved iron concentration is 0.27 mg/L, compared to 2.5 mg/L in groundwater from the Peninsula Aquifer. Furthermore, total iron concentrations in the Peninsula Aquifer greater than 20 mg/L had been found at some of the boreholes. Based on water-quality guidelines, the in-lake target dissolved iron concentration in the Upper Steenbras Dam should be kept below 0.5 mg/L to protect aquatic ecosystems. The study showed that it would be possible to discharge untreated groundwater directly into the Upper Steenbras Dam for a period of approximately three years (based on full production) before a pre-treatment plant should become operational. The design of a pre-treatment plant, which will reduce the iron and manganese concentrations, is currently underway, with construction likely to commence by late-2022.

3.10 Construction supervision

Involving the environmental team throughout construction had numerous benefits, as described below:

- Two Environmental Control Officers were employed on site full-time to monitor and actively measure compliance and initiate incident responses during borehole drilling and construction activities.
- Weekly coordination meetings took place between the CCT's ECO, Environmental Control Officers, contractors, engineers and the CCT's Environmental Management Department.
- For all new activities, Environmental Method Statements were drafted through input from specialists and were approved by the Environmental Control Officers, CCT Biodiversity Management Branch and CCT ECO (and accepted by the DEFF or DEA&DP, where activities triggered NEMA EIA listed activities). In this way, site-specific mitigation measures could be recommended, implemented and audited, with an opportunity to apply any lessons learnt through the implementation of the mitigation measures when future Environmental Method Statements are compiled and approved.
- During construction the specialists had the opportunity to be involved in the recommendation of immediate incident responses, ecological monitoring and implementation of additional mitigation measures depending on the site-specific conditions. This ensured that they could

FIGURE 7: Screenshots of SCADA system used to monitor and control the Steenbras Wellfield

pro-actively initiate erosion control measures, flood detention measures and prevent potential contamination from construction activities.

- An incident response procedure was developed, which defined the collection of water and soil samples, undertaking site assessments with specialists, analysing the sampling data and submitting reports on incidents and potential long- or short-term impacts to stakeholders and relevant authorities.
- The lessons and data collected can be applied to the planning of future wellfields, thereby limiting adverse environmental impacts in future wellfields.

3.11 Ongoing inputs from environmental specialists

All wellfields under consideration are located in environmentally sensitive areas and thus the environmental component of the project was substantial, influencing every aspect of the design and construction of the wellfield, requiring a hands-on approach from the City's Environmental Management Department, environmental specialists, stakeholders and regulatory authorities. The approach followed was to appoint environmental experts, namely a botanist and freshwater ecologist who frequently visited the sites to monitor construction activities and to provide advice on mitigation measures.

3.12 Rehabilitation specialist

Rehabilitation of vegetation was planned for by employing a rehabilitation specialist contractor for the duration of the project.

- Specific plants and seeds were actively harvested prior to clearing sites for drilling and construction activities These plants and seeds were labelled and housed in an on-site nursery, and were replanted/sown back in the area of collection to maintain genetic integrity.
- Alien vegetation has been cleared for 20 m on either side of the linear infrastructure to reduce recolonization by alien plants. This will increase the success of vegetative rehabilitation.
- Topsoil removal and stockpiling for all works has been overseen by the terrestrial ecologists or rehabilitation specialist to aid post-construction rehabilitation.
- Drilling footprints and the working widths for linear infrastructure have been reduced in areas of high environmental sensitivity to reduce the area of vegetation that needed to be cleared. For example, the working widths for DN 560 pipelines varied from 6 m to 10 m, which included the existing road width of 3.5 m.
- Sandbag barriers (trench collars) are being installed in the trenches to match the historical hydrological movement through wetland areas.

4. LONG TERM SUSTAINABILITY

4.1 Offsets

When a project will result in unavoidable residual environmental impacts, these can be compensated for by implementing positive environmental impacts at another location. These are referred to as ecological offsets. One of the license conditions as part of authorising Section 21 (c) and (i) water uses, is the requirement to calculate a wetland offset and implement an offset plan.

Due to the environmental sensitivity of the Steenbras Nature Reserve and ecological changes along the infrastructure routes from wetland to dryland, DWS replaced the need for a wetland offset by a combined biodiversity offset. This combined offset was aimed at including both wet- and dryland residual impacts to determine a suitable offset accounting for construction related impacts, as well as long-term abstraction related impacts. This is the first time that offsets due to long-term groundwater abstraction on this scale have been implemented within the South African context. Offset specialists have been appointed to provide guidance regarding construction and abstraction-related offset requirements. DWS has agreed that offsets be determined in parallel to the Section 21 c) and i) application process.

4.2 Wellfield control system and philosophy

The boreholes are connected by a fibre optic cable network (rather than a telemetry system, which is more conventional). The control room is located in a temporary structure. It will be incorporated into the pre-treatment plant building once that is complete. A SCADA system enables the automated control and operation of the wellfield. Figure 7 shows two screenshots of the type of control mechanisms that are in place.

The operation of the wellfield can be controlled automatically in one of two modes to ensure that sustainable yields are extracted from the aquifers. The two modes are level control or flow mode.

Level control is mainly used during the commissioning phase of the wellfield. Boreholes are pumped at the safe yields determined from the individual pump tests with drawdown limited to a pre-determined level. Once the water level reaches this maximum permissible drawdown level, the pump speed will be reduced to a flow rate where this water level is maintained. The level mode therefore allows for the safe yield of the boreholes to be refined once the entire wellfield is operational.

The CCT can, through their various planning and system models, determine the additional flow required from the wellfields to augment their surface water sources. As such, flow mode allows the operator at the pre-treatment plant to specify the desired flow rate, whereafter pumps will be started automatically until the required flow rate is delivered to the pre-treatment plant. In flow mode, a priority and safe yield is assigned to each of the boreholes. The priority determines the starting sequence, and the safe yields of the individual boreholes will determine the number of boreholes to be started. Preference is given to those boreholes abstracting from the deeper Peninsula Aquifer before utilising any of the boreholes abstracting from the shallower Nardouw Aquifer.

4.3 Wellfield monitoring and modelling

All data from the SCADA system on the Steenbras wellfield site will be fed through to the CCT's data system and will form inputs to their Decision Support System (DSS), currently being developed. This DSS will allow the CCT to monitor all major water sources in real time, and adjust their abstraction from the different water sources to manage the system optimally and sustainably.

An extensive monitoring programme is being developed in parallel with the project implementation. This includes a detailed groundwater model that will use the data from the SCADA to model potential long-term abstraction impacts on the environment. The calibrated model could also be used to model various abstraction scenarios and their likely impacts – which will inform the offset requirements related to abstraction impacts.

4.4 Ecological and hydrogeological monitoring

Ongoing monitoring of the groundwater and environmental impacts will continue as part of the implementation and operational phases of the Steenbras wellfield. This includes on-going baseline monitoring undertaken at a regional scale as well as wellfield-specific abstraction impact monitoring. The results from these monitoring activities are evaluated and reviewed by the Groundwater Monitoring Committee (part of the WUL conditions) who provides on-going advice on sustainable yields and monitoring requirements.

4.5 Water Quality

The potential impact of discharging treated and untreated groundwater into Steenbras Dam on the water quality in the dam was investigated, i.e. it was important to demonstrate that the addition of water from the TMG Aquifer would not negatively impact the water quality and ecology of the dam. A water quality model was set up using actual inflows to the dam (i.e. natural run-off and transfers from Palmiet) and water demands obtained from the system modelling.

5. CONCLUSIONS

The authors have endeavoured to provide a roadmap to other municipalities and water services authorities on how to successfully implement and ensure the ongoing sustainability of large-scale groundwater projects. Implementing a large-scale groundwater project under emergency conditions, in a sustainable way within a sensitive environment, was unchartered territory with valuable insights gained along the way viz;

- Lay a strong foundation – get the research done.
- Get a head start – don't wait for crises before commencing.
- Journey with seasoned travellers – engage engineers and specialists that have comparable experience to avoid pitfalls and dead-ends.
- Co-operative governance - collaboration with all tiers of government regulators must be secured in advance.
- Teamwork wins the day – robust interaction between all role-players must be maintained throughout.
- Build trust – Maintain a high duty of care through instilling a culture of compliance.
- Plan for a marathon and not a sprint – adopt a paced approach to the project by setting realistic timelines.
- Flexible Funding mechanism – fund the project not the financial year.
- Expect the unexpected – adopt an adaptive management approach to project deliverables.

The authors have shared their insights gained from the process in the express wish that other municipalities and water services authorities located elsewhere in South Africa, can benefit from their experience.

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PAPER 9

A review of acoustic pipeline monitoring systems used to detect bursts and blockages

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ABSTRACT

Pipeline leakages, bursts, and blockages are issues that are experienced by many urban communities globally and locally. These issues emerge from numerous variables such as pipe deterioration and human-instigated assembly faults. Leakages and bursts of the pipelines are some of the major causes of the increased scarcity of drinking water. These pipeline issues do not only affect the society but also apply pressure to the economy and the environment. As such, these issues need an undivided attention to prevent them from escalating. This study proposes a system design of an acoustic monitoring system for pipeline leakages, bursts, and blockages. To achieve this, a review of the existing methods and models for pipeline monitoring was conducted. Comparison of existing methods was based on system characteristics, i.e., operation efficiency, maintenance efficiency, ease of installation, cost efficiency, energy efficiency, and overall reliability. These characteristics form part of the most vital characteristics of a system concerning its reliability. To better propose the best solution, the social, environmental, and economic influences of the above-mentioned pipeline issues are just as important to consider.

A comparative analysis on the performance of the existing models and systems was performed to provide the best guide in determining the best model in pipeline monitoring for leakages, bursts, and blockages. These systems include a) Conventional and Visual Method, b) Wireless Sensor Network Systems, c) Acoustic Monitoring Systems Based on WSNs, d) Sound Variation Vibration Sensor Systems, e) SmartPipe Based on WSNs Approach, f) ADIGE Method, g) SPAMMS System, h). EARNPIPE Systems, and i) Magnetic Induction Based WSNs (MISE-PIPE). Comparisons made were based on other works by different authors, no empirical measurements were taken. A framework was then proposed and executed to examine the best design for monitoring pipelines. Based on available methods and models, the model proposed in this paper is a hybrid model which combines the best of what the existing models can offer to monitor a pipeline under and above ground. Many existing models can only manage to perform task exceptionally but with a lot of drawbacks on other features such as burst detection. The combination of the most efficient models to a single model comes with a lot of benefits and less drawbacks. As with any system in existence, a maintenance plan is needed and was discussed to ensure the best operation of the system.

INTRODUCTION

Many developing nations lack detection strategies for pipelines which increase the shortage of drinkable clean water. This also make it difficult to transport fuel and other commodities. There is a great need for new methods of monitoring pipelines as about R1 billion worth of water goes to waste every year in Johannesburg alone through unnoticed leakages and pipeline bursts (Molatlhwa & Smillie, 2015). The biggest cause to leaks, blockages and bursts is the deteriorated pipeline systems. If detection systems were detected earlier, such problems would be avoided through pipeline maintenance. Over R100 billion was allocated to fix household plumbing issues, replacement of pipelines, and to compensate for the ever-growing water demand every year by 2.4% on average (Molatlhwa & Smillie, 2015). The sum of money allocated for fixing the pipeline systems issue and the money lost in leakages, bursts and blockages is extremely large for the economy of a developing country.

Pipeline monitoring systems are important in reducing abovementioned problems. There are many different monitoring systems available in the market. They operate differently and provide different outputs. Research has shown that detection systems have proved to be the best and most useful strategy for many pipes in a wide range of these systems (Datta & Sarkar, 2016). One good reason behind this claim is because of the ability of some of these monitoring systems to detect leakages, blockages, and bursts promptly in a pipe as significantly little as 1% of its diameter (Datta & Sarkar, 2016). Most of these systems have also been found to be very economical as well as being able to operate in pipes of different shapes, pipe sizes, pipe lengths as well as for various densities (Datta & Sarkar, 2016). South Africa is faced with both water and energy crisis. This research paper will propose a system that prevents water losses while being energy efficient.

PIPELINE MONITORING SYSTEMS

When pipelines are properly maintained, they last for a considerable time without leaks or bursts (Boaz, et al., 2014). To achieve this, a leak detection system should be adopted. The primary function of a leak detection system is to aid those in charge of controlling and monitoring the pipeline distribution networks (Boaz, et al., 2014). The systems detect and localise leaks in the pipeline hence they guarantee optimal functioning as well as maintenance of pipeline distribution networks (Boaz, et al., 2014). Pipeline leakage often leads to the actual burst of the pipeline. This is due to the pipeline not being able to withstand the high pressure it is subject to. As a result of identifying and dealing with pipeline leaks at an early stage accordingly, the bursting of the pipeline is prevented.

There are two types of monitoring systems namely internal system and external system. Internal systems are referred to as computational pipeline monitoring systems (Boaz, et al., 2014). These systems use internal instruments inside the pipeline that is being monitored. These instruments are field instrumentation or handheld devices that are used to measure parameters of the liquid being transported inside the pipe such as the pressure, temperature, and flow of the fluid (Boaz, et al., 2014). External systems on the other hand as the name suggests, are operated external to the pipe. Such example is optic fibre cables which are used to detect changes in temperature due to leaks which is dependent on the type of fluid that is transported (Stajanca, et al., 2018). Acoustic systems are also a good example of external monitoring systems. Acoustic detection system work on the basis of a signal or sound created due to a moving fluid in the pipeline (Boaz, et al., 2014). When the liquid passes through an opening in the pipe, it is detected, and a frequency signal is sent to the processors which then analyses the signal (Boaz, et al., 2014). In this paper, we will look into the different monitoring systems as well as their differences, similarities, strengths, and weaknesses. A lot of monitoring systems have been by far proposed and adopted although some of these systems are still undergoing research.

Conventional and Visual Method

These are methods that require the use of observation by a personnel through the use of video capturing device and helicopter to scout for any suspicions on the ground of any leaks. Such systems are very time consuming, inefficient and ineffective. This is because underground pipeline leaks or bursts as well as blockages may take a considerable amount of time before the ground reflects the problem on the surface. At the time the problem shows, an inevitable as well as an extensive amount of damage such as sinkholes would have already occurred.

Wireless Sensor Network Systems

These are monitoring systems that do not require the physical contact between the components and the operator but rather make use of the sensing technology to make a judgement on an existing pipeline (Akyildiz, et al., 2002). These systems are called wireless sensor networking systems (WSNs) due to the non-requirement for physical connections. The wireless sensor network system is the system upon which many pipeline detection systems are based. The wireless connection reduces the possibility of damage to the connecting medium and prevents the disturbance to the operation of the system. The basic set-up of a wireless sensor network comprises of sensor nodes, master nodes, and of course the operator. The sensors detect any action in the medium under investigation and send information to the nodes and the nodes then ultimately transmit the data to an end user for analysis (Haibat & Jae-ho, 2019).

Acoustic Monitoring Systems Based on Wireless Sensor Networks

Acoustic monitoring system is a leak detection system that makes use of the hydrophone sensors to detect any unusual activity on the pipeline (Bernasconi, et al., 2012). These hydrophone sensors are placed at separate and distinct locations along the pipeline. Most acoustic monitoring systems are dependent on the emission of sound measured due to water escaping from a pipe through a leak (Khulief, et al., 2012). Acoustic detection systems basically listen to the activity of a pipeline for any unusual sounds whereby sensors work together to assess and locate leaks that may often go undetected. This system is comprised of sensors responsible for monitoring the pipeline for any variation from the normal sound on the pipeline. These sensors, should there be any changes to the sound on the pipeline, trigger other sensors to begin recording the acoustic data (Ismail & Yie, 2012). The triggered sensors only begin recording data when the sound emanating from the pipeline is higher than the ambient sound which in this case is taken as the normal sound in and around the pipeline (Ismail & Yie, 2012). This prevents false alarms or triggers as it was in the past where these systems could not differentiate between leak sounds and sounds on the ground surface (Yang, et al., 2008). The data, after being turned from signals into a digital form, can now be sent for analysis. General procedure for detecting leaks using an acoustic emission (AE) based technique is shown in Figure 1 where transformed AE signals are used to train the classifier instead of direct AE signals which improves the accuracy of the system. With the trained classifier, accurate classification of data into the presence of suspicious activity is guaranteed. As these systems are becoming more advanced, the operator is able to act on the leak as soon as possible before it turns into a secondary damage.

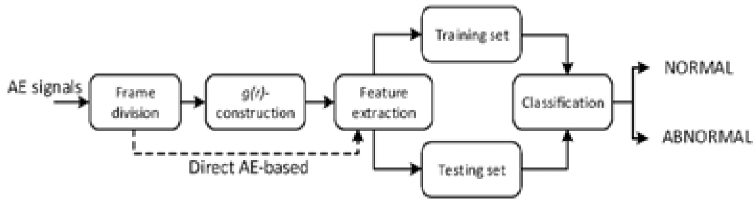

FIGURE 1: Procedure for leak detection based on acoustic emissions technique

Sound Variation Vibration Sensor Systems

These systems use sensors which detect sound variations in the pipeline. The system detect any suspicious sound made by leaking water and compare it to the normal sound of the of the pipeline (Ng, et al., 2017). This is how water leaks, and their symptoms are identified before exacerbating the already deteriorating pipeline (Haibat & Jae-ho, 2019). This system has only been used on polyvinyl chloride (PVC) and metal pipes. It is not best suited for concrete pipes. As with many pipeline monitoring systems abovementioned, the sound variation system also has a constraint to it. This system work in its optimum state when it is near the position of the leak on the pipeline (Haibat & Jae-ho, 2019). For a detection system to be a good, it is imperative that it be able to work or survey a considerable length of a pipeline.

SmartPipe Based on WSNs Approach

The SmartPipe system is a multimodal monitoring system based on WSNs. This approach is a non-invasive approach that monitors a pipeline for any variation in the pressure of the pipeline. The development of this system was on the basis of a force sensitive resistor whose resistance varies in accordance with the pressure it is subject to (Sadeghioon, et al., 2014). This system provides pipeline monitoring at low power consumption, reducing its overall cost of operation. This is achieved through a single measurement of the pressure after every 6 hours to increase the lifetime of the network (Sadeghioon, et al., 2014). The long intervals of measurements allow for the sensor node to cope and be compatible with the levels of power available through production and provision. The draw back about this approach is that it was only used on plastic pipelines. It is not known as to how it would react when used on different types of pipe materials. This approach needs to be tested on other types of pipe material.

Adige Smart Water Network

This system is founded on a long-range wireless technology (LoRa) that helps improve its capacity of area under investigation. The LoRa allows for fewer uploading gateways to upload information found by the sensors (Haibat & Jae-ho, 2019). This has a significant influence on the batteries of the system as the LoRa technology allows for a considerable reduction in the consumption of energy from the batteries (Cattani, et al., 2017).

The LoRa technology was designed and developed to achieve the following goals (Haibat & Jae-ho, 2019):

- Increase the reliability of the system.
- Cover a relatively large area.

- Increase the energy efficiency of the system and lower the cost of the system.

Although the LoRa technology promises to be very reliable or rather checks virtually all the boxes, is also has harbours constraints of its own. To accurately locate the position of a leak is the main constraint for this system. High accuracy is still a work in progress which is still undergoing a lot of research as this technology is not quite there yet. According to Cattani, et al. (2017) the system increases the condition of good health of the existing pipeline distribution networks.

Sensor-Based Pipeline Autonomous Monitoring and Maintenance System

The Sensor-Based Pipeline Autonomous Monitoring and Maintenance System (SPAMMS) is a self-controlled water pipeline monitoring system that uses a robotic technology and a variety of sensors to monitor and locate leaks (Kim, et al., 2010). This system detects and locate leaks through a coordination of dynamic and static sensors which are sonar, pressure, charge-coupled device, and chemical sensors. Although this system is in its preliminary version, it promises to reduce the need for human intervention by a significant margin hence a robot is rather used for maintenance (Karray, et al., 2016). As the robot moves in the pipeline, it distinguishes any suspicious activity. Having the robotic agent makes localisation of suspicious activities much easier as it can get as close as possible to the pipeline activity. The reduction of the need for human beings will allow for a great deal of the reduction of errors that might have been as a result of human intervention. However, this system has a lot of mobile parts which makes it very likely that an error could occur during installation. Installation may also require too many instruments thus, increasing operational and maintenance costs of the system (Karray, et al., 2016).

The Energy-Aware Reconfigurable Sensor Node for Water Pipeline Monitoring System

The energy-aware reconfigurable sensor node for water pipeline monitoring system (EARNPIPE) is a detection system proposed by Karray et al. This is a software dependant system that makes use of leak detection algorithms, localization algorithms as well as a system on cheap architecture with a wireless sensor node (Karray, et al., 2016). This system was founded on two methods namely, a leak detection predictive Kalman filter (LPKF) as well as a modified time difference of arrival (TDOA). The LPKF is a set of mathematical equations which are algorithms that make more accurate variable that are not known. The accuracy of this algorithm is dependent on the measurements of different accuracies such as noise previously measured as statistics. The newest measurements are contrasted against the already measured ones to produce variables with high accuracy (Welch & Bishop, 1997). When the sensors get information about the state of the pipeline, the information is taken to be filtered and undergoes analysis by the Kalman filter as a single algorithm (Karray, et al., 2016). One Kalman filter algorithm increases energy efficiency as compared to different algorithms working at once (Karray, et al., 2016). The system is developed for long distance pipelines. However, it only works on exposed pipelines and above ground (Haibat & Jae-ho, 2019).

The Magnetic Induction-based Wireless Sensor Network for Underground Pipeline Monitoring

Unlike the EARNPIPE system, the magnetic induction-based wireless sensor network for underground pipeline monitoring (MISE-PIPE) proposed by Sun, et al. (2011) is designed to work underground. However, although this wireless sensor network works underground, it uses various sensors to locate a leak on a pipeline in a similar manner to the EARNPIPE systems (Sun, et al., 2011). The WSNs make use of a magnetic induction as a result of a changing external magnetic field made possible by pressure sensors, acoustic sensors which are based on sound detection, as well as the soil properties sensors (Karray, et al., 2016). The sensory data is transmitted to the processing hubs which are above the ground. This system is comprised of hubs that are made of devices that connect the sensors from underneath the surface of the ground. The pressure and acoustics sensors are placed in the hubs in known or verified locations from inside the pipelines (Haibat & Jae-ho, 2019). The soil property sensors are placed in the soil along the pipeline to measure different soil parameters such as soil temperature, soil humidity to name a few (Haibat & Jae-ho, 2019). The sensors in the hubs will measure the variation in vibration and in pressure as a result of pipeline leakage which will be sent for analysis using the magnetic induction technique (Sun, et al., 2011). However, due to the frequent communication between the nodes and base stations, the battery lives are affected hence this system may not be energy efficient as a result of high energy consumption (Karray, et al., 2016).

Overview of the Different Pipeline Monitoring Systems

Pipeline monitoring systems are advancing in technology to better detect and localize leaks which habitually may turn in to a burst. Not only does this reduce the negative economic pressure but it also will prevent the loss of drinking water and environmental damage such as sinkholes for a few thus, thus preventing social pressures. However, pipeline monitoring systems still have to undergo more research as many of the systems make compromises somewhere in order to perform perfectly at a particular function. This results in a lot of pipeline monitoring systems having great strengths on one aspect and weaknesses on the other. Most monitoring systems are limited to short distances as they cannot work in very long stretches of pipeline distances. In addition, accuracy of the sensor nodes in locating the leak still need to be worked on. Some systems tend to not be cost efficient due to having a lot of parts which may be mobile. This adds to the cost of making and assembling the system. As a result, the reliability of the system is generally decreased.

A good, reliable, and efficient monitoring system possesses the following traits (Karray, et al., 2016):

- It must be able to provide active monitoring where it detects defects in damaged pipeline.
- It must be able to provide recovery action through the analysis of data and reaction provision.
- It must be relatively cheap or cost effective operationally as well as in maintenance.
- It must be scalable. This is so that the system is able to work on any length of the distribution network, that is it must adapt to different settings.
- It should be customisable and easily so.
- It should be dynamic where it is capable of allowing for a dynamic pipeline inspection. This can be from the inside of the pipeline or from outside of the pipe.
- It must possess efficient localisation techniques where a leak is located with minimal errors and a good accuracy.

Acoustic monitoring systems have been found to have been very efficient in their work and widely applied in the water and sewer industry (Yang, et al., 2008). Since 2000, pipeline monitoring systems have been advancing in technology. For example, the Enhanced Constant Fault Alarm Rate (ECFAR) is an acoustic monitoring system that makes use of fault alarm to detect any issues on the pipeline as discussed previously (Duong, et al., 2020). Comparison of different leakage detecting systems is shown in Table 1. From the table, "YES" means that the specific method is good in that criterion and "NO" means that it does not meet the criteria. System attributes rated with

TABLE 1: Key features of leak monitoring systems (Zhang, 1997)							
Method	Leakage sensitivity	Location estimation	Operational change	Availability	False alarm	Maintenance requirement	Cost
Biological	Yes	Yes	Yes	No	Low	Medium	High
Visual	Yes	Yes	Yes	No	Medium	Medium	High
Acoustic	Yes	Yes	No	Yes	High	Medium	Medium
Sampling	Yes	Yes	Yes	No	Low	Medium	High
Negative pressure	Yes	Yes	No	Yes	High	Medium	Medium
Flow change	No	No	No	Yes	High	Low	Low
Mass balance	No	No	No	Yes	High	Low	Low
Dynamic model	Yes	Yes	Yes	Yes	High	High	High
PPA	Yes	No	No	Yes	High	Medium	Medium

a "HIGH" resembles a bad performance of the system and "LOW" resembles a good performance by the systems at the identified feature. It can be observed that the acoustic method of pipeline monitoring is excellent at sensitivity to leakage. However, this system has a very high false alarm rate. In the modern acoustic systems, filters are used as sieves to filter out any unwanted data from the pipeline.

FINDINGS

This section discusses the proposed methodology and the method execution with reference to a monitoring system based on wireless sensor networks to counteract leakages, bursts, and blockages of buried and exposed pipes. The main criteria to be used in selecting the relevant works by other authors and criterial for an effective pipeline monitoring system is discussed. A comparative analysis procedure was performed between systems from literature and the proposed systems. A framework of the method will show a step-by-step procedure in selecting all the relevant sources of data from the internet which narrowed down on the type of pipeline detection system is best for monitoring.

Data Sampling Criteria

The publications that were selected for data gathering were conference proceedings and journal articles. Different research databases such as Google Scholar, Science Direct, MDPI, IEEE Xplore, and Research Gate were used to find the relevant literature and base for this methodology. This allowed for the acquisition of quantitative data and qualitative data. In order to search for the relevant papers on the databases, keywords were used to bring out results that were required. The keywords that were used are acoustic monitoring system, pipeline detection system, pipeline monitoring system model, pipeline acoustic-emission, pipeline burst detection system, pipeline leakage detection system, and pipeline blockage detection system.

Framework and Data Analysis

Many papers proposing different pipeline detection systems have been published concerning the monitoring of pipeline network systems. As this is still a developing topic, there have been many suggestions by various authors to reach a common goal which is to prevent the occurrence of pipeline leakages, bursts and blockages through the use of systems that combine sensory hardware, transmission hardware as well as computer models and analysers to prevent such unwanted events. In order to select the right types of information sources, a framework has been proposed in Figure 2. The framework is a summary that shows the method or procedure used in this project to select the best models for the hybrid model. It shows the procedure that led to the acquisition of the right and relevant papers to recommend the models chosen to be used in this project.

Data was first obtained from the literature review from the journal articles and conference papers published on various databases. The selection of the relevant papers is in accordance with the process depicted in the framework of method section. A comparison between the current and proposed systems was done where the best system was chosen from the rest. The selection of the best system is influenced by the following characteristics of monitoring systems: a) Operation efficiency, b) Maintenance efficiency, c) Ease of installation and cost efficiency, d) Energy efficiency, and e) Overall reliability.

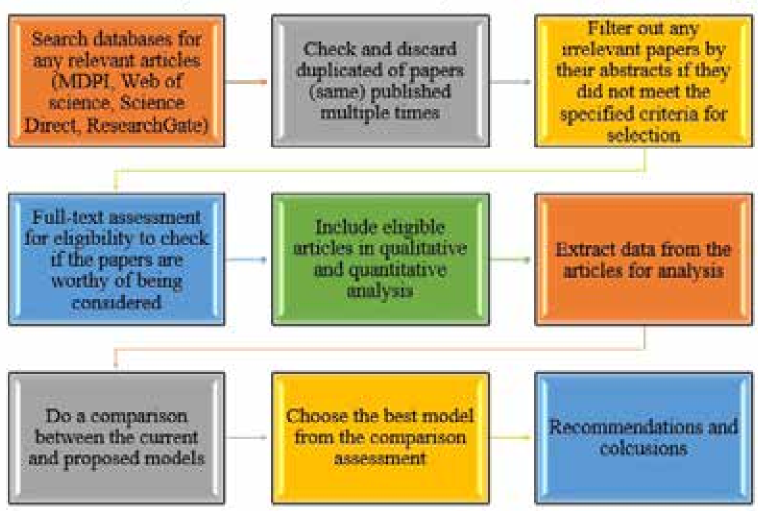

FIGURE 2: Framework of the data sampling criteria and analysis of results

RESULTS AND DISCUSSIONS

In total, 35 papers were used to extract information used in this study. These sources included journal articles and conference proceedings. Of the 35 papers, 4 were duplicate papers. All the irrelevant data sources were also filtered out by their abstracts where the abstracts were checked to find if they had the relevant data that was required. Eight papers were found to be irrelevant. Data was then extracted from the relevant sources to create this paper and a comparative analysis done on 9 papers that had proposed pipeline monitoring systems. In order to find all these papers, keywords were used to search these papers. Figure 3 shows the results of the data sampling criteria in a procedural manner in terms of the number of papers found on the databases.

There are various methods and systems proposed to monitor pipelines networks by many researchers and practitioners. Energy efficiency, cost efficiency, operation and maintenance efficiency, installation and placement of sensor nodes, and reliability of a proposed system are the components that influence how good a monitoring system is (Haibat & Jae-ho, 2019). As such, the accompanying Table 2 is a comparative analysis of the various proposed systems in terms of their efficiency in power, operation,

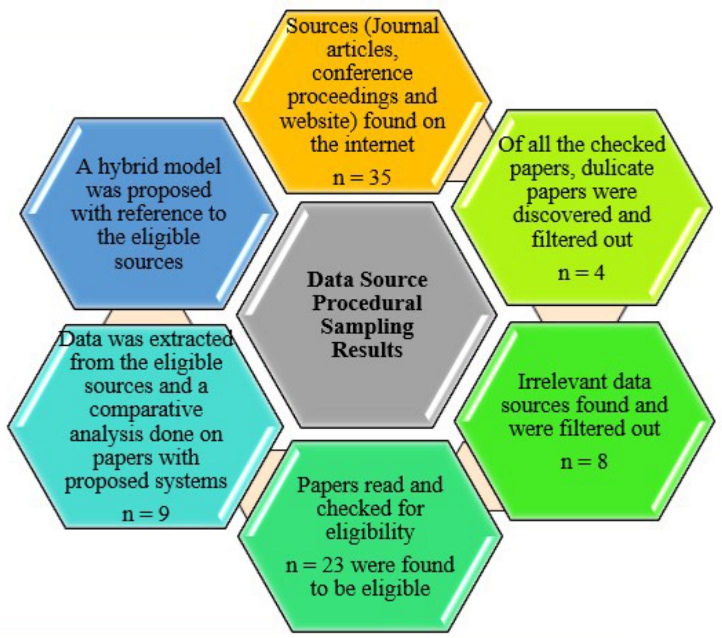

FIGURE 3: Results for data sampling criteria

maintenance, installation, and cost efficiency as well as their overall efficiency. This analysis shows that various systems are focused on different ideas of efficiencies in order to bring about the best reliability of the system. However, shifting the focus of the monitoring system to a single characteristic proved to show weaknesses in other components of the system proposed.

The model for monitoring proposed in this study is a hybrid model comprised of two models, the k-nearest neighbour (KNN) model and the Enhanced Constant Fault Alarm Rate (ECFAR). This model is able to detect a pipe burst as well as a pipe leak. According to the ECFAR monitoring model (Duong, et al., 2020) acoustic emission events happen as transients in a nonstop signal where the transient peaks overlap each other and are comprised of different lengths. To identify a burst of a pipeline, a threshold is chosen as a standard for setting off the alert. As such it is important that a correct standard is picked as this can influence the performance of the model. A low threshold will bring about a ton of alerts set off as a high number of the signals will be over the edge. A high threshold will result in not many signals identified. In that capacity, the model proposed for this method calculates a versatile (adaptive) threshold to permit the model to adjust to various noise powers or levels. The model distinguishes an impulse when the noise power surpasses the calculated threshold. The threshold for impulse detection and other parameter is determined using equations in Table

TABLE 2: Comparative analysis of various pipeline monitoring systems

Monitoring systems	Power efficiency	Operation and maintenance efficiency	Installation and cost efficiency	Overall reliability
Conventional and Visual Method	–	Exhausting as it needs a lot of human physical intervention.	May be very expensive depending on the number of personnel that is on duty.	Not very reliable as it may have errors made by the personnel and it is time consuming.
Acoustic-Emission system	The usage of power has been reduced by using components with low energy usage.	Most of the work is done by the system and associated model which makes it easy to operate.	May be expensive to maintain due to the relatively complex system.	Very reliable in monitoring and detecting any suspicious pipe activities.
Sound Variation Vibration Sensor Systems	This system uses sensors that use relatively low energy which makes the energy efficient.	This system is also easy to operate as most of the work is done by the system with less human intervention.	The low energy consumption of the components used by this system reduces the cost of operation.	Has only been used on PVC and metal pipes, performance on concrete pipes is unknown
SmartPipe Based on WSNs Approach	Very energy efficient. It uses energy harvesting approach to save more energy.	Easy to operate and maintain as many of the functions are done by the system.	With energy usage so low, it makes it to be cost efficient in that department.	Guaranteed by its simple components as they don't have complex parts.
Adige Method	Uses the long-range technology allows for fewer uploading gateways to upload data from the sensors. this allows it to save more energy.	As most of the work is done by the system, operation is relatively simple.	Reduced costs. Installation of this system is rated as good as the long-range system needs less components.	The long-range method has a constraint of accuracy. Accurately locating a leak is still a problem.
SPAMMS System	Requires a relatively high amount of energy to operate in its dynamic mode.	The need for human intervention is eliminated by the use of mobile components. Maintenance is relatively high due to many moving parts.	Less required components may reduce the cost of the system. However, high maintenance costs due to installation errors.	Less human intervention means less errors. The system also easily locates any activity as it is mobile.
EARNPIPE Systems	This system uses the Kalman filter which is very energy efficient.	Software dependant system where errors are reduced. Easy to operate.	This system is easy to install as it is designed for exposed pipeline networks.	Less accurate. The system only works on exposed pipelines and not underground pipes.
Magnetic Induction Based WSNs (MISE-PIPE)	High energy consumption due to frequent communication between the nodes and base stations.	Operation of this system is relatively easy as the sensors do most of the work with very minimal human intervention.	Energy costs are high as a result of frequent communications between the sensor nodes and base stations. Installation is relatively okay.	This system may not be energy efficient due to frequent communication. However, it is able to work on underground pipelines.

TABLE 3: The equations for the threshold for impulse detection

Measurement	Equation	Remarks
The threshold for impulse detection	1. $T = \alpha P_n$	• where P_n is the estimated noise power and α is the threshold factor (scaling constant) • The threshold adjusts to any changes in the data because of the threshold factor. The signal is spilt into a progression of continuous windows
The estimated power	2. $P_n = \frac{1}{N}\sum_{m=1}^{N} x_m^2$	• where N is the size of the window and x is the cells (sample in window) • The peak of the signal is placed on various cells on the windows • The reference window is placed further away from the test cells where the cells next to the test cells are referred to as the neighbour cells
The threshold factor	3. $\alpha = N(P_{fa}^{-1/N} - 1)$	• where P_{fa} is the required false alarm rate • Should it happen that the signal value in the test cell exceeds the threshold value,T, an impulse will be declared to be present in the test cell
P_{fa} is selected to meet the Neyman-Pearson theorem requirements for detection which are in accordance to	4. $P_{fa} = \int_{\{x:\lambda(x)>\gamma\}} f(x\|H_o)dx$	• where $\lambda(x) = likelihood\ ratio = \lambda(z) = \frac{f(x\|H_1)}{f(x\|H_0)}$ • where H_0 and H_1 represent the absence and presence of an impulse.

