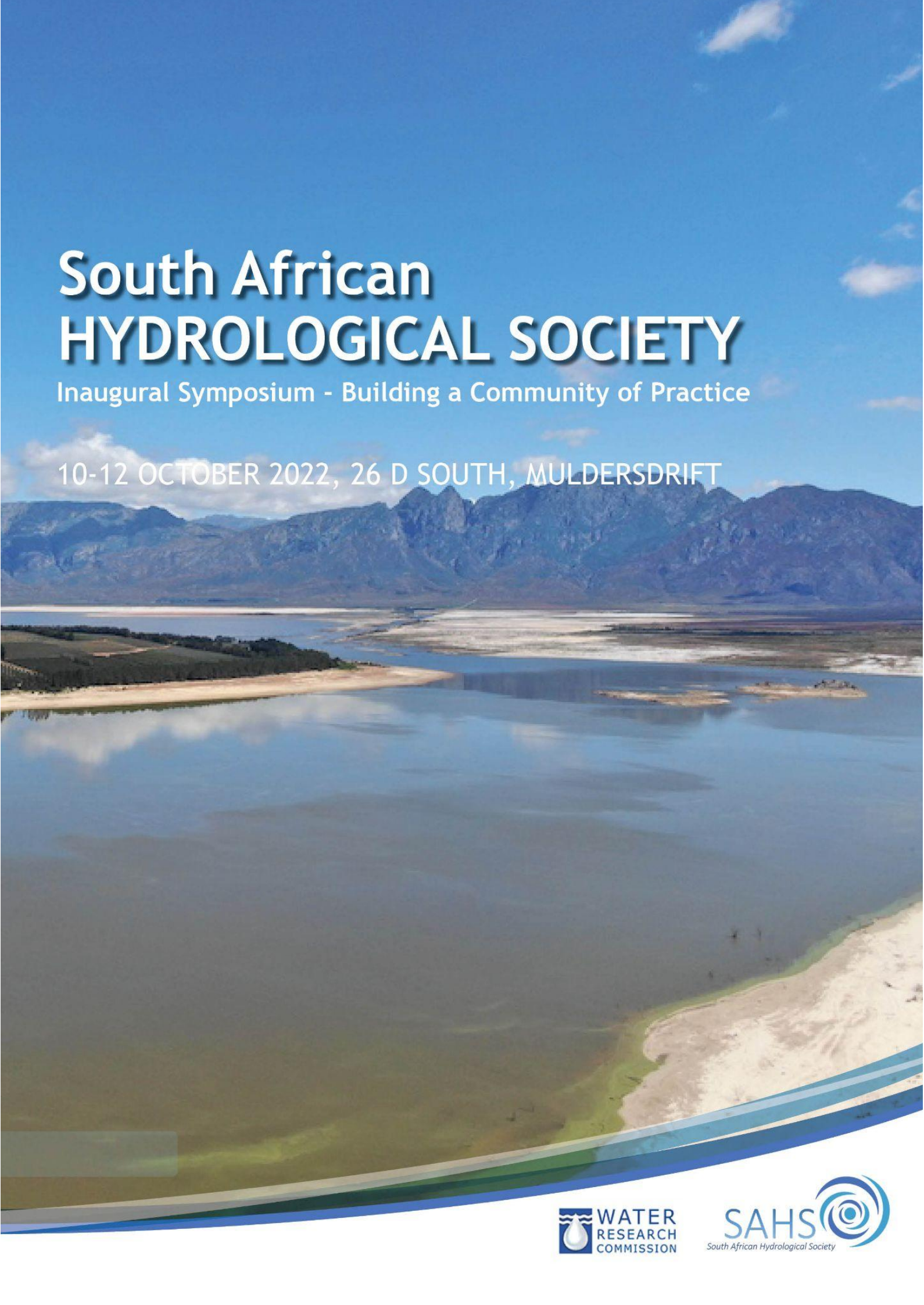

South African HYDROLOGICAL SOCIETY

Inaugural Symposium - Building a Community of Practice

10-12 OCTOBER 2022, 26 D SOUTH, MULDERSDRIFT

WATER RESEARCH COMMISSION

SAHS
South African Hydrological Society

Welcome message

In 2021, the Water Research Commission (WRC) hosted a dialogue aiming to revitalize the hydrology community of practice in South Africa. From this initiative, the South African Hydrological Society (SAHS) was born. SAHS, now in its initiation phase, is a more formal umbrella organisation which evolved from SANCIAHS (South African National Committee of the International Association of Hydrological Sciences). SANCIAHS was an informal volunteer association of hydrologists and water scientists that was formed in the early 1980s by the Department of Water Affairs (DWA), the WRC, universities and practitioners. SAHS will build on the historical legacy of SANCIAHS.

Through consultation with the hydrology community of practice, the vision formulated for the SAHS is “To be a strong, vibrant, diverse and active network of hydrologists in South Africa”. WIth its mission being “To strengthen the hydrology community of practice and to promote and advance the science of hydrology in South Africa”.

Following in the collaborative spirit of the past 19 SANCIAHS symposiums held biennially for the past 40 years, the SAHS interim committee welcomes you to the inaugural SAHS biennial symposium! The theme for this year's inaugural symposium, “Building a community of practice”, aligns with the vision and mission of the society.

On behalf of the SAHS interim committee welcome to the inaugural symposium. We wish you an enjoyable and enriching symposium, and hope this is the first of many successful SAHS events which build a strong, vibrant, diverse and active network of hydrologists in South Africa! Thank you for being here and being a part of the network!

SAHS interim committee

Dr Michele Toucher (SAEON)
Dr Alanna Rebelo (ARC)
Louise Dobinson (Zutari)
Prof Denis Hughes (RU)
Prof Graham Jewitt (IHE Delft)
Dr Julia Glenday (SAEON)
Kershani Tinisha Chetty (UKZN)
Dr Wandile Nomquphu (WRC)
Dr Evison Kapangaziwiri (CSIR)
Prof Simon Lorentz (SRK)

Preamble

This Abstracts Booklet contains the abstracts of the papers (oral and posters) to be presented in all planned Parallel Sessions of SAHS 2022. The Sessions were decided upon based on the abstracts received and approved for presentation. In total, 5 keynote presentations, 61 papers (orals and posters) and 3 workshops will be delivered. We acknowledge the large debt of gratitude we owe to all members of the SAHS 2022 Scientific Committee who conducted the review and selection of the papers to be delivered. Except for minor editing to ensure a measure of standardisation, these are the original or revised abstracts submitted.

SAHS scientific committee

Dr Julia Glenday (SAEON)
Kershani Tinisha Chetty (UKZN)
Dr Wandile Nomquphu (WRC)
Dr Evison Kapangaziwiri (CSIR)
Dr Alanna Rebelo (ARC)
Louise Dobinson (Zutari)
Prof Denis Hughes (RU)

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LINK TO SACNASP CPD CERTIFICATE
https://bit.ly/SAHS_attendance

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LINK TO ABSTRACT BOOKLET
https://bit.ly/abstractsahs2022

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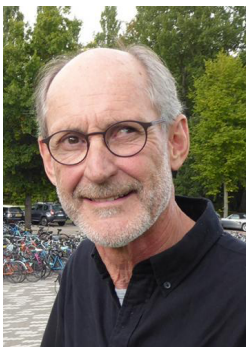
Keynote Speakers



Prof Hubert Savenije

Emeritus Professor of Hydrology, Delft University of Technology former President of the International Association for Hydrological Sciences (IAHS), 2013-2017 former Chief Executive Editor of Hydrology and Earth System Sciences (HESS), 2004-2016

About: Prof. Savenije was born in the Netherlands and studied at the Delft University of Technology, where he obtained his MSc in Hydrology in 1977. As a young graduate hydrologist, he worked for six years in Mozambique, where he developed a theory on salt intrusion in estuaries and studied the hydrology of international rivers. From 1985-1990 he worked as an international consultant, mostly in Asia and Africa. He joined academia in 1990 to complete his PhD in 1992. In 1994, he was appointed Professor of Water Resources Management at the IHE (now UNESCO-IHE, Institute for Water Education) in Delft, the Netherlands. In 1999, he became Professor of Hydrology at the Delft University of Technology, where he headed the Water Resources Section. He is one of the founding fathers of WaterNet, the Water Sector Capacity Building Network in Southern Africa. Since 2018 he is emeritus Professor at TU Delft. He holds the Alexander von Humboldt and Darcy medals of the European Geosciences Union, is Fellow of the American Geophysical Union and is recipient of the International Hydrology Prize (Dooge Medal) of the International Association of Hydrological Sciences

Abstract: The hydrological system as a living organism

Hydrology is the bloodstream of the terrestrial system. The terrestrial system is alive, with the ecosystem as its active agent. The ecosystem optimises its survival within the constraints of energy, water, climate and nutrients. The key variables that the ecosystem can modify are the controls on fluxes and storages in the hydrological system, such as: the capacities of preferential flow paths (preferential infiltration, recharge and subsurface drainage); and the storage capacities in the root zone, wetlands, canopy and ground surface. It can also, through evolution, adjust the efficiency of carbon sequestration and moisture uptake. Some of these adjustments can be made fast, particularly rootzone storage capacity, infiltration capacity, vegetation density and species composition. These system components are important controls on hydrological processes that in hydrological models are generally considered static and are determined by calibration on climatic drivers of the past. This leads to hydrological models that are dead and incapable to react to change, whereas the hydrological system is alive and will adjust.

The physical law driving this evolutionary process is the second law of thermodynamics with the Carnot limit as its constraint. This physical limit allows optimisation techniques to explore the reaction of the hydrological system and its components to change in climatic drivers. This implies a new direction in the theory of hydrology, required to deal with change and addressing the Unsolved Problems in Hydrology.

Dr Tendai Sawunyama

Acting Executive Manager: Water Resources Management Inkomati-Usuthu Catchment Management Agency

About: Dr Tendai Sawunyama is a Water Resources Engineer, currently an Acting Executive: Water Resources Management and is also leading the division of Resource Planning and Operations at Inkomati-Usuthu Catchment Agency in South Africa. Dr Sawunyama has experience in transboundary catchment management as an academic and specialist in the government sector. He has worked on projects related to information systems, guideline development, decision support systems, prediction tools, technologies and methodologies that support protection of water resources and equitable allocation of water to meet the needs of the environment, social and economic development. He has participated in multi country studies as a lead hydrology expert and study leader in Southern Africa. As a Water Resources Specialist, Dr Sawunyama, has been supporting the Technical Joint Water Commissions of the Republics of South Africa, Mozambique and Kingdom of Eswatini to reach amicable decisions on water resources planning. He has also published several academic papers and a book (Uncertainty in Water Resources: Estimation in Southern Africa, 2010). Dr Sawunyama' experience includes working in Angola, Lesotho, Guinea, Madagascar, Mozambique, Swaziland, South Africa, Tanzania, Zambia and Zimbabwe.

Abstract: Role of Catchment Management Agency's (CMAs) in Implementing Integrated Water Resources Management in South Africa

Integrated Water Resources Management (IWRM) promotes the coordinated development and management of water, land and related resources, in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. In South Africa the operationalisation of IWRM has been achieved through developing policies, legislation and institutions as well as stakeholder consultation. The implementation of IWRM at Water Management Area (WMA), requires establishment of Catchment Management Agencies (CMAs) among other institutions to manage water resources at a local level. CMAs are established in terms of Section 78 of the National Water Act 36 of 1998 (NWA), to perform water resource management at local level within the WMA. The management of the resources entails protection, use, development, conservation, management, and control of water resources within the WMA as contemplated in the National Water Act (Act 36 of 1998; NWA). Initially nine (9) water management areas were proposed, and now reduced to six (6) water management areas. The Inkomati-Usuthu Catchment Management Agency (IUCMA) is one of the CMAs that was established to manage the Inkomati-Usuthu Water Management Area (IUWMA). The IUWMA forms part of an international basin (Incomati and Maputo) shared between the Republic of South Africa, Kingdom of eSwatini and Mozambique. Its main rivers include the Sabie-Sand, the Crocodile (East), Komati and Usuthu rivers. The Inkomati-Usuthu WMA is located within a strategic water source area, downstream of mining activities, and contains high potential agricultural land as well as declared conservation areas. The water use in the WMA varies, from irrigation-based agriculture and forestry which takes up most of the water in the WMA compared to other water use sectors. The WMA is vulnerable to climate-induced risks which needs to be managed at a level at which water's benefits can be securely and sustainably realized in totality.

Keywords: IWRM, Catchment Management Agency, Water use, South Africa

Dr Jane Tanner

Head of Hydrology, Institute for Water Research, Rhodes University

About: Dr Jane Tanner is a hydrologist at Rhodes University. She runs hydrology research within the Institute for Water Research at Rhodes University and is the incoming Director of the African Research Universities Alliance (https://arua.org.za/) Centre of Excellence in Water. Her research interests are focused on understanding the interactions between surface water and groundwater and she remains active within the hydrogeological community. A recent research theme includes socio-hydrology specifically focused on the improvement of methods for integrating social science into hydrological research to increase the impact of hydrological research on the ground.