3. In order to increase the accuracy of the model, modified acoustic-emission signal data is used to train the classifier rather than the direct acoustic-emission signal data as depicted in Figure 1. By using the direct AE-based signals, a step "g(r) construction" that allows for the modification of direct AE-based signals is skipped.

For leak monitoring, n_i with i = 1 and 2 (the two sensors that identify a release signal), are acoustic signals recognized by two sensors (1 and 2) in the typical (state in which no leak is available on the pipeline). The two acoustic signs are comprised of a mean and variance of 0 and $N1 = N2 = N > 0$. At the point when a smal leak happens in the pipeline, it will bring about a little disturbance which will influence the flow in the pipeline around the leak location (turbulence). This causes a new and unknown signal be distinguished by the sensors. The first n_1 signal is now viewed as a background noise and not related to the source of the disturbance.

Maintenance Plan and Repairs

The hybrid model proposed is with a maintenance plan that should ensure the perfect operation of the model. The maintenance plan will also ensure that operators get accustomed with the system and thus be operated at its best condition. The maintenance plan of the model to the pipelines includes the following: a) Leak, burst and blockage surveys, b) Repairs, and c) Annual review of the maintenance plan. The maintenance plan for the system includes a) Regular checks of the sensor nodes, b) Regular checks of the base stations, c) Annual review of the maintenance plan, d) Leak surveys. The sensors placed along the pipeline system are required to take readings of the measurements done on the pipeline in intervals. The sensors listen for any form of sound that is above the threshold or the ambient sound level, that comes from the pipeline. Sensing should be done in intervals of 5 hours to ensure that the systems save power. In this way, leaks and bursts will be detected while still saving energy. As the system knows the different sound that different types of liquids make as they flow through the pipe, a blockage should be detectable should it happen. If a set of sensors reads the sound of a fluid passing and the next sensor does not, the system will automatically alert the operators for a check in the identified location by the system.

Should a pipeline show any indication of leakage or burst, the system automatically alerts the operators of a possible leak on the pipe and recommend a repair of the leak or burst. By identifying the event location, the operators should easily be able to make the right calls. For future purposes, the operators of the system are required to keep the records of every event that occurs. These records are of all the leaks and bursts that occurred on the pipelines. The records must show the following: a) Cause of the damage, b) The location of the damage, c) Date of the damage, d) Method of repair, e) Materials used in repairs, f) Responsible party for the repair, and g) Annual Review of The System Model Maintenance Plan. The maintenance plan of the model system has to be checked at intervals of a calendar year. The following are the things to check for when reviewing the maintenance plan: a) Any changes or updates to the system model, b) Any changes to the operators, c) Any repairs done, d) Any replacement of pipes, and e) Sensors and Base Stations.

Sensors are required to be checked as to whether they still operate to the best of their abilities in order to ensure the best operation of the entire system as everything starts with the sensors detection. Regular operation runs or tests need to be conducted on the sensors to ensure good operation. This will allow the operators to check as to whether or not there is a sensor node that needs attention. The data acquisition cards that are found in the sensors need to be checked for space for data storing. As these cards have a limit to how much data they can acquire, they need to be checked for data space as to whether or not more space is needed, or useless data needs to be erased. Data from sensors is sent to the base stations that stores the data in cloud where the end user can get access to the data for analysis and decision making. A perfect transmission of data from the base station to the cloud is required. For this to happen, regular checks on the base station are required. A check for good transmission speed is one of the checks required. The base stations, also known as master nodes, will also sample the data from the sensors along the pipeline. The sampling frequency for perfect operation is 8 Hz which needs to also be checked for good operation (Ismail & Yie, 2012). The maintenance plan of the actual system must be reviewed in intervals of a single calendar year. The review should check for: a) Any changes to the system, and b) Repairs to the system.

CONCLUSIONS

From the comparative analysis, it was found that many systems focus on certain characteristic of the monitoring system such as energy efficiency, localisation ability and cost efficiency. This tactic makes the systems reliable to a degree as they are capable of doing a particular job exceptionally well. But it was also found that placing the focus of the entire system on a single characteristic has its drawbacks. This is very evident in the SPAMMS where many faults may occur during the installation of the system due to many mobile parts that need to be installed. However, the system has a good localisation of any pipeline suspicious activity as it is able to get as close as possible to the site of the event. With all the comparative analysis done, two best models namely the KNN model and ECFAR system were then selected from all the systems that were contrasted against each other. These are widely used reliable models in the detection of leaks and bursts in pipelines and are also used in other different studies. Research by Datta and Sarkar (2016) has revealed that acoustic monitoring systems detect leakages, blockages and bursts as quickly as possible in a pipe as significantly little as 1% of its diameter. From these two chosen models, a hybrid model which is a combination of both models is proposed to monitor pipeline networks systems for bursts and leaks. This model makes use of transformed acoustic-emission signals to train the classifier which makes the model more reliable and decreases its susceptibility to normal noises.

RECOMMENDATIONS

Many available systems are focus on one characteristic which makes the systems prone to vulnerabilities in other characteristics of the system. Improvement needs to be done on the different components of the monitoring systems so that the system can work efficiently in all the areas of the system such as power consumption which will ultimately decrease the costs as far as the monitoring system is concerned. The future research may also look at obtaining empirical results for the system that was proposed in this paper.

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PAPER 10

Proactive and Prioritized Stormwater Drainage Maintenance and Management System

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ABSTRACT

Municipalities are challenged with increasing maintenance costs and budget constraints for the upgrading of municipal services such as roads and stormwater. This has again been highlighted by several flood events during the rainy season causing significant damages to roads, property as well as loss of life. A further aggravating factor is climate change which is causing more sporadic as well as intensive storm events.

The lack of maintaining existing stormwater drainage systems has a significant effect on the drainage system capacity due to blockages and siltation causing excessive runoff on roads which are severely damaged by erosion. Furthermore, the increased urbanisation and densification causes a significant increase in surface runoff which existing drainage systems can no longer accommodate.

A recent project involving a Stormwater Master Plan for Alexandra in the City of Johannesburg has highlighted the need for planned and regular maintenance of stormwater systems as well as upgrading of under capacity drainage systems to prevent excessive and uncontrolled flooding. The stormwater master plan included the visual condition assessment and survey of the existing stormwater drainage system, hydrological modelling and developed a unique and practical approach using a prioritisation algorithm to identify and prioritise the flooding problems and required maintenance activities schedules.

This paper presents a case study which highlights the implications of not maintaining stormwater drainage systems as well as the excessive capital cost required to now replace and upgrade the drainage system which could have been prevented by carrying out regular maintenance. The paper also presents a unique developed algorithm that can be used in prioritising maintenance activities for improved forward planning, budgeting and service delivery.

1. INTRODUCTION

It has been observed over the past few years that weather patterns have changed which causes more sporadic and more intense rainfall events within South Africa as well as other continents. In view of this stormwater drainage systems have become more important to drain excess stormwater and to be fully functional.

A shortcoming often encountered in South Africa is the failure to budget and carry out maintenance of stormwater networks of both artificial as well as natural drainage systems. Artificial drainage networks comprising of kerb inlets , grid inlets ,pipes and culverts. Natural drainage networks mainly comprise streams, rivers and tributaries which receive stormwater from the artificial drainage networks.

An example of a typical urban drainage network is shown in Figure 1.

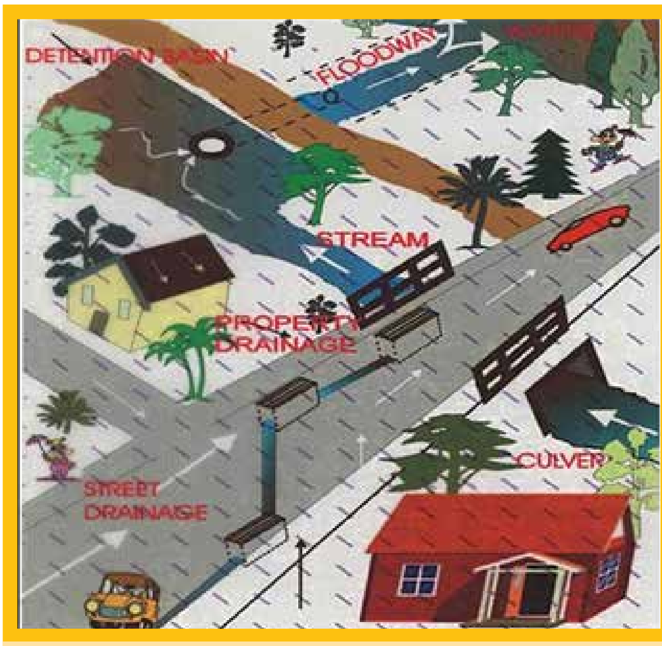

FIGURE 1: Typical urban artificial and natural drainage networks

If the drainage networks are not regularly maintained the hydraulic capacity is significantly reduced and hence flooding of developments and infrastructure occurs. This often causes damage to property as well as liability claims against a municipality.

Therefore, a proactive and prioritised maintenance system has been developed to assist a municipality in able better planning and managing maintenance activities thereby minimising the risk of flooding and potential liability claims. The approach and methodology as well as an example of the prioritization system is discussed and illustrated below.

2. PROACTIVE AND PRIORITISED STORMWATER DRAINAGE MAINTENANCE SYSTEM

A municipality is usually challenged with an insufficient maintenance budget as well as not knowing where urgent and important maintenance activities are required within a municipal area. This in turn causes a reactive rather than a pro-active approach to maintenance activities. ie. Once flooding problems and /or flood damage has occurred emergency maintenance activities are carried out. This is often costly as well as unplanned and in large storm event can cause severe damages to infrastructure and even cause loss of life.

Maintenance activities would typically comprise of cleaning kerb and grid inlets, opening manholes to remove debris and silt from an underground pipes or culverts, removing debris and excessive vegetation from road crossings. A prioritised stormwater maintenance system using a customised algorithm has been developed in order to guide a municipality and maintenance depot to proactively carry out maintenance activities in high priority areas prior to storm rainfall event causing flood damage.

2.1 Drainage network asset register

It is important that a municipality has an up-to-date asset register of the existing drainage network. It has been found that asset registers are usually outdated and/or don't have sufficient detailed information of the drainage network members. This often leads to information gaps which prohibit a detailed assessment and determination of the required maintenance activities. It was found that most stormwater drainage asset registers give the locality and type of a drainage system member but lack in defining the size of the member as well as the invert levels and gradients of underground pipes and culverts.

An asset register should at least have the following information:

a) Pipe/culvert network:

- Geo-referenced member locality, member type (pipe /culvert / channel), member material (concrete, masonry, brick);
- Member condition (functional, partly functional, broken), member size (diameter, width, depth);
- Invert level at start and end of member;
- Member length

b) Kerb and grid inlets

- Geo-referenced locality, grid dimensions (width, length);
- Kerb inlet type (transition, no transition), kerb inlet opening width and height.

An example of the typical drainage network asset register is given in Table 1 below.

2.2 Drainage network member size

A factor, which influences the risk of potential blockage, is the drainage member size. It has been established from both site observations as well as laboratory testing that the smaller the member diameter or cross section the higher the risk of blockage due to siltation and debris.

2.3 Drainage network hydraulic characteristics

An important factor that determines the risk of sedimentation and blockage within a pipe or culvert network is the gradient of the member as well as expected flow velocity. This is important as the flatter the gradient the lower is the flow velocity and hence a higher risk of blockage. It is furthermore

TABLE 1: Drainage network database

Conduit names and manhole references						Existing Main member			
Conduit Name	Inlet (manhole)	Inlet (Invert)	Outlet (manhole)	Outlet (Invert)	Length (m)	Gradient (%)	Type: pipe (P), Box culvert (BC), Channel (CH)	No Of	Diam (survey)
C5-5	N5-10	1498,981	N5-5	1498,925	13,46	0,42%	P	1	450mm Class 75D
C5-10	N5-15	1499,217	N5-10	1498,981	57,314	0,41%	P	1	450mm Class 75D
C5-15	N5-20	1499,501	N5-15	1499,217	68,018	0,42%	P	1	450mm Class 75D
C5-20	N5-25	1503,469	N5-20	1499,501	34,723	11,43%	P	1	650mm Class 75D
C5-20.1	N5-45	1501,438	N5-20	1499,501	31,143	6,22%	P	1	650mm Class 75D
C5-25	N5-30	1511,66	N5-25	1503,469	114,366	7,16%	P	1	700mm Class 75D
C5-30	N5-35	1514,87	N5-30	1511,66	57,904	5,54%	P	1	825mm Class 75D
C5-35	N5-40	1518,052	N5-35	1514,87	52,514	6,06%	P	1	450mm Class 75D
C5-05.1	N5-5	1498,925	05-1	1498,641	45,78	0,62%	p	1	450mm Class 75D
C5-50	N5-55	1500,89	N5-50	1500,438	14,799	3,05%	P	1	750mm Class 75D
C5-50.1	N5-95	1501,063	N5-50	1500,438	38,241	1,63%	P	1	625mm Class 75D
C5-55	N5-60	1502,392	N5-55	1500,89	36,485	4,12%	P	1	900mm Class 75D
C5-60	N5-65	1503,005	N5-60	1502,392	8,457	7,25%	P	1	450mm Class 75D
C5-60.1	N5-140	1502,517	N5-60	1502,392	11,857	1,05%	P	1	450mm Class 75D
C5-65	N5-70	1505,024	N5-65	1503,005	44,255	4,56%	P	1	450mm Class 75D
C5-70	N5-75	1506,071	N5-70	1505,024	27,616	3,79%	P	1	450mm Class 75D

TABLE 2: Minimum gradients for concrete pipes

Pipe Diameter (mm)		Minimum slope (%)	
Nominal	Inner	Full-flow	25% flow
450	0.445	0.48	0.23
525	0.514	0.39	0.19
600	0.585	0.33	0.16
675	0.647	0.29	0.14
750	0.718	0.25	0.12
825	0.788	0.22	0.11
900	0.853	0.20	0.10
1050	0.986	0.17	0.08
1200	1.127	0.14	0.07
1350	1.262	0.12	0.06
1500	1.383	0.11	0.05

shown that once the gradient is below a minimum threshold there is a high risk of sedimentation. Typical minimum gradients for different pipe concrete pipe diameters are given in Table 2.

The hydraulic characteristics of the drainage network can be determined by two possible methods as described below.

2.3.1 Hydraulic characteristics - existing stormwater master plan

If an existing stormwater master plan exists relevant details of the drainage member size, gradient and flow velocity should be readily available. This data can then be extracted and used for determination of the hydraulic characteristics of the existing drainage network.

2.3.2 Hydraulic characteristics - additional hydraulic modelling

If no stormwater master plan exists a hydraulic assessment of the existing drainage network can be carried out by setting up a hydraulic model. The information of the existing drainage network could be obtained from the asset register, where available. The hydraulic model can then be used to establish the expected flow velocities in each of the network members based on the member's size and gradient.

2.4 Road network type and land-use

It has been observed from previous studies that the road type and land-use has a significant impact on the risk of blocking a stormwater drainage network. This is caused by sediment being transported during a storm event which then enters the drainage network via kerb and grid inlets. In view of this a drainage network in a rural area, which is mainly unpaved, will have a higher risk of blockade than in a paved area and hence will have a higher maintenance requirement.

2.5 Prioritisation Algorithm

A prioritisation algorithm has been developed which assists the municipality in carrying out maintenance in a proactive manner rather than reactively. The prioritisation algorithm takes into account five indicators that have an impact on the potential risk of blocking a drainage network and hence are used to prioritise the drainage network reaches that need proactive maintenance.

The following indicators are taken into account:

i. Drainage member size, member gradient, member flow velocity, road type, land-use type.

The prioritisation algorithm now takes into account each of the above

TABLE 3: Drioritisation indicators and weighting

Item	Indicator category	Description	Weighting
1	Member size (mm)	< 300	15
		375-400	12
		450-525	10
		600-750	8
		800-950	6
		1 050-1 200	4
		1 350-1 500	2
		>1 500	1
2	Member gradient (%)	0-1	25
		1-2	20
		2-3	15
		3-4	10
		>4	5
3	Flow velocity (m/s)	<0,5	35
		0,5-1,0	30
		1,0-2,0	25
		2,0-3,0	20
		3,0-4,0	15
		>4,0	10
4	Road type	Gravel (unpaved)	10
		Sealed (dust suppression)	7
		Brick	5
		Paved/Asphalt	1
5	Development	Informal	15
		Business/ Commercial/ Industrial	10
		Urban (semi-formal residential)	5
			2

indicators as well as a weighting of the indicator in causing blockage and sedimentation within a drainage network reach. Each defined indictor and associated weighting is summarised in Table 3 below.

Having defined the above indicators and weighting the blockage potential for a drainage network member, which is a numeric indicator of the expected blockage potential can be calculated using the equation (1) below.

$$Blockage\ potential_{\ member} = (Member\ size_{\ weighting}) + (Member\ gradient_{\ weighting}) + (Member\ flow\ velocity_{\ weighting}) + (Road\ type_{\ weighting}) + (Development_{\ weighting}) \quad (1)$$

Having now defined the blockage potential of existing drainage network members allows one to obtain a range of blockage potentials. This indicator is now used to define the maintenance priority as given in Table 4.

3. ALEXANDRA TOWNSHIP CASE STUDY

The above approach was applied and successfully used in a project undertaken in the Alexandra township within the Johannesburg City area. Details of the study and findings as well as recommendations are given below.

3.1 Study objective

The main objective of the study was to carry out a Stormwater Master Plan of the Alexandra township. This was required in order to analyse the existing drainage network as well as define required upgrading measures .As part of the Stormwater Master Plan the current blockage of the drainage network was investigated and planned future maintenance activities were identified . A further objective was to identify the cost implications relating to unblocking of the drainage network in relation to capital costs for having to replace the blocked and damaged drainage network.

3.2 Study area

The study area is situated within the Alexandra township as shown in Figure 2 below.

FIGURE 2: Study area locality

3.3 Existing drainage system details and condition

As part of the investigation a detailed survey and visual inspection of the existing drainage network was undertaken and an asset register developed. From this assessment it was established that about 80% of the drainage network was blocked with debris and silt.

The blocked drainage network could no longer be easily cleaned and would mostly have to be replaced.

Typical details of the existing drainage network members are shown in Table 5.

TABLE 5: Typical condition of existing drainage networks

3.4 Study approach and findings

Once the asset register was completed a hydrological model of the drainage catchments as well as a hydraulic model of the existing drainage network was compiled for the study area. From the modelling data the following information was abstracted for use in the blockage prioritisation algorithm:

i. Network member size, member gradient, member flow velocity, road and development details.

TABLE 4: Maintenance priority

Maintenance priority	Blockage potential
Very high (VH)	100 - 75
High (H)	74 - 60
Medium (M)	59 - 40
Low (L)	< 40

By now applying the indicator categories and weighting factors to each of the drainage network members the expected blockage potential has been determined. Once the blockage potential was determined the maintenance priority was established based on the ranges and categories given in Table 4.

The results are shown in Table 6.

The results of the prioritisation algorithm are shown graphically on Figure 3.

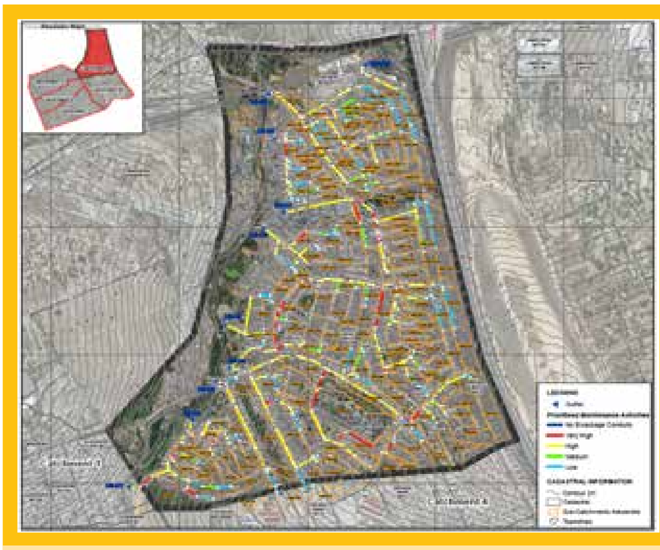

FIGURE 3: Map showing locality of prioritised maintenance requirements

3.5 Financial implications

It could be shown that there is a substantial financial implication if drainage networks are not regularly maintained. This is due to drainage networks becoming fully blocked which prohibits cleaning of the pipes both by mechanical and/or jetting operations. This in turn necessitates the removal of the drainage network which then needs to be replaced by a new network.

From the case study the following was established:

i. An annual operating cost of R400 000 would be required to regularly maintain the drainage network that was investigated;

ii. Due to the severe blockage the drainage network now has to be replaced at a capital cost of R60 million which is substantially more than the operating costs

4. CONCLUSIONS

The following is concluded:

i. Drainage network asset registers often do not have sufficient information;

ii. Existing drainage networks do not get maintained causing a significant decrease in hydraulic capacity;

TABLE 6: Drainage network blockage potential and maintenance priority

Conduit reference	Network characteristics						Blockage indicators					Maintenance prioritisation	
Conduit Name	Length (m)	Gradient (%)	Pipe Diam (mm)	Flow velocity (m/s)	Road type	Development	Weighting factors					Blockage potential rating	Maintenance category
							member size	member gradient	flow velocity	road type	Development		
C5-5	13,46	0,42%	375mm Class 75D	0,6	paved	formal residential	12,00	25,00	30,00	1,00	2,00	70,00	H
C5-10	57,314	0,41%	450mm Class 75D	0,55	paved	formal residential	10,00	25,00	30,00	1,00	2,00	68,00	H
C5-15	68,018	0,42%	450mm Class 75D	0,7	paved	formal residential	10,00	25,00	30,00	1,00	2,00	68,00	H
C5-20	34,723	11,43%	650mm Class 75D	3,5	gravel	formal residential	8,00	5,00	15,00	1,00	2,00	31,00	L
C5-20.1	31,143	6,22%	650mm Class 75D	2,8	gravel	semi-formal residential	8,00	5,00	20,00	10,00	5,00	48,00	M
C5-25	114,366	7,16%	700mm Class 75D	3,6	gravel	semi-formal residential	8,00	5,00	15,00	10,00	5,00	43,00	M
C5-30	57,904	5,54%	825mm Class 75D	2,6	paved	business	6,00	5,00	20,00	1,00	10,00	42,00	M
C5-35	52,514	6,06%	450mm Class 75D	2,6	paved	business	10,00	5,00	20,00	1,00	10,00	46,00	M
C5-05.1	45,78	0,62%	450mm Class 75D	0,76	gravel	business	10,00	25,00	30,00	10,00	10,00	85,00	VH
C5-50	14,799	3,05%	750mm Class 75D	1,8	gravel	formal residential	8,00	10,00	25,00	10,00	2,00	55,00	M
C5-50.1	38,241	1,63%	625mm Class 75D	1,3	gravel	informal	8,00	20,00	25,00	10,00	15,00	78,00	VH
C5-55	36,485	4,12%	900mm Class 75D	2,7	gravel	informal	6,00	5,00	20,00	10,00	15,00	56,00	M
C5-60	8,457	7,25%	1 050mm Class 75D	3,8	gravel	informal	4,00	5,00	15,00	10,00	15,00	49,00	M
C5-60.1	11,857	1,05%	1 200mm Class 75D	0,9	gravel	informal	4,00	20,00	30,00	10,00	15,00	79,00	VH
C5-65	44,255	4,56%	1 200mm Class 75D	3,1	paved	formal residential	4,00	5,00	15,00	1,00	2,00	27,00	L
C5-65.1	45,099	3,94%	1 500mm Class 75D	2,8	paved	formal residential	2,00	10,00	20,00	1,00	2,00	35,00	L
C5-70	27,616	3,79%	900mm Class 75D	2,5	paved	formal residential	6,00	10,00	20,00	1,00	2,00	39,00	L

iii. Non maintained drainage networks cause flood damage and liability claims against a municipality;
iv. Maintenance activities are performed reactively without proper forward planning;
v. Existing blocked drainage networks can no longer be cleaned and need to be replaced at a high capital cost;
vi. There is usually insufficient information and forward planning of maintenance activities due to the lack of As-build information;
vii. A proactive and prioritized drainage network maintenance system has been developed based on an algorithm taking into account the locality, slope and size of members to assist municipalities in carrying out required proactive maintenance in areas with a high risk of blockage.

5. RECOMMENDATIONS

The following is recommended:

i. Drainage pipes be placed at gradients higher than the minimum gradients to reduce the risk of blockage;
ii. Drainage pipes to not have a dimeter less than 450 mm;
iii. The stormwater drainage system asset register and As-build details be kept up to date;
iv. Regular maintenance be budgeted for and carried out to prevent drainage networks from being totally blocked and needing replacement at a high capital cost;
v. The developed prioritised stormwater maintenance system be used to guide a municipality to carry out pro-active maintenance activities in areas with a high risk of blockage.

6. ACNOWLEDGEMENTS

The author wishes to acknowledge the opportunity given by the Johannesburg Roads Agency to the consultant in developing the prioritised stormwater drainage maintenance system for the Alexandra stormwater project.

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PAPER 11

Hydrological Study and Hydrodynamic Modelling on Horlosiekloof, De Doorns, Western Cape

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ABSTRACT

An investigation on the flood hydrology and river hydraulics of the Horlosiekloof catchment area (De Doorns in the Western Cape) was carried out with the primary objective to determine firstly if developments in the catchment impacted on the flood peaks and secondly, the possible mitigation measures to decrease the flood risk. This was achieved by performing a flood hydrology analysis of the Horlosiekloof catchment and creating a two-dimensional (2D) model of the catchment area.

A flood analysis of the pre- and post-development of the lower catchment concluded that the agricultural developments had only a marginal impact on the expected flood peaks. However, human interaction resulted in altering the flow path, and presently most of the runoff is diverted into/concentrated in a well-defined stone pitched channel. The 2D modelling indicated that, while the combined capacity of the culverts may be adequate to deal with the 1:2-year flow, supercritical flow conditions exist upstream of the site.

Possible mitigation measures include the upgrading of the capacity of the existing culverts near the stone pitched channel, and that additional culvert may reduce the flood risk. The ground level upstream of all culverts (new and existing) must be lowered to force a hydraulic jump upstream of the site in order to create subcritical flow conditions. A flood attenuation dam was evaluated as an alternative to upgrading the capacities of the culverts.

INTRODUCTION

Flooding of the N1 road occurs near De Doorns in the Western Cape, which might cause risk to normal traffic, as well as storm damage to the N1. Consequently, an investigation on the flood hydrology and river hydraulics of the Horlosiekloof catchment area was carried out.

The primary objectives of the study were:

- Determine the expected flood peaks and hydrographs from the Horlosiekloof catchment area.
- Ascertain the impact that the agricultural development has on the flood regime.
- Perform 2D modelling of the current development of the study area to determine the extent of the flooding that can be expected by using the HecRAS software program.
- Determine possible mitigation measures to decrease the flood risk.

FLOOD HYDROLOGY

The main objective of the flood analysis was to determine the magnitude of the expected flood event at the N1 and to establish the impact of the agricultural developments upstream of the N1 on these flood peaks.

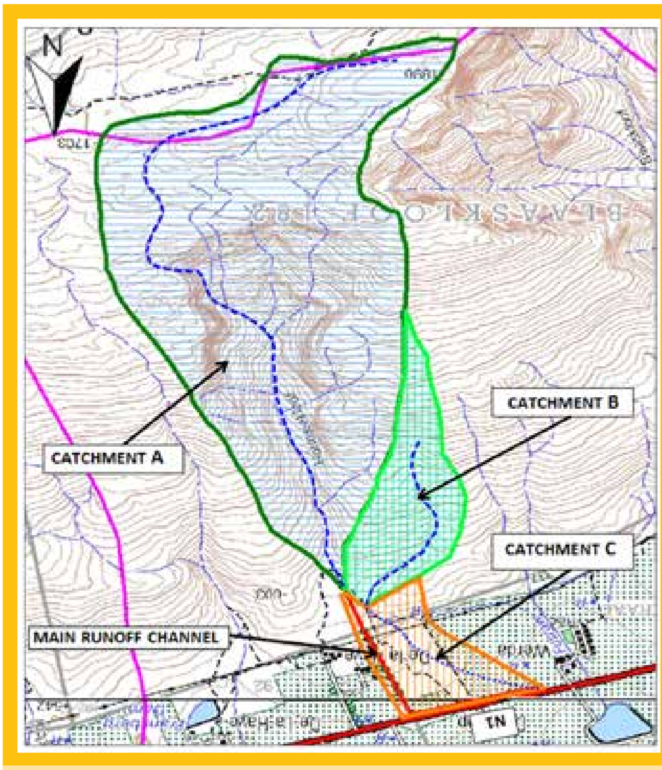

FIGURE 1: Contributing catchments requirements

Catchment characteristics

Various catchments contribute towards the runoff that needs to be dealt with at the N1 crossings. These catchments are shown in Figure 1.

Catchment A represents the main contributing catchment and reflects the catchment area that would contribute all the water that would enter the main runoff channel, leading towards the N1.

Catchment B represents a smaller catchment bordering the lower end (North-West) of catchment A. This catchment does not enter the main runoff channel, which is the main focus area. It does however influence the understanding of how the runoff from these catchment areas were influence over time and specifically the impact on the runoff after the construction of the N1.

Catchment C reflects the catchment area that was impacted significantly over time by agricultural activities. It also represents the lower delta-like catchment area, which provided the natural drainage route of all water from catchment A and B, prior to the redevelopment of the now well-defined runoff channel.

TABLE 1: Catchment characteristics

Catchment	Catchment Area (km²)	Longest Water-course (km)	Average Water Course Slope (m/m)	Time of Concentration (hours)
A	4.685	5.965	0.256	0.44
B	0.477	1.315	0.281	0.13
C	0.569	1.294	0.083	0.21
Full Area (A+B+C)	5.731	7.423 (7.259)	0.231 (0.235)	0.55 (0.53)

The catchment information required by the various flood determination methods are shown in Table 1.

The catchment characteristic values for the full catchment (A+B+C) area shown in brackets in Table 1, represent pre-development values (before the N1 was constructed) and they do differ slightly from the present day situation due to the man-made influences on the runoff path of the stormwater from the catchment area.

Rainfall

Only rainfall data from two monthly rainfall stations were available i.e. De Doorns (NIWW) and Hexvalley PP. De Doorns (NIWW) had a 40 year record length with a Mean Annual Precipitation (MAP) of 311 mm, while Hexvalley had a 9 year record length with a MAP of 406 mm.

No short duration data was available for the catchment. Moreover, since the time of concentration (Tc) for the different catchments to be analysed is less than 1 hour, the design rainfall required for the flood calculations were based on the storm rainfall data as proposed by the software application developed by Smithers and Schulze (2000). Based on this software application, the short duration catchment rainfall, calculated using a Thiessens polygon approach, are shown in Table 2 for catchment A and the full catchment.

TABLE 2: Smithers storm rainfall in mm

Catchment	Storm duration	Recurrence interval of storm event					
		2	5	10	20	50	100
A	15 m	16.8	21.8	25.1	28.2	32.3	35.3
	30 m	23.6	30.8	35.5	39.9	45.7	50.0
	45 m	29.0	37.8	43.6	49.1	56.2	61.5
	1 h	33.7	43.9	50.6	57.0	65.3	71.4
Full	15 m	17.0	22.1	25.5	28.6	32.8	35.8
	30 m	23.5	30.6	35.3	39.7	45.4	49.6
	45 m	28.6	37.2	42.9	48.3	55.2	60.3
	1 h	32.9	42.9	49.4	55.6	63.6	69.5

TABLE 3: Station H2H005: Flood calculation: Q (m³/s)

Methodology	Recurrence interval: T(a)					
	1:2	1:5	1:10	1:20	1:50	1:100
Probabilistic approach	8	11	14	16	19	23
Rational: Smithers MAP	37	51	62	74	89	102
Rational: De Doorns MAP	27	38	46	55	66	76

Flood frequency analysis

Three methods were used in calculating the flood peaks of the different catchments under evaluation, i.e the Rational, SCS-SA and SDF methodology.

Rational method

This is the most used method in South Africa and the Horlosiekloof catchment size falls well within the application range of the Rational method. The method depends on the MAP to guide the selection of the runoff coefficients used in the method and was developed with a coaxial diagram, using MAP to determine storm rainfall (Van Dijk, Van Vuuren & Smithers 2015). The MAP at De Doorns and Hexvalley are 311 mm and 406 mm respectively. These values were used as indicative values for the catchment in the Rational method, to determine the runoff coefficients.

The critical MAP ranges for the selection of appropriate runoff coefficients within the Rational method is categorised in three groups i.e.: below 600 mm/a, between 600 and 900 mm/a and above 900 mm/a. The software application (Smithers and Schulze 2000) used to calculate the storm rainfall can also provide the MAP values. These values were however suspiciously high. To verify the selection of appropriate runoff coefficients using the catchment MAP, the closes available river flow station's annual maximum peak flow series (AMS) were analysed, using a probabilistic approach.

The closes available river flow station is the Rooi Elskloof flow station (H2H005), situated just north to the Horlosiekloof catchment. While it is recognised that this catchment might receive different storm rainfall than the Horlosiekloof catchment, the general catchment characteristics in terms of slope and vegetation were judged to be able to produce similar runoff coefficients as what can be expected from the Horlosiekloof catchment. The following procedure was followed to verify the MAP values:

- Do a probabilistic analysis of the AMS of river flow station H2H005 and determine the flood peaks for the 1:2 to 1:100 year recurrence interval (RI).
- Calculate the Rooi Elskloof (H2H005) catchment MAP and design rainfall using the software application.
- Apply the Rational method to calculate the 1:2 to 1:100 year RI flood peaks.
- Compare the results with the results obtained with the probabilistic approach.
- Change the MAP category and determine the impact of a different MAP category on the associated runoff coefficients.
- Based on this finding, determine the most likely MAP category to be used to provide realistic flood peak results for the H2H005 catchment and assume that the same MAP category can be used for the Horlosiekloof catchment.

The procedure above confirmed that, using the software application to calculate the catchment MAP, produce flood peaks that overestimate the flood peak values compared to the probabilistic approach. The selection of runoff coefficients associated with a catchment MAP values below 600 mm/a provided results, when using the Rational method, which was deemed more appropriate if compared with the results obtained from the analysis of the observed AMS, than using a MAP category of more than 600 mm/a as suggested by the software for the H2H005 catchment. Following this observation, it was assumed to be also applicable to the

Horlosiekloof catchment areas and runoff coefficients associated with a catchment MAP of 600 mm/a or less was used in all further analysis.

The results of the three different methods for the flood calculation for station H2H005 are summarised in Table 3.

Rational method: Flood peaks before and after development of N1

The N1 road was developed along its present alignment between 1942 and 1962 and the catchment area upstream of the N1 was at the time undeveloped and consists of natural vegetation.

It is therefore reasonable to assume that the storm water drainage along the N1 was designed, using runoff coefficients associated with an undeveloped catchment. The storm rainfall used for the design was in all probability also those values obtained from the old coaxial diagrams (Van Dijk, Van Vuuren & Smithers 2015). For a comparison between a pre- and post-N1 scenario, the catchment characteristics for the full catchment as highlighted in Table 1 (values in brackets) were used in conjunction with the storm rainfall from the coaxial diagrams to calculate the flood peaks for different return periods. A MAP of less than 600 mm/a was again assumed for the selection of the runoff coefficients.

For the post-N1 scenario, the delta discharge drainage area was considered as almost fully developed. The Rational method was again applied with the corresponding new runoff coefficients, using the same coaxial diagram-based storm rainfall and catchment characteristics from Table 1.