Abstract: Widening our perspective: How hydrologists can contribute towards more sustainable development

Jane Tanner (Rhodes University), Sukhmani Mantel (Rhodes University), Tally Palmer (Rhodes University), David Gwapedza (Rhodes University), Ana Porroche-Escudero (Lancaster University), Olivier Barreteau (INRAE)

Despite the international focus on progressing the Sustainable Development Goals, the performance of investments in water resources management are mixed in Africa. For instance, emphasis on economic development has often overlooked the negative distributional impacts of water interventions on communities and their environments, resulting in systems with diminished resilience and increased vulnerability to climate change. We argue that key reasons for this disappointing performance are the lack of transdisciplinary approaches, generated in partnership with local actors, and poor understanding of complex interactions between economic, ecological and social systems. Several conceptual frameworks have recently emerged to facilitate a balanced analysis of these interactions, their interdependencies and their consequences in socio-ecological systems. These include an examination of both soft and hard infrastructures in these interdependencies. These frameworks and methods are being tested in a number of case studies in Africa and this presentation provides an overview of some of these frameworks and methods and their case studies. The methods reviewed include the Adaptive Systemic Approach (developed at Rhodes University), Cooplage framework including Agent Based Modelling (developed at INRAE - Institute for Research on Agriculture, Food, and the Environment, France), and Policy Simulation (developed at International Institute for Applied Systems Analysis, Austria). Case studies are located in the Kouebokkeveld, South Africa; Senegal River Basin, Senegal, and Rufiji Basin, Tanzania. All the methods aim to better integrate policy, sectoral plans and formal planning models with the reality on the ground (rules in form versus rules in use) for more effective water resource development which considers the complexities associated with local contexts. With significant parts of Africa focused on accelerated development, implementing a more sustainable and equitable trajectory of growth is urgently needed and it is argued that methods that take account of complexities and coupled socio-ecological systems offer important insights into shifting to more sustainable development practices.

Keywords: socio-hydrology, complex-social-ecological-systems, sustainable-development

Dr Michele Toucher

Researcher, Grasslands Node, South African Environmental Observation Network (SAEON)

About: Michele Toucher is a scientist at South Africa Environmental Observation Network (SAEON) based at the Grasslands-Forest-Wetlands Node in Kwa-Zulu Natal. She joined SAEON in 2016 after 10 years as a lecturer in the Hydrology Department and Centre for Water Resources Research (CWRR) at University of KwaZulu-Natal. Her research focuses are using long-term observation, monitoring and detection to improve process understanding and process representation in hydrological models, and the application of hydrological models to look at the complex interactions between land use change, climate change and water resources.

Abstract: Cathedral Peak Research Catchments: Ten years on from Reestablishment of Monitoring

The Cathedral Peak research catchments (29° 00’ S; 29° 15’ E), located on the Little Berg plateau in the northern part of the uKhahlamba Drakensberg, were established in 1935 to determine the influence of various management treatments on the vegetation and water yield of the catchments. Monitoring in the catchments was initiated in 1949, and continued to 1994. During that period various components of the hydrological cycle, including streamflow, groundwater, rainfall, temperature and evaporation, were measured. The results and data from these catchments heavily influenced the policy surrounding the planting of commercial forestry in South Africa starting from 1968 with the introduction of the Afforestation Permit System (APS) and continue to influence policy today through the declaration of streamflow reduction activities in the National Water Act (1998). The monitoring in the research catchments also addressed questions surrounding the impacts of various land management options and treatments on water resources and provided the data for the development of South African hydrological models. In 2012, the South African Environmental Observation Network (SAEON) re-established monitoring in the research catchments with funding from DST, through the NRF. Over the last 10 years, these historic research catchments have been established as a long term, living laboratory with a comprehensive equipment array for monitoring climate, water, carbon and vegetation. The intention of the design is to provide a cross-disciplinary platform for scientists to use, where the longevity and quality of the data are assured.

The presentation will provide an update on the research catchments from the initial focus on establishing monitoring, cross-calibration of historical and current equipment, protocols for data error checking and data management, the results from the catchments including those showing that woody vegetation and bracken fern significantly alter the water balance relative to the grassland, to the plans to expand the monitoring to downstream areas.

Prof Des Midgley Memorial Lecture

Prof Denis Hughes

Professor Emeritus, Institute for Water Research, Rhodes University

About: Awarded a PhD in a combination of the geomorphology and hydrology of floodplain inundation from the University of Wales, Aberystwth in 1978. Moved to South Africa to join the Hydrological Research Unit at Rhodes University under the leadership of Dr Andre Görgens, which later became the Institute for Water Research. Remained at Rhodes until retirement as Director of the IWR in 2017, but still remains active in both consulting and research. Research interests have been focussed on different aspects of hydrological modelling, including the practical use of models, uncertainty analysis and the regionalisation of model applications in data scarce areas of southern Africa. The main focus in recent years has been on further development and application of the Pitman model, but has also spent a lot of time developing and using an environmental flow assessment model. In 2016, Prof Hughes was awarded the IAHS/UNESCO/WMO International Hydrology Prize (Volker medal).

Abstract: Science into practice: From the past to the future

The presentation is intended to explore many different aspects of how science is applied in practice and what is needed for this to be effective. These requirements include issues related to data (or lack of data), the incorporation of scientific understanding into practical methods, the willingness of practitioners to use new methods, as well as how education programmes are structured to support science into practice. Part of the presentation will review past (including the contributions of Prof Des Midgley) achievements, while part will also look at the current status of practical hydrology and try and identify trends that could impact on the future relevance of hydrological science. The focus of the presentation will be predominantly on the situation in South Africa and the broader southern Africa region, but will also draw from international experience and trends.

Special Guest Speakers

Dr Jennifer Balatedi Molwantwa

Water Research Commission CEO

Dr Jennifer Molwantwa was born and bred in Kagiso Township, Mogale City in the Province of Gauteng. Her career started at Pulles Howard & de Lange, later Golder Associates Africa as a research assistant and water resource consultant, respectively before joining Digby Wells Environmental as Unit Manager. She joined the Water Research Commission (WRC) in 2014 as a Research Manager responsible for water resource quality prior to being appointed Executive: Water Resource Management at the Inkomati-Usuthu Catchment Management Agency (IUCMA) where she served for five years (2016 to 2022). She holds a PhD: Biotechnology and a Postgraduate Diploma in Enterprise Management from Rhodes University. A Registered Professional Natural Scientist (Pr. Sci. Nat.) with SACNASP, a member of the Institute of Directors SA (IoDSA), she completed the International Executive Development Programme offered jointly by Wits Business School and the London School of Business. She gained extensive governance experience from serving on the Governing Board of IUCMA, the Council of the University of KwaZulu Natal (UKZN) where she also represented the Council on the University Senate. Currently, she serves on the boards of the Water Institute of Southern Africa (WISA) and the Environmental Assessment Practitioners Association of South Africa (EAPASA). She is also a member of the Department of Fisheries Forestry and the Environment (DFFE) Sub-Committee appointed to develop the National Implementation Plan (NIP) for the management of chemicals in South Africa. Dr Molwantwa served as a Commissioner on the 1st National Planning Commission (2010-2015), an advisory body to the President of the Republic of South Africa, that developed the National Development Plan (NDP) and Vision 2030 for the Republic of South Africa. Her passion is capacity building, skills development, and inclusion of Historically Disadvantaged Individuals (HDI) in the mainstream science and technology careers and economy of which water and land are integral. She believes: “the way for women to participate at all levels of the economy, science and technology, knowledge generation and business depends on the opportunities created by women before them”.

Abstracts

Estimating the Effect of Woody Encroachment on Evapotranspiration in a Semi-Arid Savanna using Surface Renewal

Tiffany Aldworth (UKZN/SAEON, PMB), Michele Toucher (SAEON) and Alistair Clulow (UKZN)

tiff.aldworth@gmail.com

Widespread woody encroachment has been observed in South Africa's semi-arid savannas, where approximately 8 million hectares of land have undergone transformation. Despite growing concern that WE may increase evapotranspiration losses and escalate the risk of water shortages in these already water-limited ecosystems, this has not been demonstrated by empirical evidence. The aim of this study was to determine the effect of *Colophospermum mopane* encroachment on ET in a semi-arid savanna ecosystem located in the Limpopo Province. The site was an experimental woody plant clearing trial, comprising of 'control' plots, containing dense monotypic *Colophospermum mopane* stands, and adjacent 'cut' plots, containing open savanna grassland that had been cleared of most *Colophospermum mopane* trees. Due to cost and fetch constraints of the plots, the surface renewal method was chosen to estimate evapotranspiration. Following an assessment of the validity of two surface renewal approaches, SR1 and SR-D, for evapotranspiration estimation against short eddy covariance campaigns, SR1 was found to show better agreement with eddy covariance. Hence, SR1 was used to estimate evapotranspiration from November 2019 to July 2022 in one control plot and one cut plot. Over the three hydrological years of the study, woody encroachment was found to have little effect on evapotranspiration (< 8 % difference in annual ET between the plots) and all rainfall was evaporated irrespective of the vegetation cover. However, 2019-2020 was a much drier year and the annual evapotranspiration exceeded the annual rainfall at the control and cut plots by 76 and 89 %, respectively. This suggested that during dry years vegetation was able to supplement its water use with water that had accumulated in the soil during previous wet seasons, or that tree roots could access water from a shallow water table through hydraulic lift.

Keywords: water-limited ecosystems, *Colophospermum mopane*, woody plant clearing trial, eddy covariance

Pesticides residues accumulation in freshwater, sediments and fish in the Guiers Lake basin: Risks for Senegal's strategic water reservoir

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"While some agricultural pesticides have been prohibited or severely restricted for use worldwide, alarming levels continue to be reported in many tropical and subtropical regions of the world. Guiers Lake is a strategic reservoir of 650.106 m3 of fresh water for biodiversity and a national resource for its socio-economic function. The lake is supplied by the Senegal River (36.2 m^3/s), the drainage of non-conforming water (1.48 m3/s) and by rainfall (2.3 m^3/s). Significant amounts of pesticide residues used in agriculture could be arriving from these recharge areas. We have studied the spatiotemporal distribution of pesticide residues in water and sediments in the Guiers Lake basin using multivariate and geostatistical analysis methods. The sediments (n = 22) collected from the largest inflows to the lake showed significant levels of pollutants, with concentrations ranging from 343 µg kg^{-1} to 49200 µg kg^{-1} between 2015 and 2022. The levels of heptachlor, methyl parathion, trifluralin, cypermethrin, dimethoate and permethrin were above the toxicity guidelines for sediment. Similarly, the levels of pesticides residues in surface water (n = 76) increased by 39 ng g^{-1} to 10865 ng g^{-1} between 1999 and 2022. The results confirmed the presence of agricultural pesticides. The herbicides and insecticides residues were the most dominant compounds in surface water and the distribution of pesticides are different indicating different sources of contamination.

The bioaccumulation was assessed by examining the residue concentrations in the muscle tissue of fish (n=8). The pesticide residues were detected in samples, with total concentrations ranging from 0.04-2.75 mg kg^{-1}. A health risk assessment indicated a potential dietary risk associated with exposure to trifluralin, acetamiprid, malathion and methamidophos.

The study revealed high concentrations of some pesticide residues in water, sediment and fish that highlight potential toxicological risks in the Guiers Lake basin.

Keywords: pesticides residues, freshwater, sediment, fish, Guiers Lake basin, toxicological risks

An assessment of Satellite Rainfall products for Hydrological Modelling

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In-situ rain gauge networks are diminishing, especially in southern Africa, resulting in sparse networks whose records give a poor representation of rainfall occurrence, patterns and magnitudes. Hydrological models are important tools generally used to generate information for water resources management decisions. However, model performance is directly linked to the quality of input data used to drive the model, such as rainfall. The use of satellite-derived rainfall is being increasingly advocated as a viable alternative or supplement to existing rainfall data. The aim of this study was to evaluate the representativeness of satellite-derived rainfall and assess its applicability for use in the ACRU agro-hydrological model to simulate stream flow magnitudes, distributions and patterns. The satellite-derived rainfall products selected for use in this study included TRMM3B42, FEWSARC2.0, FEWSRFE2.0, TAMSAT3.0 and GPM-IMERG4. The satellite rainfall products were validated against available historical observed records and then were used to drive simulations using the ACRU hydrological model in selected catchments in South Africa.

Keywords: rainfall, modelling, satellite remote sensing

Estimation of the inflows to the Berg River Estuary in support of its health and value as a RAMSAR site

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The Berg River estuary is one of four perennial estuaries on the west coast of South Africa. It is a valuable natural asset that provides essential ecological as well as economic services. Freshwater inflows and marine water provide unique conditions for diverse habitats to develop. From an economic perspective, the estuary supports several local industries.

The Berg River Estuary had no official conservation status up until February 2021 when it was declared a RAMSAR site. Two vital components for the conservation of the estuary are firstly to ensure that adequate quantity and quality of freshwater inflows are provided to maintain healthy functioning of the system and second, management of activities in and around the estuary. An important policy that supports the provision of the river inflows is the implementation of Resource Quality Objectives (RQO) which were gazetted for the Berg River catchment and estuary by the Department of Water and Sanitation in 2019. The maintenance of the Ecological Water Requirements (EWR) specified in the RQO and Classification Study is critical. The Berg River Estuary Management Plan updated in 2019 guides the management of the estuary system.

A recent study by the Department of Environmental Affairs and Development Planning (DEAD&DP, 2020) investigated the environmental flows and the health and value of the Berg River Estuary. The study provided an updated understanding of the ecological functioning, and the intrinsic, cultural and socio-economic value of the Berg River Estuary, and the implications of these for management of the estuary and its catchment water supplies.

This paper focuses on the hydrological assessment undertaken during the DEA&DP study and presents a more detailed understanding of the inflows to the estuary taking into consideration natural flow regimes and the influence of the recent drought, water use allocations and the potential impacts of climate change.

Keywords: Berg Estuary, hydrology, drought, climate change, EWR

Intercomparison of catchment modelling tools commonly used in South Africa: structures and process representation

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Catchment hydrological modelling has become a critical component of water resources management in South Africa. Globally and locally, a wide range of modelling approaches have been encoded into software tools that greatly facilitate their application. To support the wise-use of the diversity of modelling tools available, the Critical catchment hydrological model inter-comparison and model use guidance development (WRC K5-2927) project explored the structural options across several tools in use in South Africa: WRSM-Pitman, SPATSIM-Pitman, ACRU4, SWAT2012, and MIKE-SHE. The tools showed high-level similarities in their basic capabilities and process representation; however, there were many notable differences across models' spatial units and subsurface layers, flows between layers and units, the scale at which climate inputs are specified, algorithms that calculate various fluxes, and time steps used. These result in differences in what processes and change scenarios can be explicitly modelled. Tool interfaces also differ significantly. Software interfaces influence model set-up efficiency and transparency, the ease with which parameters can be explored for calibration and uncertainty analyses, and the ease with which different water balance outputs can be obtained to assess model realism. Each tool that was assessed had some form of advantage over others in terms of process representation, analysis capabilities, or interface features. To assist users in weighting what is important for their use-cases, tool capabilities and options were summarised side-by-side on a modelling 'wiki' website: https://hydromodel-sa-wiki.saeon.ac.za/. This study also included a preliminary exploration of the potential impacts of tool differences on model predictions. This was done by applying the set of tools to a set of case studies. A key finding of the case study modelling was that, while models with acceptable performance against observed streamflow could be built with any of the tools, these models could be predicting quite different balances of contributing processes, leading to divergent predictions for scenarios. This strongly highlighted the importance of being able to easily access model output for the full water balance, rather than only the modelled catchment outlet streamflow. This was found to be time and labour intensive to do in most tools.

Keywords: Hydrological modelling, catchment hydrology, model intercomparison, hydrological processes, water balance

Exploring the implications of hydrological modelling tool selection: applying commonly used tools to a set of case study catchments

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There are many hydrological modelling software tools available, each with its own set of approaches to represent catchment processes. Given our reliance on models to inform weighty decisions, there is a need to explore the implications of using different tools and the likely degree of structural uncertainty in our model predictions. To this end, WRC project K5-2927 attempted to apply five tools used in South Africa, WRSM-Pitman, SPATSIM-Pitman, ACRU4, SWAT2012, and MIKE-SHE, to four case studies representing common use cases. These were the Mistley catchment of the Mvoti River (KwaZulu-Natal), Upper Berg River (Western Cape), Upper Kromme River, (Eastern Cape), and Middle Letaba River (Limpopo). For each, the present condition and alternative scenarios were modelled: land cover change for the Mistley, Berg, and Kromme, and a change in irrigation water sources in the Letaba. All models were run with the same rainfall and evaporative demand at the catchment scale. Efforts were made to represent the same conceptual understanding of catchment properties across all tools. Model outputs were compared in terms of fit to observed streamflow, changes predicted for scenarios, and predicted catchment water balances. The process of setting up the models through team workshops highlighted the many best-judgement decisions and representation trade-offs modellers must make. All the tools had the basic capabilities to explicitly represent the scenarios being assessed, except for in the Letaba case, which required modelling irrigation from both farm dams and groundwater. However, while models with acceptable prediction performance against observed streamflow could be built with any of the tools; it was found that these models could be predicting quite different balances of processes to one another (i.e. ET, storage, surface flow, interflow, groundwater outflow). Differences in baseline process representation resulted in differing predicted changes for scenarios. In the most extreme example, looking at the impact of removing riparian Eucalyptus plantation in the Mistley catchment, predicted changes in mean annual runoff (MAR) varied by as much as 20% of the baseline MAR between models. This highlighted the need to assess the realism of model water balances and find ways to address the challenges in doing so.

Keywords: Hydrological modelling, structural uncertainty, catchment management, land cover change, irrigation

Identifying Potential Significant Sediment Contributing Areas and Assessment of Interventions to Limit Sediment Yield into the Proposed Smithfield Dam on the uMkhomazi River

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The Department of Water and Sanitation (DWS) is planning to construct the Smithfield Dam on the uMkhomazi River to meet the long-term water demand in the KwaZulu-Natal Province. Soil erosion has been identified as an issue that will affect the proposed dam. It is estimated that the dam will lose approximately 60% of its storage capacity within 100 years due to sediment deposition, thus resulting in a reduced lifespan, with the sedimentation also impacting on water quality from the dam. Therefore, the identification of significant erosion source areas and assessment of interventions to limit erosion are required to extend the operational life of the dam. Agronomic and mechanical measures have been identified as interventions that can possibly limit sediment yield from the uMkhomazi Catchment. Some small-scale interventions such as brush packing and vetiver grass plantings have already been identified and applied on a small scale to reduce erosion in the uMkhomazi Catchment in a project funded by Umgeni Water working and undertaken by the Institute of Natural Resources (INR). In order to assess the required scale of interventions and before the widespread construction of these measures, a modelling study is being conducted to identify vulnerable catchments to erosion and to assess the effectiveness of interventions in reducing erosion and sediment yield in the vulnerable catchments. The ACRU and SWAT daily time-step and process-based models have been identified as potential simulation tools that can be used to conduct the study based on their availability in South Africa (SA), data required, simulation time-step, scale of application, and performance in previous sediment yield studies. The aims of the study reported in this paper are to assess the effectiveness of the interventions, identify sub-catchments vulnerable to soil erosion and to determine the scale of interventions required to limit sediment yield from the vulnerable catchments.

Keywords: Erosion, sediment yield, modelling erosion

Mapping land use land cover in smallholder agricultural systems using very-high spatial resolution unmanned aerial vehicle imagery

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Smallholder farms are major contributors to agricultural production, food security, and socio-economic growth in many developing countries. However, they generally lack the resources to fully maximize their potential. Subsequently they require innovative, evidence-based and lower-cost solutions to optimise their productivity. Recently, precision agricultural practices facilitated by unmanned aerial vehicles (UAVs) have gained traction in the agricultural sector and have great potential for smallholder farm applications. Furthermore, advances in geospatial cloud computing have opened new and exciting possibilities in the remote sensing arena. In light of these recent developments, the focus of this study was to explore and demonstrate the utility of using the advanced image processing capabilities of the Google Earth Engine (GEE) geospatial cloud computing platform to process and analyse a very high spatial resolution multispectral UAV image for mapping land use land cover (LULC) within smallholder farms. The results showed that LULC could be mapped at a 1.00 m spatial resolution with an overall accuracy of 90%. Overall, we found GEE to be an extremely useful platform for conducting advanced image analysis on UAV imagery and rapid communication of results. Notwithstanding the limitations of the study, the findings presented herein are quite promising and clearly demonstrate how modern agricultural practices can be implemented to facilitate improved agricultural management in smallholder farmers.

Keywords: Smallholder farms; Drones; Geospatial cloud computing; Landcover; Machine learning

Deriving moderate spatial resolution leaf area index estimates from coarser spatial resolution satellite products

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Leaf Area Index (LAI) is a key parameter used to characterize vegetation biophysical properties and plays an important regulatory role in terrestrial-atmospheric exchanges. Subsequently, LAI is often a critical data input to various evapotranspiration, hydrological and climatic models. While LAI data can generally be easily obtained, it is seldom available at spatio-temporal scales that can be used to guide and inform management decisions for localised applications. To this end, we propose a methodology to acquire moderate resolution LAI (LAIMR) estimates from freely available satellite-earth observation data sets and data processing platforms. Fifteen sites distributed within the KwaZulu-Natal and Mpumalanga provinces of South Africa were selected as study areas. Coarse spatial resolution MODIS LAI and vegetation index (VI) products were acquired for each of these sites to establish the LAI-VI relationship which was then used to develop machine learning-based models (MLBMs) to estimate LAIMR using VIs derived from Landsat or Sentinel-2 data. During the validation and testing phases of the study, LAI estimates were compared against the corresponding MODIS LAI product values. The results of these investigations demonstrated that MLBMs performed satisfactorily across the majority of the study sites, producing correlation coefficients ranging from 0.62-0.97 and 0.29-0.84 for the validation and testing phases, respectively. The poorer performance of the MLBMs when using VIs derived from Landsat or Sentinel-2 data can be largely attributed to inherent limitations associated with the proposed methodology, such as i) the lack of moderate-high spatial resolution LAI records that could be used for training and testing purposes and ii) saturation effects associated with the use of VIs. Notwithstanding these limitations, the proposed methodology has been shown to be flexible and robust and can be a useful approach to acquire LAIMR estimates with fairly reasonable accuracy in data limited circumstances.

Keywords: LAI, Vegetation Indices, Google Earth Engine, Machine Learning, Commercial Forestry

A SWAT-Based assessment of the impacts of landcover on hydrology and soil loss in the T35A Quaternary Catchment, Eastern Cape

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Land degradation remains one of the most significant environmental issues in South African catchments. As the country is generally semi-arid, land degradation has become a huge problem for people living in dryland areas. Loss of ecosystem services and related livelihoods in these areas is driven by erosion, sedimentation, and invasive alien species. In order to manage rangeland systems more effectively, an understanding of the drivers of degradation and related impacts is necessary. The present research aims to analyse the impacts of land cover on hydrology and soil loss in the T35A Quaternary Catchment using the Soil and Water Assessment Tool (SWAT+). Specifically, this research will apply QSWAT+ to model water balance and sediment yield. Model simulations will be validated using available records of discharge and sediment yield. An evaluation of the relationship between varying land cover categories and water balance will be performed. The evaluation will pay particular attention to alien invasive species that have replaced large portions of natural forests. A key research interest will be to evaluate potentially contrasting effects of land cover on water balance and soil loss to anticipate the trade-offs of alien clearing on the broader ecological system. The outcomes of this study will provide vital information that will inform ongoing initiatives for catchment management in the area.

Keywords: Land degradation, SWAT, sediment yield, soil loss, South Africa

Provision of ecological goods and services in headwater catchments: An assessment of anthropogenic influences

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Headwater catchments, though small in spatial extent, have a unique ability to influence the characteristics of the resulting river to which they contribute. It is generally ideal to keep these water source regions in their pristine state for the integrity of the entire basin. However, land use and land cover (LULC)changes brought about by human development can affect the ecological functioning of fragile headwater catchments. Growing populations, the need for living space and expanding food production have led to massive LULC changes. With technological advancements and the need to develop land, once hard to reach, hilly areas are being invaded by human settlements affecting their provision of hydro-ecological goods and services. This paper assesses the human influence on the ability of headwater catchments to provide ecological goods and services between two headwater streams (Luvuvhu and Sterkstroom). The study uses interviews of key informants to understand the hydro-ecological functions of the flow characteristics of the two streams. LULC changes were then assessed to see the impact of human activities on the functions of the streams. The results show how the streams behaved in the past and determine the level of intensification of the anthropogenic activities and their impacts on hydro-ecology. A time series of LULC changes were produced to show changes over time. This study emphasizes the need to manage water source areas efficiently, especially when climate change threatens the availability of the resource.

Keywords: Anthropogenic alterations, ecosystems, climate change, hydrology, Vhembe Biosphere Reserve

A stakeholder-driven process to develop a water resources management plan

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Background/aims

Water scarcity is a significant problem in South Africa. Low average rainfall results in limited water available for human and environmental needs. Consequently, competition for water resources is increasing and has resulted in water-related conflicts among the various water users in many areas of South Africa. Unfortunately, when competition for water use exists, Environmental Water Requirements (EWRs) are often ignored, thus impacting the health of riverine ecosystems and downstream ecosystem services. Such a situation occurs in the Koue Bokkeveld farming region. Conflicts are rife between upstream farmers who have initial access to river water and downstream farmers forced to use what remains after upstream users satisfy their needs. The situation entrenches inequality and fuels conflict and, if left unmanaged, may lead to a breakdown in the farming community. The resultant loss in agricultural productivity will affect food security and the livelihood of the thousands of farmworkers who work in the area. This research project responds to this problem by negotiating a shared water management strategy that achieves equity in water access and respects EWR. The broader aim is to assist Koue Bokkeveld (KBV) stakeholders in co-developing a water resources management strategy that results from a shared understanding.