In evaluating the results presented in Table 4, it is clear that the development of the delta discharge drainage area did not have any impact on the flood peaks. This is due to a very small percentage of area developed, while the runoff path (longest water course) was artificially lengthened at the same time.

TABLE 4: Sational method: Pre & Post – N1 flood peaks (m³/s)

Methodology	Recurrence interval: T(a)					
	1:2	1:5	1:10	1:20	1:50	1:100
Rational: Pre-N1	15	22	29	39	53	68
Rational: Post-N1	15	22	29	38	53	68

Rational method: Present day flood peaks

For the calculation of the present day flood peaks to be dealt with, given the problems experience at the N1, two factors need to be considered:

- Improved storm rainfall is available through the software application, and
- a newly defined catchment exists as a result of the well-defined man-made runoff channel, which only deals with the runoff from catchment A (see Figure 1). The water from catchment B does not enter this channel, but also need to pass underneath the N1.

The present-day flood peak calculations using the catchment characteristics for catchment A and the storm rainfall from the software application and runoff coefficients associated with a MAP less than 600 mm/a is presented in Table 5.

It is clear that there is only a marginally difference in the flood peaks if the full catchments are used as opposed to only using catchment A, which is the only catchment producing runoff that flows in the man-made runoff channel.

TABLE 5: Rational method: Present day floods (m³/s)

Methodology	Recurrence interval: T(a)					
	1:2	1:5	1:10	1:20	1:50	1:100
Rational: Catchment A: present day	25	34	42	50	60	70
Rational: Full Catchment: present day	27	38	46	55	66	76

TABLE 6: Summary: Catchment A: Present day flood peaks (m³/s)

Methodology	Recurrence interval: T(a)					
	1:2	1:5	1:10	1:20	1:50	1:100
Rational	25	34	42	50	60	70
SCS-SA	26	46	62	81	107	131
SDF	11	26	39	53	73	90

SCS-SA method

The SCS-SA methodology is specifically adapted to suit South African conditions and is suitable for small catchment taking different development zones within one catchment area into consideration. Given the simplicity of the specific catchment, it was necessary to identify only two different homogenous development zones, reflected as curve numbers (CN). One zone, representing 37% of catchment A's area, was considered to have a high runoff potential (CN = 84) which was associated with the steep mountain slopes, while the second area, representing 63% of catchment A's area, was considered to have a lower runoff potential (CN= 80).

The storm rainfall that is used with the SCS-SA method is based on a 1-day storm rainfall event which can be obtained from either the SCS-SA own dataset, the TR102 dataset or a user defined 1 day storm rainfall analysis. The first approach (using the SCS-SA dataset), which is similar to the software applications storm rainfall data, provided results way in excess of the results obtained with the Rational and SDF methods. It was therefore decided to use the 1-day storm rainfall as provided in TR102. This approach provided results comparable to the other two alternatives approaches used.

SDF method

The SDF methodology is the most recent developed flood determination methodology in South Africa, developed specifically to allow for less engineering judgement in the application process of the methodology. The method makes use of a pre-selected SDF basin (Basin 18 in this case) and calibration coefficients. Some serious shortfalls have been identified in recent research (Gericke and Du Plessis 2012) with the development of the runoff coefficients and a need for the re-calibration of some of the coefficients used in the method was highlighted. The method is however simple to apply and is always used as a benchmark value for road drainage designs.

Summary of flood peaks

With the focus on the problems experienced with the runoff in the well-defined runoff channel when it reaches the N1, the results of the different flood determination methods for only catchment A, are presented in Table 6.

The three approaches used to calculate the expected flood peaks to be dealt with in the main runoff channel provide reasonable similar results, with the Rational method providing reasonable results for the smaller return periods and slightly lower values for the higher return periods. It was therefore decided to use the results from the Rational method as representative of the Horlosiekloof catchment in all further analysis.

RIVER HYDRAULICS

Hydrodynamic Model Setup

A detailed 2D hydrodynamic modelling (HecRAS 5.0.3. (Brunner 2016)) simulation was conducted on the catchment.

A LIDAR Survey was carried out by aircraft to cover the area and 1 m interval contour lines were made available for the modelling. The topographical survey data on a grid of 2 x 2 m was read into the model to create the model bathymetry.

The hydraulic roughness was specified in the model to compensate for the effects of vegetation and a Manning n-value of 0.055 was used (Chadwick et al. 2013). The N1 road, crossing the study area, was also included with the culverts.

The upstream boundary of the model is located at the start of the gorge, while the downstream boundary was placed several hundred meters (on average) downstream of the study area so that the downstream boundary does not affect the main model domain and flow patterns. At the upstream inflow boundary, a typical flow hydrograph shape was specified for the various recurrence interval floods. At the downstream boundary, normal flow depth was specified. The model simulates the hydrodynamics in a fully hydrodynamic mode, with time steps of the unsteady simulation typically less than 1 second.

Culvert Discharge Capacities

The total combined discharge capacity of the existing culverts is 30.7 m^3/s, which is only marginally greater than the 2-year peak flood of 27 m^3/s (for full catchment). The 2-year flood peak of 25 m^3/s associated with the flow from catchment A, following the well-defined man-made flow path, is slightly less than the calculated culvert capacities.

The modelling indicated that, while the combined capacity of the culverts may be adequate to deal with the 1:2-year flow, supercritical flow conditions exist upstream of the N1 due to the steep flow path slope. Supercritical oncoming flow must be allowed to pass through the culverts virtually undisturbed (Rooseboom & Van Vuuren 2015), otherwise considerable damming would occur upstream of the N1, that would flood the road surface.

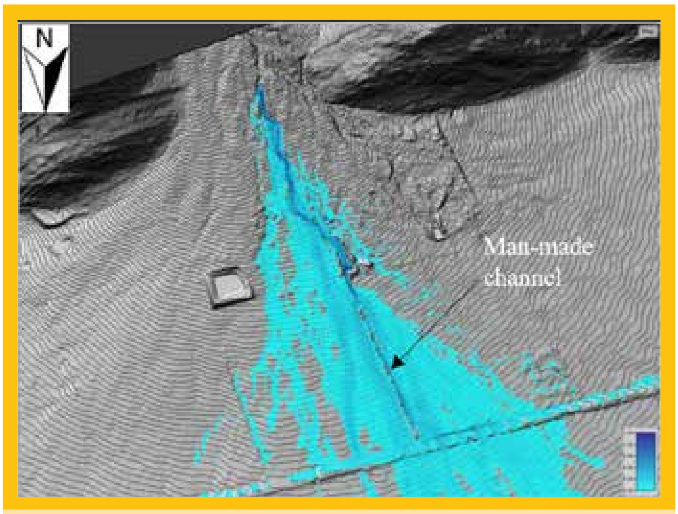

FIGURE 2: Simulated study area flow depths (m) at peak of the 20-year flood (50 m^3/s)

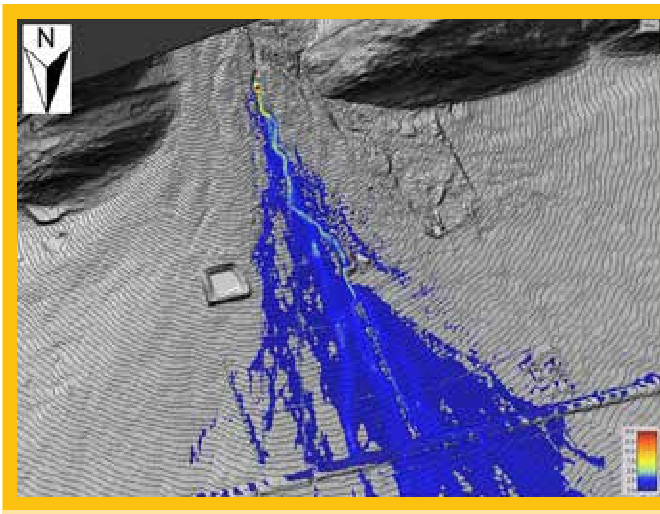

FIGURE 3: Simulated study area flow velocities (m/s) at peak of the 20-year flood (50 m^3/s)

Simulation results on current development

The simulation results for the 20-year flood (current scenario) are illustrated in Figure 2 and Figure 3. The simulated flow depths are shown in Figure 2. The maximum flow depth just upstream of the N1 is 1.2 m and is caused by the road as an obstruction across the floodplain. Spillage occurs over the road to a maximum flow depth of 0.4 m. The damming causes flooding upstream of the road over a distance for about 1.8 km along the N1, and spillage over the N1 over a distance of approximately 700 m.

The simulation results indicate that most of the storm runoff flows down the catchment along and near the man-made channel as seen in Figure 2. The limited capacity of the waterway underneath the N1 at the point where the channel reaches the N1 still results in the overtopping of the N1.

The simulated flow velocities for the 20-year flood peak are shown in Figure 3. The flow velocities just upstream of the N1 road are below 2.6 m/s due to the damming. Higher velocities up to 2.8 m/s were simulated just downstream of the N1 road. However, higher flow velocities up to 21.6 m^3/s higher up in the catchment were simulated, due to the steep slope of the catchment. Supercritical flow conditions occur upstream of the N1 road.

Results for the 1:50 year flood simulation are similar to the 1:20 year flood simulation results.

The results from the hydrodynamic modelling indicated that the limited capacity of the culverts cause damming upstream of the road. The flow velocities in the catchment are high with supercritical flow conditions upstream of the road.

The best way to reduce the damming would be to construct a bridge(s) or culverts on the road in order to allow the supercritical flow to traverse the road undisturbed, but the road is low and it is doubtful whether sufficient freeboard is available. A flood attenuation dam could also be constructed to attenuate the flood to a river flow discharge capacity equal to the combined culvert capacity at the N1 road.

POSSIBLE MITIGATION MEASURES TO DECREASE FLOOD RISK

SANRAL proposed that for the future flood remedial measures for the Horlosiekloof catchment area, the 20-year (50 m^3/s) flood recurrence should be used in designs.

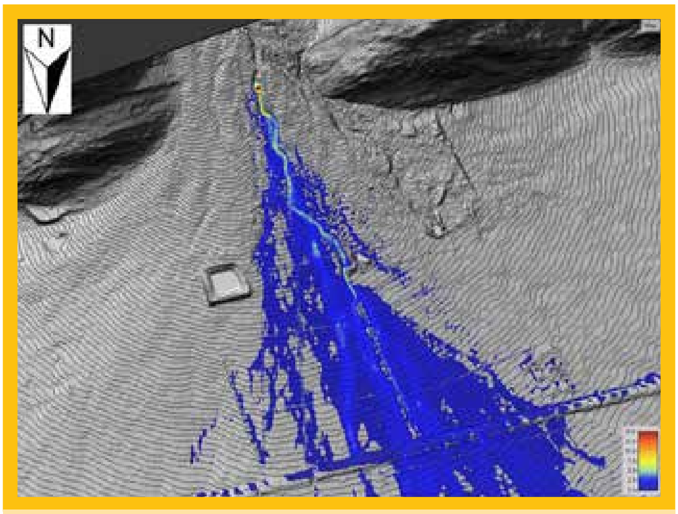

FIGURE 4: Proposed attenuation dam site

The following long-term flood mitigation measures were considered:
- Upgrade of N1 culvert discharge capacity.
- Flood attenuation dam.

Upgrade of N1 culvert discharge capacity

It is proposed that the discharge capacity of the existing culverts near the man-made channel be upgraded, and that additional culverts be constructed in certain areas to convey the 1:20 year flood (50 m^3/s).

All the culverts (existing, as well as additional culverts) have to be designed with intake structures and USBR type stilling basins at the upstream and downstream end respectively.

The natural ground levels upstream of all the culverts has to be lowered so that a hydraulic jump would form upstream of the N1, forcing the supercritical flow to return to subcritical flow conditions. The discharge capacity of the culverts has to be adequate so that the hydraulic jump would remain upstream of the N1, thus preventing flooding of the road. The damming height upstream of the N1 has to be at least 10% greater than the required water depth in order to sustain a stable hydraulic jump.

Flood attenuation dam

The intension with a flood attenuation dam is that it is used to attenuate the flood to the available culvert discharge capacity at the N1. The dam is normally empty and has a bottom outlet.

TABLE 7: Flood attenuation dam required heights

Flood attenuation dam characteristic with 1:20 year inflow hydrograph		
Flood peak target	**2 year**	**5 year**
Maximum outflow	26.8	35.1
Culvert height (d) (m)	1.8	1.4
Culvert width (b) (m)	1.6	1.6
Number of culverts	1	2
Bottom dam elevation (masl)	521	
Dam height (h) (excl. freeboard) (m)	8.3	6
Dam crest (excl. freeboard) (masl)	529.3	527
Total wall length (m)	354	324

Problems associated with attenuation dams are bed aggradation upstream and degradation downstream of the dam, as well as attenuation of small floods, not only large floods. The sinuosity of the main channel of the river downstream of the dam may also change as the river has less sediment to transport (initially following dam construction) and would experience smaller floods. The possible dam site that was investigated is shown in Figure 4.

Table 7 summarises the dam characteristics for different outflows. The proposed peak release discharges investigated were 25 m^3/s (2-year flood peak) and 34 m^3/s (5-year flood peak).

For the scenario where the outflow hydrograph peak is equal to the 2-year flood peak (25 m^3/s), the natural ground levels upstream of all the N1 culverts has to be lowered to form a hydraulic jump upstream of the road, forcing the supercritical flow from the attenuation dam to return to subcritical flow conditions. However, for the scenario where the outflow hydrograph peak is greater than the 2-year flood peak, the joint capacity of the existing N1 culverts near the man-made channel must be upgraded, and additional culverts are required in order to allow the outflow from the attenuation dam to traverse the N1 undisturbed. Concomitant with the upgrading of the culverts, the ground level upstream of all the N1 culverts have to be lowered to obtain subcritical flow conditions. For both scenarios, the capacity of the culverts has to be adequate so that the hydraulic jump would remain upstream of the N1 and not flood the road. The damming height upstream of the N1 has to be at least 10% greater than the required water depth in order to sustain a stable hydraulic jump. All culverts underneath the N1 must be designed with a USBR type stilling basin at the downstream end.

The simulation results for the study area with an attenuation dam with the 20 year flood as the inflow hydrograph and the 2 year flood peak (25 m^3/s) as the outflow hydrograph are illustrated in Figure 5 (flow depths) and Figure 6 (flow velocities). The number of culverts and culvert dimensions underneath the N1 road, as well as the ground levels upstream of the road were not amended for the simulations done on the study area with an attenuation dam.

Figure 5 to Figure 6 indicate that the supercritical flow downstream of the dam (2-year flood peak) still cause spillage over the road. If the ground levels upstream of all the culverts is lowered to form a hydraulic jump to create subcritical flow conditions for this scenario, the flood risk might be reduced.

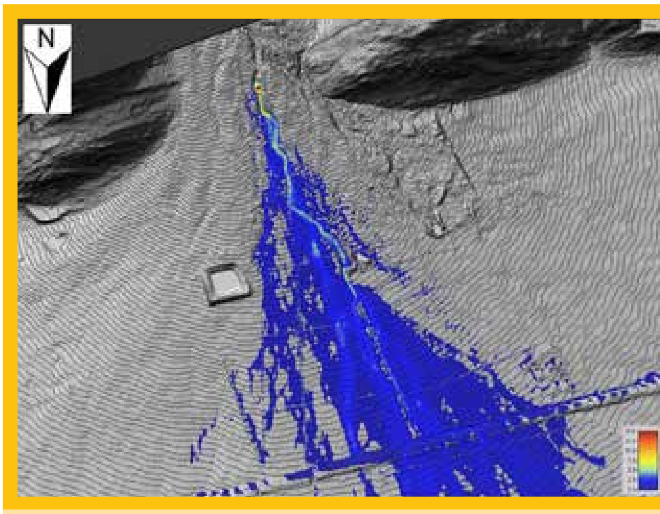

FIGURE 5: Simulated attenuation dam flow depths (m) at 20-year inflow peak (50 m^3/s) and 2-year peak outflow (25 m^3/s)

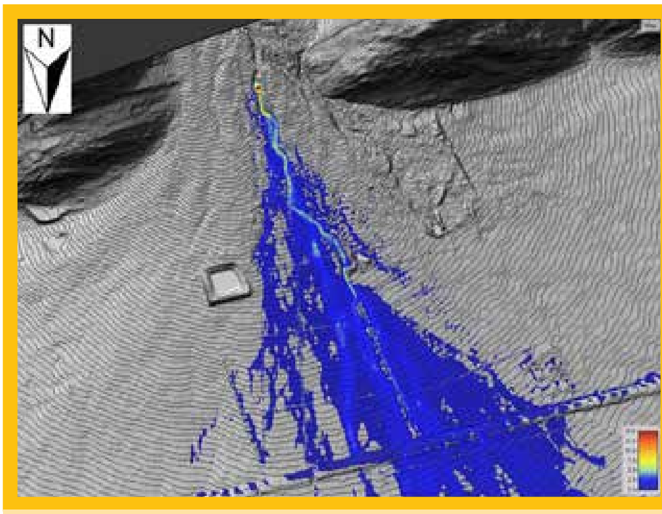

FIGURE 6: Simulated attenuation dam flow velocities (m/s) at 20-year inflow flood peak (50 m³/s) and 2-year peak outflow (25 m³/s)

FIGURE 7: Sam water levels (masl) at 20-year inflow flood peak (50 m³/s) and 2-year peak outflow (25 m³/s)

Figure 7 depicts the water levels through the attenuation dam with the 20-year flood peak as inflow hydrograph and the 2-year flood peak as the outflow hydrograph.

A flood attenuation dam has the benefit that local stormwater downstream of the dam could drain towards the man-made channel as seen in Figure 5 and Figure 6. The capital cost of an attenuation dam concomitant with the upgrade of the culvert discharge capacities traversing the N1 would be more costly than only upgrading the total culvert capacities to pass the 1:20 year flood (50 m³/s) underneath the N1. Moreover, an attenuation dam may lead to fluvial morphological impacts upstream and downstream of the dam. Therefore, a flood attenuation dam does not result into a viable option to reduce the flood risk.

Other short-term measures to consider

Some alternative short-term measures could also reduce the flood risk:

- Clear the area of boulders, alien vegetation, fallen and excessive trees planted on the floodplain that could block the culvert entrances. A riparian ecologist specialist should coordinate this so that ground erosion is not increased.
- Clear flow paths through the culverts and streamline the approaching flow conditions.
- The stability of the erosion protection along the floodplain should be monitored.

CONCLUSION

The flood analysis concluded that the agricultural developments did not have an impact on specifically the flood peaks. The developments did however change the flow regime. A probabilistic analysis of the AMS of H2H005 catchment confirmed that the Smithers software application, in this case, provided MAP values in excess of what is reasonable to expect in the Horlosiekloof catchment. The Rational method proved to be the more appropriate approach to be used.

A detailed 2D hydrodynamic modelling (HecRAS 5.0.3) simulation was conducted on the catchment. The modelling indicated that, while the combined capacity of the culverts may be adequate to deal with the 1:2-year flow, supercritical flow conditions exist upstream of the N1.

It was found that upgrading the discharge capacity of the existing culverts near the channel, and that additional culverts might reduce the flood risk. The lowering of the ground level upstream of all culverts will result into the formation of a hydraulic jump upstream of the N1 which will create subcritical flow conditions. The damming height upstream of the N1 has to be at least 10% greater than the required water depth in order to sustain a stable hydraulic jump.

A flood attenuation dam was evaluated as an alternative to upgrading the capacities of the culverts, but was found to be more costly than the proposed solution. Moreover, an attenuation dam may lead to fluvial morphological impacts upstream and downstream of the dam.

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PAPER 12

Spatio-temporal Analysis of Land-use and Land-cover Changes in the Transboundary Mara River Basin

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ABSTRACT

Limited water availability during the dry season in the Mara River Basin has been a major problem to sustain ecosystems, domestic demands and other socio-economic requirements. Currently, there is no enough water allocated to meet these demands and its management is also inefficient. The problem is directly linked to land-use/land-cover and landscape pattern changes. Conversion of land poses risks of reduction in infiltration rates, ground water recharge or short-circuiting of vital hydrological process such as evapotranspiration. Objective of this study was to use open source GIS tools and remote sensing techniques to analyze Spatio- temporal land-use and land-cover changes in the Mara River Basin for the period 1961-2016. The study focused on three selected areas. Area 1 comprised of the upper Mara Nyangores and Amala tributaries. Area 2 included the Nyangores and Amala confluence at Emarti Bridge while area 3 includes the meandering section on the mainstream Mara River, and in Mara national reserve. These areas were purposely selected since they cover sites where environmental flow surveys were undertaken in 2015 and 2016. In this study, multi-temporal satellite images (1973, 1984, 2002, 2009, 2014 and 2016) and aerial photographs of 1961 were used. For the satellite image time series, a supervised image classification was applied. Reference data for the classification was derived from high resolution imagery provided by Google Earth. For the aerial photographs, manual digitization of land-use/land-cover classes was performed. Prior to digitization, aerial photographs were pre-processed. Image composite editor (ICE) was used for stitching while ImageJ was used to enhance contrast. Statistics derived from classification of the time series were analyzed. Results indicated that in study area 1, forests decreased from 7 473.7 ha (1961) to 2 270.8 ha (2016) while grasslands reduced from 5 208.8 .8 ha to 120.9 ha over the same period. In study area 2, forests reduced from 1 041.9 ha (1961) to 126.0 ha (2016) and grasslands from 640.7 ha (1961) to 481.6 ha (2016). In study area 3, the forest cover decreased from 1572 ha (1961) to 198.5 ha (2016), while grassland cover increased from 5 192.9 ha (1961) to 14 017.8 ha (2016). The study found that agriculture is the main driver of land-cover change in the basin. The study further demonstrated that remote sensing data from satellite sensors and aerial photographs in combination with open-source GIS tools are important for land-cover change detection in basins with poor in situ data.

1. INTRODUCTION

Land-use/land-cover (LULC) change is a major concern of the hydrological cycle and the environment (Qian et al. 2007). Land-cover refers to the biophysical material covering the earth surface such as forests, shrubs, grasslands while land-use refer to human activity or modifications such as agriculture (Odera, Kiio & Achola 2016; Wang, 2014). Scarcity of land, urbanization, rapid population growth and urban sprawl are some of the major drivers of global LULC changes (Barros 2004). Permanent LULC is a complex response to demographic, socio-economic, demographic and development pursuit forces triggered by human activities (Liu et al. 2017). Allocation of expansive land to elite and marginalization of the poor has also been cited as one the drivers of LULC change (De Waroux & Lambin 2012). LULC of any nature is often negative as it results to loss of diversity; increase in runoff, soil erosion, debris flows and accelerated climatological related events (Cheruto et al. 2016; Liu et al. 2017). Conversion of pristine lands to farmlands and urban centres increases evapotranspiration and reduces groundwater recharge respectively (Mati et al 2008). The consequence of reduced groundwater recharge is reduced streamflows during the dry seasons, and prolonged droughts (Pan et al 2011; Gbadebo 2013; Tran et al 2019; Adhikari 2020). Boretti & Rosa (2019) indicates freshwater will become more scarce due to human demand and LULC induced climate change. LULC change is thus an interesting entity whose effects affect hydrological processes such as infiltration, runoff genesis, streamflow regimes and evapotranspiration (Owuor et al 2016). One of the effects of LULC change is the reduction of low flow regime in streams especially during the dry periods (Gennaretti et.al 2011). Further, riparian vegetation loss subjects' rivers to nutrient loading from adjacent farms (Chua et al. 2016). Excessive nutrients expose downstream users to water related problems (NEMA 2011). The problem is even more crucial in developing countries where population and urban centres are increasing along the river reaches (Cullis 2019).

Natural forests in upper, middle Mara and along Amala and Nyangores tributaries have rapidly been converted to agricultural lands (Kilonzo 2014; Ayuyo et al 2020). The previously mixed forests and shrubs covered lands have become large scale ranches and irrigated farmlands (Mati et al. 2008). Pressure arises from rapid population growth, unplanned infrastructure development, poor land-use management practices and unregulated agricultural expansion. Scholars such as (Mati 2005; Hoffman 2007; Mati 2008; Mwania 2014; Kilonzo 2014 and Ayuyo et al 2020) have studied LULC change in Upper Mara between 1973-2007 upto 2016. There is a gap between 1961 and 2016 which this study fills as well as detailing viability of using aerial photos, open source dataset, GIS and remote sensing techniques for land-use/land-cover studies in basins with little in Situ data such as the Mara basin. Further, the study explores LULC changes in areas covering the environmental flow assessment (efa) sites. The main objective was to detect, map and assess the extent and rate of land-use and land-cover changes at the three (efa) selected study areas and within a 100 m buffer riparian zone for the three areas.

The study further analyzes the spatial metrics on fragmentation of different land covers in Upper Mara. Upper Mara is considered for spatial metrics because it covers the main town (Bomet) and other urban centres which have over years expanded into the formerly protected forests. The Upper Mara also forms a vital recharge area for Nyangores and Amala distributaries which joins to form the Mara River at Emarti Bridge. The research has also looked at the criteria of combining different sensors for sustainable monitoring of LULC change in Mara River Basin (MRB). Finally, the study has assessed efficiency of using open source datasets, open source GIS tools, remote sensing (RS) techniques, QGIS SCP plugin, and Lecos, which is a spatial metrics plugin in QGIS). Application of Image J and Image composite editor tools to detect land-use/land-cover studies on old aerial photography in MRB has also been assessed.

TABLE 1: Remotely sensed data

Satellite	Sensor	Observed date	Scene ID	Resolution
Landsat	1-5 MSS	31-Jul-73	LM11820611973212AAA05	60 m
Landsat	4-5 TM	29-May-84	LT51690611984151XXX03	30 m
Landsat	4-5 TM	20-Jun-09	LT51690612009171MLK00	30 m
Landsat	7 ETM	24-May-02	LE71690612002144SGS00	30 m
Landsat	8 OLI	02-Jun-14	LC81690612014153LGN00	30 m
Landsat	8 OLI	22-May-16	LC81690612016143LGN00	30 m

2. STUDY AREA

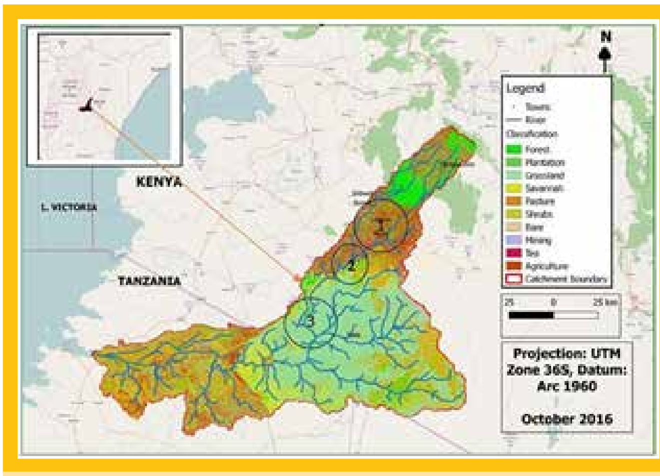

FIGURE 1: Location of the study area and study areas

The three study areas lie in Mara river Basin (MRB) which has a total area of about 13 750 sq.km. MRB is located between 33º 47′ E and 35º 47′ E and 0º 38′ S and 1º 52′ S. Topography varies from 2 932 m at the headwaters in the Upper Mara to about 1 134 m near Lake Victoria. Amala and Nyangores perennial tributaries originate from Napuiyapui Swamp located in Mau escarpment. The two join at Emarti bridge to form the Mara river. Mara river is also fed by Talek and the ephemeral sand rivers near the border between Kenya and Tanzania. Talek originate from Loita plains. The Mara then flows through the Mara national reserve, through Mosirori swamp (Mara wetland), opening onto Mara bay before entering Lake Victoria, near Musoma on Tanzanian side.

The upper, middle and lower MRB receive about 1 000 to 1 750 mm, 900-1 000 mm and between 900 and 1 000 mm rainfall per annum respectively. Lower Mara near Loita hills and Musoma area receives between 700-850 mm per annum. The rains are highly variable with major rains being experienced between March and start of June. The second season starts from November to December (Mwania 2014; GLOWS- FIU 2012). MRB boasts the world famous wildebeests migration that occurs between Serengeti National Park and the Maasai Mara National Reserve on annual basis (Mati et al. 2008). In this context, water availability in MRB plays a vital a key role of sustaining livelihoods, ecological role of sustaining wildlife and enhancing biodiversity.

Study area 1 extents an area of 351.4 km^2 that covers Nyangores and Amala tributaries, Bomet town, smallholder rain-fed agricultural farms and large-scale tea farms. Population in Bomet was estimated as 875 689 persons according to 2019 census report (KNBS, 2019). Main land covers include forests, shrubs and tea farms, with small randomly distributed grassland patches. River reaches in this area are dominated by Hippos as the main wildlife whose grazing is now limited by the changing riparian vegetation. Other diversified animal and bird species are confined in the remaining protected forest patch. LULC changes in these areas are rapid and more concerning due to population growth and rise in food demand (Omonge et al 2020).

Study area 2 extents 37.8 km^2 and covers Nyangores and Amala river confluence area. Main land covers in this area include shrubs, partly forested riparian zone and randomly distributed grasslands. It is characterized with extensive commercial pivot irrigation in South-East direction of the confluence. Subsistence farming with few homes is also evident in the study area. Wildlife in this area consists of hippos, and a variety of bird species.

Study area 3 has an area of 147 km^2 and covers the mainstream Mara river meanders and a section where Talek River joins the Mara river. It further covers part of the Mara national reserve which is a habitat to wildebeests, hippos, lions, leopards, elephants, and a variety of bird species.

3.MATERIALS AND METHODS

3.1. Data collection

Landsat satellite family project provide freely available spatio-temporal products for environmental studies and natural resources monitoring. The 1973, 1984, 2002, 2009, 2014 and 2016 Landsat imagery were collected from the USGS earth explorer website (USGS 2017). Time series from end of a rainy season were selected in order to reduce chances of encountering images with much cloud cover. Aerial photos taken by the Royal Airforce were also used to study land-cover change for the year 1961. Summary of remotely sensed data used is presented in Table 1.

3.1. Image manipulation

Various techniques were applied to develop a dynamic reference dataset. The reference dataset was used to generate the training samples, and to assess classification accuracy. High resolution imagery provided by Google Earth and an MRB land-use map of August 2015 (scale 1:30 000) were used as ancillary data during classification. Validation was accomplished using data from Biopama, which is a group dedicated in global LULC change analysis (Biopama 2017). Further validation was done using the 1961 aerial photos composite.

3.2. Classification, spatial metrics and analysis

Storing, analysis and presentation of land-cover maps was done using open source QGIS tool. Atmospheric correction of remotely sensed

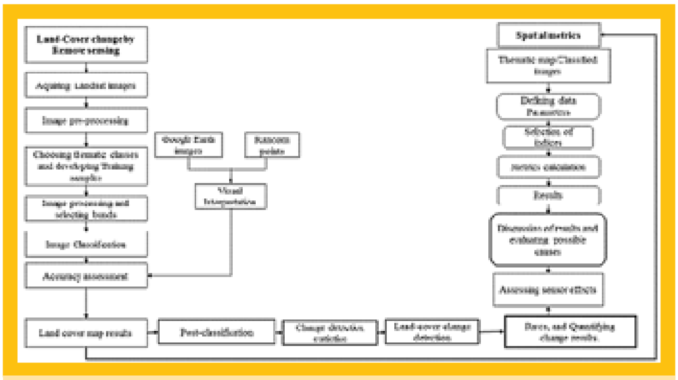

FIGURE 2: Remotely sensed data methodology

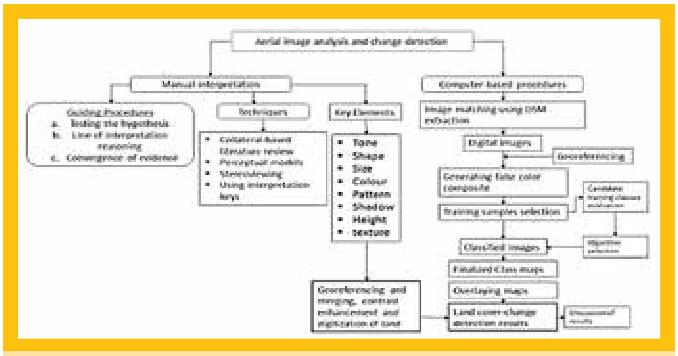

FIGURE 3: Aerial photo methodology

data, band setting, classification and accuracy assessment of classified maps was done using the QGIS-SCP plugin (Congendo 2016). QGIS enabled Lecos plugin McGarigal (2015) was used to study spatial metrics and fragmentation in Upper MRB (Study area 1).

Methods used for LULC change detection on Landsat Imagery and Royal Airforce photos are presented in Figure 2 & 3.

Analysis of aerial photos first involved identification of flight path. Photos were then sorted according to study area and stitched together into a composite tiff file using the open source Microsoft Image Composite Editor (ICE) tool. ImageJ, an open source tool, was then used to improve contrast of the land-covers on the stitched photo composite by adding a green channel. Land covers were then digitized into polygons and converted to raster (Tiff) formats for visualization. Lastly, PCRaster python Library was used to change tiff files into maps and resampling classified maps from 30 m to 60 m spatial resolution for visualization.

4. RESULTS AND DISCUSSION

4.1. Classification accuracy

Accuracy assessment was done by comparing classified against the reference dataset. For each year and study area, a separate dataset was used to generate random points on each class during which, high resolution Google earth image was used as a reference. In addition, QGIS also allows use of open layers as a reference. Error matrices were generated to calculate the overall, producer and user accuracies. Overall accuracies for the study areas 1, 2 and 3 were all above 80% and Kappa statistic above 75%. Producer and user accuracies for each class in the three study areas were above 60 % although some classes were of small areas, and random points falling on them were less. This hence led to either 50%-100% user or producer accuracy. Accuracy assessment results indicated that the higher the number of random test samples, the higher the effectiveness of the accuracy assessment. The accuracy

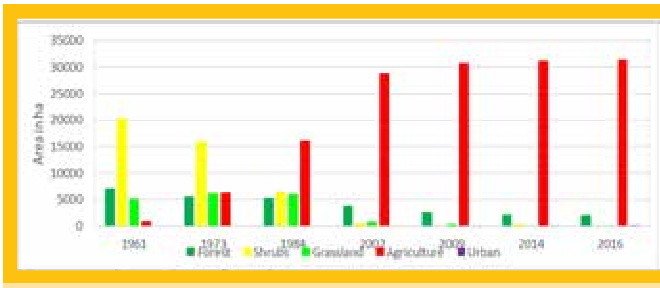

FIGURE 4: Land cover maps for study area 1

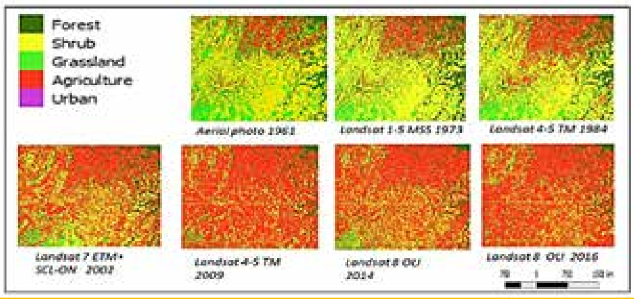

FIGURE 5: Land-cover change for study area 1

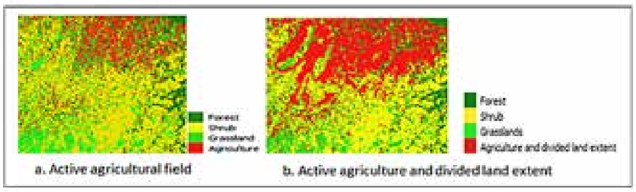

FIGURE 6: Divided land extent and active field comparison

results also depended on the percentage of land-cover classes in the study area and each random point generated had equal chance of falling in a certain class.

4.2 Study area 1 land-cover change detection

Figure 4 and 5 shows land-cover changes in the formerly forested study area 1 between 1961 and 2016.