Methodological framework

To achieve the research aim, a mixed methodological approach driven by Agent-Based Modelling is employed. A companion modelling approach is adopted, thus placing stakeholders at the centre of the model development and application. A series of stakeholder workshops are lined up where stakeholders will provide input into and validate the model. Future scenarios (and subsequent impacts on an agreed water management plan) will be evaluated, assisted by hydrological modelling of future flows.

Preliminary results

An initial conceptual ABM model based on literature and an understanding of the study area representing the key actors, resources and dynamics obtained in the catchment has been developed. Stakeholder workshops to solicit stakeholder buy-in and co-develop a conceptual model have been conducted and model implementation is underway . Although stakeholders remain sceptical about their identities and activities being kept confidential, they are keen to participate in the following workshops.

Keywords: ABM, South Africa, stakeholder, water resources, modelling

Drought ravaged Algoa Water Supply System: Short-term operational and allocation strategy

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The Algoa Water Supply System (WSS) is situated in the Eastern Cape Province and supplies domestic water requirements for Gqeberha, Jeffreys Bay, Humansdorp, St Francis Bay and 5 other smaller coastal and inland towns. The WSS also supplies approximately 268 km2 (roughly the size of Gqeberha) of commercial irrigation activities largely situated in the Langkloof area and in the Gamtoos Irrigation Board. The WSS storage levels have systematically dropped for the past 6.5 years since the last time the WSS was spilling.

The Department of Water and Sanitation does Annual Operating Analyses (AOA) for all the bulk water WSS in South Africa, which aims at the protection of water resources against failure by implementing restrictions of water use sectors' allocations, in years when required. The analysis is done by means of a stochastic hydrology-based forecasting model called the Water Resources Planning Model (WRPM). The WRPM makes use of short-term yield-capacity relationships, developed from long-term stochastic hydrology for each resource, to estimate the available yield from the WSS given the resource's starting conditions.

Nelson Mandela Bay Municipality (NMBM) is the largest water user of the Algoa WSS and has for the past few years planned and partially implemented numerous interventions to lower water requirements or increase the available water resources of the system. The 2022/2023 Algoa AOA analysed scenarios using the WRPM to determine the impact of the planned interventions on the proposed water allocation restrictions

The results from the analysis showed that successful implementation of interventions during the year, could reduce restrictions considerably. However, the DWS Operating Strategy for the WSS had to be more conservative than recommended restrictions levels to accommodate the protection and recovery of failed or soon to fail sub-systems to ensure WSS resilience, and since most of the planned interventions were not implemented yet at the date of the AOA. Restrictions will have to be reviewed later as new interventions are successfully implemented.

Keywords: water allocation water resource operations

Drought monitoring provided through Cloud-based processing of Satellite data "Eye in the sky no longer pie in the sky"

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Water is a critical and scarce resource in southern Africa and is likely to become even more so as the regional impacts of global climate change become more evident. Being able to accurately and repeatedly monitor available water resources across the entire landscape is a key information requirement for successful water resource management. Currently, water resources management activities across Africa are hampered due to lack of credible, reliable and consistent data. This means that it is difficult to perform assessments effectively to support major development initiatives. Satellite data has now become reliable and can provide information at a level of accuracy which can support many water resource assessments.

A service has been developed where, Cloud-based satellite image data archives, combined with big data processing capabilities are used to automatically generate spatially relevant information on a number of drought indicators providing information on rainfall anomalies, vegetative condition, water resources availability and groundwater status. The service uses a number of the freely available satellite products developed by various organisations such as the European Space Agency's (ESA), National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA).

The monitoring of the extent of all surface water features, from small farm dams and natural pans to large impoundments, across the South African landscape, on a monthly basis is a unique operational feature. The service is based primarily on the European Space Agency's (ESA) 20m resolution Sentinel2 satellite imagery, which allows all surface water bodies typically > 0.25 ha to be identified and mapped in a repeatable and accurate manner. The service is currently able to generate information on water surface areas and dam volume estimates across South Africa and is being extended to a global service.

The service provides the means for water resource managers, and other interested parties to be able to access highly detailed, reliable, and regular information on the status of water resources across the continent, in support of activities such as compliance monitoring, water security, water licence applications and water resource inventory.

Keywords: Cloud Processing, Satellite Monitoring, Drought

Creation of an improved set of Quaternary Catchment Altitudinal Zones for use in National Scale Hydrological Modelling

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In 2011 Schulze and Horan undertook a study on the physiographic heterogeneity across the Department of Water Affair and Forestry Quaternary Catchments (QCs). Variability in altitude and mean annual precipitation within the QCs showed that approximately 1000 of the 1946 QCs required subdivision to create a more homogenous unit for national scale hydrological modelling. Seven discretisation methods were investigated, with the use altitude as the driver being the one selected. Altitude, and indirectly slope and aspect, influences the rainfall, temperature, soils, vegetation and runoff of a catchment, and so it was, and is, a logical property to use as the divider.

The original study was based upon the DWAF 2000 QCs and the 200m Digital Elevation Model (DEM) from the Department of Surveys and Mapping. A series of algorithms were derived to divide each QC into three sub-divisions based on “natural breaks” in altitude, governed by the Jenk’s Optimisation process. This divides the QCs into zones of similar altitudes, where the divisions will occur at different elevations in each QC depending on the nature of the landscape.

In 2011 the Water Research Commission tasked the Agricultural Research Council to re-investigate the QCs using the new technologies available, including the 90m resolution DEM Shuttle Radar Telemetry Mission (SRTM) data freely available from NASA.

The completed products (new QC boundaries and improved flow path DEM) were used to create a new set of altitudinal relatively homogeneous zones based on “natural breaks” in altitude.

Each QC was isolated and the boundary buffered. The buffered boundary was used to clip the altitude from the 90m DEM, where the clipped DEM was then sliced into three divisions based on the Jenk’s Optimisation technique. The sub-divisions were then converted from raster to polygon to create a vector set of altitudinal zone boundaries.

Small and insignificant “rogue” polygons were eliminated from the boundaries and then identification and flow routing were derived based on QC to QC flow, and then the zone to zone flows within each QC.

The final stage will be to assign climatic and physical variables to the zones, for utilisation in hydrological modelling.

Keywords: Quaternary Catchments, Hydrological Modelling, Altitude

Estimation of High-Return Period Design Rainfalls and Probable Maximum Precipitation in South Africa

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The estimation of design rainfalls and design floods are required by engineers and hydrologists to design and quantify the risk of failure of hydraulic structures. Extreme design rainfall quantities such as high-return period rainfalls and the probable maximum precipitation (PMP) are needed to design high-hazard hydraulic structures. In South Africa, previous design rainfall estimates have been produced up to the 200 year return period. PMP estimates were last determined nearly 50 years ago based on only 30 years of data

The aims of this study are (i) to estimate extreme design rainfall values, with a focus on return periods greater than 200 years, and (ii) to update PMP estimates using updated data and modernised methods. Frequency analysis using LH-moments, which more accurately fit the upper tail of distributions, have been used to estimate high-return period design rainfalls. Regular L-moments are shown to overestimate the extreme rainfall quantities when compared to LH-moments by giving undue favour to outliers. PMP estimates have been determined using a storm maximisation and transposition approach. Radial Basis Functions (RFBs) have been used to transpose PMP estimates to ungauged locations, producing PMPs for the entire country. Approximately 80 % of the new PMPs are greater than the previous estimates. This is likely due to the many limitations of the old approach and differences used in the new approach, indicating that the new approach undertaken in this study may provide improved estimates. The PMP is meant to represent the upper limit of extreme rainfall, however, comparisons of the high-return period rainfalls to the PMP show that the PMP is sometimes exceeded by the high-return period estimates. Continual revision of extreme rainfall estimates is recommended to include newly occurring extreme rainfall events.

Keywords: Design rainfall estimation, Extreme rainfalls, Probable Maximum Precipitation

Hydrology and society, Catchment management and restoration, Data synthesis, partnerships, planning – are we pulling together for the best outcome for freshwater ecosystems in South Africa?

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Scientific research is essential to inform good decision making and for establishing the context for sustainable water management. This requires improved understanding and communication of all facets of freshwater biodiversity. A central goal of the SANBI freshwater programme is to synthesise and generate information that aids in better freshwater management, restoration and conservation decisions, and to regularly provide a freshwater ecosystem and species status update as part of the National Biodiversity Assessment. This paper is an opportunity to communicate recent work by this relatively new programme within SANBI, on recent spatial dataset coordination and updates, freshwater data pipeline and data visualisation platforms, identification of fragmented efforts and knowledge gaps on freshwater ecosystem status and distribution. The paper hopes to stimulate discussion and to invite collaboration with the SANBI freshwater programme to advance research, positively impact society and the freshwater environment, and influence policy.

Keywords: Freshwater data and information synthesis, communication; freshwater policy

The Development of Methods to Account for Non-stationary Climate Data in Design Rainfalls in South Africa

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Estimates of extreme design rainfall are routinely needed for Design Flood Estimation to design and construct hydraulic structures including dam walls, spillways, culverts, and stormwater drains. Standard methods for frequency analysis of extreme events are based on the assumption of a stationary climate. However, this assumption in rainfall and flood frequency analysis is challenged with growing evidence of climate change. As a consequence of a changing climate, the frequency and magnitude of extreme rainfall events has been reported to have increased in parts of South Africa and these and other changes in extreme rainfall occurrences are expected to continue into the future. The possible non-stationarity in climate resulting in changes in rainfall may impact on the accuracy of the estimation of extreme rainfall quantities and design rainfall estimations. Hence, methods that account for non-stationary data, such as those caused by climate change, need to be developed. Given the importance of flood risk management, the shortcomings of the methods currently used by practitioners, and the potential impact of climate change, dealing with a non-stationary climate data series currently requires urgent attention in South Africa.

This study aims to account for non-stationary climate data in the estimation of extreme rainfall events in South Africa. Data from downscaled global circulation models will be analysed in order to identify non-stationary climate variables which affect rainfall, which can then be analysed using extreme value analysis. To develop methods to estimate extreme design rainfall events in a non-stationary climate, this study explores the impacts of climate drivers, such as the Southern Oscillation Index (SOI), Sea Surface Temperature (SST), and changes in atmospheric variables, such as dew point temperature, on extreme rainfall estimates such as high-return period rainfalls and the Probable Maximum Precipitation.

Keywords: Design flood estimation, Extreme rainfalls, Climate change, Non-stationarity

Temporal variation of soil water content and groundwater under different landcover types in a floodplain of a semi-arid mountainous catchment

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Invasions of floodplains by alien woody species have altered the hydrological and ecosystem functioning in catchments when they replace herbaceous indigenous vegetation, particularly in semi-arid regions. Although existing studies have examined and provided evidence of changes in river flows following the establishment or clearing of alien woody vegetation, our understanding of impacts on soil water content and groundwater remains poor. As such, this work compared temporal variations in soil water content and groundwater levels at three locations with different vegetation types: invasive black wattle trees (Acacia mearnsii), palmiet (Prionium serratum), and grass (dominated by Pennisetum clandestinum spp), within a floodplain site in the Kromme Catchment (Eastern Cape Province of South Africa). Soil water content and shallow groundwater levels (<4m below ground) were monitored from August 2017 to December 2019 using soil moisture probes and piezometers. On average, soil water content and water retention were significantly higher ($p<0.05$) at the palmiet site, whilst the wattle site had the lowest among the three sites. Across all sites, soil water content in shallow soils (0-20 cm) had noticeable responses to light and medium rainfall events (5-20 mm/day). However, the responses of deep soils at 50-60 cm depths were dependant on the magnitude of rainfall events and antecedent conditions, and varied significantly across the three sites. Groundwater levels were highest at the palmiet site and lowest at the wattle site. A MIKE SHE numerical model was used to simulate possible impacts of alien invasion on streamflow and groundwater. The model outputs suggested that floodplain alien invasion resulted in reduced groundwater levels by 15%, baseflow by 8% and total outflow by 5%. Predicted results also indicated that wattle trees use more water in riparian areas where it is readily available than upland areas.

Keywords: Alien plant invasion, groundwater, soil water content, water table

Monitoring of streamflow benefits and establishment of a decision support model for the Greater Cape Town Water Fund

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The streamflow reductions caused by afforestation are relatively well researched in South Africa, but to date only limited studies have been undertaken to measure the streamflow reductions of IAP invasions directly. The Greater Cape Town Water Fund (GCTWF) was initiated by The Nature Conservancy in 2019 to investigate and implement interventions in ecological infrastructure to improve runoff into the dams of the Western Cape Water Supply System (WCWSS). A multiple catchment study has been established in the headwaters of Theewaterskloof Dam, the largest dam in the WCWSS, with two catchment pairs containing dense invasions of IAPs, predominantly with Pinus Pinaster, and the fifth and sixth catchments being relatively pristine. The experiment utilises natural bedrock hydraulic controls with deep pools upstream and waterfalls downstream and has now collected nearly 3 years of baseline streamflow, water temperature, water conductivity and rainfall data. An additional component of the GCTWF has been the establishment of a Decision Support System (DSS) that optimises alien clearing efforts in the catchments based on the objective of maximising yield from the WCWSS at minimum cost. This required delineation of management catchments at a scale suitable for clearing in one financial year, determination of each catchment's contribution to streamflow and dam yields, detailed IAP mapping, estimations of IAP streamflow reductions, and costs for clearing of IAPs. The DSS is currently in use by the GCTWF and the next phase of the multiple catchment experiment is due to begin in the next two years when one catchment in each pair is cleared, followed by monitoring for a further three to five years.

Keywords: Invasive alien plants streamflow reduction

Quantifying the influence of urban development on runoff in South Africa: a Tshwane case study

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It is widely accepted that urban development results in larger flood peak discharges with faster catchment response times, larger total runoff volumes and lower base flow volumes. However, these effects have not previously been studied in the context of the specific characteristics of fast-growing urban areas in developing countries, which are generally unregulated. This study quantifies the effects of urban development on runoff, including: a) runoff volumes, b) base flow volumes and c) flood peaks from eight South African catchments using the Mann-Kendall test and Kendall's τ. Five urban catchment areas and three undeveloped catchment areas were used as case studies and trends in urban and rural catchments were compared. It was established that strong increasing trends exist in the urban catchments in the temporal runoff/rainfall (Q/P) ratios and base flows, as well as between Q/P ratios and the urban extent (URBEXT), and between base flow and URBEXT. Despite the strong correlation for Q/P ratios and base flows, the magnitudes of flood peaks do not seem to be affected to the same extent by the degree of urban development, with statistically insignificant changes in most catchments, negative trends evident in some catchments and an unexpected positive trend in the where urban development started most recently and has limited formal drainage infrastructure.

Keywords: Urbanisation; Urban hydrology; Development impacts; Flood trends

SWAT+ hydrological model Application for water balance assessment in an intensive irrigated agricultural catchment in the Western Cape, South Africa

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Changing climate and expanding irrigated agriculture exert significant pressure on the already limited water resources in many regions of the world. This study is located in a South African strategic water source area called the Koue Bokkeveld (KBV). The area is characterised by a strongly seasonal flow regime, where winter flash flood flows dominate, and long dry summer periods are experienced. Numerous reservoirs have been constructed in the catchment to capture the extreme winter flows. The region is a biodiversity hotspot with a number of endemic species and forms part of the strategic water source area in South Africa (10% of South Africa's land surface produces 80% of the country's runoff).

During the long dry summer period, conflicts over water use and allocation among farmers in the study catchment emerge. When this happens, river flows are abstracted without considering ecological reserve (environmental flow) requirements.

This study quantifies the availability of water resources in the KBV catchment to contribute to creating an equitable and more sustainable water management plan that addresses water-related conflicts among farmers and ensures that ecological reserve requirements are met. SWAT+ has been set up for this study as it allows the representation of spatially distributed reservoirs and river diversion points within a catchment. This study also simulates future flow scenarios in the context of changing climate.

The outcomes of this project will be used to support decision-making regarding sustainable water management. This includes being used as input into an Agent-Based Model (ABM) that will be utilised to explore various management scenarios. Furthermore, the modelled current and future water availability information will assist catchment managers in making informed decisions about how water management could be adapted to changes in water availability.

Keywords: Future flow scenarios, Irrigation, SWAT+, Water transfers, Water availability

Improved Performance of the SCS-SA Model and Development of a Framework for Uncertainty Estimation for Design Flood Estimation in South Africa

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The increased intensity and frequency of rainfall events has highlighted the need for updated design flood estimates in South Africa (SA). Design Flood Estimation (DFE) is required for the design of hydraulic structures and to limit the risk of failure with the consequent potential loss of life and economic losses. The DFE methods currently used in SA need to be revised and updated. The Soil Conservation Service Curve Number (SCS-CN) model is a widely used DFE method for small catchments, and the stormflow depths estimated using the SCS-CN equation is extremely sensitive to the rainfall depths and Curve Number (CN). However, there is uncertainty surrounding the published CN tables used in practice. The long periods of observed rainfall-runoff (P-Q) data, that are currently available in SA, could be used to assess the performance of CN derivation techniques to derive CNs specific to South Africa. Furthermore, hydrological modelling should include uncertainty analysis to allow for risk-informed decision making and design. When using event-based P-Q methods for DFE, generally only the probabilistic nature of rainfall is accounted for, however, if all important input variables are treated probabilistically, the key shortcomings associated with P-Q methods for DFE could be addressed. There are many principles and techniques that deal with uncertainty, but there is a lack of clear rules to implement these techniques. The general approach of this study was to investigate whether the published CNs could be replicated, and to evaluate the performance of the SCS-CN equation when applied with published CNs or the CNs derived using observed P-Q data from small South African catchments. Subsequently, the probabilistic nature of the empirical CNs derived for catchments in SA has been investigated, and an additional objective is to develop a methodology to quantify the uncertainty associated with the SCS-CN model.

Keywords: Design Flood Estimation, Curve Number, Uncertainty

Detection and Early Warning of Lightning and Extreme Storm Events in KwaZulu-Natal, South Africa

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During the past decade, increasing concerns about the impacts of climate change have emerged, which stipulate an increased risk of climate-driven events. Climate change projections of increases in lightning activity are an added concern for lightning-prone countries such as South Africa. South Africa's high levels of poverty, lack of education and awareness, as well as a poorly developed infrastructure increases the vulnerability of rural communities to the threat of lightning. Despite the existence of national lightning networks, lightning alerts and warnings are not disseminated well to such rural communities. Technological advancements can play a key role in reducing the vulnerability of communities and small-scale farmers to the impacts of lightning and improve the access to lightning information for all. We therefore developed a community-based near real-time lightning warning system (NRT-LWS) to detect and disseminate lightning threats and alerts in a timeous and comprehensible manner within Swayimane, KwaZulu-Natal, South Africa. In addition to the lightning threats and alerts, meteorological warnings for rainfall and possible flooding, heat and windspeeds were disseminated to the community. A systematic evaluation on the performance of the NRT-LWS using an existing national network was also conducted. Lightning data from the system was further investigated to provide early warnings for extreme weather phenomena on a local scale for South Africa by examining the lightning data within a recent supercell tornado event. The NRT-LWS showed its capability as a risk-based warning system that can be beneficial to farmers, community members, municipal officials and disaster risk management agencies with measurable thresholds upon which actions can be initiated. In addition, meteorological conditions are automatically stored and published on a web page for public access. Poor network signals in the rural community was an initial challenge delaying data transmission to the central server until rectified using multiple network providers.

Keywords: alert system, climate change, rural communities, thunderstorms

Impact of climate change on crop water requirements in the Luvuvhu River Catchment, South Africa

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The impacts of climate change on crop water requirements were investigated for Luvuvhu River Catchment (LRC). The LRC is of paramount importance since it is a commercial hub for agricultural production in the Limpopo Province. It is important to determine water required by crops for sustainable and efficient use of water resources under variable climatic conditions. Historical temperature data, climate projections from Conformal Cubic Atmospheric Model (CCAM), estimated reference crop evapotranspiration and duration of different crop growth stages were used to estimate water requirements for selected crops within the LRC. The period considered for the estimation ranged from 2010-2099. The results showed an increase in crop water requirements for banana, maize and tomatoes. Highest crop water requirements were obtained from the most downstream station (Tshanzhe) with values ranging from 5.40-24.65, 17.10-25.87, and 5.00-22.97 mm/day for maize, tomato and banana for the periods 2010-2019, 2050-2059 and 2090-2099. Increased crop water requirements will have negative consequences on agriculture and livelihoods of the communities and subsistence farmers. Similar studies in other catchments and covering more crops are essential to further contribute knowledge on climate change impacts.

Keywords: climate change; climate projections; reference crop evapotranspiration; crop water requirements

Ecological infrastructure as a sustainable solution for water security of rural communities

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The recent South African drought has resulted in crop losses, imposition of water restrictions, and impacts on water and food security. Instead of building more dams or conducting interbasin transfers, the approach of protection and rehabilitation of ecological infrastructure (EI) or nature-based solutions is gaining steam globally for benefits of water security and ecosystem functioning. South African landscapes are a legacy of unsustainable land practices and historical inequitable ownership that is being redressed through land redistribution and sustainable land management. Intact or well-managed EI provide various ecosystem services including water filtration/purification, seasonal flow regulation, erosion and sediment control, and habitat preservation. Our presentation will share results from a Water Research Commission study that evaluated how EI could facilitate drought mitigation in the rural area of Machubeni in the Eastern Cape. We focused on four EI land cover types (grasslands/rangelands, riparian zones, wetlands, and abandoned croplands) that are known focal areas for invasive alien plant invasion, and which provide benefits to local communities and support flow regulation ecosystem service (SDG Target 6.6).

Restoration interventions in line with SDG 15.3, to achieve a land degradation neutral world by 2030, need to be targeted to specific locations to increase their effectiveness. Therefore, an evaluation of land degradation of the four EI land types (using Conservation International's Trends.Earth tool) was conducted before identification of priority restoration areas for improving flow regulation. A stakeholder-driven (local and expert) Analytic Hierarchical Process that integrated indicators for ecosystem health, hydrological functionality, and social benefit, was utilised for this end. Finally, hydrological modelling using the Pitman Model was conducted to represent the runoff regime in natural vs modified catchment areas. This study presents a methodology for application in other rural areas where local communities are directly dependent on ecosystem services for livelihoods, in addition to food and water security.

Keywords: hydrological functionality, rural water security, land degradation, nature-based solutions, ecological infrastructure

Using the water balance approach to understand pool dynamics along non-perennial rivers in semi-arid areas of South Africa

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The study sought to improve the understanding of pool dynamics along non-perennial rivers (NPRs) by utilizing the water balance approach to assess the water fluxes that influence pool dynamics in the Touws River. The water balance model made use of various in-situ and satellite-derived data. The analysis of water losses from the pool showed that 90% of water was lost through evaporation, while only 10% (~60 mm/month) was lost to the surrounding areas. This points towards seasonal and minimal interaction between groundwater and the pool water. When the Wolverfontein 2 pool is full, it can retain water for approximately 258 days without surface water inflow. A water balance model was established and it simulated the water levels with a high correlation (r = 0.9). The water balance model was also tested in neighbouring pools, the model simulated water levels of the upstream pool well, but not so well with the pool downstream. When remote sensing rainfall and evaporation data was used in the model. The simulated water levels had slightly lower correlation (r = 0.7) with observed water levels. Overall, the remotely sensing based monthly flux estimates could not provide detailed pool information as required for water balance. Errors may have arisen from being inherited from any of the remotely sensed three parameters: surface area, rainfall, and evaporation. Although remote sensing did not provide detailed information, it is noteworthy that it provides a baseline information on pool dynamics. Overall, the study showed that the water balance approach with limited data can be used to understand pool dynamics for better management of NPRs

Keywords: Pool hydrodynamics, Temporary rivers, Water budget, River Ponds

Hydrological modelling for estimating water availability for irrigation supply in selected schemes in Nzhelele Area.

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The aim of the study was to undertake hydrological modelling for estimating water availability for irrigation supply in selected schemes in the Nzhelele area. To achieve this, the SWAT model with Arc-SWAT interface was used to estimate streamflow while Hargreaves evapotranspiration together with crop coefficient equations were used to determine crop water requirements. Daily hydrometeorological data (1987 – 2014) were used to build the SWAT model. Due to data limitations, the model calibration was done from 1991-2000 and validation from 2001-2009. Crop water requirements were computed for four major crops (maize, groundnuts, sweet potato, and green beans) that are planted in the smallholder irrigation schemes. Inflows into the irrigation schemes were simulated from the calibrated model. The model performance was assessed using the coefficient of determination (R2), Nash-Sutcliffe coefficient efficiency (NSE) and the percent bias (PBIAS). The R2, NSE and PBIAS values for calibration and validation ranged from 0.78, 0.56 and 7.7%, and 0.60, 0.56 and -8.3%, respectively, indicating good model performance. The crop water requirements for all crops were found to increase with a development stage. The results indicated that the available water is not able to meet the crop water requirements for most periods. Findings of the study will help in irrigation planning and increase water use sustainability while improving performance of smallholder irrigation schemes.