Forests decreased from 7 474 ha in 1961 to 2 220 ha in 2016 with a rapid change being detected as from 1984. About 3 404 ha of grasslands were converted to agriculture between 1973 and 2002 and since then, intensification of agriculture and increased reduced land parcels sizes were evidenced. Urban centres are not detected before 2009 since most of them had grass thatched roofs whose spectral signatures resemble shrubs. Increase in iron sheets covered buildings was noticeable from 2009 with a positive trend from 47.7 ha in 2009 to 181.7 ha in 2016 (Figure 5). While shrubs decreased from 20 414 ha in 1961 to 6 494 ha in 1984, and to 188 ha in 2016 and the conversion has been to farmlands and urban centres.

Aerial photos of 1961 availed rich information on status of MRB before independence. In 1961, data mining from aerial photos showed a land cover mix of mostly shrubs grasslands and forests. Farm fields especially those near roads, and rivers as shown in Figure 6 (a) ranged from small and large sizes with rectangular and trapezoidal shapes and had crops on them.

4.3. Study area 2 land-cover change detection

Figure 7 and 8 shows land-cover change in study area 2 between 1961 and 2016. The size of the area is 3 780 ha and is significant since

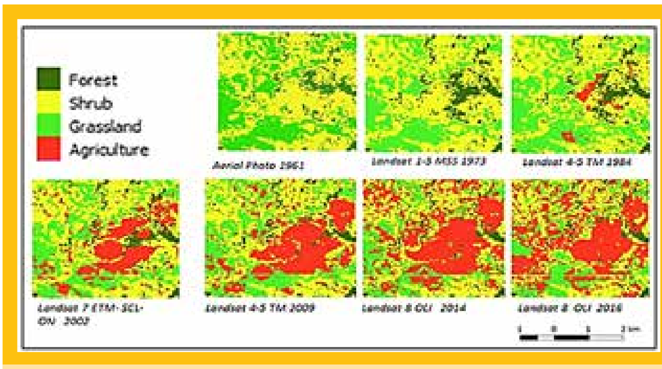

FIGURE 7: Land cover maps for study area 2

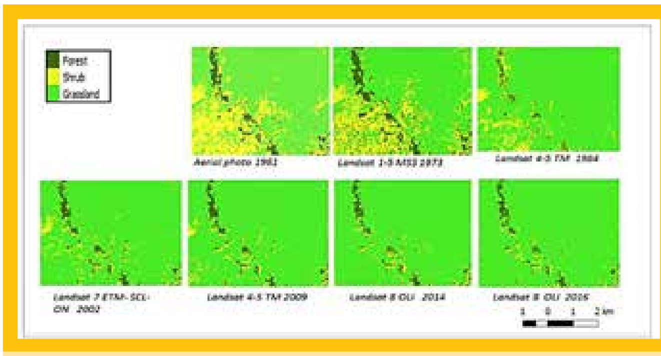

FIGURE 9: Land-cover change maps for study area 3

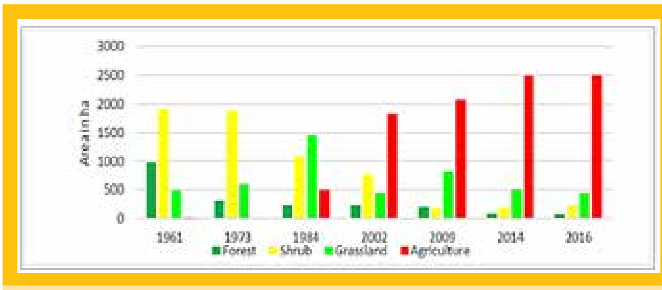

FIGURE 8: Land-cover change for study area 2

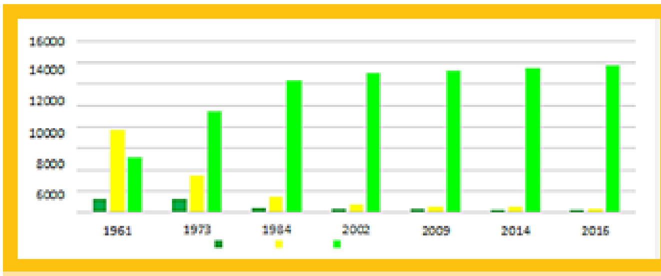

FIGURE 10: Temporal land-cover change for study area 3

it consists of Amala and Nyangores confluence that gives birth to the Mara River. The aerial composite photo of 1961 showed little human activity. In this year, only rectangular strips running through grasslands and shrubs where the current pivot irrigation is located were observed.

Rectangular plots in the North-West direction of the confluence were also observed. These plots appeared as burnt fields associated with shifting cultivation practice.

Using a Landsat 1-5 MSS for 1973 analysis detected no change and that the land-cover was naturally intact compared to 1961 analysis that involved use of Royal Airforce photos. Technically, this indicates influence of sensor choice for land-use/land-cover change detection. Landsat 1-5 MSS satellite which was operational in 1973 has a coarse spatial resolution of 60 m and could not capture the small land-cover details captured by a low moving Royal Airforce aircraft in 1961. In 1984 rectangular and trapezoidal farms concentrated near the confluence were detected. This might have started even before 1984 and the changes are linked to an era when water decline might have started in Mara river. This is because flows significantly respond to any change in land-cover as cited by (Maasai Mara Science and Development initiative 2015). A combination of water from Nyangores and Amala tributaries played a key role to start rectangular and trapezoidal irrigation that existed by then and that changed and expanded to pivot irrigation in 2016. Forests generally reduced by 739 ha between 1961 and 1984 and the forest reduction by 121 ha between 1973 and 2009 matches with an increase in commercial farming in form of rectangular irrigation blocks and pivot irrigation (commercial farming) which increased from 3 in 2002 to 5 in 2009 through 2016. Shrubs however, changed to grasslands (783 ha) between 1973 and 1984 while the grasslands increased by 12.8% for the year period 1961-1973 and then reduced to agriculture between 1984 and 2016.

4.4 Study area 3 Land-cover change detection

Study area 3 falls within the Mara National Reserve. Results for this area are presented inform of maps to visualize and compare changes. Figure 9 and 10 shows a land-cover change time-series for hotspot 3 from 1961 to 2016.

It covers an area of 14 700 ha and lies in Maasai Mara National Reserve. The reserve is a protected area under the directives of the Kenyan wildlife act of 1977 revised in 1989 and 1997 as mentioned by Anon (2014). The directives protect the wildlife against hunting and other illegal activities from the general public and the Maasai community living in the Reserve under the Trust land law (G.O.K 2010). Analysis of 1961 aerial photo composite revealed presence of regularly shaped cuts in parts of the forests. The shapes indicated intervention of human activity. These formerly forested areas gradually reduced to shrub patches over time while other forest patches directly changed to grassland evidently starting from 1973.

4.4.1. Riparian vegetation in study area 3

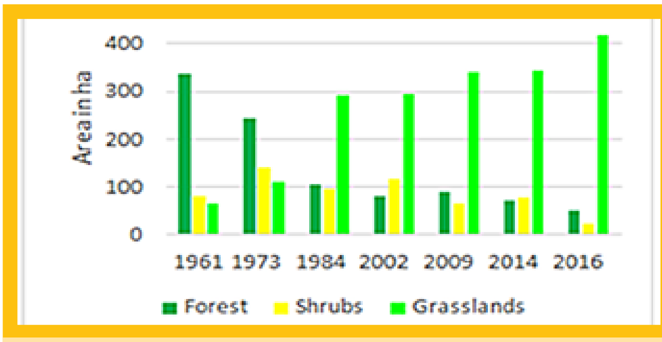

FIGURE 11: Riparian changes

Figure 11 presented below shows land-cover change in a 100 m riparian buffer for study area 3.

Statistics indicate that grasslands increased from 66 ha in 1961 to 419 ha in 2016, while forests declined by 138.2 ha between 1973 and

1984. Forests to shrubs conversion was evidenced between 1984 and 2002 with a direct conversion of forests to grasslands between 2009 and 2016 (a sign of illegal logging). The findings call for protection of the Mara reserve in order to protect wildlife ecosystems and minimize human-wildlife conflicts.

5. SPATIAL METRICS RESULTS AND DISCUSSION FOR STUDY AREA 1

Spatial metrics are used to detect level of fragmentation in a landscape. Upper MRB is located in Mau forest, a key recharge area where most tributaries originate. The area also consists of springs which sustain flow regime of various streams. In 1961, forests and shrubs were dominant. However this is no longer the case as many have been converted to urban centres and permanent team farms. The population in this sensitive part of MRB is rocketing is with settlements also expanding at faster rates. It was therefore considered important to analyze fragmentation patterns to inform sustainable restoration programs, reforestation efforts, water allocation programs, spatial planning best practices for watershed management. This section therefore describes fragmentation patterns of LULC classes in study area 1 (Upper MRB). Classified LULC maps for study area 1presented in Figure 4 formed the input into Lecos, which is a landscape metrics analysis plugin in QGIS (McGarigal & Marks 1994).

5.1 Shannon evenness Index

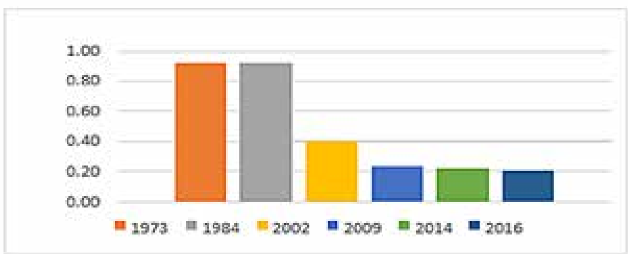

FIGURE 12: Shannon evenness index

The index is used to describe the status of even distribution of different land-cover class patches. Land- cover patches of all classes (forests, shrubs, grasslands, agriculture and urban) are used in calculations. A value of 1 indicates an even distribution of different land-cover class patches in terms of size and 0 indicates poor distribution.

As shown in Figure 12, the indicator measures how different LULC classes co-existed. These classes have been separating from each other beginning in 1973 as detected from the Landsat 1-5 MSS and their closeness even reduced faster between 1984 and 2002. The reduction matched with the increased conversion of forests, shrubs and grasslands into farmlands and urban centres.

5.2 Number of patches

As shown in Figure 13, number of forest patches increased from 1 032 in 1973 to 11 156 in 2002. 2002 recorded the highest fragmentation in Upper Mara as agricultural activities and urbanization increased. Intensification of agriculture on subdivided land parcels was even faster between 2002 and 2009, a scenario which was detected as a decrease in patches. Forest patches slightly increased from 4 753 ha in 2009 to 9 302 ha in 2014, and decreased again by 2 315 ha between 2014 and 2016. The increase between 2009 and 2014 is associated with reforestation efforts that were initiated to save Mau forest.

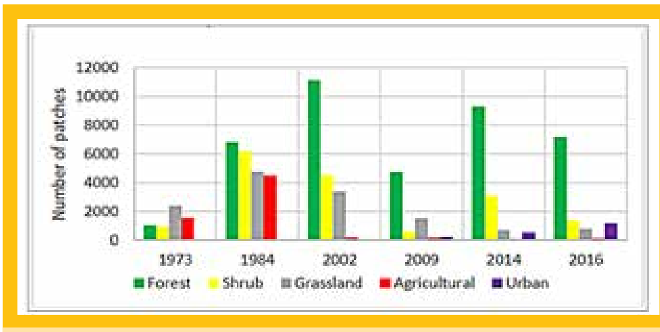

FIGURE 13: Number of patches

A decline between 2002 and 2009 indicated more conversion of the existing forest patches to farmlands and urban set-ups rather than targeting new forest covers.

5.3 Largest patch area

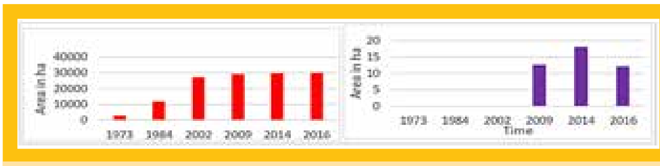

FIGURE 14: Largest patch area (a) Agriculture and (b) Urban

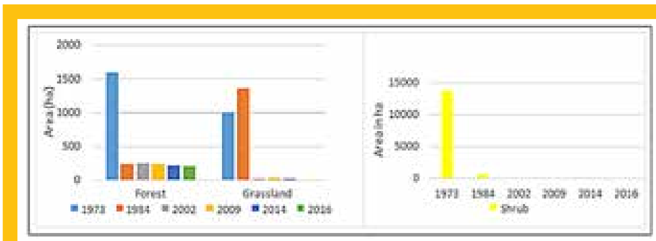

FIGURE 15: Largest patch area (a) Forest and grassland (b) Shrubs

An increase in largest patch for agriculture coincides with an increase in agricultural activities as large parcels of land continued to be subdivided into smaller parcels beyond the detection capabilities of the Landsat satellites. Urbanization also spread very fast in 2014 with more interconnections.

Fragmentation results into different sizes of land-cover classes and changes over time. Hence 15 shows the variation of largest patch size of forest over time. The trend of forest-cover change showed a general decline. Forests were converted to agriculture, shrubs and possibly, timber for development. Increase in population and families has further divided forests into small areas and the resilience of the existing degraded forests is low such that permanent conversion is persistently affecting the hydrology of MRB (Mati et al., 2008). Shrubs largest area decreased between 1973 and 2016 as shown in Figure 15.

5.4 Edge density

Edge segments in a landscape consist of lengths which correspond to different patch type. Edge density is computed by dividing the sum of edge segments of the (landscape) area. Edge density results are presented below in Figure 16.

The edge density of forest-cover increased by 0.007 m-1 between 1973 and 1984. This is the same period when forest patches increased hence leading to increase in edge density. A decrease was experienced between 1984 and 2002 when formerly fragmented patches were

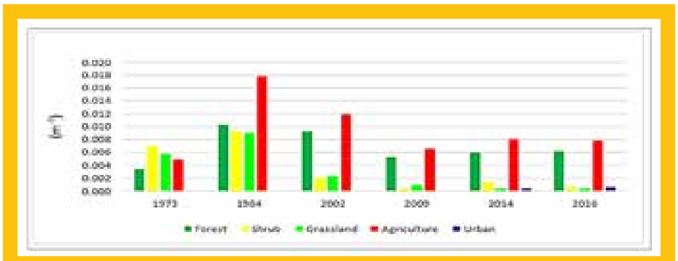

FIGURE 16: Largest patch area (a) Forest and grassland (b) Shrubs

further converted to agricultural lands. This was followed by a faster decrease of 0.004 m-1 between 2002 and 2009 as intensification of agriculture took place. Another increase for 2009-2014-2016 period is linked to increase in demand for forest products which also coincided with an increase in population and urbanization (Bomet County, 2013). Edge of shrubs decreased between 1984 and 2016 due to a reduction in its coverage (Figure 4 & 5) while urban edges increased between 2002 and 2016 as urban centres increased. However, agriculture decreased between 2009 and 2016 as the land parcels continued to be subdivided and detected by satellites as one large parcel.

6. CONCLUSION

Combining old photos and remotely sensed products forms the best approach of studying LULC changes especially in developing countries. Even though tools to analyze old aerial photos are not readily available, they do provide vital information about the state of the MRB during the 1960s and before satellite missions for environmental modelling became popular. The study has also found that fragmentation existed in the upper part of Mara basin as early as 1960s. This was in form of divided parcels of land. However, most conversation from pristine vegetation to agriculture lands and grasslands is seen from 1970 and becoming more intensive in the first and second decade of the 21st century. Findings further suggest the need for governments and policy makers to establish archives that combine remotely sensed data and old imagery in order to have a better understanding of what sustainable restoration efforts are required to manage fragmented catchments.

7. RECOMMENDATIONS

The author of this research would like to recommend further research that will apply use of the 10 m spatial resolution sentinel 2A and 2B products because of their fine resolution when compared to Landsat products which have been used in this study. Lastly, the author would like to recommend a study to look at how land-use and land-cover has changed the water balance scenario in MRB using the freely available water accounting datasets.

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PAPER 13

Developing Geo-information Based Selection Algorithms to Identify Water Resource Interventions

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ABSTRACT

The Southern African region is subject to frequent droughts which contribute to crop failures, famines and epidemics, often coupled with devastating socio-economic impacts. To encourage proactive planning in securing water for drought prone areas, the Southern African Development Community Groundwater Management Institute (SADC-GMI) implemented the project: Assessment of Groundwater Resources Development Priority Intervention Areas in the Southern African Development Community Region.

As part of the analyses undertaken to identify drought-prone areas, existing geospatial, hydrological and hydrogeological global datasets were researched and analysed according to their validity and applicability to the region. Global datasets were interrogated to produce several risk indices representative of surface water availability, groundwater availability and population vulnerability, which were weighted and combined to identify so-called hotspot areas within the SADC region which are most vulnerable to drought.

To mitigate the potential impacts of drought in the identified hotspot areas, different types of interventions were conceptualised and evaluated. These include boreholes, sand dams, managed aquifer recharge, surface water dams, rainwater harvesting, stormwater harvesting as well as desalination and water reuse. Selection criteria were developed for each intervention type by means of a typology matrix, which took into consideration a number of physical criteria which had to be satisfied for the intervention to be considered feasible. The criteria were further refined in workflow diagrams to aid incorporation of algorithms and decision-making methodologies in a GIS environment. By using these geo-information based selection algorithms, a suite of possible technically feasible interventions was identified, on a geographic grid by grid basis, for each hotspot area through spatial analyses.

The different types of interventions identified in each hotspot area were evaluated by performing high-level analyses taking into account reliability of supply, population served, level of technical skills required for maintenance and operation, energy requirements and associated capital and operational costs. Finally, after assessing institutional and environmental factors, a list of targeted interventions per hot spot area was compiled, which typically included a combination of large scale and local scale interventions aiming to strengthen water resources diversity and to improve water resilience in communities within the SADC region. The targeted suite of interventions, which was presented at stakeholder workshops, constitute sustainable water supply investments in drought susceptible regions and can assist relevant organisations in these regions in making informed decisions with regard to water resources investments.

INTRODUCTION

Water availability in the Southern African Development Community (SADC) varies greatly in space and time, giving rise to unevenly distributed water resources compared to population and settlement patters. The northern and eastern parts of the region experience significant precipitation in the tropical and sub-tropical climate zones, while the southern region and the western region experience highly seasonal rainfall and are classified as semi-arid and arid climates. The SADC region is prone to recurring droughts, having undergone a series of severe droughts during the 2015/2016 and 2016/2017 summer rainfall seasons (Archer, et al., 2017). In the past, droughts were driven by natural climate variability, however with increasing anthropogenic influences, the characteristics of droughts have shifted and are changing to include a type of drought that has a rapid onset and short duration. Generally, droughts in the SADC region are associated with increased risks to vulnerable communities due to crop failure, food shortages, famine and epidemics.

According to Wilhite & Glantz (1985), droughts are defined by the degree of dryness and the duration of dryness which can have far reaching consequences. Meteorological droughts can arise from a range of hydrometeorological drivers which suppress precipitation and/or limit surface water and groundwater availability, causing significantly drier conditions than normal, and leading to water shortage (Svoboda & Fuchs, 2016).

Drought indices are typically used to quantify hydrometeorological information and to ultimately identify locations, severity and duration of droughts (Nagarajan, 2009). To assess and quantify the severity and duration of droughts requires regional analysis of spatial and time-series data. Long-term trend analysis as well as weighted index methodologies are increasingly applied when assessing data with high spatial and temporal variability (Villholth, et al., 2013).

Water management is a pivotal instrument in managing the widely distributed water resources in an environmentally sustainable way, while providing for the increasing water requirements of communities. To account for geographic, climatic and socio-economic factors within the SADC member states; water resources sharing has been implemented in fifteen transboundary river basins as well as the transboundary aquifers (SADC Secretariat, 2019). Water resources interventions which are gaining increasing traction within the African continent include the conjunctive use of a diverse suit of interventions. Interventions such as sand dams, new surface water storage dams, desalination, stormwater and rainwater harvesting, managed aquifer recharge, new boreholes, as well as water reuse and desalination are considered part of the suit of interventions.

To encourage proactive planning in securing water supply during periods of drought, the Southern African Development Community Groundwater Management Institute (SADC-GMI) is implementing the project: Assessment of Groundwater Resources Development Priority Intervention Areas in the Southern African Development Community (SADC) Region (SADC GMI-GDRI). The project aims to identify and map areas prone to drought based on groundwater and surface water availability and population vulnerability. Moreover, the project provides guidance and recommendations on possible future water resources interventions to enhance water resilience and diversify the current water resources as well as identify possible infrastructure investment opportunities to secure water supply in drought conditions.

This paper highlights the main aspects of producing a drought risk map for the SADC region, which included surface water, groundwater and population vulnerability assessments, with a specific emphasis on surface water resources assessment aspects. In addition, the approach towards the identification and evaluation of potential interventions through typology matrices and geo-information-based selection algorithms is presented. As such, this paper provides findings on some of the available hydrological time-series global datasets, the processing of such 'large' datasets as well as the weighted index approach to overlay these datasets. Furthermore, it presents a decision-based methodology to assess the technical viability and suitability of surface and groundwater interventions within the SADC region on a grid-by-grid basis.

The methodologies developed during this project could be applied to smaller study areas and potentially aid decision making processes.

APPROACH AND METHODOLOGY

The project essentially entailed two main tasks: Firstly, the identification and mapping of SADC areas prone to drought based on groundwater and surface water availability and population vulnerability. Secondly, the development of a pragmatic approach to guide and recommend possible future water resources engineering interventions to mitigate drought risk and enhance water resilience in the identified drought-prone areas where high population vulnerability and drought risk coincides. The approach and methodologies associated with these two tasks are briefly described in this section.

THE IDENTIFICATION OF DROUGHT RISK HOTSPOT AREAS

As mentioned above, in order to identify drought risk areas (hotspots) within the SADC region, three separate maps were produced, namely surface water drought risk, groundwater drought risk and population vulnerability, which were subsequently overlaid and weighted to identify hotspot areas for further consideration of drought mitigation interventions. To assess groundwater drought risk, the current SADC Groundwater Drought Risk (GDR) map (Villholth, et al., 2013) was revised to identify areas that are prone to groundwater drought in the SADC region (SADC-GMI, 2020). In parallel, population vulnerability within the SADC region was mapped based on a number of criteria (SADC-GMI, 2020).

Although mention is made in this paper on how the surface water risk map was integrated with the groundwater risk map and the population vulnerability map, the focus of this paper, in relation to drought risk, is the assessment of surface water drought risk.

SURFACE WATER DROUGHT RISK MAP

A surface water resources assessment informed the mapping of surface water availability and variability across the study area. Existing spatial data, catchment characteristics derived from satellite imagery and global DEMs as well as readily available time-series data were utilised for this assessment.

Figure 1 presents the process followed to assess surface water resources. Existing time-series global datasets were reviewed, and surface water risk indices were determined to quantify the availability and variability of these long-term historical datasets. Subsequently, the surface water risk indices underwent a process of normalisation and were then weighted to produce a combined surface water risk index which was used to produce the surface water risk map.

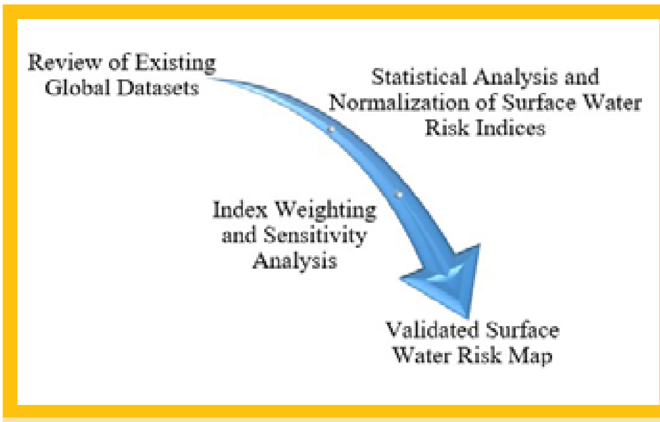

FIGURE 1: Surface water risk map process overview

Generally, surface water data are presented at varying scales. Given the need for a uniform scale across the surface water data layers in order to compare the different datasets and considering the 'catchment-nature' of surface water, catchment unit polygons were used as spatial unit to ensure uniformity for the analyses. **Hydro**logical data and maps based on **SH**uttle **E**levation **D**erivatives at multiple Scale (HydroSHEDS) is a mapping product that provides hydrographic information for regional and global-scale applications. HydroBASINS presents a sub dataset of HydroSHEDS and entails a series of polygon layers derived from HydroSHEDS data at 15 arc-second resolution depicting watershed boundaries and sub-basin delineations at a global scale (Lehner, 2014). These sub-basins provide a global coverage of consistently sized and hierarchically nested catchment areas at different scales. A level 1 catchment distinguishes the continents, level 2 splits the continents into 9 sub-units and at level 3 the largest river basins of each continent start to break out. From level 4 onwards the largest river basins are broken down into the tributaries using high resolution elevation data (Lehner, 2014) up to level 12. A level 8 catchment unit was applied during this project, providing a total of 15 202 catchment units over the SADC region.

Review of Existing Global Datasets

Time-series precipitation and surface water runoff datasets were the predominant datasets used to assess surface water availability and variability. Sun et al., (2017) summarised global precipitation and runoff data into three main categories: gauge-based, satellite-based (precipitation) or model-derived (runoff), and reanalysis datasets. All three dataset types are generally presented in the form of multi-dimensional gridded raster files (sometimes referred to as netCDF files). These files store the spatial distribution of the data at a given time step as a separate raster band.

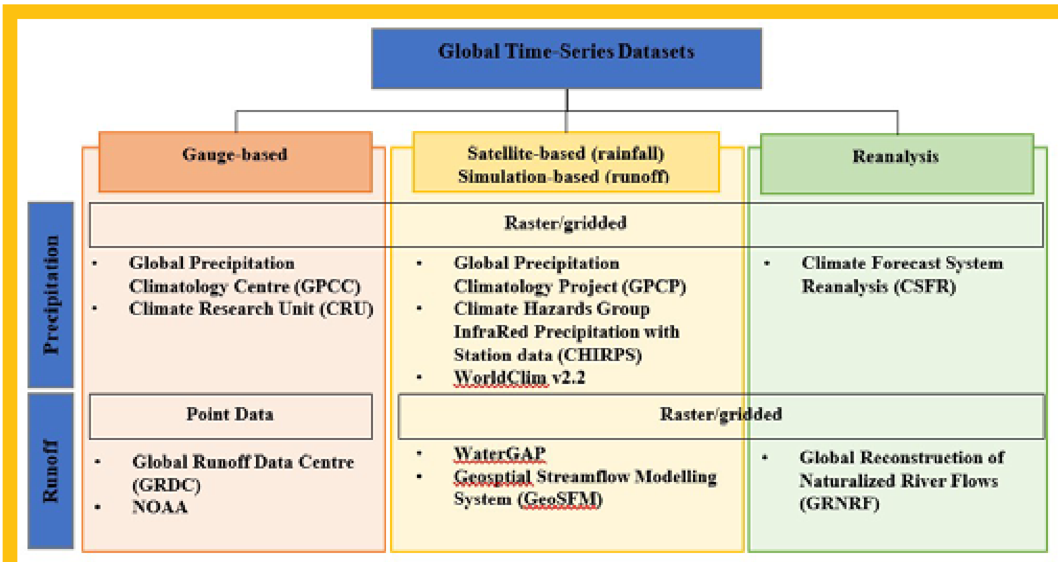

FIGURE 2: Global time-series datasets and possible examples

Figure 2 presents the three main types of global hydromet time-series datasets, as well as identified example datasets that were investigated for potential application Global time-series datasets and possible examples.

Gauge-based precipitation datasets are a collection of historical precipitation data from gauge observations across the world. These observations are generally collected with the assistance of national weather services. As such, these gauges tend to be more prolific in developed areas, causing an irregular distribution of observation stations. Due to the irregular distribution of observation stations, gridding of the data is required for many climate-related applications (Sun, et al., 2017). Weighted empirical interpolation methods are generally applied to extrapolate gauge data to gridpoints so that a gridded precipitation dataset is created (Sun, et al., 2017). Two precipitation gauge-based datasets that have undergone weighted empirical interpolation include the Global Precipitation Climatology Centre (GPCC) and the Climate Research Unit (CRU) datasets.

The Global Runoff Data Centre (GRDC) is an international data centre operating under the auspices of the World Meteorological Organization (WMO). Their dataset is a collection of quality controlled historical mean daily and monthly discharge data. Time series data on river discharge is available for more than 9 900 stations in 159 countries. The Southern Africa Flow Database of SA FRIEND is also available from the GRDC. The National Oceanic and Atmospheric Administration (NOAA) dataset which contains both satellite and point data. Runoff data is available for NOAA stations across Africa, which are often cross referenced and patched and thus provide a good validation dataset.

Satellite data is needed when surface observations of precipitation data is sparse. Data scarcity is often the case in developing countries where infrastructural development is costly and requires high maintenance (Wang, et al., 2019). Sensors onboard satellites measure clouds and related convection to predict the probability and intensity of rainfall. These predictions are typically supported by land-based measurements. Satellite sensors are currently the only method of providing homogenous precipitation measurements on a global scale, but satellite data also contains random errors and biases, and data is only available over a smaller time period. Satellite data is typically merged with rain gauge data to increase the accuracy of the dataset (Sun, et al., 2017). The most widely recognised merged dataset (Sun, et al., 2017) is the Global Precipitation Climatology Project (GPCP) dataset, which is based on sequential combination of microwave, infrared as well as gauge data). The CHIRPS dataset used interpolation techniques and long periods of precipitation estimates based on infrared Cold Cloud Duration observations as well as in-situ station data. Satellite information is incorporated to represent sparsely gauged locations, while daily and monthly Cold Cloud Duration observations are also included from 1981 (Funk, et al., 2015). The WorldClim dataset is considered one of the most popular global datasets providing invaluable data for data-sparse areas (Wango, et al., 2018; Fick & Hijmans, 2017). WorldClim v2.1 contains average monthly climatic gridded data for the period between 1960 to 2018, the CRU was used to perform bias-correction.

Simulation-based or model-based runoff datasets make use of rainfall data and typically model a catchment response to simulate runoff data. WaterGAP v2.2 is a global water assessment model consisting of two main components, namely: the Global Water Use model and the Global Hydrology model. The Water Use model considers basic socio-economic factors that lead to domestic, industrial and agricultural water use, while the Hydrology model incorporates physical and climate factors that lead to runoff and groundwater recharge based on the computation of daily water balances of the soil and canopy. A further model-based runoff dataset is generated with the Geospatial Streamflow Model (GeoSFM). The geospatial streamflow modeling system is parameterised with global terrain, soils and land cover data and runs with satellite-derived precipitation and evapotranspiration datasets (Asante, et al., 2008).

Reanalysis data are generated by using advanced numerical modelling techniques to combine observations from multiple sources. Observational data and numerical weather prediction and runoff model products are typically fused and integrated by data assimilation systems to produce reanalysis datasets (Wang, et al., 2019). The result is usually a synthesised estimate of rainfall across a uniform grid that is spatially and temporally homogenous (Sun, et al., 2017). A further reanalysis runoff dataset is the Global Reconstruction of Naturalized River Flows (GRNRF) dataset. The GRNRF is classified as a reanalysis dataset rather than a model-based dataset, as is the case with GRUN, because a merged precipitation dataset consisting of gauge, satellite as well as reanalysis-based datasets is used in the GRNRF. The dataset is a reconstruction of daily and monthly streamflow records ranging from 1979 to 2014, covering the spectrum of stream orders (Lin, et al., 2019).

Based on a comprehensive review of the above datasets, surface water indices capturing variability (annual, seasonal) were derived from the selected datasets for the period 1971 to 2016 at a temporal resolution of monthly and a spatial resolution of 0.5°x 0.5° for the purpose of the surface water analyses undertaken as part of this study. WorldClim v2.1 was used as primary rainfall dataset and WaterGAP v2.2 was selected as primary runoff dataset. Both datasets were validated against gauge-based datasets such as NOAA and the GRDC respectively. Note that for some of the island states within the SADC region only precipitation data and no runoff data were available. Consequently, for these islands, surface water drought risk was determined based solely on precipitation data.

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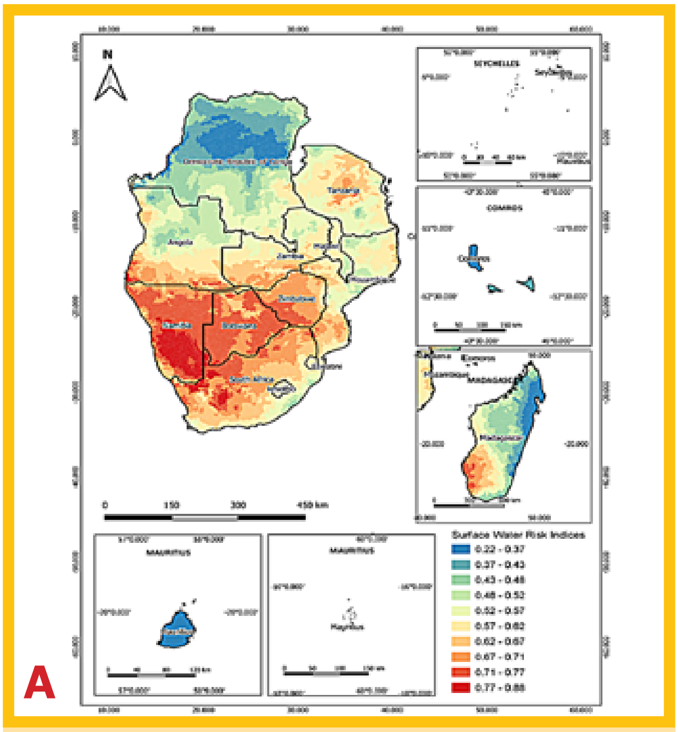
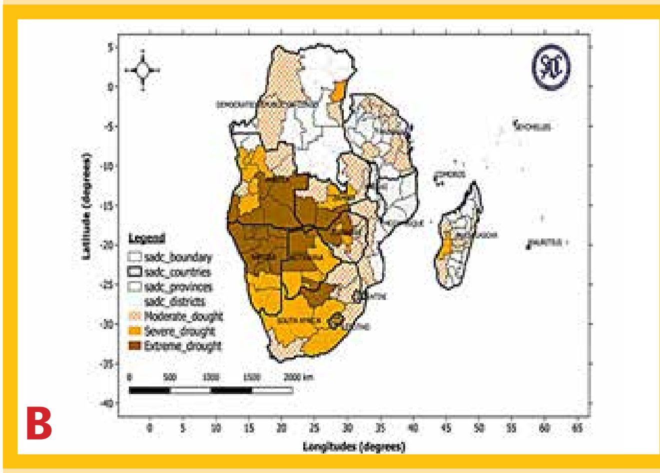
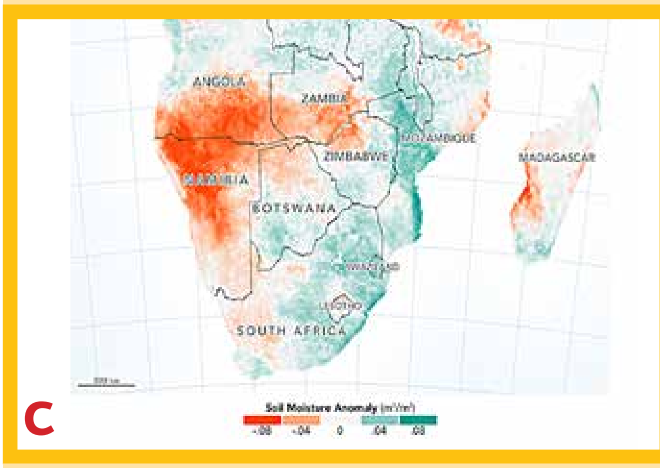


FIGURE 3: Surface water drought risk map and validation maps



Drought situation over SADC region for 2019/2019 rainfall season (https://www.sadc.int/files/5615/5991/5186/SADC_DROUGHT_MONITOR_2018-19_SEASON_JUNE_2019.pdf)



Soil moisture anomaly February 2019 (https://earthobservatory.nasa.gov/images/144704/drought-harms-corn-crops-in-southern-africa)

Statistical Analysis and Normalisation of Surface Water Risk Indices

Statistical indices based on hydro-meteorological data are commonly used to quantify droughts on the landscape for any given period (Svoboda & Fuchs, 2016) and provide numerical representations of drought severity. For the purpose of this surface water resources assessment, statistical indices were calculated at catchment unit scale and represented and/or included long-term mean annual values, seasonality indices, indices of seasonal variability, coefficients of variation as well as runoff coefficients.