Keywords: crop water requirements, hydrological modelling, smallholder irrigation scheme, SWAT

Assessing Impact of Land use Cover Change in Houtbosloop Catchment

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Human activities, particularly a considerable rise in population, and rapid socioeconomic activities are continually changing the land use and land cover pattern. The influence of such variations in land use and cover on a catchment hydrological system is a widespread concern and a significant issue for water resource management. The difficulty that emerges while analyzing these consequences is the selection of a hydrological model that may be able to handle the geographical and temporal dynamics of the basin with greater precision. In this study, the effect of land use and cover change on streamflow was assessed in the Houtbosloop River (X22A). Houtbosloop River is a commercial forest that is subjected to continuous spatial changes in the forestry. To measure the effect of Land use and Land cover on streamflow SPATSIM was selected to simulate parameters. To classify satellite images, ENVI 5.3 software was used employing the supervised-maximum likelihood classification method. The results show that in 1993 forested land is 65% and bare land is 35%, in 1996 forested land is 71% and bare land is 29%, in 1997 forested land is 61% and bare land is 39%, in 1999 forested land is 59 and bare land is 41%, in 2001 forested land is 53% where bare land 47% and in 2018% the forested land is 57 and bare land is 43%. After the segmentation of the result, it was then justified that land cover associated with afforestation and low flows are 1993,1996, and 1999 and land cover associated with deforestation and high flows are 1997, 2001, and 2018. This result implies that the catchment needs proper management, furthermore commercial forest is not the problem but through management, stream flow can be managed.

Keywords: Land use and Land Cover Change (LULCC) 1; 2 Spatial and Time Information Modelling SPATSIM; 3 Environment of Visualising Images (Envi 5.3)

Are all wetland models the same? Comparing the modelled impacts of a valley-bottom wetland on floods and droughts

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Wetlands are valued for their potential to increase the resilience of water resources to climate-related extremes such as floods and droughts. With many hydrological modelling tools available for use, wetlands are simulated differently in each tool and most tools focus on a specific wetland type. In addition to this, streamflow regulation varies by wetland type and the extent of the regulation varies between events. This study investigated whether different models predict the same streamflow regulation associated with an unchannelled valley-bottom wetland.

A case study wetland in the Krom catchment, Eastern Cape, was modelled using three configurations: 'riparian zone' and 'wetland' units in ACRU4 and the 'comprehensive wetland' option in WRSM-Pitman. Modelled streamflow regulation was described using two metrics: hydrological impact and wetland fluxes. Hydrological impact compared predicted streamflow from scenarios with and without a wetland. The wetland fluxes evaluated the predicted change in wetland storage (inflows versus outflows). The metrics were estimated for the full simulation period (October 1989 – September 2019) and a subset of extreme events (four flood events and three drought periods).

All wetland models predicted flood attenuation with the hydrological impact ranging from 0.42 – 6.02 Mm3/month. One model, ACRU4's riparian zone, simulated streamflow supplementation during droughts. For all models, the predicted streamflow regulation role of the wetland during drought periods was the same as the role predicted for the long-term average.

These results suggest that the selected modelling tools are suitable for modelling wetlands in South Africa's water-limited environment. However, the models do not yield the same streamflow regulation roles. Awareness of this difference is important for minimising the risk of inaccurately excluding or including a wetland's impact on water yields in water resources planning. The findings highlight the necessity for monitoring more wetlands to determine the thresholds of streamflow regulation and developing hydrological models to represent these processes.

Keywords: extremes; modelling; streamflow regulation; wetlands

Modelling, Assessment And Optimisation Of Rules For Selected Umgeni Water Distribution Systems

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Umgeni Water is a water board that supplies most parts of KwaZulu Natal with bulk potable water. Currently Umgeni Water is running their distribution system based on required reservoir levels and demands and does not consider the energy cost at different times of the day, number of pump switches and background leakages. Including these constraints can reduce operational cost, energy usage, leakages and increase performance. Optimising pump schedules can reduce energy usage and costs while adhering to hydraulic and operational constraints. Umgeni Water has installed an online hydraulic software, WaterNet Advisor, that allows running different operational scenarios prior to implementation in order to optimise the distribution system.

This study will investigate operation scenarios using optimisation techniques and WaterNet Advisor for a local water distribution system. Based on studies reported in the literature, introducing pump scheduling optimisation can reduce energy usage by approximately 30% without any change in infrastructure. Including tariff structures in an optimisation problem can reduce pumping costs by 15%, while including leakages decrease cost by 10% and pressure drop in the system can be up to 12 m. Genetical optimisation algorithms are widely used due to their ability to solve nonlinear, non-convex and mixed integer problems. Other methods such as branch and bound, linear programming have also been successfully used. A suitable optimisation method will be chosen based on its efficiency. The objective of the study is to reduce energy usage, operational cost, and leakages and the feasibility of optimal solution will be checked using the Waternet Advisor. This presentation will provide an overview of the optimisation of hydraulic networks and progress made to date in multi-objective optimisation for a selected sub-system operated by Umgeni Water.

Keywords: Energy usage, pump scheduling, WaterNet Advisor, Leakages

Assessing the water productivity of sweet potato

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In water-stressed countries like South Africa, the reliable quantification of crop evapotranspiration (ET) and yield across a wide range of farming environments is important for improved agricultural water management. As a result, researchers are shifting their primary focus from well-studied major crops to neglected and underutilised crops. Sweet potato (Ipomoea batatas L.) remains an underutilised root and tuber crop (RTC) in South Africa, despite its potential as a nutrient-dense, high yielding, and water use efficient crop. It is important to investigate whether the water use of sweet potato will hinder its production at the commercial scale. This study aims to quantify crop ET, yield, crop water productivity (CWP) and nutritional water productivity (NWP) of orange-fleshed sweet potato (OFSP). This crop was selected due to its drought tolerance, high yield potential and high nutrient content, particularly beta-carotene. On 14 December 2021, OFSP was planted and grown for 120 days under rainfed conditions at Fountainhill Estate (KwaZulu-Natal, South Africa). Crop ET was estimated using the soil water balance method accumulated over the growing season to determine crop water use. This presentation will include results of tuber yield, final biomass production, nutrient content and crop water use, as well as CWP and NWP. Other growth measurements were used to partially calibrate certain crop parameters required by FAO's AquaCrop model. The model was run to simulate yield, crop ET and CWP of OFSP. A comparison between observations and simulations will be provided in the presentation. The research output will be used to develop suitable management practices, which should help promote the production of OFSP. Agricultural expansion via OFSP cultivation in rural communities can help create jobs and alleviate hunger, malnutrition and poverty.

Keywords: Sweet potato, evapotranspiration, water productivity, AquaCrop

A review of the trends in hydrological extremes and incorporation of non-stationary hydrological data into design flood estimation in South Africa

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The current methods and models used to estimate design floods in South Africa assume that data and hydrological processes are stationary. However, the magnitude and frequency of extreme events have in recent years shown non-stationarity behaviours due to climate change. Climate change is due to high accumulation of greenhouse gases in the atmosphere, which has resulted in global warming. It is proposed that global warming is driving the increase in frequency and magnitude of extreme hydrological processes such as storm and flood events in some parts of the world. Studies in South Africa reported that temperature is likely to be at least 3 ℃ warmer than the period 1961 – 2000 by 2050. Atmospheric models generally indicate an increase in extreme events for South Africa. However, there is currently no consensus in the literature between the trends of detected and observed rainfall and runoff data. There is also no consensus on whether the prevailing trends in observed flood series are caused by anthropogenic factors such as land use, climate change, and changes in water use. The recent April 2022 flood events in KwaZulu-Natal province challenge the assumption of stationarity as currently practiced in flood frequency analysis in South Africa. Design flood estimation is required to minimise the risk of failure of hydraulic structures. However, no studies in South Africa have estimated design floods using non-stationary data. Moreover, the current methods used globally to determine trends in hydrological extremes are primarily on a catchment scale. The current methods include the Mann-Kendall test, regression model, and magnification factors. Therefore, the current research aims to incorporate non-stationary data in estimating design floods. This presentation will provide an overview of the literature and state-of-the-art on the detection of trends in South African data as well as a methodological overview, including the use of regional magnification factors. It will also review links between projected changes to output from climate and rainfall from atmospheric modelling. Finally, the review will outline a roadmap to incorporate non-stationary data in modelling design flood estimates in South Africa.

Keywords: design floods, hydrological extremes, and non-stationarity.

Modelling the impact of climate change on hydrology of Latonyanda River Quaternary Catchment (LRQC)

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This study assessed the impact of climate change on hydrology of Latonyanda River Quaternary Catchment (LRQC) using an integrated hydrological model. Using a model that integrates both land-use/land cover and climate change is crucial as it will help in improving the understanding of their impacts on hydrology. Arc-GIS 10.7 model with a compatible version of Arc-SWAT interface was used to model the impact of climate change on hydrology of LRQC. The Soil and Water Assessment Tool (SWAT) model was set up for calibration and validation using historic data for 13 and 6 years, respectively. Model performance was evaluated using graphical fits and performance measures which include coefficient of determination (R2), Nash Sutcliffe efficiency (NSE) and percent bias (PBIAS) was assessed based on scatter plots. Climate change projections were input in the calibrated model to simulate streamflow for the near and far future. Regression analysis was conducted to determine trends on annual average historical, near and far future flows and their statistical significance using the Data Analysis tool in Microsoft Excel. The model performance was good and acceptable with R2, NSE, and PBIAS for both calibration and validation as 0.70 and 0.69, 0.67 and 0.68 and -9.3 and -13.4%, respectively. Regression analysis displayed variable trends for historical, near and far future flows, respectively, which were not statistically significant. Findings of the study show that streamflow amount is decreased over time with annual average totals of 4.849, 2.340 and 2.051 m3/s for the historical, near and far future respectively. This study recommends venturing into water smart development technologies that can be implemented to minimise the impact caused by climate change.

Keywords: Climate change; integrated hydrological model; streamflow; regression analysis

Investigating the accuracy of various speckle filters for soil water content estimations in north-eastern Hungary

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For centuries, soil water content (SWC) measurements have been of great interest in agricultural studies. To measure SWC in field conditions, commercial sensors have been commonly used. However, remote sensing has recently been used to develop regional and global SWC products. The most common active microwave sensor in SWC mapping is Synthetic Aperture Radar (SAR). SAR instruments use a synthetic technique that measures high-resolution backscatter images reflected off objects on earth. The measurement of backscatter coefficients can be challenging due to the 'speckle/noise' of SAR remote sensed images. The presence of speckles reduces the quality of ground detected surfaces and brightens pixels in neighbouring areas. To fully understand the application of the speckle filters, a study area in north-eastern Hungary was chosen with undulating terrain and various geomorphological units. The study used the EnviroScan sensor, a stand-alone continuous soil water monitoring system, to record in-situ SWC real-time, demonstrating the crop's complex water usage in response to changing environmental conditions and irrigation management strategies. Then, spatial interpolation methods were utilized using terrain covariates and refined satellite imagery to estimate SWC. Model accuracy was tested by investigating the application of three speckle filters to Sentinel-1 imagery. The study's findings show that all speckle filters directly impacted the model's performance in estimating SWC and the estimation error of the model. Of all the speckle filters used, when the Lee Sigma filter was applied to the Sentinel-1 imagery, the best SWC model results were achieved, improving the mean model performance from an R2 of 0.30 to 0.74 and reducing the mean RMSE of the estimation from 7.56% to 2.83%. In conclusion, speckle filtering is useful in improving the quality of the backscatter coefficient and valuable in improving model performance even when using a small sampling density.

Keywords: Soil Water Content, SAR, Speckle Filters

Identification and prioritization of areas for riparian buffer restoration in the Sout River catchment, Overberg District, Western Cape

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Phosphorus-rich sediments contaminate rivers in agricultural settings. Phosphorus binds to fine sediments and gets transported to the rivers through surface runoff. Therefore, measures need to be put in place to prevent further degradation and protect water resources. Riparian vegetation strips absorb nutrients and can limit the amount of pollution entering streams. They slow down sediment-laden runoff and may deposit or absorb nutrient and pollutant-bound sediments. However, their effectiveness depends on their spatial placement within the catchment. Therefore, this study aims to develop an approach to prioritizing riparian areas for buffer restoration that incorporates both buffer effectiveness (connectivity) and opportunity (phosphorus concentration).

The aim was achieved by determining the spatial variation in the index of connectivity (IC) in the catchment, measuring longitudinal variation of adsorbed phosphorus concentrations and comparing them with background levels at a natural reference site. IC was assessed using the SedInConnect geospatial modelling tool. NDVI was used as a vegetation cover model alongside IC to produce a sediment-associated phosphorus contamination risk map. Sediment samples were collected from slack water deposits and analysed for adsorbed total phosphorus concentration, particle size and organic carbon percentage. Water samples were also collected and analysed for orthophosphate concentrations.

The results show low IC values upstream and on the southern side of the catchment, whereas high IC values are observed on the north-eastern side and downstream. Adsorbed phosphorus concentrations are lower upstream and higher downstream compared to background concentrations. There are no statistically significant correlations between adsorbed phosphorus concentration and orthophosphate, organic matter, and particle size. The sediment-associated phosphorus contamination risk map shows that areas with high connectivity are associated with high concentrations of adsorbed phosphorus and vice versa. Therefore, these results suggest that areas that should be prioritized for riparian buffer restoration are those located on the north-eastern side of the catchment.