Index normalization was undertaken to standardise the different index values to values between 0 and 1, and to allow comparison and integration of a number of indices. Normalisation techniques which were considered include the percentage of a maximum, percentage of range and unit vector techniques. There is no one single method that can prove itself to be the globally acceptable approach for normalisation. Rather, characteristics of various indicators and parameters were evaluated in selecting a normalisation technique able to support comparison of various parameters at an appropriate scale. A direction for each index was selected based on how the index impacts drought risk, such that the drought risk is maximized. The statistical indices as well as the normalisation technique applied are summarised in Table 1. (Note that maximum drought risk is represented by a value of 1 and minimum drought risk by a value of zero).

TABLE 1: Surface water risk indices and normalization

Index	Definition	Direction: Drought Risk	Normalization
Mean Annual Values	Mean annual values, provide an indication of average long-term precipitation, discharge and runoff averaged over the available time series length and per catchment unit.	Max as 0; Min as 1 The higher the rainfall, the lower the drought risk	Percentage of Max
Index of Seasonal Variability	The index of seasonal variability indicates the extent of intra-annual (month-to-month) fluctuation of rainfall and streamflow over a single year (Pitman, et al., 2008). It is calculated by using a mass curve method.	Max as 1, Min as 0 The higher the index of seasonal variability, the greater the drought risk.	Percentage of Range
Coefficient of Variation	The coefficient of variation of mean annual precipitation or discharge provides an index of climatic risk, indicating the likelihood of fluctuations from year to year (inter-annually).	Max as 1, Min as 0 The higher the coefficient of variation, the more variable is the inter-annual variability and the greater the drought risk.	Percentage of Range
Runoff Coefficient	The runoff coefficient is a dimensionless factor that relates the amount of surface water runoff from a catchment to the amount of precipitation received.	Max as 0; Min as 1 A high runoff coefficient may indicate flash flooding areas during storms.	Percentage of Max

Surface Water Index Weighting

A surface water risk index was produced by combining the surface water indices determined for rainfall, discharge and runoff. Runoff (often measured in mm) is a result of precipitation (e.g. rainfall), after infiltration has taken place, that moves along the surface of the earth and subsequently drains to low lying areas where it accumulates to flow into or form rivers and streams. The discharge in a river (often measured as a flow rate in m^3/sec) is the flow in a river as a result of both surface water and groundwater (baseflow).

The different indices were combined through a simple linear algorithm and associated weighting scheme based on the relative importance of various indices to derive a spatially distributed surface water risk map across the SADC region. The indices include average values representing absolute precipitation, discharge or runoff in mm, as well as dimensionless indices e.g. seasonal variability, coefficient of variation and runoff coefficient. A sensitivity analysis was also undertaken to determine the most appropriate combination of the respective indices. The sensitivity analysis confirmed the importance of not assigning too great a weight to absolute values as this could potentially skew the resulting surface water risk index.

The final indices used to determine the combined surface water risk index and their associated weightings are presented in Table 2.

TABLE 2: Surface water risk indices and normalization

	Surface Water Indices	Final Weightings
Rainfall	Average rainfall (mm)	0.11
	Seasonality	0.06
	Index of Seasonality	0.06
	Coefficient of variation (%)	0.15
Discharge	Average discharge (mm)	0.11
	Seasonality	0.06
	Index of Seasonality	0.06
	Coefficient of variation (%)	0.15
Runoff	Mean annual runoff (mm)	0.11
	Runoff coefficient (%)	0.15

Validation of Surface Water Drought Risk Map

The surface water risk map, which was developed during this study, as presented in Figure 3a, was validated qualitatively with existing maps and information indicating frequent drought prone areas in the SADC region.

For example, the SADC Climate Services Centre (2018/2019) indicated extreme drought being experienced over most of the south-western parts of SADC due to below average rainfall during the 2018/2019 rainfall season (Figure 3b). Extreme drought conditions were prevalent over southern Angola, southern Zambia, northern Zimbabwe, northern Botswana, north-western South Africa and most of central-northern Namibia. Moderate to severe drought is also affecting most of Angola, Namibia, Botswana, Zimbabwe, South Africa, Lesotho and Zambia. Pockets of dryness also occurred over most of Tanzania, western and eastern DRC, Eswatini, southern Mozambique and western Madagascar. Most of these areas concur with the identified drought areas of the surface water drought risk map.

Similarly, the map in Figure 3c depicts soil moisture anomalies during February 2019 based on remote information as monitored by the U.S. Geological Survey for the Famine Early Warning System Network, showing areas with more (green) or less (red) water in the upper soil layers for the month (Stevens & Hansen, 2019). Namibia and southern Angola and southern Zambia, northern Botswana and norther Zimbabwe as well as western Madagascar showed especially dry soils. The areas characterised by low soil moisture to a large extent coincide with similar regions as identified in the surface water drought risk map.

MAP OVERLAY AND HOTSPOT IDENTIFICATION

The surface water drought risk map (Figure 3a) was subsequently overlaid with the groundwater drought risk and population vulnerability maps (Figure 4) to identify hotspot areas for further consideration of drought mitigation interventions. A final number of 26 hotspots were identified within the SADC region.

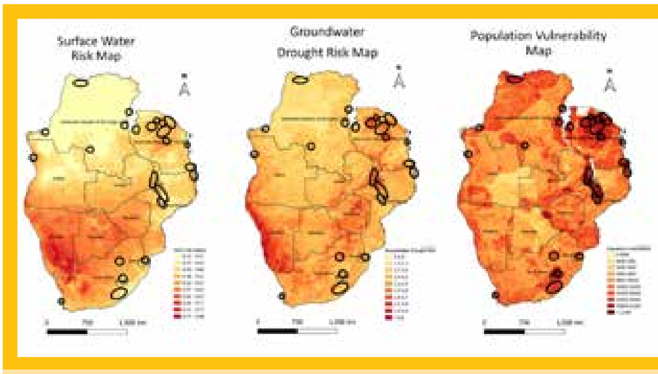


FIGURE 4: a) Population Vulnerability Areas of Priority, identified for consideration of interventions, b) Population Vulnerability Areas of Priority overlaid with the GDR map, c) Population Vulnerability Areas of Priority overlaid with the surface water risk map for SADC mainland.

DOMESTIC WATER SUPPLY INTERVENTIONS

A key component of this project related to identifying feasible and cost-effective domestic water supply interventions for water demand centres which are most at risk i.e., located in the hotspot areas identified above. The list of interventions which has been proposed provide a roadmap for further water supply development in SADC, and a starting point for more detailed feasibility studies.

CONCEPTUAL APPROACH

The conceptual methodology is summarized in Figure 5 and discussed in the following paragraphs.

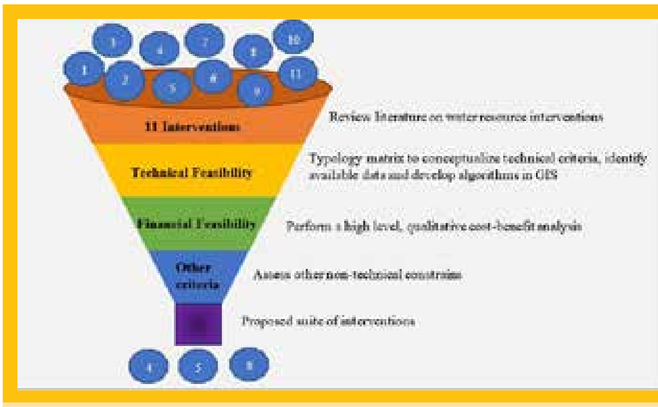


FIGURE 5: Conceptual methodology to assess the suitability of water supply interventions (by process of elimination)

Eleven domestic water supply interventions were considered:

1. Sand dams
2. Rainwater harvesting

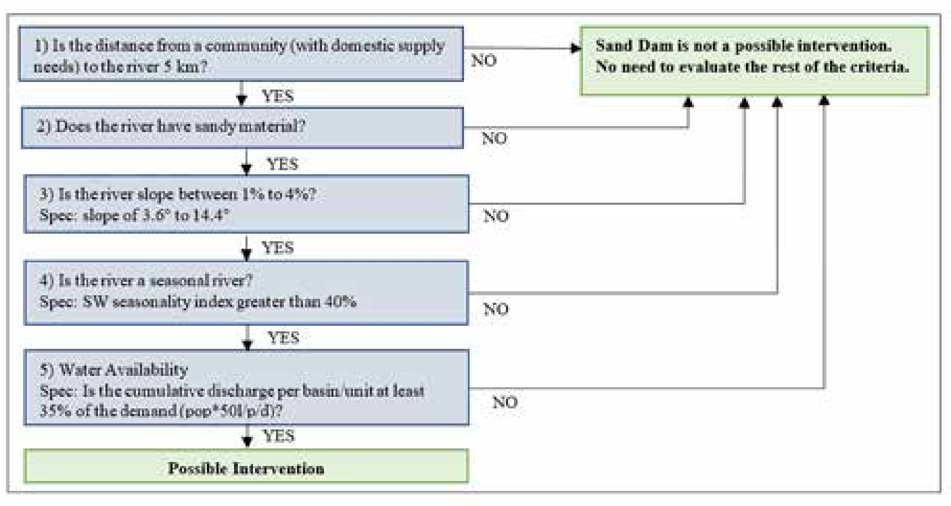


FIGURE 6: Work-flow diagram of sand dams to aid GIS based selection algorithms

3. Stormwater harvesting
4. Surface water reservoirs (dams)
5. Run of river abstraction
6. Desalination
7. Water reclamation and reuse
8. Groundwater reclamation and reuse
9. Managed aquifer recharge
10. Drilling of new boreholes
11. Conjunctive use

The final selection of the most applicable suite of interventions (from the above list) was based on the consideration of:

- the population served by the intervention;
- the technical feasibility of the interventions, for the specific region;
- the financial viability of the intervention within the context of the specific country and region;
- other important considerations, such as environmentally sensitive or protected areas;

The above factors fed into a typology matrix that was used to conceptualise and evaluate the different intervention types based on pre-defined criteria and readily available data, and to ultimately arrive at the most feasible interventions through a process of elimination for each of the 26 hotspots. The evaluation criteria were primarily derived from technical requirements associated with each intervention type.

To accommodate the size of the hotspot areas, and the often significant variability in terms of geophysical characteristics within some of the hotspot areas, the assessment of different intervention types within each hotspot area involved subdividing each hotspot area into uniform grid cells and undertaking the intervention analysis per grid cell through data queries and models in a GIS environment.

For those interventions deemed technically feasible, a high level, qualitative cost-benefit analysis was also used to further refine the suite of technically feasible interventions per hotspot zone.

Finally, to further assess the applicability of the identified interventions, literature studies were conducted to assess whether there might be other, non-technical constraints which could affect the implementation and/or operation and maintenance of the interventions related to political, institutional, environmental or other factors.

IDENTIFYING INTERVENTIONS USING SAND DAMS AS EXAMPLE

To illustrate the methodology (outlined in above Figure 5) sand dams are considered as a show case example intervention. The typology matrix and the development of the technical criteria into workflow diagrams and algorithms for GIS algorithms is discussed below.

A sand dam is a small dam which is built in the riverbed of a seasonal sandy river. The sand from flash floods accumulates behind the dam wall which provides additional storage to the riverbed aquifer (Beswetherick, et al., 2018). The aquifer fills with water during the wet season, resulting from surface runoff and groundwater within the catchment. The riverbed is also recharged through the groundwater flow, which is obstructed by the sand dam, creating additional groundwater storage communities. The typology matrix used to conceptualize technical criteria of sand dams is presented in Table 3. Through research, the criteria identified in the typology matrix were expanded to include specific boundary conditions which were used in GIS software, to aid the GIS-based decision algorithms. Figure 6 presents a workflow diagram for sand dams. A typology matrix and workflow diagrams were conceptualized and developed for all 11 interventions and applied to every grid cell within the hotspot.

TABLE 3: Sand dams example typology matrix

Implementation Requirements	Data Needed
Distance to river: preferably less than 5 km radius, generally people do not walk further than within a 5km radius to retrieve water.	Rivers with 5 km buffer
Sandy river underlain by impermeable or less permeable bedrock or clay to store water in the sand pores without letting it percolate to lower soil layers.	Regional Geology Map 1:1000000 (1:250000)
Regions sloping 1 to 2%. Highest water storage due to lower gradient of the channel bottom.	Slope map
Seasonal sandy rivers, which experience high siltation during the rainy season (high water runoff, high seasonality)	Discharge Seasonality
Water availability: there should be enough water available in the river during the rainy season to satisfy a significant portion of the water demand in the area.	Mean Annual Discharge

To illustrate the geo-spatial results of this GIS based selection algorithm, an example hotspot with identified technically feasible interventions is presented in Figure 7. In some grid cells, more than one intervention was identified as technically feasible.

Through the high-level cost benefit analysis, which considered amongst others, the financial capacity of cities or towns to implement

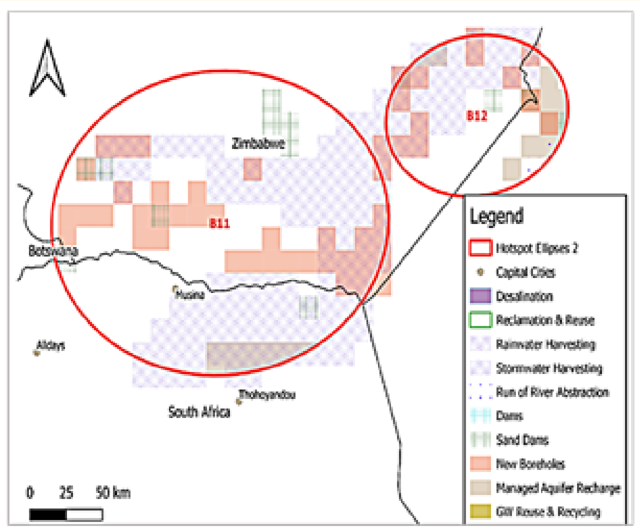


FIGURE 7: Technically feasible interventions

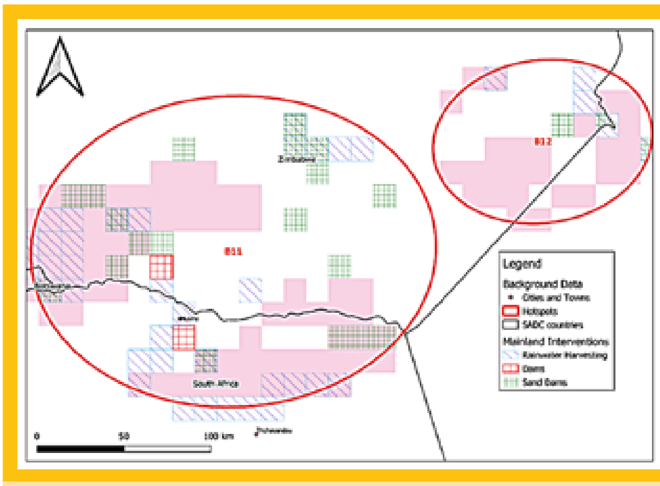


FIGURE 8: Proposed suit of interventions

interventions with a high reliability of supply, which would require specialized and expert skills, as well as potentially high energy consumption as well as the relative capital and operational cost. Contextual research about the area, nature reserves as well as specific aquifer types provided other criteria to further streamline the interventions per gridcell in the hotspot. The resulting proposed suit of interventions is presented in Figure 8. Out of the 11 possible interventions considered for the hotspot area, 6 interventions were identified as technically feasible (Figure 7), while only 4 intervention became part of the final proposed interventions (Figure 8), namely; rainwater harvesting, off-channel dams, sand dams and new boreholes.

RESULTS AND DISCUSSION

Temporal and spatial variability regarding water availability creates a greater need for integrated, diversified water planning and management to create more resilient and sustainable water supply options.

To encourage proactive planning in drought prone areas, the water availability and variability of existing surface and groundwater resources in the SADC region were assessed in conjunction with population vulnerability. Drought risk hotspots were successfully identified by:

- Reviewing existing global time series datasets;
- Identifying the most appropriate datasets to perform a statistical analysis and derive surface water risk indices as well as normalizing these risk indices;
- Weighting the surface water risk indices to produce a surface water risk map;
- Overlaying the population vulnerability map over the groundwater and surface water risk maps resulting in the identification of 26 hotspots.

Furthermore, by using geo-information based selection algorithms, a suite of possible technically feasible interventions was identified, on a geographic grid by grid basis, for each hotspot area through spatial analyses. A process of elimination was applied to identify technical feasible interventions by means of selection based decision algorithms using GIS-software. To this effect, typology matrices were used to conceptualise the interventions and data requirements, whereafter specific criteria were formulated into work flow diagrams and GIS algorithms, making it possible to identify grid-cells in the hotspots which would satisfy the technical evaluation criteria. The identified technically feasible interventions were further refined through high-level cost-benefit analysis as well as other considerations to produce a final suite of interventions.

CONCLUSIONS

This paper demonstrates that readily available demographic, hydrological and hydrogeological global datasets allow the identification of drought-prone areas at regional level using geospatial analyses; and that a typology matrix approach allows the identification and evaluation of a range of possible engineering interventions, at conceptual level, based on technical, economic, institutional and environmental parameters. This can assist relevant organisations within the SADC region in making informed decisions with regard to water resources investments.

The methodologies developed during the study provide a valuable toolset for firstly, understanding the context of an area by using geospatial and temporal data, and secondly, providing a conceptual approach to identifying possible solutions over large geographical areas. Further research can add to the powerful spatial data processing tools that exist and streamline methodologies for various end purposes on both a regional or a more localized scale.

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PAPER 14

Impact of Climate Change on Spatial Planning and Stormwater Management for Greenfield Site Development

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ABSTRACT

Climate change is indisputably recognised as one of the major global concerns which has multiple negative impacts. Projected climate change impacts such as increased droughts, more intense precipitation and rising sea levels suggest that human goods and lives will be adversely impacted through increased flood risk, among other impacts. Consequently, this study aimed to adapt the current spatial planning principles to address and mitigate the impact of climate change in an urban setting by integrating stormwater management practices. Statistical methods were used to extend the available historical rainfall data to predict the likely frequency of future rainfall events. Autodesk Civil 3D Storm and Sanitary application enabled the simulation of the impact of future rainfall over greenfield sites development.

Flood frequency analysis was conducted as a direct method of estimating flood frequency, indicating that a 21% increase would be expected between the 2020 and 2069 period with the intensity of a 2-year return period expected to increase by 40%. The simulated changes in precipitation were incorporated into spatial planning by using catchment characteristics to derive key land-use zoning factors for future consideration when designing urban areas. The analysis of the study revealed that the amount of greenfield area that is available for stormwater management should be identified at an early stage in project planning. This analysis will largely dictate the extent to which different stormwater design elements are feasible in any development to ensure that climate change impacts are considered. This study provided a methodology to determine the impact of climate change on future rainfall events over greenfield sites for pre-development and post-development conditions. Outcomes of this study may aid in understanding the increasing frequency and intensity of extreme rainfall events, which will have a significant impact on existing stormwater infrastructure. The study may aid Provincial and local municipalities to adapt to changing rainfall regimes to ensure that adequate levels of spatial planning for greenfield sites are effectively integrated with stormwater management to ensure that climate impacts are accounted for prior to any development.

INTRODUCTION

The sequels of climate change are bestowing on humanity great tasks when planning future cities. Climate change is increasingly recognised as a developmental challenge and an impediment to achieving the United Nations 2030 Sustainable Development Goals worldwide (Rosa, 2017). Climate change exacerbates stormwater issues due to the dual impacts of mean sea-level rise and intense precipitation. Climate change, however, has been part and parcel of the occurrence of extreme events in the world (Mann & Gleick, 2015). Strong scientific evidence highlights that the recent climate changes are likely attributable to human activities and the increase in greenhouse gas concentrations in the atmosphere. Greenhouse gases play a vital role in regulating the 'Earth's climate. The substantial increase in atmospheric carbon dioxide over the last 100 years, which increased by over 35%, is believed to be induced by anthropogenic activities (Hulley et al., 2008). The anthropogenically forced global warming and the associated trends in increased temperature result from the enhanced greenhouse effects through which atmospheric greenhouse gas emissions are increased. The most vital concern over climate change's effects on stormwater management is its effects on precipitation.

The increase and intensification in precipitation have put a strain on urban drainage infrastructure (Embertsén, 2012). Africa remains one of the most vulnerable continents to climate change and its impacts. An emerging commonality is a shift towards more intense rainfall. The rainfall arrives in shorter bursts, causing more run-off and dry seasons in between. Although some parts of Africa will experience extreme droughts, some parts will experience extreme rainfall. The global annual average temperature will rise by 1.4 - 5.8°C by 2100, increasing global warming over continental landmasses and higher latitudes. This suggests that it is highly likely that more intense precipitation events will occur in many areas of the world under climate change (Cooper et al., 2002). In November 2016, natural disasters such as flooding resulted in enormous destruction to infrastructure resulting in property damage, strain on stormwater infrastructure and fatalities in one of South Africa's urban areas (Mbangeni, 2016). Land-use changes have resulted in tremendous challenges in designing and implementing stormwater management systems. New developments are at risk of climate change impacts if old spatial planning policies coupled with traditional stormwater management systems continue to be used.

In a study conducted in Sweden by (Cettner et al., 2013), it was highlighted that there is a significant gap that exists between spatial planning and stormwater management planning. Traditional spatial planning approaches mainly focus on zoning areas based on land use, economic explanation of population density but largely disregard stormwater management in urban drainage systems. Thought must be given to the adaption measures for spatial planning to incorporate stormwater management experts to consider climate change effects such as flooding of urban areas for sustainable urban development. Adaptation measures when developing new greenfield sites have been considered one of the solutions to alleviate the detrimental effects of climate change (Demuzere et al., 2014). (Serfontein & Oranje, 2008) evaluated the spatial planning in the City of Tshwane Metropolitan Municipality in South Africa. They identified a profound disconnection between the planning, thought process and the emerging spatiality of the 21st century. They concluded that this was due to the persistence of how planners interpret and act upon space in a manner still based on the nineteenth-century industrial cities. (Mlambo, 2018) has highlighted that some of the internationally identified principles for new urban planning spaces are also applicable to spatial planning in South Africa.

Spatial planning plays a very important economic and social role. However, planning the infrastructure for spatial developments remains the key role in ensuring that planning remains effective and efficient (du Plessis, 2014). The two roles must be strategically planned simultaneously to ensure a sustainable integration between infrastructure development and spatial planning. Spatial planning is a significant area of land use planning and a crucial tool in achieving sustainability, development, and climate change adaptation strategies in urban areas. It is crucial to ensure that every sustainable urban development plan has an accepted infrastructure implementation plan for the area which can be implemented.

The main motivation of this research aimed at determining the impact of climate change within an urban environment by predicting future flood events that are likely attributed to climate change for future consideration over new developments on existing greenfield sites. Innovative considerations are required to be made regarding spatial planning of greenfield site developments to mitigate climate change impact on stormwater management. This research combines spatial planning and engineering concepts in stormwater management, considering climate change as an integral part of integrated stormwater management.

1. MATERIALS AND METHODS

1.1 Location and climate

Roodekrans 492-JQ (study location) is situated within the Gauteng province, west of Pretoria in The Crocodile West and Marico Catchment. Geographically, it lies between 25.855° S and 27.948° E. Roodekrans 492-JQ is situated in a humid subtropical climate with temperatures that vary average of 18.7 °C annually with summer rainfall season. Rain events typically occur in the afternoon between October and April months. Rainfall seldom occurs during winter. The current annual average rainfall is 732 mm, mostly during the December, January and February months.

Roodekrans 492-JQ, previously zoned as a peri-urban development in 1975, is boarded by Hennopsrivier 489-JQ and Riverside Estate 497-JQ located in the South-Western area near Hartebees Dam in the City of Tshwane Metropolitan Municipality as presented in Figure 1. The location has been purposefully selected because of its potential for growth development in the country in terms of urbanisation. The total land surface area is 38 km^2.

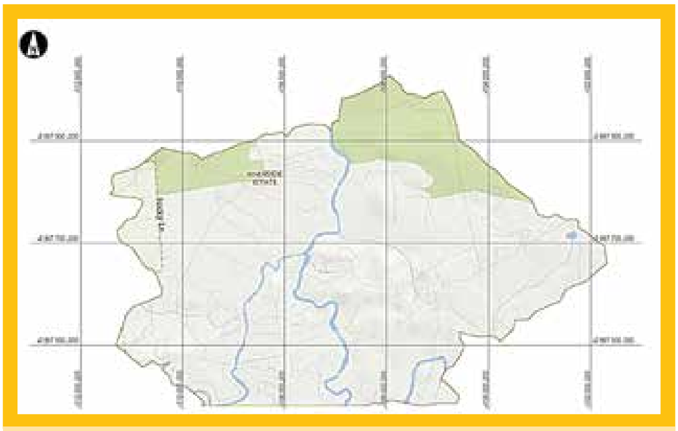

FIGURE 1: Catchment for selected study location (Roodekrans, 492 JQ)

1.2 Rainfall data and topographical data

The daily rainfall at station number 6 545 weather station for the Pelindaba gauging station was obtained from the South African Weather Services. The daily rainfall (mm) data, for the years 1969 to 2019 (51 years) for Roodekrans 492 JQ were obtained. The maximum annual daily rainfall (MADR) event was extracted for each year. The Roodekrans 492 JQ intersects by the Hennops River, which rises to approximately 1530 metres above sea level (m.a.s.l) near Atteridgeville, far west of Pretoria. The United States Geological Survey (USGS), provides users with various Data Elevation Models (DEM)s. The GDEM model was downloaded, and Hexagon Geospatial provided GIS tools to retrieve the topographical information. This information was transferred to Autodesk Civil 3D Storm & Sanitary Analysis tool software package for hydrological modelling. The GDEM was used for hydrological modelling purposes. From the Geo.tiff image, we developed a raster image for visualising the topographical data and subsequently generated it to develop the hydrological model.

1.3 Land cover and land use typology

It is crucial to understand the characteristics of the spatial distribution of South Africa's land cover. Landsat images were downloaded from the USGS Earth Explore together with the DEM files. Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images consist of nine spectral bands and two thermal bands. The Landsat images loaded into Erdas Imagine to further develop the image. The Landsat was georeferenced to the WGS 84 coordinate system. The classification complete after the different bands were stacked to develop one image in which classification was performed to identify soil, vegetation, and water classes based on the spectral reflectance soil, vegetational and water. The Roodekrans current land use satellite image detection Landsat thematic mapper (Landsat 8) which shows the current land properties of the study location.

1.4 Frequency analysis of annual maximum events

Stochastic methods or frequency analysis can be used to evaluate peak flows where satisfactory measured streamflow information exist. The frequency analysis was conducted to determine the appropriate probability distribution function (PDF) for the extreme events between 1969 and 2019. The Annual Maximum Run-off events (24 hrs) for the selected period were determined. The probability of exceedances (p) of Annual Maximum run-off events was determined by ranking the largest Annual Maximum run-off events to the smallest.

The Weibull formula was applied to determine the estimates of exceedance probabilities associated with historical rainfall observations, as shown in Equations 1 and 2.

$$p = \frac{i}{n+1} \qquad \text{Equation 1.}$$

$$T = \frac{1}{1-p} \qquad \text{Equation 2.}$$

Where:

P = Exceedance probability associated with a specific observation.

N = Number of annual maximum daily events (51 evens in this case);

x = Observed rainfall (mm)

i = Rank of specification observed event with i = 1 being the largest event to i = N being the smallest event

T = Return period (T) of each event is the inverse of its exceedance probability. **Equation 3.**

1.5 Selection of suitable probability distribution function for the study area

The maximum annual rainfall selected for this study area involved estimating the distributions selected and identifying the best distribution model suited for estimating extreme hydrological events for the study area. To estimate the maximum annual rainfall quantiles, the PDF that suits the said events had to be applied (Masereka et al., 2018). The three goodness of best-fit test, which was tested and then applied, were the chi-square test, Kolmogorov-Smirnov test, and the Anderson-Darling test. Through identifying the best-fit PDF models for our sample, we were able to identify the best fit model for our data. The selection of an appropriate model depends mainly on the characteristics of available rainfall data for a particular study area of interest. A PDF that provides a good fit to daily precipitation depth is key. Therefore, for this study, the PDF model was analysed for the current data to determine the best fit model for the current data of our study area. For this study, different PDF types such as Log-Pearson Type III, generalised extreme value, Weibull and Gumbel were assessed to find the best fit PDF for maximum annual extreme rainfall. This was done to visually identify the candidate PDFs for analysis of magnitude and frequency of analysed extreme events. (Masereka et al., 2018) identified a method of identifying the best fit, which was subsequently used for this study. The PDF selected for this study was Gumbel's distribution.

1.6 Forecasting precipitation for the 50 years (2020-2069)

The technique used for the forecasting of the next 50 years of rainfall was under the assumption that the future rainfall series will indicate similar trends as the historical series. The technique applied simulates the historical series by identifying a specific pattern in the series to predict or simulate the historical pattern into the future without trying to understand the causes or effects of the historical patterns. The analysis from the previous sections was repeated for the forecasted data with the assumption that the selected PDF would be suitable in assisting to predict the future causes. The Gumbel's Extreme Value was selected as the best PDF for the historical data analysis. Therefore, the calculation for the maximum extreme discharge recurrence interval for the different return period was determined using the Gumbel extreme values. The PDF for Gumbel's distribution is given as follows:

$$F(x)' = exp[-exp\left(-\frac{x-u}{a}\right)] \qquad \text{Equation 4.}$$

The following equations were used for Gumbel's Extreme Value calculation;

$$P' = e^{-e^{-y}} \qquad \text{Equation 5.}$$

$$y = -(ln\,x\,(ln\left(\frac{T}{T-1}\right)) \qquad \text{Equation 6.}$$

$$T = \frac{1}{1-P_r} \qquad \text{Equation 7.}$$

Where:
P' = probability of non-occurrence of an even X in T year
y = reduced variate for a given T
y(n) = reduced mean using (Gumbel's extreme-value distribution)
s(n) = reduced standard deviation using Gumbel's extreme value distribution)

To determine the frequency of the highest extreme events for the forecasted events, it was established that;

$$x(t) = `x + K\sigma_{n-1} \qquad \text{Equation 8.}$$

$$\sigma_{n-1} = \sqrt{\frac{\Sigma(x-`x)^2}{N-1}} \qquad \text{Equation 9.}$$

$$K = \frac{(y(t)-y(n)}{s(n)} \qquad \text{Equation 10.}$$

Where:
σ = standard deviation of the series
K= frequency factor
N = Number of years of record

1.7 Impact of climate change

The extreme events were determined and applied to a hypothetical example. A hydrological simulation was conducted over the study area to assess the different simulation results to assess the impact. The peak flows were determined for both pre- and post-development for each scenario selected for this study. In this study, the catchment was split based on basin characteristics. This was done to determine the extent to which land-use planning (zoning) conditions can impact the stormwater management of the catchment. Also, the 50-year projection or scenario is based upon assumed trends and changes in fertility, mortality, migration and productivity in urban areas. The model simulates different stages of annual average rainfall over three (3) different climate categories to indicate the exact changes in annual rainfall generation.

1.8 Simulation of stormwater generation for different future climatic conditions

The rapid increase in development contributes to increased non-point source pollution and degradation of receiving waters. For the study, we introduced pre-development conditions and post-development scenario for historical and forecasted rainfall trends. To facilitate the hypothetical catchments management of the study area, the area was divided into different sub-catchments to understand the full impact of the simulated rainfall over the study area and its impact on the stormwater run-off. The catchment was delineated based on the DEM to create 13 sub-catchments with an average area of 100 hectares. The pre-development scenario represented the existing conditions of the study area, which is currently a greenfield site with very little development. The sub-catchment areas were used for surface analysis and were found to resemble similar natural catchment areas as derived from historical topographic maps.

The area reduction factor was applied for the different return periods, namely 1:25 and 1:50 year. The equation applied was as shown in equation 11.

$$ARF = (90000 - 12\,800lnA + 9830\,\ln(60T_c))^{0.4} \qquad \text{Equation 11}$$

Where:
ARF = site area reduction factor
A = catchment area (km^2)
Tc = time of concentration (hours)

1.9 Post-development conditions

The post-development conditions were determined solely for this study to understand the impact of climate change on land-use developmental conditions. The sub-catchment characteristics were revised to determine the peak discharge when the area has been developed.

<u>Surface Run-off Analysis</u>

In South Africa, there are different methods available to determine the normal stormwater run-off. The Rational Method, Standard Design Flood (SDF) Method and the Alternative Rational Method can determine design floods at various points within the area to estimate the overall surface run-off. In order to calculate the peak surface run-off, the Alternative Rational Method was used, and the Standard Design Flood methods were used to calibrate the results. The flows were determined for a daily extreme rainfall event through the frequency analysis and PDF selections. Peak Flows for the 1:25- and 1:50-year extreme rainfall events were calculated for the selected catchment and each sub-catchment.

<u>Alternative Rational Method</u>

The alternative rational method was used for determining the peak surface run-off flows for the study area. This method is based on the rational method, with the point precipitation being adjusted to account for local South African conditions. The representative rainfall is available from the TR102 However, the frequency analysis was conducted for the historical data, and the daily rainfall for the required return periods was established. This information can be used to calibrate the hydrological model. To determine the rainfall intensity for the study location, the Alternative Rational Method uses the Hershfield Equation. The modified Hershfield method of estimating point rainfall is a very useful and reliable tool for hydrological designs. It is mainly based on the analysis of a vast amount of rainfall (Koutsoyiannis, 1999). To determine the point rainfall for the specific return period the Hershfield's equation was used in Equation 12.

$$P_{i(T)} = 1.13(0.41 + 0.64 lnT)(-0.11 + 0.27\ln(t))(0.79M^{0.69}R^{0.20})$$

Equation 12

Where:

Pi(T) = rainfall depth for duration of t and return period of (T) years in (mm)

t = duration (minutes)

T = return period

M= 25- and 50-year return period (GEV)

R = average number of days per year on which thunder was heard (days/year) obtained by establishing the study area's position.

1.10 Incorporation of the simulated climatic variation into land-use planning.

Storm & Sanitary Analysis (SSA) program has various relevant deterministic, statistical and empirical methods which the user can incorporate for their designs. The catchment was partitioned into 13 sub-catchments, and their effective areas were also determined based on the current natural sub-basin. To conduct a hydrological model for the study area, the different sub-catchments were thus given hypothetical land development conditions. These land conditions were introduced for all three (3) scenarios (base, historical and future climatic conditions). The hydrological model was simulated using the Rational Method to determine each sub-catchment peak flows. The following equation explains the rational method:

$$Q = \frac{CIA}{3.6} \qquad \text{Equation 13}$$

Where:

Q = Peak flow for the given return period (m^3/s)

C= Run-off coefficient given by the catchment characteristics

I = rainfall intensity for the study area (mm/h)

A = Effective Area (km^2) as calculated in Equation 13 above.

The pre-development conditions were determined using the current state of the catchment characteristics. The post-development conditions were hypothetically determined to understand the impact of the point rainfall over the catchment area and, subsequently, its impact on the overall climate change findings. The different sub-catchment was hypothetically zoned to quantify the overall surface run-off should the area be developed.

The base, historical and forecasted point rainfall were all analysed for pre- and post-development conditions. This was done to understand the impact of climate change determined over the study location. The base and historical scenario used was for 1969 to 2019, and the future conditions used was for the 2020 to 2069 period. Land clearing can lead to soil degradation and massive erosion during rainfall events (Busayo et al., 2019).

RESULTS & DISCUSSION

2.1 Rainfall data and topographical data

Rainfall Data

The daily rainfall at station number 6 545 weather station for the Pelindaba gauging station is illustrated. The mean annual rainfall series for the Pelindaba gauging station exhibits significant seasonal variations. This can be attributed to climate variations for each year. The increasing trend of Spring rainfall is statistically insignificant since the coefficient of variation of (47.3%) for Summer rainfall is higher than that of Spring rainfall (39.9%) which implies more interannual variability of Summer rainfall than the Spring rainfall.

The mean annual rainfall of the area during the study period was 64.8 mm with a 21.97 mm standard deviation. The highest mean annual rainfall event was 139.8 mm, which was experienced on the 25th of March 1995, and the second highest was 115.8 mm, which was experienced on the 2nd of February 2014. In the study area, summer is the major rainy season, contributing about 34.6% of the total rainfall (where over 30% comes only in two months: December and January). In contrast, February contributed 3.6% of the summer rainfall. The short rainy season, which lasts from September, October and November (Spring season), also contributes a considerable rainfall (around 27%) of the total maximum annual rainfall. Since the maximum average annual rainfall was experienced in 1995 and 2014 (almost 20 years apart), the rainfall data for the period (1969 to 1995) was compared with the rainfall data for the period (1996 to 2019). The results indicate an 8% increase in annual mean rainfall and 10% rainfall for the Summer season. For instance, the mean annual rainfall and the Summer rainfall (December to February) in the study area from 1969 to 1995 were 60.6 mm and 27.5 mm. This amount had increased to 69.3 mm and 38.9 mm during 1996–2019 for both annual and summer season, respectively. The linear regression model of the data indicate the rate of change, which in the three cases is +0.0498 mm/year, +0.028 mm/year and +0.0282 mm/year for annual, Summer and Spring rainfall respectively.

The mean annual rainfall and summer rainfall has increased, on average, by 8.7 mm and 11.4 mm, respectively, over the past 25 years compared with the period between 1969 and 1995. We can conclude that an extension of the rain season is likely to occur in early spring, with an increase in rainfall predicted for September, October and November. The number of rain events is expected to increase, which could conclude that the chances of floods may increase based on wetter antecedent conditions attributed to climate change. There is an existing relationship between rainfall and run-off, as it is evident that the increase in rainfall is expected to impact the existing stormwater infrastructure. Increases in future rainfall due to climate change in combination with sea-level rise could cause flooding in stormwater drainage infrastructure. More stormwater overflows can be expected with the increasing stormwater volumes, which will exacerbate the existing infrastructure. The amount of water generated within a catchment steadily increases with sprawling development. The amount of run-off volume will be dependent on the urbanisation of areas. Therefore, it is prudent that the development of greenfield sites considers the increase of rainfall to manage stormwater within the catchment area.

Topographical Data

The Roodekrans 492 JQ intersects by the Hennops River, which rises to approximately 1 530 metres above sea level (m.a.s.l) near Attridgeville, far west of Pretoria. The elevation variation over the study area, which ranges between approximately 80 meters (m.a.s.l) towards the west and approximately 155 metres (m.a.s.l) along the south-eastern boundary of the study area. The high interior highland and the low-lying region have relatively steep terrain, while the ridge zone has flat rolling terrain with smooth valley flanks. The study area generally slopes from the northwest to the east. Slope

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analysis of the catchment area was within the 3% to 20% gradient range. Small isolated areas reached a maximum gradient of 30% along the lower edges of the catchment area. The basic statistical analysis of the rainfall in the study area revealed that it is evident that rainfall in the selected study area is predicted to increase over the upcoming years. The majority of the increased rainfall that is projected is expected to occur during the summer months. The chances of flooding in the area are thus higher due to the fairly flat topography, which does not encourage natural surface flow. Should any development occur, it will interfere with the run-off patterns.

2.2 Land cover and land-use typology

From general observation of the land cover for the study area, a significant proportion of the land remains undeveloped. Satellite images and the subsequent thematic maps extracted from available sources such as the USGS are crucial for environmental protection and spatial planning. The image classification process involves converting multi-band raster imagery into a single-band raster with different categorical classes related to diverse land cover types. The study area is predominantly made up of greenfield areas. The study area is characterised by agriculture (cultivated land, plantation areas, pasture, dryland). It is also characterised by mining and a small fraction of industrial activities. The northern and southern portions have been intensively mined over the years. Private agriculture also predominates. The greenfield area is in the vicinity of the Hennops River. Land use plays an important role mainly because of the effect of the infiltration rate; therefore, present and future conditions should be properly taken into account, especially regarding urbanisation.

2.3 Frequency analysis of annual maximum events

The historical data collected for this study indicate that most of the increased rainfall projected is expected to occur during the summer months, namely December, January and February. An extension of the rainy season may occur in early spring, with an increase in rainfall predicted between September to November (CSIR, 2019). The statistical analysis of this study indicates that the number of rain events is expected to increase, which could conclude that the chances of floods may increase based on wetter antecedent conditions and increased urban developments. The rainfall data were patched using the linear regression patch method. The descriptive statistical results derived for the Maximum Annual Rainfall data indicate the mean of 64.88 mm, which is larger than the median at 63mm with a positive skewness of 0.909 and the data had a tail that was on the right. The statistical results also show that the sample data is far from normal distribution, reflected in kurtosis, which is at 15.802.

Evaluations of the risks of extreme weather events such as heavy rain require methods to statistically determine their return periods from existing measured data. The ranking and plotting positions have gone under mathematical analysis, such as the Gumbel 1958 plotting method, so that the theoretical practicalities are understood in principle. The equations were used to determine the relationship between the plotting positions representing the Maximum Annual Rainfall events for the historical rainfall data. These return periods have been selected because stormwater drainage systems are generally designed for the 1:50 and 1:25 year design period. The results indicate that the probability of an extreme event for the 1:50 years and 1:25 years selected for this study is approximately 139.8 mm and 115 mm, respectively.

The Gumbel's distribution was selected as it is mainly used to analyse extreme values and survival analysis. The different plots were developed to identify the best PDF for the study area's rainfall data. Only the three distribution functions were assessed. From Figure 2, we can observe that the Gumbel distribution function, together with the other two distribution functions, followed a similar trend to the linear plot. The data for the PDF should have fallen on a single line inclined at 45° to the axes. The data demonstrate some scatter, but the band in which all the data are plotted can be considered reasonable. This shows that the prediction by the present method compares favourably with the Gumbel method. This representation of the results indicates that the Gumbel distribution method is the best representation that can be used to estimate the values corresponding to any return period, namely 2-, 5-, 10-, 20-, 25-, 50- and 100 years. The Gumbel distribution represents the rainfall data received better than the other two methods, namely, Weibull and Log-Pearson Type III.

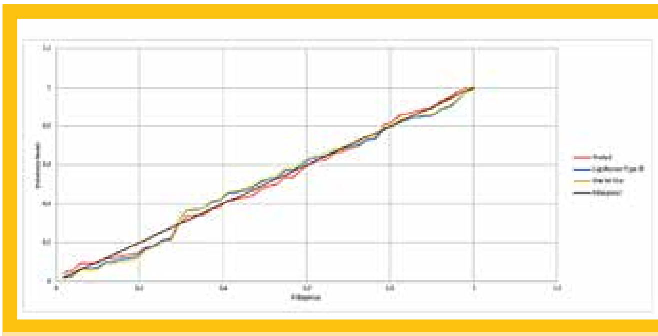

FIGURE 2: Probability distribution plot of maximum annual rainfall events for the Roodekrans area (1969 to 2019)

2.4 Selection of suitable PDF for the study area

The PDFs were selected based on their ranking. The PDFs selected were Gumbel, Log Pearson Type III and Weibull, closely following the theoretical PDF trendline. The Gumbel distribution function closely follows the theoretical estimates for the rainfall data's maximum annual rainfall events. Quantile fitting of distribution for the Maximum Annual Rainfall series for the data, which has computed the theoretically expected value for each data input. The quantile plot demonstrates that the data follows a fairly normal probability distribution except in the extreme ends, for example, the 1:100-year return period.

With this information in hand, we can determine the return periods for the data received using the Gumbel distribution method to further determine the magnitude events used in stormwater infrastructure design. Among the PDFs presented in this study, the Gumbel distribution function yielded the best-fit PDF. The PDF yielded the best fit as presented in this study. For this study, the Gumbel distribution was selected. The Gumbel distribution function. It should be noted that rainfall data received has only 51 years of rainfall data available, which unavoidably yields much lower confidence in the results as the return period increases. For this study, the 1, 2, 5, 10, 20, 25 and 50-year return periods were assessed. Quantile plots curve follows the distribution very well for lower daily rainfall then drifts away from the theoretical distribution at extreme rainfall returns. The data also shows that longer return periods have more uncertainty around the quantile estimates. The selection of the probability of exceedance is also related to the risk that one is willing to accept and the project's lifetime.

2.5 Forecasting precipitation for the 50 years (2020-2069)

The Gumbel (Generalised Extreme Value Type I) distribution function was selected for the data. We were then able to derive the return levels of extreme annual maximum rainfall. The T year return level is the level that exceeded on average only once in T years. The return level for 2, 5, 10, 15, 20, 25, 50- and 100-year return levels are indicated in Table 1. We were then able to forecast the values for the period 2020-2069. From the values, we could see the climate impact for the next 50 years, which indicated that the

TABLE 1: Return level of maximum extreme rainfall (mm)					
T (return period)	yt	K	1969 to 2019 (mm)	2020 to 2069 (mm)	Climate Change Impact
2.00	0.366513	-0.15692	61.4281	86.33431	40.55%
5.00	1.49994	0.81824	82.85328	105.4584	27.28%
10.00	2.250367	1.46388	97.03861	118.1203	21.73%
15.00	2.673752	1.828144	105.0419	125.264	19.25%
20.00	2.970195	2.083193	110.6455	130.2658	17.73%
25.00	3.198534	2.279647	114.9618	134.1185	16.66%
50.00	3.901939	2.884831	128.2583	145.987	13.82%
100.00	4.600149	3.485545	141.4565	157.7678	11.53%

expected average was a 21% increase in the rainfall frequency to be expected overall. The results demonstrate that rainfall is expected to increase over the study area under future climate change scenarios. The increase is estimated at 40% for a 2-year return period and 11.53% for a 100-year return period. This equates to an increase in rainfall of between 20% and 40% by 2070. These results suggest that precipitation will become more intense and more frequent over time. The results depicted the 2, 5, 10, 20, 25, 50 and 100-year return periods. Using the Gumbel distribution function for 50 years shows that we would anticipate that the average monthly rainfall will increase by 13.82%. This can develop more detailed risk and damage estimates such as flooding levels and stormwater infrastructure damage.

2.6 Simulation of stormwater generation for different future climatic conditions

Three scenarios selected were namely, the base, historical and forecasted scenario. The base scenario was extracted from the TR102 data as provided by the South African Weather Services for the daily rainfall. Daily design rainfall was determined using the frequency analysis for the scenario 1 (1969 to 2019 - historical) period and the scenario 2 (2020 to 2069 - forecasted) period. These data sets were used to calculate peak flows for the catchments within the Alternative Rational and SDF methodologies. The extreme rainfall events for the three (3) scenarios. The extreme rainfall depths are representative of the extreme daily event over the catchment.

2.7 Catchment characterisation and hypothetical land use development conditions

The catchment was delineated based on the DEMs to create 13 sub-catchments with an average area of 3 square kilometres (km^2). The pre-development scenario represented the existing conditions of the study area, which is currently defined as a greenfield site with very little development. The hypothetical zoning conditions were subjected to the hydrological scenarios developed for this study. Each daily rainfall for the applicable periods was considered to determine the run-off for the entire study area.

This analysis will provide insight into the impact of the development over the study area for each of the scenarios selected for this study. The hypothetical examples were subjected to peak run-off calculations for both the pre-development and post-development conditions. This was to understand the pre- and post-development run-off. The current daily rainfall, the base scenario, is modelled as received from SAWS TR102 systems. Historical scenario (scenario 1) used historical rainfall data to develop a theoretical PDF to predict future development conditions by using frequency analysis. The forecasted values, scenario 2 (forecasted scenario), indicate the future rainfall conditions that may need to be designed. The impact of future rainfall may be severe. Thus, looking into the urban developmental conditions will assist in understanding developmental conditions on stormwater management and how to strategise for this. To assess the response to daily flow indices to land-use changes and the impact of climate change, the daily flows were simulated by changing the land use under specific climate conditions.

2.8 Pre-development and post development conditions

The pre-development conditions of the study area consist of mainly. It is also characterised by mining and a small fraction of industrial activities. The area has thus been sub-divided into different sub-catchment areas based on the current flow characteristics of the natural ground. The pre-development characteristic assumptions were based on the existing site conditions and measured properties. The general slope of the site is 3%, of which the area is mostly naturally landscaped, which encourages permeability. The vegetation and land characteristics of the area were used to determine the coefficient characteristics to determine run-off. The overall elevation throughout the site varies between 80 metres (m.a.s.l) towards the west and approximately 155 metres (m.a.s.l) along the south-eastern boundary of the study area.

These are critical elements to determining the stormwater run-off for the study area at its pre-development state. The post-development conditions (catchments characteristics) were based on the proposed development conditions for the study area. The proposed development consists of 4 different development conditions based on the post-development characteristic assumptions for the future land-use characteristics. The -post-development conditions consisted of residential development, landscaped or undeveloped areas, commercial development, and impervious areas, consisting of surfaced roads and other building uses. The proposed development results in changes to the existing catchment areas. The land use between the different sub-catchment areas is dominated by residential areas in urban spaces and urban-rural development. The areas have high densification, which may increase surface run-off. The different land-use percentages were shown to consist of lawn and street land-use for consideration into the stormwater simulation for post-development conditions. The general slope of the site for post-development conditions is 2.5%, of which the area is predominately developed, resulting in high surface run-off and volume.

Base Scenario Mapping

The base scenario mapping consisted of the daily rainfall received from the TR102 for the Hennopsriver rain station. Although this daily rainfall is average, we considered it to understand its impact on the run-off results for the study area. The simulation was conducted using the selected design program. The model was run on Autocad Civil 3D for 24 hours to match the design storm durations. The total inflow volume is for the full mode 24-hour duration. The peak flows for the base scenario are also indicated in Table 2.

Scenario 1

The results show that a combined discharge of 917.79 m^3/s and 1 082.62 m^3/s for pre- and post-development conditions, respectively, can be expected for the overall study area. Prior to the zoning conditions being imposed on the study area, the pre-development conditions consisted of a fairly natural

TABLE 2: Results of Storm and Sanitary Analysis model on Civil 3D for Base Scenario Mapping, Scenario 1 and Scenario 2

Recurrence Internal	1 in 25 year	1 in 50 year	1 in 25 year	**1 in 50 year**	**1 in 25 year**	**1 in 50 year**
Peak flow at Outfall (m^3/s)	917.79	1 082.62	994.37	1 172.95	1 262.25	1 488.94
Total inflow volume (m^3)	3 263 210	3 442 077	3 535 495	3 729 286	4 487 953	4 733 952

landscape which encouraged stormwater infiltration. The introduction of post-development conditions yielded an 18% increase in stormwater run-off volume for the study area. Climate change impacts may exacerbate the stormwater impact resulting from the post-development conditions. The results shown of the Autocad Civil 3D modelling are summarised. The model was run for 24 hours to match the design storm durations. Scenario 1's amount of peak run-off for the entire area is summarised in Table 2. The results show that a combined discharge of 994.37 m^3/s and 1 172.95 m^3/s for pre- and post-development conditions, respectively, can be expected for the overall study area. The introduction of post-development conditions yielded an 18% increase in stormwater run-off volume for the study area. Climate change impacts may exacerbate the stormwater impact resulting from the post-development conditions.

Scenario 2

The existing and proposed post-development conditions for the model were kept consistent throughout the scenario analysis. Scenario 2 consisted of the daily rainfall analysed from the frequency analysis for the Pelindaba rain station and forecasted. As above, the simulation was conducted using the Civil 3D Storm and Sanitary Analysis. As provided in Chapter 3, the peak discharge for our proposed scenario 2 with the daily rainfall retrieved from the frequency analysis and subsequently forecasted for the 2020 to 2069 period. The results shown of the Civil 3D modelling are summarised. The model was run for 24 hours to match the design storm durations. The total inflow volume is for the full mode 24-hour duration, also shown in Table 2.

From the results, we can see that more frequent and intense rainfall is projected for the region, and the development of an area can affect the overall drainage of the area. Stormwater run-off can wash away sediments, important nutrients or any other pollutants into the natural watercourse, which may have adverse effects on the overall natural water cycle and other systems such as the environment and ecosystems. From the analysis, it is evident that climate change impacted rainfall and predicted rainfall could have an impact on the current development conditions of any region. Each of the hydrographs for the different scenarios peaked higher and faster than in pre-development conditions, which indicate that both the run-off volume and peak discharge are substantially increased under the developed conditions. Therefore, based on previous trends, there is a likelihood that the hypothetical area analysed in this dissertation will be under-designed over the next 50-year period should the climate impacts not be incorporated. This implies that the magnitude of these flood events will increase.

For the Roodekrans area, which was analysed with hypothetical land-use requirements, this will translate to an increase in precipitation in the area that may be subjected to flooding due to under-design. The stormwater run-off showed that we could expect an average increase of 26% over the study area between 2020 and 2069. From the assumption made on post-development conditions for this study and with the input information obtained from the design rainfall program, a peak flow value for this area could be determined for the 1 in 50- and 1 in 100-year extreme events, respectively, which takes into account the climate change impacts. This will allow for the accurate size determination of major stormwater infrastructure to facilitate the drainage of this volume of water from the study area.

CONCLUSION

The data received for this report indicated that over the area, there had been a substantial increase in rainfall events between 1969 to 1995 and 1995 to 2019. The percentage increase was the largest for most of the extreme rainfall events. The frequency analysis conducted for this study indicated that a 21% increase should be expected between the 2020 and 2069 period, with the intensity of a 2-year return period expected to increase by a staggering 40%. In light of this, the impact of climate change is evident, and thus stormwater management within this study area requires extensive thought process for future urban development. The rainfall and discharge for the base scenario were used to calibrate the model parameters of the catchment. The study area was divided into different sub-catchment with different catchment characteristics for post-development (urban development). These sub-catchments were established for the three (3) different scenarios. To analyse the impact, the stormwater run-off was analysed for the different scenarios. From the results, we could see how the different scenarios reacted to the increase in rainfall. Thus, to maintain the base scenario stormwater run-off, with the forecasted rainfall intensity, the areas were reduced to ensure that the developments do not become vulnerable to the risks of climate change.

From the analysis, it is very clear that the amount of greenfield area available for stormwater management should be identified early in project planning. This will largely dictate the extent to which different stormwater design elements are feasible in any development to ensure that climate change impacts are considered.

RECOMMENDATIONS

The rainfall data limitations, particularly the lack of rainfall data for longer periods, present challenges for planners and engineer. Although there are methods for replacing the data, an accurate representation of the required data would have ensured the homogeneity of the results is maintained. Considering the above, there is a need for a project funded by the government, which undertakes maintenance and backup rain gauges to be implemented across the country. This will be useful in providing the first approximation for a hydrological modeller or any practitioner to estimate peak discharges with accurate rainfall data.

The literature review shows that there is very little consideration for stormwater analysis during the feasibility and zoning stages of Greenfields. The increase in development poses a major risk for areas that may already be prone to flooding. Further consideration by the government to incorporate planners and engineer's recommendation in the planning of zoning of areas will ensure that the issues such as climate change are considered from the beginning.

An integrated approach needs to be adopted to determine the extent of encroachment of new development. Depending on the specific area, decisions can be made whether to allow no development at all or whether to allow some development with special conditions. For proactive planning of developments, impacts of climate change on stormwater management for the greenfield areas should be pre-defined.

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PAPER 15

Bulk Scale Industrial Effluent Reuse Potential in South Africa

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ABSTRACT

Rationale: Water scarcity, increased pollution, unprecedented population growth and climate change are collectively driving the need to reuse water with the aim to enhance water security, sustainability, and resilience. It is clear that South Africa's already strained water resources will become even more stressed in the near future. The Department of Water and Sanitation predicted that by 2030 water demand will reach 17.7 billion m^{3,} far more than what is available to allocate. Globally, responsible and efficient water management is fast becoming a pressing reality for domestic users, agriculture and industry alike. The challenge is therefore to capitalise on the limited water we currently have.

Solution: Bulk-scale reuse of industrial water effluent can play a significant role in water security in a water scarce country, such as South Africa, as it can augment or partially substitute freshwater resources needed for domestic purposes and future development. Water reuse in South Africa is however lagging.

Approach: An Atlas for potential industrial bulk scale water reuse was produced from publicly available Natsurv and WARMS data. It highlights the urgent need for water reuse to form an integral part of an integrated water management supply approach in South Africa. While South Africa has progressive legislation to support the implementation of wastewater reuse, it can also be regarded as a barrier in implementing reuse projects, as often water reuse standards and guidelines are far too stringent to allow for cost-effective reuse options to be developed and implemented.

Findings: Currently, very little to no data exists regarding wastewater reuse options, treatment options and capabilities, or costs, which can be used for decision making, and much more directed research and information is needed in order to identify wastewater and industrial effluent volume availability, quality and fitness for use in South Africa. A web-based Decision Support System (DSS) tool is being developed to enable municipal and industry partners, and water quality managers to make informed decisions for possible reuse options. The tool aims to directly assist by linking industrial effluent volumes and quality to fitness for use, and linking it with specific industries in the geographical vicinity based on industry specific water quality and quantity requirements. The DSS can be particularly useful in wastewater reuse as it can provide assistance in the evaluation and selection of alternatives for a given reuse application. In addition, the tool will enable engineers and industry partners to collaborate to identify and employ treatment technologies and capabilities to link industrial effluent quality and volumes available to that of potential user requirements in a geographical area.

INTRODUCTION

Industrial water use is an estimated 22% of the global water demand. In heavily industrial and developed countries industry water demand can reach 50% of the country's water use, whereas in developing counterparts, which are not relatively industry intense, industry water demand accounts for 4 – 12% (UN Water, 2018). Considering rising global industrialization and urbanization, industrial water use is likely to increase in developing nations, adding to the pressure on already vulnerable water resources (WWAP, 2009).

South Africa's water supply is currently strained, and it is anticipated that the vulnerability extent will continue to rise in the near future due to population growth, climate change and increased pollution (DWS 2013a – NWRS II). A water deficit has been predicted by 2030 as water demand will reach 17.7 billion m^3/annum exceeding the available water supply of 15 billion m^3 (WWF, 2016). Commercial agriculture, mainly irrigation accounts for 61% of South Africa's water use followed by municipal (mainly domestic and some industry) (27%) and industry (7%) (DWS, 2018a,b)

South Africa's economy is predominantly driven by mining, agriculture, and industrial manufacturing. Mining accounts for 5% of the country's water use and is predominantly concentrated in water resource scarce catchments (e.g., upper Vaal, Olifants, Steelpoort, Lephalale) where water availability poses a significant business risk. Such a situation bears consequential implication for South Africa's socio-economic development; hence water resources management should prioritise implementation of water conservation and water demand management (WC/WDM) measures across various sectors to avoid stunting socio-economic development (DWS, 2016).

The need for sustainable water use has fast become a reality for various users considering the current water supply vulnerability, hence solutions that enhance WC/WDM and widen water resources are a priority need. Wastewater reuse is amongst the measures to improve water sustainability as global demand for freshwater resources rises; requiring a paradigm shift in wastewater management from 'treatment and disposal' to 'reuse, recycle and resource recovery'. Wastewater is a resource that can contribute to improving sustainability of water supply and enhance the achievement of the UN's 2030 Sustainable Development Goals (SDGs) (WWAP, 2017) suggesting that improved wastewater management could facilitate the achievement of. South Africa's National Water and Sanitation Master Plan (DWS, 2018a) is aligned to the SDGs, specifically SDG6 which stipulates: "to ensure the availability and sustainable management of water and sanitation for all". SDG-6 specifically has a target to reduce the proportion of untreated wastewater by half by 2030, while sustainably increasing water recycling and safe reuse (WWAP, 2017).

Wastewater reclamation in South Africa is poorly utilized and is currently estimated to be below 14% (DWS 2011, – Water reuse strategy) and this is in spite of local examples which have earned global recognition (Durban Water Recycling Plant) (World Bank 2018) A review of current literature on wastewater reuse in South Africa is limited Most of the examples of reclaimed water are related to agriculture (Jiménez et al., 2010), with only a few exceptions (Eckart et al., 2011; Adewumi et al., 2010). Treated domestic wastewater has long since been reused for various purposes such as irrigation of sports fields and crops as well as for reclaimed drinking water (e.g. Atlantis managed aquifer recharge plant in the Western Cape). More recently wastewater has been treated and used directly for drinking (e.g., Beaufort West in the Western Cape). While there is still much more that can be done with domestic wastewater, the value of industrial effluent is yet to be optimally understood. This can be reflected in the Green Cape's Market Intelligence Report (2018) where the total Gross Value Add (GVA) for moderate and highly water intense users in the Western Cape Province in 2016, excluding agriculture, was calculated to be R155 billion (Quantec, 2017). Water reclamation in industry is already practiced around the world, supported by advanced treatment technologies. Gulamussen et al. (2019) recently highlighted the need to identify industries with potential for use of reclaimed wastewater, and the evaluation of industrial water use locations and patterns. In addition, sewage flows available for reclamation should be identified to find links for incorporation of water reclamation in urban and industrial planning, within the framework of green cities.

A country level assessment of the industrial effluent reuse potential can assist in identifying opportunities to unlock "new water". Industry is increasingly exploring the reuse of their effluent (wastewater) streams, some even achieving zero effluent status. A globally recognized local example is the DWR which receives treated domestic effluent from the eThekwini Southern Wastewater Treatment Works and supplies water to petroleum refining and paper manufacturing industries and this case has conservatively availed drinking water for approximately 300 000 residents in the Durban Metro area (eThekweni Municipality, 2011). Internationally, there is a general move towards zero liquid discharge, and several industries in South Africa already reclaim and reuse significant amounts of wastewater. In June 2018, Nestlé South Africa announced the launch of its R88 million zero-water dairy manufacturing facility in Mossel Bay, in the Western Cape. It was estimated that the facility would allow Nestlé to reduce the factory's water consumption by more than 50% during the first year of implementation by reusing the water recovered from the milk evaporation process, saving 168-million litres of water per annum. Nestle will eventually reduce its municipal water consumption to zero (Engineering News, 2018).

Therefore, the aim of this research study was to develop a national Atlas for the potential bulk scale reuse of industrial effluent in South Africa. The Atlas is essentially a compilation of Geographic Information System (GIS) maps that have been created by digitising large volume (bulk) water users / consumers of water in South Africa as well as the respective industry sectors producing and discharging bulk volumes of wastewater in South Africa. In that context, the Atlas has : 1) defined water reuse and discusses the drivers of industrial reuse in South Africa; 2) summarises the legislation underpinning industrial water reuse in the country; 3) provides examples of a few existing industrial reuse projects/activities currently taking place in South Africa; 4) describes "fitness for use" and the typical wastewater effluent quality for different industries; 5) identifies some of the current barriers to industrial effluent reuse; and 6) geographically maps the largest consumers of water and effluent producers in South Africa both at a national and provincial level. This paper provides an overview of the potential for bulk scale reuse of industrial effluent in South Africa.

Defining reuse of water

Reuse can be defined as "the beneficial use of reclaimed or treated wastewater". Reclamation is "the treatment of wastewater for reuse, either directly or indirectly as potable or non-potable water" while recycling is "the reuse of wastewater, with or without treatment" (DWA, 2013b). Water reuse recovers water from a variety of sources from where it is then treated and reused for various purposes. The types of wastewater reuse are further classified in four main categories (Asano et al., 2007): urban, industrial, agricultural, and groundwater recharge. Water reuse can play an important role in water security in a water scarce country such as South Africa. Not only can it augment or partially substitute freshwater resources needed for domestic purposes and future development, it can also enhance sustainability and resilience (US EPA, 2020).

Drivers of industrial water reuse

An understanding of the drivers for and against water reuse can facilitate efforts to meet associated water reuse policy goals (Gulamussen et al., 2019). Global drivers of water reuse include multiple factors: pressure on water supply as a consequence of climate change (Nazari et al., 2012; Jiménez et al., 2010); water stress derived from population growth and, consequently, growth of cities that challenge the water resources and sanitation systems (Lautze et al., 2014); environmental and economic concerns that limit the use of other solutions to combat water scarcity, such as long-distance water transfer, construction of large dams and desalination (GWI, 2009); and increased confidence in and reduced costs treatment technologies, which provide assurance of the safety of reclaimed water blended into reservoirs or aquifers for potable uses (GWI, 2009).

Table 1 provides a summary of the general drivers for and main applications of water reclamation for industrial use in different regions of the world. Aside from water scarcity, water reclamation for industrial use in developed countries seem to be driven mainly by environmental concerns, with sewage treatment plant effluent typically utilized for purposes such as cooling, boiler feeds, condensing and steam production, firefighting, and dust mitigation. Water scarcity is however the main reason for water reclamation in developing countries (Gulamussen et al., 2019).

TABLE 1: Drivers and industrial applications of reclaimed water globally

Region	Drivers	Main application	References
Region	• High industrial water demand in highly populated areas • Resource efficiency • Environmental concerns	Cooling	(Asano and Jimenez, 2008; USEPA, 1992; Ryan, 2016; Marecos do Monte, Angelakis and Gikas, 2014)
Region	• Water scarcity • Cost effectiveness of reclaimed water and resource efficiency • Environmental concerns	Process water, cooling, condensing and steam generation	(Asano and Jimenez, 2008; USEPA, 1992; Schaefer et al., 2004; Smith, 2015)
Region	• Water scarcity • Political pressure	Cooling, washing and process water	(Asano and Jimenez, 2008; Indian Institutes of Technology, 2011; USEPA, 1992)
Region	• Water scarcity • Environmental concerns	Cooling, boiler feed, firefighting and dust repression	(Asano and Jimenez, 2008; USEPA, 1992; Apostolidis et al., 2011)
Region	• Water scarcity	Cooling, mining and process water	(Indian Institute of Technology, 2011)

(Source: Adopted from Gulamussen et al., 2019).

Figure 1 provides a summary of driving forces impacting industrial water reuse in South Africa, based predominantly on water scarcity and costs.

FIGURE 1: Drivers for industrial reuse (adopted from Steyn et al., 2021)

Legislation guiding industrial reuse in South Africa

South Africa has extensive and comprehensive laws and guidelines regarding water use, reuse applications and effluent discharge. The Constitution, (Act 108 of 1996) (RSA, 1996) guarantees every person in the country the right of access to water and the right to an environment that is not harmful to their health or wellbeing now and in the future. Sustainable water reuse is further underpinned by the principles of the National Water Policy Review (DWA, 2013c) as follows: "Water resources shall be developed, apportioned and managed in such a manner as to enable all user sectors to gain equitable water. The main legislation that governs water use and the discharge thereof in South Africa is the National Water Act (Act 36 of 1998) (RSA, 1998a). This Act aims to ensure that the country's water resources are protected and managed to reduce and prevent pollution and degradation of water resources. Reuse of effluent in the country requires environmental authorization in terms of the National Environmental Management Act (Act 107 of 1998) (RSA, 1998b), and in some cases requires water use licenses (WULs) in terms of the NWA (36:1998) (RSA, 1998a). In terms of the NWA (36:1998), NEMA (107:1998), together with the Mineral and Petroleum Resources Development Act (Act No. 28 of 2002) (MPRDA) (RSA, 2002), all new and existing mines are required to optimize water reuse and reclamation (DWA, 2013b).

The Water Services Act (Act 108 of 1997) (RSA, 1997) relates more to the management of human drinking water and directs bulk water suppliers to the compulsory national standards in the form of SANS 241-1:2015.

In line with the NWA and the WSA, water conservation (WC) and demand management (WDM) is an important step in promoting water use efficiency and viewed as a useful tool in achieving Integrated Water Resource Management (IWRM) (Gutterres and Aquim, 2013). Implementation of WC/ WDM programmes by all sectors is essential in ensuring economic efficiency. The National Water Reuse Strategy (DWA, 2013b) encourages wise decisions relating to water reuse at different scales and levels. The performance of existing wastewater treatment plants in terms of meeting discharge standards and reliability is critical to the successful integration of water reuse into reconciliation strategies and into water supply systems in South Africa (DWS, 2013, 2018). Other Acts, policies, frameworks and strategies which are also important include the Environment Conservation Act (Act 73 of 1989) (RSA, 1989), the National Environmental Management: Waste Act, (Act 59 of 2008) (RSA, 2008a), and the National Environmental Management: Integrated Coastal Management Act, (Act 24 of 2008) (RSA, 2008b), the Mine Water Management Policy (DWS, 2017) , the National Water Resource Strategy (DWA, 2013a; 2013b)) and the National Water and Sanitation Masterplan (DWS, 2018). In some instances, recent amendments to these acts and municipal bylaws may also be relevant.

Wastewater generation per industrial sector

The water consumption rates of industrial users are significantly higher than those of individual households. Provincial average values for individual water consumption range from 182 litres per capita per day (l/c/d) for Limpopo to 305 l/c/d for Gauteng, suggesting average consumption rates for a household of four persons in the order of one kilolitre per day, or 0.001 megalitres per day (Ml/d). By contrast, manufacturing plant/factory water consumption rates are three orders of magnitude higher in some industries. Paper and pulp use between 0.1 to 150 Ml/d, wet-cooled power stations (e.g., Matla and Lethabo) requires in the order of up to 100 Ml/d, while dry-cooled power stations (e.g., Kendal and Matimba) uses in the order of 10 Ml/d. Sugar mills consume between 0.6 to 6.8 Ml/d, while water consumption of between 5 and 10.5 Ml/d have been recorded for oil refineries.

Industrial water users return significant fractions of their water consumption to the municipal wastewater system or the environment as effluent, with the exception of wet-cooled power stations where water use is nearly entirely consumptive. Van der Merwe et al (2009) and Cloete et al (2010) studied water use by industry in South Africa and identified the paper and pulp industry as the biggest contributor to wastewater generation. Power generation, mining, and petroleum industries were also identified as major contributors. The food and beverage industry contributed greater than 5% in each case, however it encompasses many sub-industries. The textile industry contributes a small portion in each case. Classified as "Other", includes chemicals, pharmaceuticals, cement, metals processing, paint, plastics, tanneries, and waste management. Figure 2 provides a schematic breakdown of the main industrial water users and producers in South Africa (based on the Cloete et al., 2010 data).

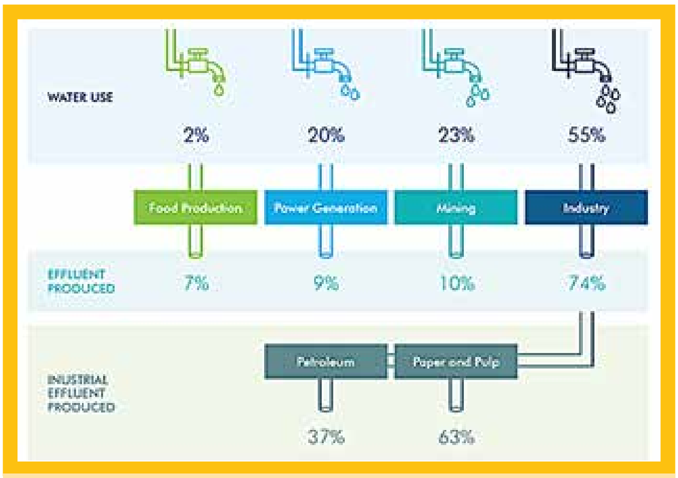

FIGURE 2: Industrial water use and effluent produced in South Africa (adopted from Cloete et al., 2010)

Managing water for potential reuse and fitness for use

A number of novel technologies are readily available to treat industrial wastewaters, and judicious decision making is therefore required before selecting appropriate technologies. The technology selection depends on the quantity and quality of waste impurities, and desired quality goal for subsequent treatment. Furthermore, the choice of technology is influenced by wastewater re-use goals: e.g., recovery of valuable materials from wastewater, possible water recycling and reuse, complying with the statuary norms for discharge into water bodies and/or the economics of the treatment process itself (Need a Ref for this?). The quality of the effluent makes the task of technology selection, oftentimes, rather complex. However, for the majority of wastewater qualities, appropriate remediation technologies already exist.