Keywords: Geospatial modelling, Index of connectivity, Phosphorus-rich

Groundwater Modelling Of Lake Sibaya Under Various Landcover And Climate Scenarios Advised By Plant Water Source Partitioning Using Isotopes

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Within the past three decades, research has been conducted within the Lake Sibaya groundwater-dependent catchment, located in uMhlabuyalingana (KwaZulu-Natal), driven by the continuous decline in lake water levels and groundwater stores. Below average rainfall and expanding forestry plantations are evoked as the primary causes of water depletion in the area. Bush encroachment is also speculated to contribute to the decrease in groundwater stores. Extended periods of below average rainfall are thought to be caused by climate change, however, there has not been any conclusive climate change projections made for the region. An existing MODFLOW groundwater model is being updated based on improved input data as well as more accurate land-use and land cover (LULC) changes, factoring climate change projections. LULC changes and land-surface hydrological processes are being modelled using the ACRU surface-water model and accounted for in the groundwater model through recharge matrixes provided by ACRU. Simulations of future scenarios (ending in 2050) of LULC changes focus on forestry plantations (Eucalyptus grandis and Pinus elliottii) and bush encroachment, climate projections look at wetter and drier conditions under a warmer climate. Source water uptake by plants is being increasingly studied using stable water isotope tracing techniques. Results from stable water isotope analysis of plant transpired water, rainwater and groundwater are used to validate landcover water source parametrization in the ACRU model. The aim of the study is to illustrate the response of the Lake Sibaya water system (lake and groundwater) under various LULC changes and under various climate change scenarios. Final results are expected to unravel the respective importance of changes in LULC and climate on the degree of impact on water levels by 2050. Intuitively, with wetter climate conditions, increased water levels are expected irrespective of the land-use conditions and vice versa for drier conditions, exacerbated by a warmer climate.

Evaluation of Soil Moisture Estimates From Satellite-based and Reanalysis Products over Two Network Regions

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The soil is an important variable of the hydrological cycle. It plays a key role in the distribution of water and energy fluxes between the surface and atmosphere. Soil moisture data can be used to develop early warning systems for flood and drought monitoring, improve weather and climate forecasting and provide an indication of crop water requirements. Therefore, the regular monitoring of this variable can prove to be beneficial to various management applications. One of the main issues associated with estimating soil moisture is to adequately account for its spatial and temporal variability as it is influenced by factors such as climate, topography, soil properties and land cover. There are different methods available to derive soil moisture estimations such as in-situ, remote sensing and modelling based approaches. In-situ methods generally produce reliable soil moisture estimates, however, are only suitable for small scale studies. Alternatively, remote sensing and modelled reanalysis methods can provide soil moisture estimates over a large spatial extent, however, they are generally limited by their coarse spatial resolutions and may not be suitable for localised applications. In-situ methods can be used to validate remote sensing and reanalysis data, however, the scale mismatch between these methods make validation using in-situ data unreliable. Therefore, the aim of this study was to implement and evaluate a downscaling technique across two regions (South Africa and USA) to ultimately produce finer scale soil moisture and address the scale mismatch between in-situ methods and coarse resolution products. This procedure was facilitated by GEE and R, which showed significant potential for data processing and analysis. Additionally, satellite-based and reanalysis products were also evaluated to determine which of these methods are more suitable for soil moisture estimation. The soil moisture products and the downscaled products were validated against the CRNS instrument, which was particularly chosen for its performance at an intermediate spatial resolution. Based on the validation results obtained for the soil moisture products, both the CFSV2 and SMAP_25 km products performed best. The CFSV2 product was ultimately selected for the downscaling component of the study. It was deduced that the application of downscaling was only successful for the Mead CSP3 study site in the USA. The downscaled data for the York Benny site, however, only exhibited small differences when compared to the CFSV2 product. The Two Streams site produced poor downscaled soil moisture estimates with significant differences observed in the statistical results. Therefore, the application of downscaling in this study did not necessarily lead to an improvement of results.

Keywords: Soil, Moisture, Estimation, Downscaling, Observations

Assessing and improving the simulation of runoff and design flood estimation in urban areas using the ACRU and SCS-SA models

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Urbanisation is increasing at a fast rate. Pervious and vegetated land is being rapidly replaced by impermeable surfaces (roads, pavements, driveways, parking lots, etc.) resulting in large portions of total imperviousness in catchments. The expansion of urban areas alters the natural underlying surface condition affecting catchment characteristics. The most common impacts of urbanisation on the hydrology of a catchment are increased runoff volumes, reduced baseflows owing to less infiltration taking place and a decrease in catchment response time. These changes can result in increased flood risk and subsequent damage to urban infrastructure and affect livelihoods. Therefore, accurate modelling of runoff and estimation of design floods of highly urbanised areas is necessary, especially in catchments that comprise of a mix of informal urban land uses such as peri-urban areas. Peri urban areas are defined as those areas located adjacent to a city area and have a mix of both rural and urban characteristics. The ACRU and the Visual SCS-SA rainfall-runoff models were selected for application on catchments with typical South African urban conditions. The models have been developed and tested in urban catchments, however not extensively. The study areas are located in the South African urbanised cities of Tshwane and Pietermaritzburg. ACRU is a daily time step conceptual and physically-based agro-hydrological model that is relatively more data intensive compared to the simplistic SCS-SA model. Therefore, information systems such as Remote Sensing (RS) and Geographic Information System (GIS) have been explored to aid as data sources and tools for acquiring model input parameters, at a more accurate level. Land cover classifications using the supervised pixel-based method was carried out and completed for the three urban study catchments. Additional land cover classification and impervious data was also used and extracted from the readily available datasets i.e. South African National Land Cover Database (SANLC), Global Man-made Impervious Surface (GMIS) and the Global Artificial Impervious Areas (GAIA). Several model input data such as slope, elevation, and total imperviousness were estimated through the application of RS and GIS methods

Keywords: Remote sensing, ACRU, SCS, pixel-based classification

Orographic influence on the distribution of rainfall in the Luvuvhu River Catchment

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The study was carried out in the Luvuvhu River Catchment (LRC) to investigate the influence of topography on rainfall distribution. Rainfall distribution is an important hydrometeorological variable which determines the livelihood of communities and biodiversity. Rainfall data for more than thirty years, from 1960-to 2018, for 20 rainfall stations within LRC were used. Principal component analysis (PCA) with factor analysis was used for analysing rainfall to identify different classes that share similar rainfall behaviour. In addition, canonical correlation analysis was used to show the effect of the relationship between rainfall variables and topography. For PCA, two factors extracted after varimax rotation showed 59.7% and 39.3% rainfall variance within the LRC. The rainfall variables used were average rainfall, standard deviation and coefficient of variation. Topography variables included altitude, slope and aspect. The results revealed a high correlation coefficient (r=0.8) between average rainfall amount and altitude. Analysed spatial pattern of rainfall was analysed and revealed that rainfall increased towards the mountain on the south-east-facing slope. The study recommended further analysis of stations on the leeward side of the Soutpansberg mountain.

Keywords: orography, rainfall distribution, canonical correlation analysis, Soutpansberg, principal component analysis

Rainfall-Groundwater Relationship, groundwater-surface water relationship, and groundwater dynamics in the Maputaland Coastal Plain

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Understanding the recharge process and its relationship to rainfall is critical to managing the groundwater system in Maputaland Coastal. Maputaland Coastal Plain (catchment W071A) has the largest freshwater lake Sibayi, a topographically closed freshwater lake fed by groundwaters from coastal aquifers surrounding it. The lake has undergone a substantial decline in volume-area and depth. The cause of the shrinking of the lake may be related to changes in rainfall or land use or both. To better understand the cause of the lake level decline one must first understand the relation between rainfalls and response of the groundwater to rainfall intensities. Modelling the hydrological responses require a well-constructed realistic conceptual model on interconnectivity between aquifers and the groundwater discharge mechanisms. Therefore, this study investigates the rainfall-groundwater recharge relationship, aquifer connectivity, and groundwater discharge mechanisms using stable water isotopes (δ180 and δ2H) of water. Monthly groundwater and surface water, and daily rainfall samples were collected. The results indicated that groundwater in the region could be clustered into two groups. Group one encountered under the range of 2.173‰ -2.6‰ and fell far from the local meteorological water line indicating a mixture between the lake water and groundwater. Group two falling under the range of -3‰ to ‰-4.6, recharged from the local precipitation as they fell around the local meteorological water line. Stable isotopes (δ180 and δ2H) of group two groundwater samples regress to values along the local meteorological water line that is depleted relative to the composition of rainfall isotopes, consistent with a conclusion that rainfall above 35 mm of daily precipitation intensity is required to recharge the aquifers. The less than +/- 0.26 δ180 difference between the shallow and the deeper groundwater indicates the presence of a connection between aquifers, regardless of their depth further indicating that a one aquifer layer model is a viable conceptual model. Lake and surrounding streams isotope data indicated a high contribution of groundwater to the streams.

Microplastics dispersal patterns across an anabranching reach of the Orange River, Northern Cape, South Africa

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Microplastics (size less than 5 mm) transported into and by a river system are likely to be retained in riverbank and floodplain sediments as a function of fluvial dispersal and sedimentation processes, and may be stored for months, years or decades depending on the location of deposition and depth of burial. Changes in river energy induced by (but not limited to) high rainfall events may result in the remobilization and reintroduction of stored microplastics into flowing water thus leading to further distribution of microplastics in rivers. This illustrates the importance of understanding fluvial sediment dispersal and exchange flux systems in investigating the dispersal patterns of microplastics in freshwater systems, as they are potential retention zones for both buoyant and non-buoyant microplastics. This is especially applicable for Anabranching Rivers characterised by stable mid-channel islands overgrown with dense vegetation thus creating conducive environments for efficient sediment and microplastics trapping. This study assessed the distribution patterns of microplastics across an anabranching reach of the Orange River, with a view to understanding the overall pattern of dispersal and its controls, and the extent to which microplastics are sequestered within deposited sediments. To achieve these objectives, 45 sediment samples were collected from waterlain slackwater deposits which were analysed for microplastics content. The sample concentrations recorded ranged from 0 items 100/g to 140 items/g. Fragments accounted for 62% of the total observed microplastic items sampled, followed by fibres (29%) and microbeads (9%). In contrast to previous studies conducted in depositional environments, no significant relationship was found between microplastics and environmental variables (organic content, clay, and silt and sand fractions). This study provides insight into the linkage of the spatial distribution of microplastics with sediment transportation patterns in dynamic river systems where multiple channels exist, which may potentially filter and reduce microplastics transported into oceans.

Key words: Emerging contaminants; fluvial dispersal; hydro-geomorphological controls

Comparison and Validation of Global Hydrological Model Outputs against Local Hydrological Data: A Case of Sub-Saharan Africa

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Highly uncertain outputs are being used for assessment, planning and management of water resources in Sub-Saharan Africa (SSA) as a result of poor data quality and quantity within the region. The data scarcity is a threat to sustainable water resources assessment in SSA and is propelled by paucity and absence of hydro-climatic and hydro-meteorological monitoring networks, and deteriorating data recording and reporting systems. Additionally, lack of local capacity in generation of data and the modelling process as a whole, has led to unfamiliarity with hydrological models among Africans as many of the hydrological modelling studies are conducted by non-Africans. The limited professional competence and required expertise to develop, setup and update modelling systems besides interpreting results, threatens the future sustainability of water management with the imminent changes in climate, water demand, and population. As regional models have numerous parameters and data requirements demanding technical expertise, along with the scarce in-situ data, studies within the region often use global hydrological models (GHMs) and datasets to extrapolate outputs for applications at basin-scale. However, the success of these outputs is highly debatable as different models produce different outputs even when applied in the same basin and studies have shown that GHMs outputs either overestimate or underestimate observed parameters. This paper, therefore, seeks to identify regions in SSA where information exists and where local capacity was involved in information gathering and the modelling process using systematic literature review on hydrological modelling in SSA. Additionally, performance of outputs from global hydrological models was compared to outputs from available local observation datasets using case studies that applied goodness-of-fit measures within the region to determine the validity of GHMs at basin scale.