Therefore, the concept of "fitness for use" is central tenet to water quality management in South Africa as it is embedded in the development and use of our national water quality guidelines (DWS, 1996). In the current context; wastewater aimed for re-use will be managed and/or treated to be fit for the intended use. The concept of "fit-for-purpose" specifications are to meet treatment requirements to bring the water from a particular source to the quality needed, to ensure public health, environmental protection, or specific user needs. For example, reclaimed water for crop irrigation would need to be of sufficient quality to prevent harm to plants and soils, maintain food safety, and protect the health of farm workers. In uses where there is a greater risk to human health, the water may require additional treatment (US EPA, 2020).

Industrial water demand and wastewater production are sector-specific. The concentration and composition of the industrial effluent (mass/time) can vary significantly depending on the industrial process (Mhlanga and Brouckaert, 2013; Iloms et al., 2020). Wastewater is typically characterized by biological, physical and chemical characteristics.

Water quality parameters specified in the South African Water Quality Guidelines for Industrial use (DWS, 1996) are limited in comparison to other water uses. A review of available literature in South Africa, however revealed, that only four commonly listed parameters are used to measure wastewater quality. These were pH, total suspended solids (TSS), chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Mining and power generation did not list BOD but placed importance on total dissolved solids (TDS) and ion concentrations (Harding et al., 2020). The guidelines further describe four categories of water for use in different industrial processes. Wastewater, because it must often meet stringent discharge regulations, may unnecessarily be of higher quality than required for other uses, such as for recycling applications.

METHODOLOGY

The information in the Atlas was developed using open-source data obtained from the Department of Water Sanitations, Water use Authorization and Registration Management System (WARMS), QA Data Reports for water consumption and effluents produced. The WARMS database (DWS, 2019) is the official national register of water use in South Africa as defined in terms of section 139(2)(d) of the National Water Act 1998 (RSA, 1998a), viz, to store and produce accurate water use information to advance economic growth, development, and democracy. The DWS WARMS database contain detailed information and reports on South Africa water users who use water for: irrigation, industrial use: including mining, power generation, recreational purposes and watering livestock for both surface and groundwater resources in the country.

The data was plotted using proprietary ArcGIS® software (ArcMap™ 10.5.1). For the purpose of the Atlas, standardized WGS84 reference spheroid was used for geographic coordinates. The GIS data used to generate the map products of the Atlas are supplied in ArcGIS native formats (e.g., Shapefiles containing the relevant provincial boundaries). The Atlas presents maps at both national and provincial context and provides a visual account of both the volumes of water used and effluent produced per industry sector. In order to achieve optimum robustness and comprehensiveness, lower volume limits were set low to accommodate the majority of entries in the database, whilst maintaining practical information. Additionally, the authors acknowledge and recognize that the water use applications are commonly pitched at high registered volumes rather than actual volumes (consumed or produced) in order to factor in future forecast scenarios. Hence real water use and effluent discharges can be significantly lower compared to licensed volumes. For water consumption, the data was sorted to include those bulk water consumers, with the minimum consumption volumes set at 200 000 m^3/annum. For effluent discharges, the data was analysed to include bulk industrial effluent producers, which for the purposes of this Atlas, the minimum effluent volumes were set at 100 000 m^3/annum. Bulk domestic wastewater effluent was mapped as this can provide industries or municipal decision makers with an indication where large volumes of wastewater effluent is available and in close proximity to industries for potential reuse. The difference in volumes for consumption compared to effluent discharge volumes used in the Atlas is based on the fact that water is lost as a result of industrial processes. Loss of water volumes of up to 50% of the consumption volume was therefore standardised and used throughout. Future research will entail more detailed data analysis at higher resolution, for example at municipal level. This will allow more scenario-specific opportunities to be identified using detailed criterion such as area specific water billing data.

RESULTS AND DISCUSSION

Bulk water use

From a national perspective, water use intensive industries were largely represented by the agriculture sector, mostly through irrigation. Second to agriculture was water supply services, urban industry, mining and non-urban industry. Water use for mining was the highest in Mpumalanga, followed by Gauteng, North West, Northern Cape and Limpopo. Mpumalanga had the highest water withdrawals, followed by the Free State, Eastern Cape and Gauteng provinces. In all provinces, the largest water use was for agricultural irrigation, except in Gauteng, where industrial water use was the highest. The second highest industrial water use was the Western Cape. In the Western Cape, the highest water withdrawals per sector were for agricultural

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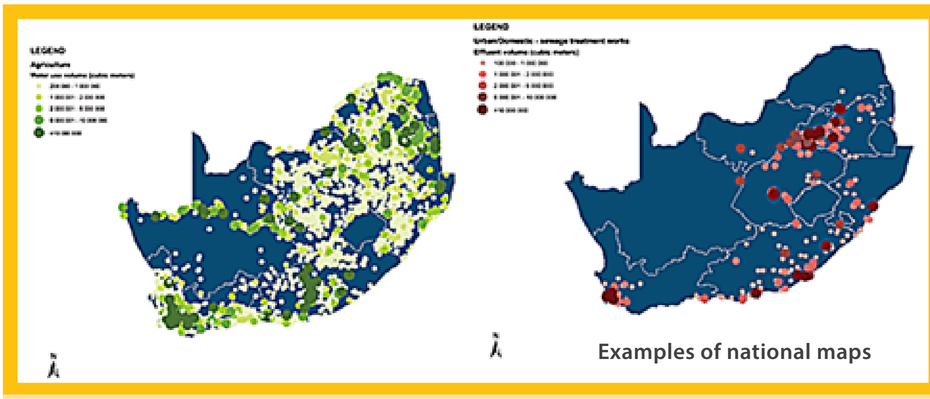

FIGURE 3: National bulk water consumption (agriculture) (left) and national bulk effluent production (domestic wastewater effluent) (right)

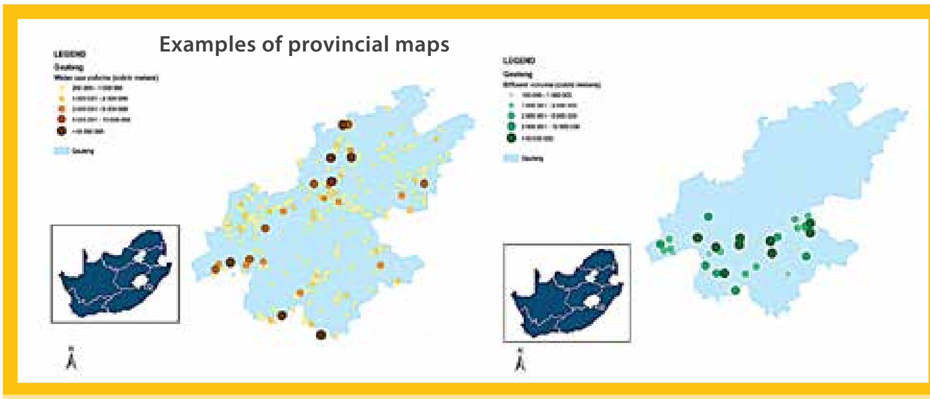

FIGURE 4: Industrial bulk water consumption and effluent produced in Gauteng Province

irrigation, followed by urban industry and water supply services. A large portion of non-urban industrial water use was identified in Kwa Zulu Natal and Mpumalanga. The Northern Cape province had the lowest registered water withdrawal of all provinces. Figure 3 depicts examples of national maps. The map on the left is a national bulk scale water consumption map for the Agriculture sector. The map on the right depicts bulk scale domestic wastewater effluent at national level.

Bulk effluent production

Effluent reuse (treating the final effluent to potable standards for onsite reuse, typically for non-product contact purposes) with or without energy recovery (biogas), represents the largest opportunity for water savings in the sector. From a national perspective, the highest effluent produced was registered by urban/domestic (sewage treatment works), followed by mining. Mining effluent was recorded in all provinces except the Western Cape.

Gauteng was the highest ranked province in terms of wastewater discharge, followed by Mpumalanga and the Eastern Cape provinces, respectively. Discharging wastewater effluent was associated with urban areas and industry. Large-scale irrigation with wastewater is largely limited to the Breede-Gouritz catchment in the Western Cape. The provinces that registered the lowest effluent volumes included Limpopo and Northern Cape provinces. Figure 4 depicts examples of provincial maps (Gauteng) of bulk scale water consumption and bulk effluent production (all sectors).

Even though country and municipality specific information on industrial reuse options, water quality and quantity (volumes), are not widely accessible, this study was able to present a "current point in time" reflection which highlighted the largest water consumers in each province and at a national scale (a critical first step towards unlocking industrial waste water reuse potential. Similarly, high volume industrial effluent producers for each of the different industrial sectors were highlighted per province and at a national level, which provided a good geographical overview of industrial effluent production.

From the above examples, there are a clear need for water reuse to become an integral part of an integrated water management supply approach in South Africa. The authors realized that this Atlas provided only a one dimensional and geographical overview of industrial reuse effluent volumes (based on water use license registrations). As a result, an Excel-based decision support system (DSS) for bulk scale reuse of industrial effluent was developed (a web-based and mobile application in the process of being developed). This DSS (Figure 5) will enable municipal and industry partners, and water quality managers to make informed decisions for possible reuse options. The tool aims to directly assist by linking industrial effluent volumes and quality to fitness for use and linking it to specific industries in the geographical vicinity based on industry specific water quality and quantity requirements. In addition, the tool will enable engineers and industry partners to collaborate to identify and employ treatment

FIGURE 5: Flow diagram of the current steps in the DSS

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technologies and capabilities to link industrial effluent quality and volumes available to that of potential user requirements in a geographical area.

The underlying systemic approach of the tool makes it intuitive also for users with limited prior knowledge in the field to identify most adequate solutions based on multi-parameter inputs. This will promote water reuse and spearhead initiatives for more detailed feasibility and design commissioning for implementation of water reuse schemes.

CONCLUSION

Water reuse in South Africa is lagging behind the rest of the world. The Atlas produced from publicly available Natsurv and WARMS data, shows huge potential for the reuse of bulk industrial effluent. A limiting factor to date is the fact that this data does not give a true reflection of actual volumes available for reuse. The Atlas as well as the Decision Support System (demonstration model) needs to be updated with real-time data from municipalities and industries. Similarly, actual effluent quality requirements are not known. While South Africa has progressive legislation to support the implementation of wastewater reuse, it can also be regarded as a barrier in implementing reuse projects, as often water reuse standards and guidelines are far too stringent to allow for cost-effective reuse options to be developed and implemented. Currently, very little to no data exists regarding wastewater reuse options, treatment options and capabilities, or costs which can be used for decision making, and much more directed research and information is needed in order to identify wastewater and industrial effluent volume availability, quality and fitness for use in South Africa. A web-based Decision Support System (DSS) tool is being developed to enable municipal and industry partners, and water quality managers to make informed decisions for possible reuse options. The tool aims to directly assist by linking industrial effluent volumes and quality to fitness for use, and linking it with specific industries in the geographical vicinity based on industry specific water quality and quantity requirements. In addition, the tool will enable engineers and industry partners to collaborate to identify and employ treatment technologies and capabilities to link industrial effluent quality and volumes available to that of potential user requirements in a geographical area.

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PAPER 16

Distributed Clean Energy: Advocating for Micro-grids as a Solution for South African Municipalities

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ABSTRACT

Reliable, clean energy is critical for sustainability today and sustainability into the future. While various leaders across the world grapple to meet greenhouse gas emission targets as well as 'keep the lights on, private industry is moving full steam ahead to find solutions to what is deemed an energy crisis for some countries such as South Africa. Steady, reliable, and cost-effective electricity production and supply is the backbone of any first-world country. It is hard to imagine how society would function without electricity, yet in this day there still exist communities located on the periphery of cities as well as remote areas with no connection to the transmission grid. In addition, the Eskom grid is under strain due to high demand and aging infrastructure and 'blackouts' have become a common daily occurrence. Considering the current constraints to generate reliable energy at a national level, it makes sense for municipalities to have the autonomy at a local level to explore and implement clean energy technologies as an affordable, reliable option to serving communities and businesses in their jurisdiction.

The reality is that there is an urgent drive across the globe to cleaner, more sustainable ways of generating electricity for various applications and renewable energy is now more prominent and prevalent in many countries. In addition, it has been seen globally that the traditional grid is ailing under increased demand from growing population and industry. There is a shift towards a decentralized way of generating and distributing electricity.

Micro-grids underpinned by advanced storage systems have been used extensively for various applications including serving large industries as well remote and rural communities. In addition, they act as a buffer for the municipality against loading shedding of the national grid, therefore, doing away with rolling blackouts in those areas. South Africa's energy crises together with the current recession create a perfect storm and exploring alternative ways of generating electricity from clean natural sources may be the immediate solution.

The global community including South Africa has acknowledged that greenhouse gas emissions are a contributor to the rapid changes to the natural environment as seen in the unusual occurrence of flooding in some parts of the world, drought in other parts.

The South African government recognizes the challenges faced by the existing national grid as well the commitment to Sustainable Development Goals and has updated the Integrated Resource Plan (IRP) to reflect the same. The latest update to the IRP (2019) sees a greater integration of renewable energy generation as well as an inclusion for energy storage technologies. In addition, the IRP (2019) gives Municipalities permission to consider alternative ways to generate electricity through the decentralized approach.

The shift to decentralized energy globally will increase significantly and with micro-grids underpinned by energy storage playing a very important role in this regard. This paper affirms that municipalities can depend on microgrids as a solution supply clean steady electricity to for key infrastructure such as water treatment and distribution thus building energy resilience.

1 INTRODUCTION

The existence of modern-day society highly depends on energy for electricity, heating, transportation, etc. Research shows that areas that have no electricity, lose out on better sanitation, health care, and education[1]. In South Africa, there are 2.2 million households still with no access to electricity[2]. And of these, 95% are classified in the low-income group, therefore not being able to afford the cost associated with connecting to the grid[3]. The South African government, through its Integrated Resource Plan (IRP, 2019) acknowledges that there are parts of the country that just don't have electricity and that a connection to the national grid would be costly, thus provision has been made for accelerated advancement of micro-grid deployment by municipalities.

It is proven that a reliable source of energy is essential for long-term population sustainability and economic advancement.

Climate Change has been the biggest contributor to extreme weather patterns thus negatively impacting the environment for humans and living organisms to thrive. The burning of fossil fuels for power generation has been identified as not sustainable and an emitter of carbon emissions.

Renewable energy has proven to be a strong alternative to fossil fuel energy. IRENA (International Renewable Energy Agency) highlights that Africa is 'endowed with substantial renewable energy resources, and is in a position to adopt innovative, sustainable technologies and play a leading role in global action to shape a sustainable energy future'[4].

South Africa is one of the 77 countries that has signed up to the Paris Agreement with an undertaking to significantly reduce carbon emissions by 2030. At a micro-level, municipalities have been given that mandate to explore and implement ways to improve energy resilience through clean energy technologies thus reducing reliance on fossil fuels for energy supply.

Microgrids powered by renewable energy technologies underpinned by battery storage has gained popularity as a proven implementable solution to providing clean energy to power various applications including residential areas. This paper seeks to demonstrate how micro-grids can assist municipalities to achieve energy security through self-generation and distribution and ultimately to support long-term development goals with a focus on optimizing battery storage.

2 THE MICROGRID

The function of the conventional national electrical grid is to transmit electricity using a network to meet end-user demands. The microgrid is also known as mini-grids operate similarly, although on a smaller scale. They are standalone isolated grids that can be connected to the national grid. Micro-grids are a collection of electricity generators, energy storage, consumption points connected to operate as a small grid as shown in Figure 1 and have proven to be reliable with transmitting low to medium voltage electricity generated by renewable energy sources such as solar PV, wind, etc.[5].

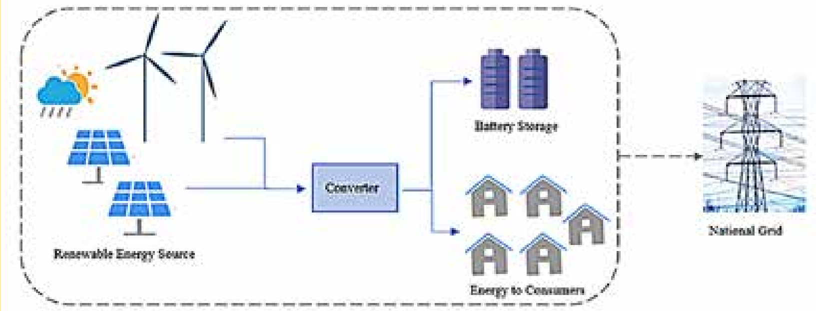

FIGURE 1: Typical Micro-grid from Renewable Energy Sources

According to ESMAP, there are '47 million people connected to 19,000 mini-grids, mostly hydro and diesel-powered, at an investment cost of $28 billion. Plus: 7,500 mini-grids planned, mostly in Africa, mostly solar-hybrid, connecting more than 27 million people[6]. Clean energy-powered microgrids can have proven to have a generation capacity from 10 kilowatts (kW) to over 100 megawatts (MW)[7].

Some examples of successful large-scale applications of the microgrid include the New York Affordable Housing Microgrid project, the powering the large commuter rail system of New Jersey as well as for strategic reasons, the powering the domestic military base for the United States of America[8].

Microgrids can act in alleviating strain on the national grid and compensate where there is a fault in the national grid which may result in a blackout or load shedding. The microgrid can be disconnected to continue operating without being affected by the fault on the national grid. Modern microgrids have unique characteristics in that they rely on clean energy generation sources and storage systems. They reduce energy consumption because of the level of controls afforded to a smaller network, as well as provide system security and flexibility[9].

3 A CASE FOR MICROGRIDS

South Africa which relies heavily on coal for energy generation, is currently faced with an energy crisis and rising cost of electricity, as the grid is under huge strain due to aging infrastructure, periodic breakdowns, lack of maintenance, and increased demand from a growing population. This has resulted in regular, rolling power blackouts (power outages), leaving parts of the country and municipalities in darkness regularly.

The energy crises have had a huge impact on the economy and have reduced the GDP growth by roughly 0.30% contributing to the further contraction of a struggling economy[10]. In addition, Municipalities have been crippled by the lack of energy supply to an area. This lack of stable electricity has had an impact on water purification and waste-water management.

Microgrids have achieved the fastest gains worldwide with deployment and have recently seen a rapid rise in popularity, by using 19 000 microgrids to provide electricity to 47 million people[11]. They are diverse in nature and size and can utilize fixed or variable speed wind turbines, solar panels, microturbines, various types of fuel cells, small hydro, and storage depending upon the load, location, and resources[12]. Microgrids have been in use in rural and remote areas for the past 20 years[13].

A microgrid very simply uses renewable energy sources for energy generation that can either be obtained via solar photovoltaic systems, wind turbines, hydropower, or biomass, or some hybrid of these which incorporates diesel. The choice of components of a microgrid (Figure 2) 'will depend on specific conditions related to location, energy source availability, density, and distribution of the houses to be served and electricity supply management[14]. The micro-grid is connected to the low to medium voltage distribution network allowing for the supply of reliable, quality electricity.

Microgrids make use of storage systems such as batteries to overcome variability and meet the demand for energy which occurs at clearly defined peaks to meet the electricity needs of the end consumer.

4 BATTERY STORAGE SYSTEMS

Energy storage which includes battery storage plays a critical function in a renewable energy microgrid in terms of making energy supply predictable and readily available on demand. Also, energy storage enhances the microgrid as well as providing a solution for operational issues such as power quality, dynamic stability, reliability, and controllability caused by renewable energy generators[15]. Further, it improves microgrid stability by acting as a buffer against renewable intermittency and mitigates load uncertainties. Therefore, for optimal performance of the overall microgrid, the most suitable battery storage system selected must be 'based on economical, technical, and environmental considerations[16].

Energy storage has gained vast attention especially with the increased deployment of renewable energy generation and is recognized as an essential component in clean energy supply and meeting carbon emission reduction targets. Also, energy storage has improved energy access and security, provide backup storage for peak times in the national grid thereby bringing stability to the grid.

Battery storage in microgrids currently exists in various systems and degrees of complexity depending on the microgrid application. These battery storage systems include Redox Flow batteries, Lead-acid, Li-ion, Nickel-Cadmium batteries, and Nickel Metal Hydride

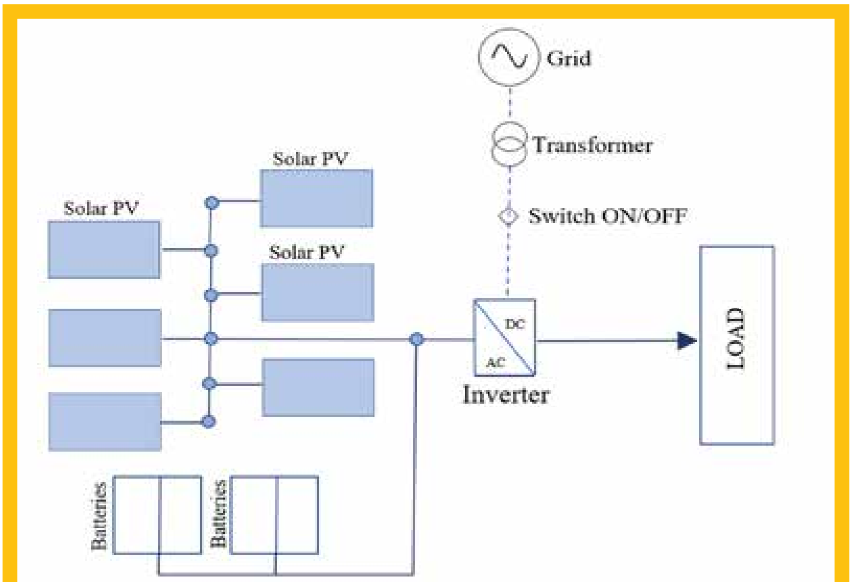

FIGURE 2: Typical Microgrid Components

batteries, with the Li-ion and Lead-acid battery having preference in the rural microgrid market. Research on energy demand at a household level has shown that energy consumption varies per user and as well as per household and that this variability introduces its challenges to understanding the dynamics of energy demand[17]. Therefore, the energy generated must be temporarily stored to cater to the variability of demand.

For the past two recent decades, battery storage has continued to grow taking strength from a growing wind and solar energy market. Storage has the potential to e deployment of renewable energy generation and is thus considered a key technology and key driver.

4.1 Battery Storage Systems in Micro-grids

Battery storage plays a significant role in micro-grid applications as well as off-grid application. The rise in demand for battery storage globally is due to the increase in deployment of distributed power. This is being driven by the reduction of overdependence on national power grids and another key driver is the implementation structural reform by governments such as the European Union, the United States of America and Japan issuing "relevant policies and support plans to promote the development of Microgrid projects" and also, China's Thirteenth Five Year Plan for Electricity Development incorporating Microgrids[18].

FIGURE 3: 10 MW Battery Installation, Texas US[19]

Battery storage systems is one of the most expensive items in the microgrid. And where financial resources are limited, cost plays a crucial role in deciding on the extent and scale of the microgrid installation. Therefore, to justify the investment and to obtain a return on the investment, it is essential to achieve optimum performance of the Battery Storage System (BSS) and indeed the microgrid, by minimizing any losses. Optimization requires an understanding of the behaviour of batteries under various operating conditions and exposure to variable temperatures as well as charging-discharging etc.[20], as these inform battery performance.

Typically, a microgrid comprises several battery storage units with each unit having a varying degree of output capacity depending on factors such as initial State of Charge (SOC), efficiency, aging (i.e., number of cycles), and temperature conditions [16]. Ideally, the BSS should function as a well-synchronized system. To be able to manage any differences between the various batteries, and to ensure stability, a Battery Management System (BMS) is necessary. Battery Management Systems can be basic whereby they are applied in simple microgrids or smarter BMS can be applied to large complex microgrids as they operate in real-time and control vital functions of the BSS[21]. The BMS provides information on the 'monitoring of temperatures, voltages, and currents, maintenance scheduling, battery performance optimization, failure prediction and/or prevention as well as battery data collection/analysis'[21].

The function of battery optimisation must be considered as part of the overall microgrid design right from the onset to achieve maximum results from the storage system as well as from the overall ability of the microgrid to respond adequately to the energy demand.

For microgrid applications, there are some quick wins in terms of achieving optimisation of the battery. These include:

- on the ground optimizing incorporating the correct positioning of batteries, adequate ventilation, or insulation of the battery storage facility,
- fully trained resources to carry out repairs and maintenance,
- The quality and technology of the energy storage systems must be carefully selected and designed.

Studies shows battery storage worldwide growing from 2 gigawatts (GW) in 2017 to around 175 GW in 2030 and that costs will continue to fall as technology improves to provide longer lifetimes, increased numbers of cycles, and improved overall storage performance[22].

5 MICRO-GRID IN MUNICIPAL APPLICATIONS

Micro-grids offer autonomy from the main transmission grid. Because the Municipality will be involved in the design of the electrical infrastructure from the location and size of the micro-grid grid to the provision of the connection to the end-user. Also, any additional power that is not used can be pushed into the transmission grid and offset as savings to the municipality.

Some Municipalities bulk buy electricity from Eskom but are faced with revenue collection backlog leading to major financial losses for the Municipality. By adding a prepaid system at the consumer point, the Municipality obtains ownership of the electrical infrastructure and thus more control on how electricity is generated, distributed, and consumed.

With the prevalence of load shedding in South Africa, micro-grids, provide resilience against power outages or threats of destruction.

Micro-grids have proven to provide reliable and secure electricity to both rural and urban communities. And examples can be seen through applications in countries such as Indonesia, China, United States and in Africa.

FIGURE 4: St. Cloud Wastewater Treatment Facility, Minnesota, USA[23]

Municipalities can deploy micro-grids to the following applications.

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TABLE 1: Micro-grid Applications	
Municipal Infrastructure	A grid-connected micro-grid network that provides power to municipal buildings that are nearby.
Urban Electrification	Micro-grids with battery storage give municipalities greater control on energy usage and thus cost savings.
Rural Electrification	As seen in rural parts of India, off-grid micro-grids have been successfully deployed. These micro-grids are managed by the locals who trade electricity.
Waste-Water Treatment Plants and Water Purification and Reticulation	These are severely impacted by load-shedding. A micro-grid is a cleaner and cheaper solution for generating energy for use only at the waste-water treatment plant. See Figure 2.
Back-Up Power to City or Town	Large-scale batteries are used worldwide to provide backup power to towns and parts of a city's operations.
Electric Bus Fleet	There is a shift worldwide for cities switching to electric buses as they are cleaner and cheaper to run. These buses can be charged by micro-grids.

6 CASE STUDIES

6.1 Electricity for African Communities: Tanzania

According to various literature, just under 40% of the population of Tanzania had access to electricity in 2017. Meaning that most of the population lived in underdeveloped areas requiring access to consistent, reliable electricity.

As a result, microgrids have become a key technology for deployment, and Tanzania is recognized as a regional leader in micro-grid deployment with over 100 micro-grid systems serving businesses and local communities[24]. Further[24], the adoption of micro-grid policy and framework in 2008 lead to the doubling of the number of micro-grids being deployed.

Micro-grids are either government-owned or owned by private developers selling electricity back into the national grid through power purchase agreements or sold directly to end consumers. Whilst Tanzania has been successful in the deployment of micro-grids, there have been challenges, one of which has been funding.

6.2 Power for Residents: Netherlands[25]

The first micro-grid installation in the Netherlands was at a holiday park in Bronsbergen, approximately 100 km west of Amsterdam. A micro-grid was built to provide 208 homes with solar-generated power of 315 kW. Micro-grid has 700 kWh energy storage to increase power quality and stability[26]. The micro-grid is connected to the national grid via a 10 kV line.

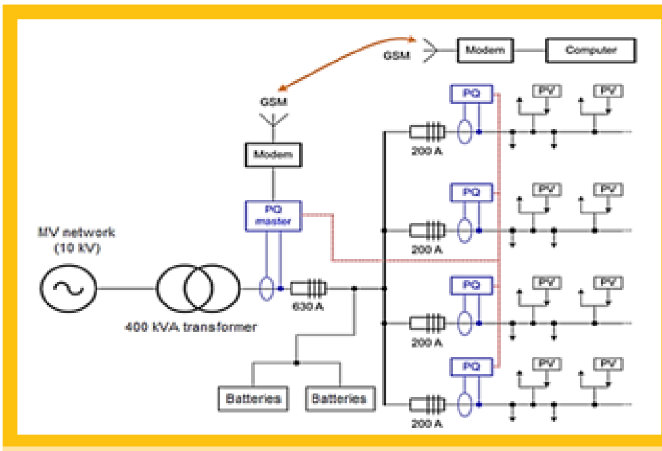

FIGURE 5: Residential Microgrid in Bronsbergen, Nederlands[25]

FIGURE 6: Residential Microgrid in Bronsbergen, Nederlands[25]

This pilot project highlighted the technical challenges of connecting to the national grid.

6.3 Clean Energy for Wastewater Treatment: California[27]

A proposed micro-grid project is underway for the wastewater facilities in McKinleyville Community Services District in California incorporating the existing diesel generators with solar PV and battery storage. The McKinleyville Community Services District (MCSD) serves 16 900 residents and provides key services such as providing clean water reticulation, wastewater processing, maintenance of parks, etc. The outcome of the project is a wastewater treatment facility that has a target of net-zero emissions. In addition, the micro-grid will provide the facility with energy resilience.

FIGURE 7: Hiller Park Wastewater Treatment Plant[27]

7 CONCLUSIONS

Ensuring a continuous reliable source of electricity is critical for the overall functioning and growth of a Municipality. Power supply has a direct impact on service delivery. And the lack of power for water reticulation or wastewater treatment can have catastrophic implications for a Municipality.

Microgrids are an attractive option for Municipalities for the many reasons listed in this document. In addition, they give municipalities greater control to improve energy efficiencies as well as options on how to deal with revenue collection due to their modularity and scalability.

The evaluation of microgrids does involve a significant degree of uncertainty and complexity which relates to two factors i.e. the design of the microgrid which considers, the scale of the energy source, the storage system, and the installation and maintenance of the system, as well as including the long-term operation of the microgrid which involves the dispatch algorithms for storage and generation which are all interdependent[28]. Battery Storage is an essential part of the overall micro-grid system. The battery contributes to 20-30% of the overall capital cost over the lifespan of the microgrid, and therefore, understanding how the battery operates and optimizing its output and lifespan makes for a sustainable business case for investment in the microgrid.

There are many examples of successful deployment of micro-grids including opportunities for the lesson learned from which Municipalities can draw information and design a system that is fit for purpose. Funding mechanisms are available to support the deployment of micro-grids in Africa, However, the financial modelling must make a sound business case for lenders and investors.

The IRP 2019 identifies distributed generation and a key mechanism for bringing electricity to those areas that don't have electricity and it goes on to make provision for Municipalities in South Africa to investigate the deployment of micro-grid technology to bring electricity to the areas in which serve. New legislation in South Africa has now been published which allows for the generation of energy of up to 100 MW without license requirements provides an ideal opportunity for Municipalities to investigate developing micro-grids in their respective regions.

Ultimately in municipal deployment, the main aim is to produce clean electricity at the lowest cost through optimization.

8 RECOMMENDATIONS

There are many case studies worldwide of the successful deployment of micro-grids to meet municipal needs. They can assist municipalities to become energy generators for their consumption thus giving greater control.

Micro-grids could be the catalyst that can lead to the economic recovery and growth of a municipality. And therefore, should be considered in any strategic development plans for a municipality.

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PAPER 17

Leliefontein Pump-As-Turbine Station – Utilising Hydropower Potential Within the Drakenstein Muncipal Water Network: A Case Study

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ABSTRACT

The Leliefontein Pump-As-Turbine (PAT) Station is deemed to be a first of its kind in South Africa. Originally intended as a booster station to supply water to Wellington during peak summer, Leliefontein has evolved into a practical, easily maintainable and exciting green energy solution which can be utilised by various municipalities.

As per its original intention, the booster pump station, along with the local reservoirs, would operate as a back-up water supply to Wellington when the Wemmershoek water treatment works supply is unavailable during planned and unplanned maintenance. This occurs for about two weeks per year, which meant the booster pump station's mechanical equipment would be severely underutilised, leading to premature equipment failure. To address this problem of underutilisation, the design engineers, together with the Drakenstein Municipality, identified Leliefontein's location within the municipality's bulk water network as a prime opportunity for a productive mini hydropower station. This led to the idea to convert the booster pump station to a Pump-As-Turbine station, an installation with the dual functionality of pumping water and generating electricity. While using pumps as turbines is not a new technology, Leliefontein uses the same set of pumps to pump water and generate electricity, which ensures that the PATs are active for most of the year, solving the problem of underutilisation. This dual functionality is accomplished by reversing flow through the pumps and controlling the speed of the PATs to generate electricity at the available flow rates. This is achieved through the innovative application of active front end variable speed drives to lower the speed of the PATs, actuated valves, a centralised control system, off-the-shelf pumps, and some creative pipe work.

The estimated annual generation for Leliefontein is 320MWh, depending on water demand and load-shedding, translating to 44 days of free pumping for Drakenstein Municipality. The power generated at Leliefontein is distributed into the municipality's electrical grid, offsetting the power consumed during pumping with the remaining balance of the generated power reducing the Municipality's electrical consumption bill. The municipality can utilise the savings, due to these reduced power purchase costs, to reinvest into the community through avenues such as service delivery.

Leliefontein is a collaboration between a municipality, design consultants and a contracting team spread through the Civil, Mechanical and Electrical engineering disciplines and serves as an example of how municipalities can use low cost, off-the-shelf equipment like centrifugal pumps and induction motors to generate clean power using potential energy in their existing infrastructure. The knowledge gained from Leliefontein also allows the adjustment of a PAT's characteristic curve to ensure it is able to match the available hydropower potential of a specific site.

INTRODUCTION

Small-scale hydroelectric power is a field of growing interest in the South African Municipal community. With the drive for clean energy being at its peak in the country and projects including in-line turbines within water pipes and Pump-As-Turbine (PAT) installations gaining traction, particularly in the northern regions of South Africa, new and existing municipal networks are still an underutilised resource, rich in potential renewable energy [Van Vuuren et al. 2013]. For small-scale hydroelectric power to be feasible, low cost hydraulic and electrical

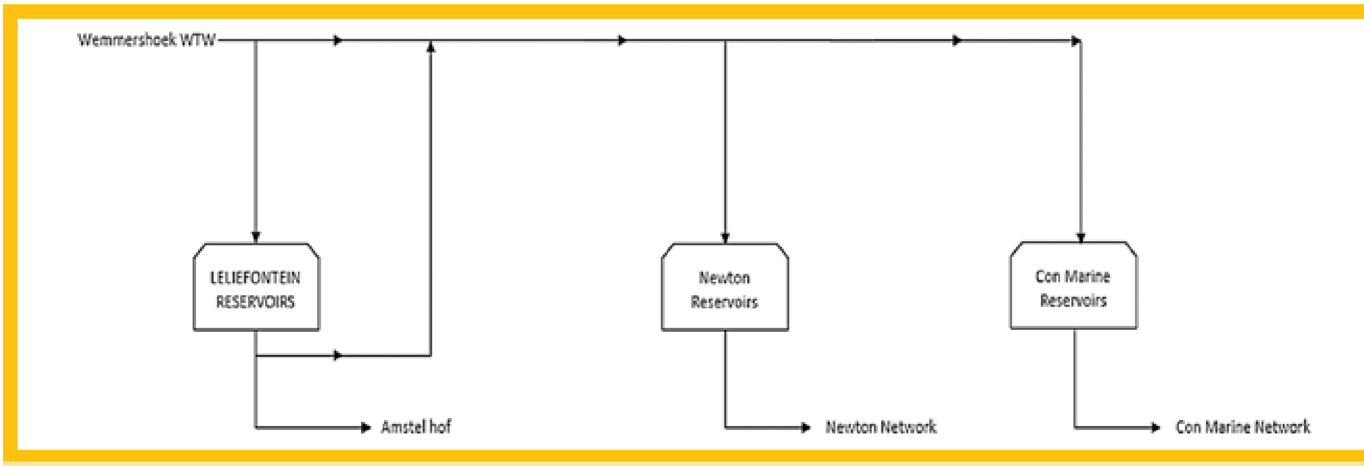

FIGURE 1: Existing Network Under Gravity Flow

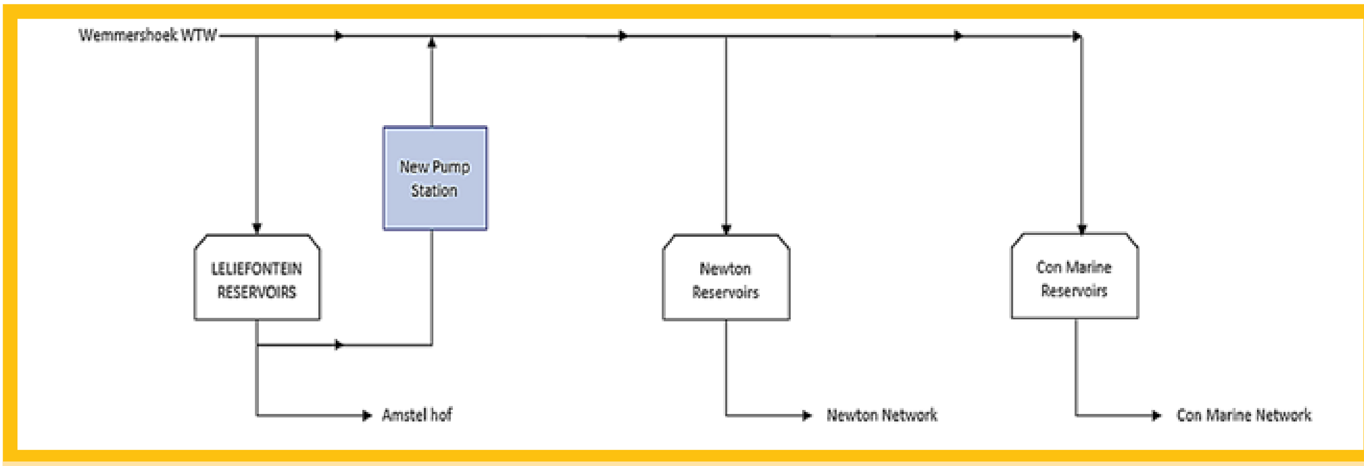

FIGURE 2: New Leliefontein Booster Pump Station Addition to Existing Gravity Network

equipment is required [Carravetta et al, 2013]. A limiting factor thus far for small-scale hydro has been the cost of turbines, where PATs would be a more successful solution [Agarwal, 2012]. This paper looks at a PAT station installed for the Drakenstein Municiplity in the Western Cape. This installation is considered a first in South Africa due to its unique challenges and solutions, which have resulted in a productive pumping and generation station. The purpose of the project and project conditions and criteria/requirements leading to a PAT solution being selected will be discussed.

PURPOSE OF PROJECT

Wellington is home to a growing industrial and agricultural sector which is highly dependent on a reliable water supply. Wemmershoek Water Treatment Works (WTW) (owned and operated by the City of Cape Town) supplies water to the Leliefontein Bulk Reservoir Complex (LBRC) via a 19 km gravity pipeline and to Wellington's Con Marine and Newton zone reservoirs, via a further 11 km pipeline, at a maximum capacity of 19 Mℓ/d. Figure 1 shows a schematic representation of the system.

The supply capacity to Wellington is deemed sufficient to meet the summer peak demand of Wellington up until the year 2034. However, there are periods when the supply from Wemmershoek is interrupted, due to planned and or unplanned maintenance. These interruptions in water supply are expected to occur for a period of 1 – 2 weeks in the year. When this occurs, water from LBRC can gravitate towards Wellington at a maximum capacity of 11.2 Mℓ/d. This capacity is deemed sufficient to meet Wellington's lower winter demand for the foreseeable future, but

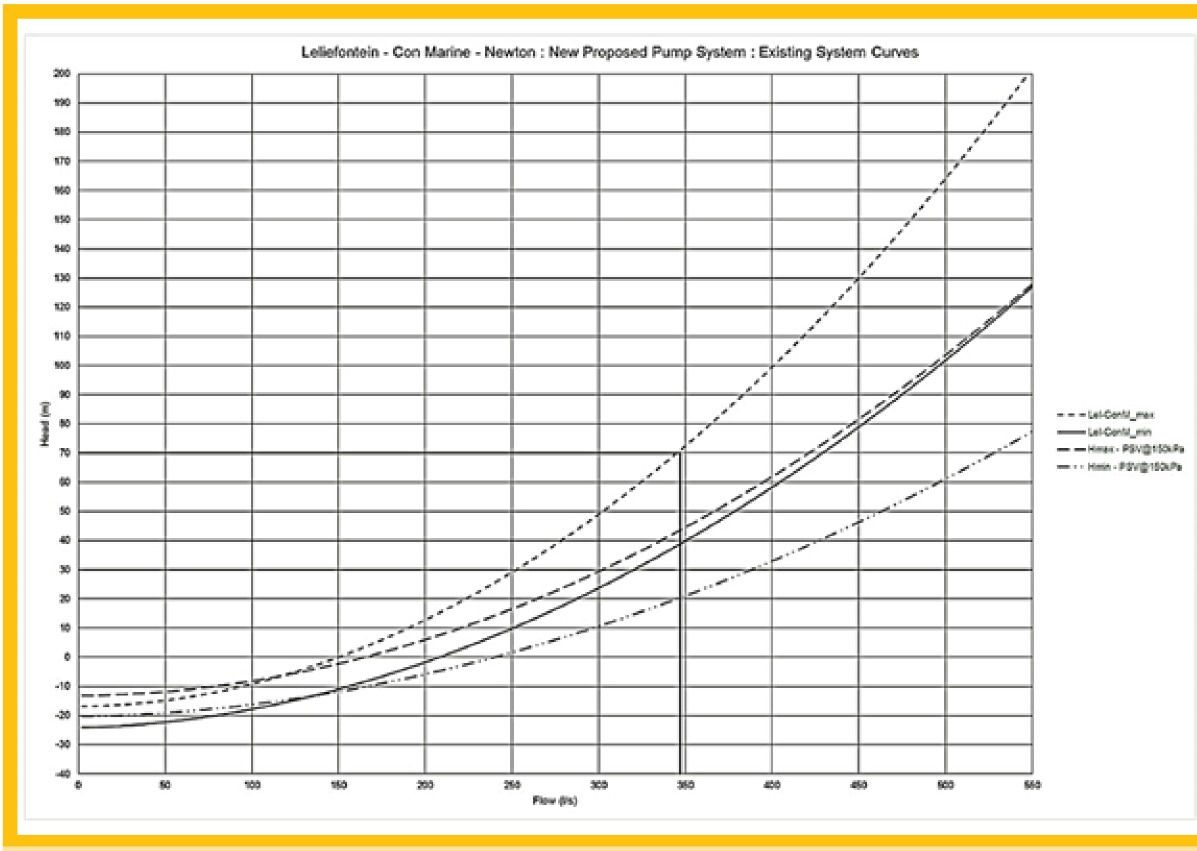

FIGURE 3: Leliefontein Pump Station System Curves - Initial System

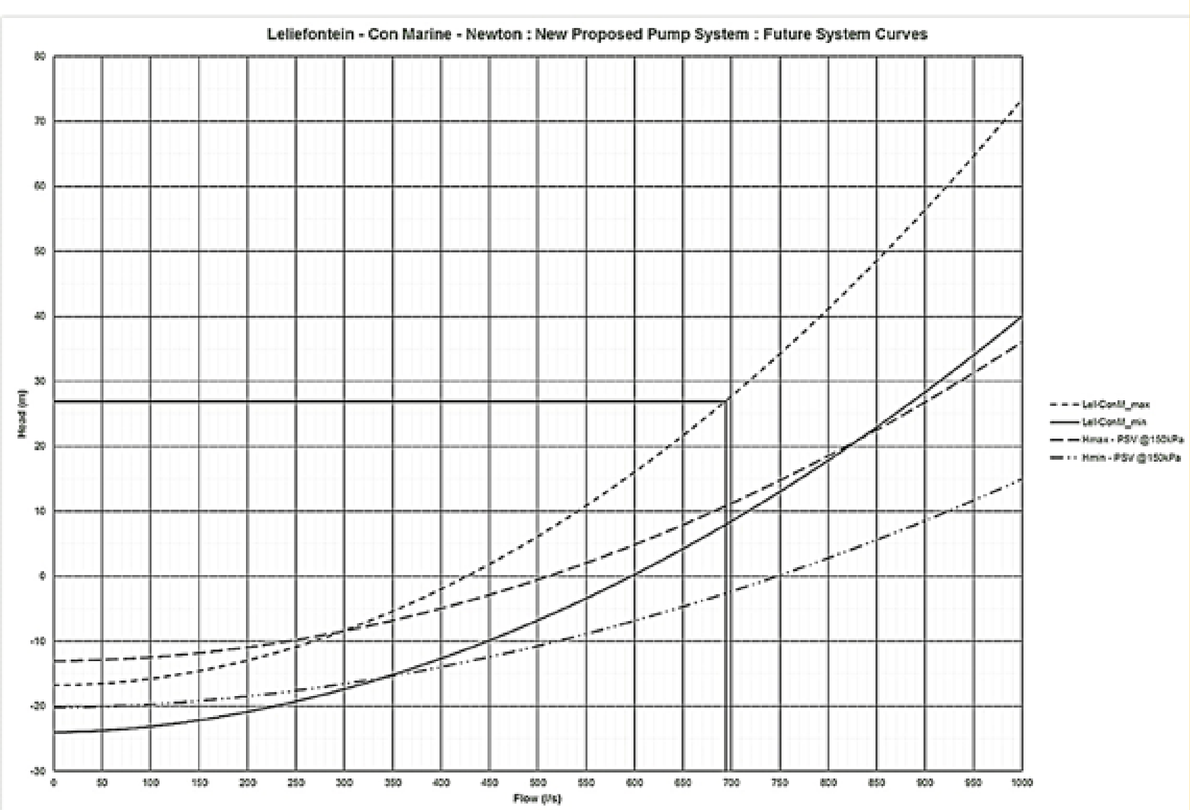

FIGURE 4: Leliefontein Pump Station System Curves - Future System

if this would occur during summer, when the demand is at it's highest, there is high probability that Wellington would suffer water shortages.

Drakenstein Municipality initiated a project to augment the supply of potable water to Wellington during the WTWs down periods during summer, to ensure a reliable supply is maintained to Wellington. A pump station was identified as the most suitable method to increase the conveyance capacity to 30 Mℓ/d, with the potential for a further increase to 60 Mℓ/d capacity possible by upgrading the pipeline from Leliefontein to Con Marine reservoir by adding a new DN 700 parallel gravity pipeline.

IDENTIFYING THE SITE LOCATION

The evaluation of the optimal pump station location took cognisance of a range of factors, including security of the installation, the impact the operation of the pumps would have on users along the pipeline, as well as hydropower potential. Based on the investigations and results, the LBRC was identified as the most appropriate location within the network for the new Leliefontein pump station, as shown in Figure 2.

PUMP SELECTION

The guaranteed duty point of the pump station for the initial capacity of 30 Mℓ/d was 347 ℓ/s at a differential head of 70 m, pumping into the 11 km DN500/450 Asbestos Cement (AC) pipeline towards the Con Marine and Newton reservoirs. The pump selection and pump control design had to consider the various operating scenarios under which this system should be able to operate, due to it delivering water to either Con Marine or Newton reservoirs, or both at the same time, depending on the level in the reservoirs. The system curves for the various scenarios for the initial system is depicted in Figure 3.

The pump selection for the initial duty took into consideration the final design duty of 694 ℓ/s for the capacity of 60 Mℓ/d, at a differential head of 27 m, pumping into the 11 km DN500/DN450 with a new DN700 pipe installed parallel to the existing pipeline. As with the initial system, the future system would also have different operational scenarios, the system curves of which are depicted in Figure 4.

The selection of the type and number of duty pumps was to ensure that the same pumps are used for the initial and future pump duty, removing the need to make changes to the pump station pipework or oversize the civil structure to accommodate future equipment. Due to the varying head requirements between the initial (70 m differential pressure) and future (27 m differential pressure), finding a fixed speed pump selection that will operate efficiently over the entire range of the system's flow-rates, was impossible. The only feasible way to prevent changing of pumps, suitable to operate under the initial conditions and under the future conditions once the pipeline system is upgraded, was to incorporate the use of variable speed drives (VSD) in the pump control system. This would allow the control system to adjust the pump's rotational speed and thus it's performance curve to meet the different system duties. The optimum pump selection to meet the criteria for the pumping operation of the station was to install two duty pumps for the initial duty point, with one standby, and to add another pump for the future duty point.

UTILISING THE HYDROPOWER POTENTIAL AT LBRC TO SOLVE THE UNDER-UTILISATION OF THE LELIEFONTEIN PUMP STATION

With the booster pump station together with the LBRC expected to operate for two weeks in a year as a back-up water supply to Wellington when the Wemmershoek WTW and/or the supply pipeline are undergoing maintenance, the pumps installed at the Leliefontein pump station were at risk of being severely underutilised. This underutilisation increased the probability of premature failure of the mechanical equipment, putting Wellington's water supply at risk, should the pumps fail to run when required.

As part of the investigation into the location of the pump station, discussed earlier in this paper, it was identified that there is hydropower potential at the LBRC, due to the Wemmershoek supply pipeline operating under gravitational energy. To confirm the feasibility of utilising this hydropower, the quantum of the available hydropower potential at Leliefontein was calculated. It was found that at the average inflow rate to LBRC over a 30-year period, estimated at 31 Mℓ/d, the residual head within the Wemmershoek supply pipeline at LBRC was calculated to be 19 m. This equates to a total hydropower potential of 46.8 kW, at an assumed generator efficiency of 70%. It was evaluated whether it would be feasible to augment the available hydropower using fit-for-purpose turbines, such as Francis turbine or a PAT, which are both reaction water turbines. The reason reaction water turbines were considered was that these turbines can operate with a flooded draft tube, which means the turbine can be installed below the tail race water level, which would allow them to also be used as pumps. Due to the topography of the Leliefontein reservoir site, the pumps would have to be installed below ground to ensure sufficient suction head.

The major disadvantage of PATs versus turbines, according to [Williams, 1996], is that the characteristic curves in turbine modes are not supplied with the pump, which makes it harder to select the appropriate PAT for your application. Other differences between turbines and PATs are summarised in Table 1 below.

TABLE 1: Differences between turbines and PAT [Teuteberg, 2010]

	Turbine	PAT
Advantages	Well-documented	Cost-efficient
	Best efficiency	Widely available in South Africa and abroad
	Variable guide vanes for varying flow	Simple design and easy maintenance
Disadvantages	Expensive	Difficult to find correct turbine operation curves
	Very few South African suppliers	Lower efficiency
	Complex design may require expert maintenance	No variable guide vanes for varying flow
		Not as well-documented as turbines

Budget quotes were obtained for a suitable Francis turbine and PAT to be used as a dedicated turbine for the LBRC site. The budget costs from different suppliers for a Francis turbine varied between R5 500 000 and R6 400 000, whereas for a PAT the budget costs ranged between R150 000 to R200 000. Although a Francis turbine is able to reach mechanical efficiencies in excess of 90%, whereas PAT efficiency is around 80%, due the low hydropower potential of the site, the gain in increased power generated is insufficient to reimburse the owner for the much higher capital cost of the Francis turbine. The conclusion was that the quantum of hydropower potential isn't significant enough to consider the installation of a dedicated turbine-installation at LBRC. However, the Drakenstein Municipality, together with the design engineers, considered that if it would be possible to use the proposed Leliefontein pump station equipment, to generate electricity using the hydropower potential at LBRC, i.e. use the same pumps to pump water and generate electricity, this would have a number of positive impacts on the project, such as:

- It would solve the problem of under-utilisation of the Leliefontein pump station,
- It would allow the Drakenstein Municipality to augment the available hydropower at LBRC at a reduced capital investment compared to a dedicated turbine installation,
- The power generated at the LBRC can be off-set against the power that the Drakenstein Municipality purchase from the national energy provider,
- It would reduce the carbon footprint of the pump station, when operating as a pump station, and
- It would not introduce complexities to the Municipality's maintenance operations as all equipment would be as per the pump station design, which they are familiar with.

CONVERSION OF DESIGN FROM PUMP STATION TO PUMP-AS-TURBINE STATION

A multidisciplinary design team, comprising of civil, mechanical and electrical engineers, collaborated to design an installation never done before in South Africa. The LBRC receives approximately 73% of the total volume of water conveyed through the Wemmershoek pipeline, with the balance conveyed to the Wellington reservoirs. As the Leliefontein reservoirs are located closer to Wemmershoek Water Treatment Works, the flowrate into the Leliefontein reservoirs is controlled by means of two electric-actuated sleeve valves. The residual head available at the Leliefontein reservoirs is dissipated across the sleeve valves.

A PAT is essentially a centrifugal pump which can be used as a turbine. The most efficient way for a PAT to operate is by reversing the direction of water flow through the volute. In addition to reversing the direction of water flow, the rotational direction of the pump shaft is also reversed, thus a PAT's shaft rotates in the opposite direction as to that of a similar pump.

The Municipality gave approval to proceed with the PAT station design, with the condition of designing an efficient pump station rather than efficient generation station, since pumping is the primary purpose of the project. The pumps were therefore sized to be efficient pumps rather than efficient generators.

For an induction machine to generate power, the rotor needs to be rotating at speeds greater than the synchronous speed of the machine, which in this case is over 1 500 rpm for a 4-pole motor, at a frequency of 50 Hz. It was found that there is insufficient hydropower potential available at the LBRC to push the rotor of the induction machines of the selected pumps above synchronous speed. Figure 5, shows the selected Leliefontein pump's turbine curves, with flow-rate in liters per second plotted on the horizontal axis and differential pressure across the turbine in meters plotted on the vertical axis. The black line curving upwards with increasing flow-rate is the turbine generating curve. The black lines, curving slightly downwards with increasing flow-rate is the available residual head from the Wemmershoek system. For the selected PAT to be able to generate power, the two lines should intersect between the "Qmin" and "Qmax" marks on the turbine generating curve. It is clear that with the PAT's rotational speed at 1 520 rpm (turbine/generation speed), this will not occur. This was a significant stumbling block for the design team.

The project team, in consultation with the PAT suppliers, used their knowledge of pump affinity laws and applied it to the turbine curve of the selected PAT. Through reducing the rotational speed at which the turbine

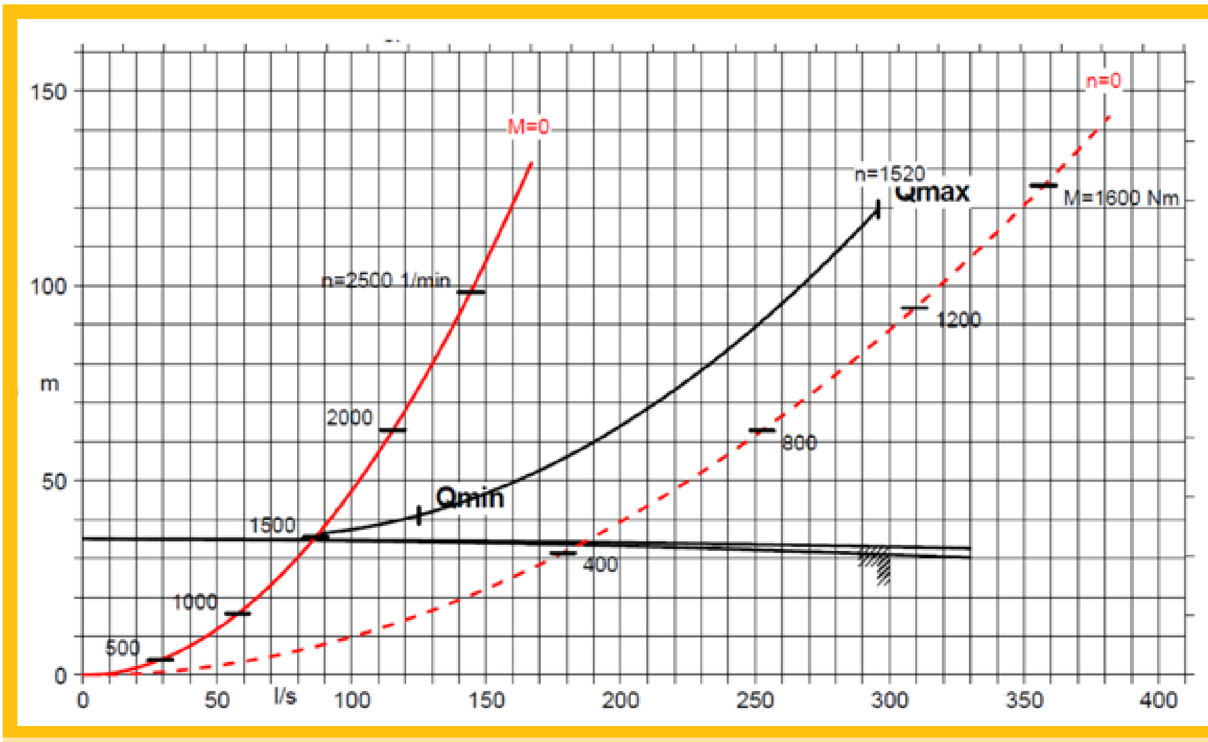

FIGURE 5: Leliefontein PAT turbine curves at 1520 rpm (Source: KSB South Africa)

should generate power, the properties of the turbine generating curve changes, as shown in Figure 6. By reducing the turbine's rotational speed from 1 520 to 920 rpm, which is just above the synchronous speed of a 6-pole induction machine at 50 Hz grid frequency, the turbine generating curve and the residual head curve intersects within the operational range of the turbine. Therefore, reducing the rotational speed of the PAT would allow the system to generate electrical power at the available residual pressure.

For a dedicated turbine-installation, i.e. having a dedicated turbine set and a dedicated pumping set, the adjustment of the turbine's characterstic curve, by changing it's rotational speed, would allow the engineer to ensure the turbine is operating at it's peak generating efficiency. To achieve this, the simplest method would be to use a 6-pole induction machine for the turbines which would need to rotate at 920 rpm to generate electricity. However, as the intention was to also use the PAT as a pump and a turbine, reducing the rotational speed in pump mode would have caused the selected pump's characteristic curve to also be adjusted. This would result in the pump not being able to meet the required conveyance capacity of 30 Mℓ/d and the installation not meeting the Municipality's condition of having an efficient pumping station. Thus, a solution had to be found to allow the PAT to operate at a rotational speed of 920 rpm (generation speed) when in turbine-mode and at 1 495 rpm (pumping speed) when in pump-mode. It should also be considered that the direction of rotation of the PAT is different between the Pump-As-Turbine- and pump-mode, thus this would require the phases of the inducation machines to be changed between the two modes. A possible solution to this problem would have been to fit two induction electrical motors to the centrifugal pump, with the one motor being a four pole motor, which would be used in pump mode and the other motor being a six pole motor, which would only be used in turbine mode. The 4-pole induction machines phases would be orientated for clockwise rotation and the phases for the 6-pole induction machine rotated for anticlockwise rotation.

Although attaching two different electrical drives to horizontal split-casing or horizontal multi-stage pumps is relatively easy, the selected pump for this application was of end-suction configuration. Attaching two different electrical induction drives to an end-suction pump, would have required significant alteration to one of the electrical motors. This would also have resulted in an increase in footprint of the pump station building to allow space for the additional electrical motor.

The solution for this problem was to change the single quadrant variable speed drives, required for pumping at varying flow and pump head conditions, to active front end variable speed drives (AFE VSDs). The AFE drives allowed for four quadrant operation, which meant they could change the speed of the PATs in pump and generation modes as well as allow discharge of electrical power into the municipal grid at the required power quality. It would also be possible to easily change the shaft rotation, depending on whether the unit is in turbine- or pump mode, through the AFE settings.

To allow the Leliefontein PAT station to operate as either a pump station or a power generation station, some modifications were also required to the pipeline configuration at the LBRC. As noted earlier, for a PAT to operate as efficiently as possible both the shaft rotational direction, as well as the flow direction, through the PAT, should be reversed.

In summary, the conversion of the pump station design to a PAT station required the following alterations:

- Addition of high-pressure turbine supply pipeline (DN630 HDPE) from the Wemmershoek-Leliefontein pipeline up to the pump delivery pipeline valve chamber.
- Addition of turbine return pipeline (DN630 HDPE) to the Leliefontein Reservoirs Inlet Valve Chamber.
- Converting the pumps to PATs, which required locking screws on the pump impellers to allow reverse rotation.
- Converting the single quadrant variable speed drives to active front-end drives to allow the conversion of the 30 Hz generated power to 50 Hz grid power and bi-directional flow of electricity.

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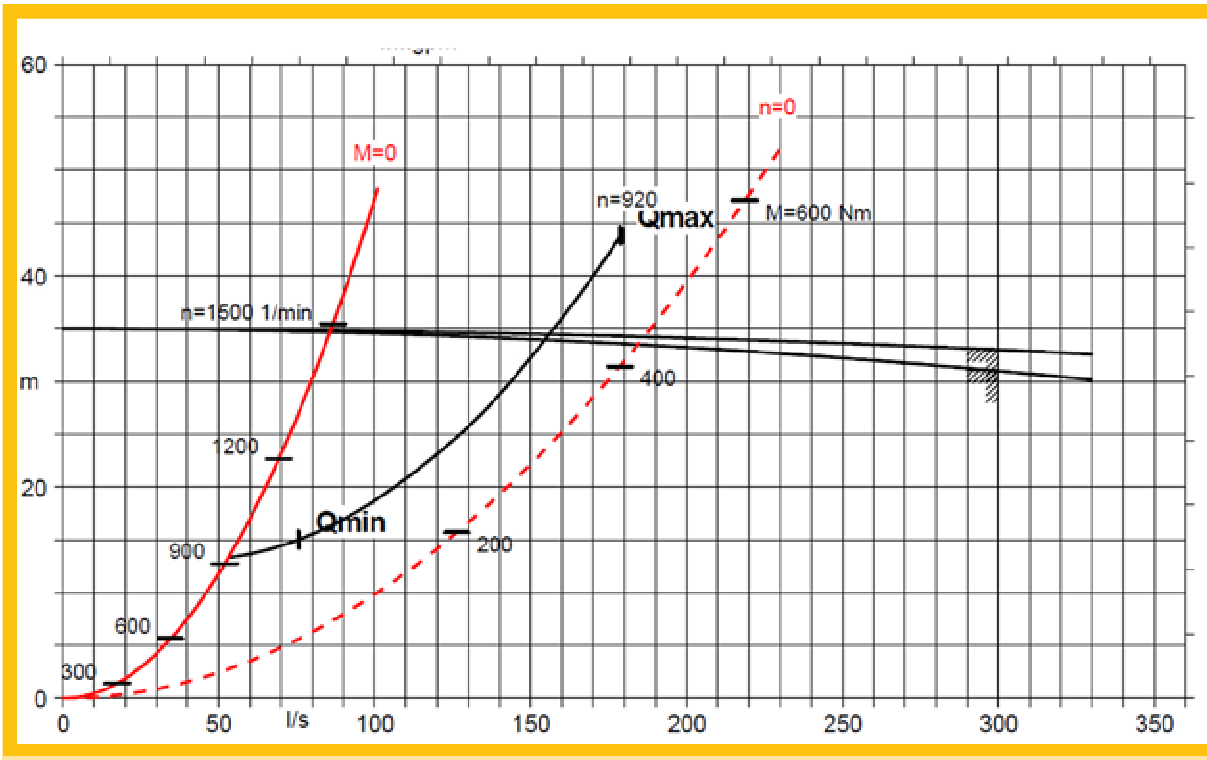

FIGURE 6: Leliefontein PAT turbine curves at 920 rpm (Source: KSB South Africa)

- Converting the non-return valves located on the pump discharge pipework to actuated ball valves, to allow flow in two directions through the PAT.
- Addition of power meter to measure the power generated and supplied to the grid and bi-directional electrical protection.

PUMP-AS-TURBINE STATION PERFORMANCE

The PAT station has been in operation from June 2018 and has to date generated 271 236 MWh of renewable energy and consumed 53 577 MWh during pumping (Figure 8), it has thus generated more than five times the energy required for pumping over this period.

If the station is continuously active, the estimated power generated at Leliefontein would result in a saving of R198 000 in power purchase costs for the Municipality per annum and the estimated maximum monthly power generated (2018 to 2041) is 42 400 kWh (enough to power 63 households), with an estimated total power generation (2018 to 2041) of 9.9 GWh.

Due to the fact that the PAT station utilises the mechanical equipment almost continuously throughout the year, the risk of premature failure of the mechanical components due to under-utilisation is significantly reduced. Using a SCADA and SCADA reporting software and dashboard, the Drakenstein Municipality is able to monitor the status, performance and efficiency of the installation, making the municipality more effective in scheduling preventative maintenance services.

FINANCIAL SUSTAINABILTY OVER THE LIFE CYCLE OF THE PROJECT

The conversion of the Leliefontein pump station into the Leliefontein PAT station increased the project's capital cost by about 10%, however through the hydropower generated from this installation, off-set against

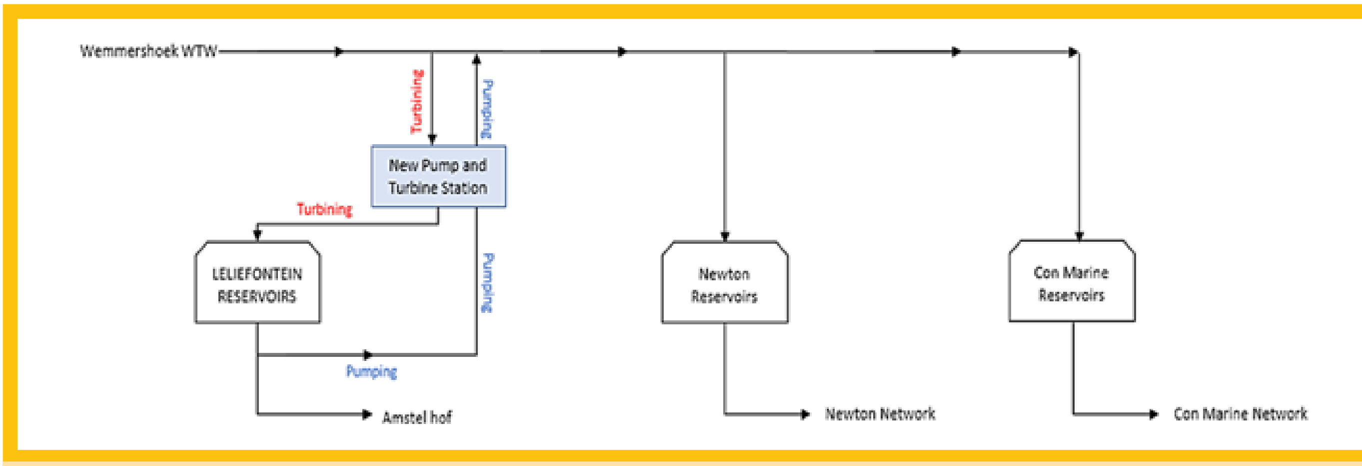

FIGURE 7: New Leliefontein Pump-As-Turbine Station addition to existing gravity network

FIGURE 8: Bi-directional power meter at Leliefontein PAT

FIGURE 9: Completed Leliefontein PAT station in foreground, with 36 Mℓ and 100 Mℓ reservoirs in background

FIGURE 10: Leliefontein PAT Motor Control Centre

the municipality's electricity bill from the national energy provider, the pay-back period for this conversion cost is estimated to be less than 10 years.

ENVIRONMENTAL AND SOCIAL IMPACT

The PAT station generates green hydro-electric power, which offsets the Municipality's use of electricity generated from coal-fired power stations. The generated power is estimated to result in a reduction in carbon emissions of 346 tons of CO_2 over a 23-year period (2018 to 2041).

By generating a portion of its own power through the Leliefontein PAT station, the Drakenstein Municipality's power purchase expenditure has reduced, making additional funding available for other infrastructure projects to the benefit of the Municipality's residents and local job creation.

An interesting fact is that the PAT station would only need to generate at peak generating capacity of 57 kW for six hours to offset the energy consumption of the pump station operating as a pump station for one hour, when pumping at 30 Mℓ/d capacity (300 kW energy consumed). With the station only expected to operate as a pumping station for about two weeks in a year, it will generate more power operating as a turbine/generation station than it will consume during the two weeks of pumping (refer to Figure 8), thus making this pump station carbon negative.

Furthermore, most of the equipment used was manufactured locally in the Western Cape or in South Africa, with minimal imported equipment required, also reducing the carbon footprint. Stainless steel was used where metal pipes were required. In using stainless steel pipes, the necessity to protect the pipes against corrosion, through inorganic epoxy paint systems was negated. The pump station structure was constructed from reinforced concrete, with infill face brick, which reduces the amount of maintenance required to maintain the structure.

CONCLUSION

The Leliefontein Pump-As-Turbine station is a true marriage between the civil, mechanical and electrical engineering disciplines, and serves as an example of how municipalities can use low cost, off-the-shelf equipment like centrifugal pumps and induction motors to generate clean power using potential energy in their existing infrastructure.

The successful PAT conversion is achieved through the innovative use of active front-end variable speed drives to lower the speed of the PATs to generate electricity at the available hydropower potential, a series of actuated valves and some creative pipework. The power generated at the station is fed back into the municipal grid, offsetting the power consumed during pumping. The PAT conversion cost an additional 10% more of the total contract value. The estimated average annual generation is 320 MWh, which is dependent on the water demand of the town of Paarl, which translates to 44 days of free pumping.

The power generated at Leliefontein can be offset against the power that the Drakenstein Municipality would have had to purchase from the electricity public utility. Not only does it reduce the Municipality's environmental impact through the consumption of renewable energy, but it also has a social impact because the client can invest the money saved by utilising the renewable free energy, back into the community through the delivery of services.

Through the innovative use of a simple off the shelf pump, the Municipality's supply capacity problem to Wellington was solved, clean electricity was generated, the Municipality's electrical bill was reduced and the mechanical equipment was kept active throughout the year without adding any complexity to the Municipality's maintenance procedures.

This project has been awarded the 2018 SAICE National Water Division Project Award and CESA AON 2019 Engineering Excellence Award for projects less than R50 million.

Although the Leliefontein PAT project is a unique solution to a client's problem, what was learned through this project could be applied to other projects, where a client wants to augment hydropower potential.

FIGURE 11: Leliefontein Pump-As-Turbines installed, with space for future unit in background

Some of the key points that would positively influence this technology being applied elsewhere are:

- Utilising PAT technology is feasible to augment sites within a utility owner's water network, even if the site's hydropower potential is deemed too low for dedicated turbine installations.
- As PATs are able to use mass-produced pump designs, the utility owner's maintenance staff will be able to succesfully maintain PATs.
- Adjusting the speed of a PAT allows that one selected PAT-model, could be used at different sites with different hydropower potential. This would reduce the maintenance complexity of the system. As the speed reduction would be fixed for each hydropower site within the municipality's network, this speed adjustment can be achieved through a gearbox or belt and pulley system.

RECOMMENDATIONS

South African municipalities jointly hold a substantial amount of hydropower potential in their existing infrastructure. With the country facing power shortages through supply from conventional coal fired power stations, renewable energy is an environmentally responsible answer to increase power into the national grid or to use in standalone/islanded infrastructures, reducing pressure on the grid. Municipalities should actively evaluate their networks to identify areas to exploit hydropower potential in their existing infrastructures or new projects. Utilising familiar equipment, such as PATs and induction motors, would allow the municipalities to maintain this equipment, using existing staff and tools. The financial savings that would be made from generated electricity would further the national municipal agenda of reliable service delivery to their communities and the environmental benefit of producing green energy would reduce impact of our energy demands on the earth.

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