Keywords: Data scarcity, information reliability, local capacity, model performance, sub-Saharan Africa

An approach to evaluate the effects of complexity on water quality modelling performance and uncertainty

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The Hartbeespoort Dam Catchment is a highly modified system characterized by high return flows from wastewater treatment works of water transferred from other catchments. It drains off the two major cities in the Gauteng Province (Johannesburg and Pretoria), and it is dominated by urban, agricultural land uses and, to a lesser extent, mining activities. Eutrophication is a looming threat in this catchment. This is evident in the hypertrophic condition of the Hartbeespoort Dam. This article aims to use the Hartbeespoort Dam Catchment as a case study catchment to conduct a comparative analysis of the use of a simple and a complex water quality model, to derive uncertainties associated with the modelling outputs and incorporate these uncertainties, to compare the applicability of results for water quality management decision making. The VLB Stochastic rainfall generator will derive stochastic rainfall sequences based on mean annual precipitation, dry year, median year, and wet year rainfalls to drive the water quality simulations. The Water Quality Systems Assessment Model (WQSAM) was selected as a simple model because of its simplified structure of applying water quality signatures and its reliance on flows from existing water resource models. The WRSM daily version was used to simulate incremental runoff. The SWAT+ was selected for application as a more complex model as it represents hydrological processes more comprehensively and is flexible in model configuration and interlinked with GIS. Baseline results from a simple model show that the Jukskei River yields high concentrations of Phosphates (PO4) (>0.35 mg/l) and Nitrates (NO3) (> 3.9 mg/l) on a long-term median. Most of the nutrients from the Rietvlei River are retained by the Rietvlei Dam, while phosphates and nitrates from the Jukskei River ends-up at the Hartbeespoort Dam through the Crocodile River.

Keywords: Hartbeespoort Dam Catchment; Water Quality Modelling: Water Quality Systems Assessment Model; SWAT+.

National State of Water Report 2021

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The Department of Water and Sanitation (DWS) collects data through its monitoring programmes, which is captured, stored, and analysed in various information systems. Data is collected to check compliance to licence conditions, monitor water use, as well as to assess trends and status of the quality and quantity of water resources in the country. DWS, as part of its water resource management functions, disseminates data and information available to the public. The National State of Water report sets out to communicate the available water resources information through an integrated reporting that assists water managers and policymakers in decision making. The report highlights include: identified problem areas; the status of water resources and sanitation; measures taken to improve water supply and demand; status of monitoring programmes, and analysis of report outputs. The National State of Water Report is completed and published annually with most of the indicators reported based on a hydrological year period. The report is published on the DWS: Website: DWS: National State of Water Report. Highlights from the 2021 report are that the past decade has been hotter than the average annual surface temperatures; The southern parts of the Eastern Cape and south-eastern parts of the Northern Cape are still experiencing drought; hydrological year 2020/21 was the highest in terms of dam levels in the past five years; The average groundwater level status is at below normal compared to historical status, however, a recovery from the 2014-2019 period; Below normal streamflows are experienced in the Vaal and Orange Rivers due to large dams and system operations; Surface water cannot be consumed without any treatment for almost every parts of the country due to microbial contamination. Between 50-60% of the rivers have remained in moderately modified ecological conditions in the last three years. Largely modified rivers are in the Upper Crocodile(west) and Upper Vaal sub-catchments.

Keywords: Department of Water and Sanitation (DWS); National State of Water Report; Ecological Condition, Groundwater level status, Drought, Dam levels.

Updating the rainfall-runoff model for Latonyanda River Catchment in Limpopo Province, South Africa

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In this study, MIKE 11 NAM rainfall-runoff model for Latonyanda River Quaternary Catchment (LRQC) was updated. Updating a hydrological model assists in enhancing the understanding of catchment response to variable climate. This is crucial as continuous streamflow data is required to ensure proper water resources allocation, planning and management. The upper LRQC, was delineated for rainfall-runoff modelling using MIKE 11 NAM model due to that the outlet of the catchment is ungauged. Calibration and validation were carried out using data for periods of 4 and 3 years, respectively. The shuffled complex evolution optimizer was used to calibrate the model. The model performance was tested using graphical fits, coefficient of determination (R2), root mean square error (RMSE), correlation coefficient (R), percentage bias (PBIAS) and overall water balance error (OWBE). The observed and the simulated streamflow showed similar trends and measures of performances for both calibration and validation runs fell within acceptable ranges. The pairs of values obtained for R^2, RMSE, R, PBIAS and OWBE for calibration and verification were 0.66 and 0.61, 3.71 and 2.93, 0.81 and 0.78, 1.81 and 1.33, 1.8 and 1.3, respectively. This indicates that the model can be successfully used for future hydrological modelling in the area. In order to improve the modelling results through capturing the spatial variability of areal rainfall within the study area, the two non-functioning rain gauge stations must be reinstalled.

Keywords: hydrological model, MIKE 11 NAM, ungauged, performance measures, rainfall-runoff modelling

The hydrological impacts of restoration: A modelling study of alien tree clearing in four mountain catchments in South Africa

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Ecological restoration efforts at scale have been shown to play an important role in reducing human impact on the environment, improving climate change adaptation and halting extinctions globally. Upscaling restoration efforts requires funding, and therefore evidence of the benefits of restoration is needed. This study aims to contribute towards addressing these gaps by: (1) bolstering the evidence base of the water-related impacts of investment into ecological restoration by improving the methods of predicting the streamflow impacts of alien tree clearing; and (2) exploring the potential size of the variability in catchment responses at a fine-scale (60x60 m) in one particular region by comparing four different neighbouring catchments. We model the impacts on streamflow in four strategic water providing catchments using the fully-distributed MIKE-SHE modelling tool. We find that the benefits of clearing mature infestations of alien trees, such as pines, from naturally tree-less ecosystems can increase available surface water resources by 15.1 to 29.5%. Clearing riparian invasions is predicted to have a 1.7 times greater impact compared to terrestrial (non-riparian) invasions. The largest modelled impact of restoration on streamflow is on the mid to low flows, and this impact is greater in dry years relative to wet years. The findings are novel in that they shed light on the types of spatial uncertainties that can be expected in modelled gains, with implications for generalisation. These findings are important for leveraging investment to upscale restoration efforts in water scarce regions, as they suggest improved water security during the dry season and droughts. Upscaling efforts are essential if the degradation of ecosystems globally is to be prevented, halted and reversed, as proposed by the United Nations Decade on Ecosystem Restoration.

Keywords: Nature-based solutions, Ecosystem services, Ecohydrology, MIKE-SHE, Restoration, Biodiversity hotspots

Quantifying water use and nutritional water productivity of sweet potato (Ipomoea Batatas)

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Root and tuber crops (RTCs) such as cassava, sweet potato, taro and yams are the important food crops for direct human consumption in Africa. RTCs play an important role in world food security due to their high nutritional value when compared to other crop groups. However, with global freshwater resources declining, there is increased pressure on agriculture to produce more food using less water. Despite emerging interest in RTCs due to their high nutritional value and their resilience to climate extremes, a paucity of information describing their agronomic requirements, production guidelines, water use, and yield has hindered their widespread adoption by farmers in Southern Africa. The aim of this study was to quantify the water use, yield, and nutrient content of selected landraces of sweet potato from KwaZulu-Natal, South Africa. From the results, crop and nutritional water productivity were estimated. Research trials were conducted at Fountainhill Estate in KwaZulu-Natal (South Africa), where two micrometeorological techniques (eddy covariance and surface renewal) were setup to measure crop water use. From measurements of crop development over the growing season, certain crop parameters were calibrated for use in FAO's AquaCrop model. The model can be run for up to 5838 homogeneous response zones in the country, each driven with 50 years of daily climate data, to produce national-scale maps of crop yield, including crop and nutritional water productivity. The crop model can also be used to derive crop coefficients, which are required as input into a hydrological model (ACRU) to estimate the impact of RTC production on downstream water availability. Overall, reliable research focusing on the agronomy, water productivity and nutritional value of different RTCs will help to successfully promote their production by both emerging and commercial farmers, which would help particularly in rural areas in addressing food security, unemployment, and inequality.

Keywords: agronomy, eddy covariance, sweet potato, surface renewal, water productivity

Can freely available weather data and deep learning accurately predict stream flow in a South African semi-arid catchment?

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Accurate streamflow information is important to properly manage South Africa's scarce water resources and to develop informed climate change adaptation strategies. Monitoring of streamflow is, however, declining. This study hypothesized that freely available weather data can be combined with deep learning for streamflow prediction. The weather data included maximum and minimum temperature, precipitation, relative humidity, wind speed and solar radiation (sourced from the Climate Forecast System Reanalysis database). Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) network models were trained using 30 years of daily weather and streamflow data. Five years of daily streamflow values not used in model training were then compared to simulated streamflow. The root mean squared error (RMSE) and the coefficient of determination (R2) were used to assess model performance, with lower RMSE and higher R2 values indicating better performance. The lowest RMSE value obtained for both the LSTM and GRU models, which performed similarly, was 2.9 $m^3 s^{-1}$ and is considered low (for reference, the mean streamflow is 2.2 $m^3 s^{-1}$ and the standard deviation is 3.3 $m^3 s^{-1}$). The highest R2 value obtained was 0.42, therefore, the models were considered only moderately accurate. Actual weather station data were then run to test the impact on model performance. Results showed a considerable increase in accuracy, with RMSE and R2 values of 2.5 $m^3 s^{-1}$ and 0.69, respectively. All the models captured the general seasonal trends, such as high flows during wet seasons and low flows during dry seasons. The models failed, however, to accurately predict peak flows, apart from a few cases where the weather station data driven models showed increased accuracy. Future work will aim to improve peak flow predictions and investigate the most important variables to enable extension of the models to other catchments.

Keywords: Streamflow prediction, rainfall-runoff modelling, artificial intelligence, deep learning

A National Assessment of Potential Climate Change Impacts on Water Resources in South Africa

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To be able to plan for the future, it is important to assess what climate change is likely to mean for water resources in South Africa. Projections for RCP8.5 from six CMIP5 global climate models were dynamically downscaled and bias-corrected, then converted from point to catchment resolution. These daily climate scenarios were used as inputs into the process-based, agro-hydrological ACRU model. Projected changes in hydrological responses (e.g. streamflow and hydrological yield) were determined for South Africa (SA) at altitudinal Quinary Catchment and Quaternary Catchment scale. While temperatures and potential evaporation are projected to increase throughout SA, projected changes in rainfall, streamflow and hydrological yield vary regionally. Design rainfall and design streamflows for the 1 in 10-year and 1 in 50-year return periods were also determined and are projected to increase in many areas of SA. This means increases in extreme rainfall and flood events are to be expected and need to be adapted to.

Keywords: Climate change, water resources, hydrological yield, global change

Impacts of soil carbon on hydrological responses – a sensitivity study of scenarios across diverse climatic zones in South Africa

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Soil organic carbon (SOC) content and the water holding capacity of soils are two properties which link the carbon and hydrological cycles. Hydrological model inputs seldom include soil carbon as a parameter even though soil carbon content is known to influence soil water retention capacities. This study is a sensitivity analysis of changes in hydrological responses when the model inputs include different soil carbon percentages for the topsoil horizon. Sensitivities of hydrological responses such as transpiration, runoff volumes, the stormflow component of runoff and extreme runoff events to SOC content were quantified under various climatic conditions in South Africa. The soil water holding capacities at the drained upper limit (i.e. field capacity), permanent wilting point and saturation were calculated for the topsoil horizon, using SOC dependent pedo (soil)-transfer functions for different soil carbon scenarios and locations in South Africa. These variables, together with other pre-determined soil- and location-related inputs, as well as 50 years of daily climate, were then used as inputs in a process-based hydrological model. Overall, it was found that increased SOC content in the topsoil horizon leads to an increase in transpiration, a reduction in runoff, especially in its stormflow component, and a reduction of extreme runoff events. However, these changes are relatively small compared to the influence of climate, particularly of rainfall amount and distribution.

Keywords: Hydrological modelling, Organic matter, Soil water holding capacity, Soil properties

Understanding the hydrological impacts of replacing commercial forestry with macadamia orchards: A case study from a groundwater-driven South African catchment

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As an attempt to reduce water demand, while maintaining livelihood, in the water-stressed Lake Sibayi catchment (Maputaland Coastal Plain, KwaZulu-Natal, South Africa), a 29 000 ha commercial forest plantation will be gradually replaced by macadamia nut orchards. This study seeks to unpack the hydrological and socioeconomic implications of this land use conversion through measuring the water use of three land cover types, viz. macadamia trees, commercial plantations and natural, undisturbed grasslands. Following the development of the first macadamia orchard (100 ha) in 2019, water use monitoring equipment, namely the eddy covariance (macadamia and grassland) and surface renewal (eucalyptus) systems, were installed at these three sites. In addition, groundwater levels were monitored beneath these land uses. Water use follows a distinct seasonal pattern with higher values being observed in summer and lower values in winter for all sites. Daily evaporation values are relatively similar for the three vegetative surfaces and eucalyptus water use is likely to grow rapidly. The macadamia trees are non-bearing due to age and lack of adequate on-farm management activities. The eucalyptus trees, on the other hand, are relatively young (recently planted). Physio-environmental factors contributing to low macadamia water use are centred around the generally low levels of soil moisture due to the combined effects of; (i) the sandy nature of the soils; (ii) high soil temperature; (iii) high atmospheric demand for water vapour and (iv) low precipitation in the area.

Keywords: Eddy Covariance, Eucalyptus, Land Use Change, Macadamia, Water Use

The National Flood Studies Programme for South Africa: Overview and Progress to Date

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Floods have an impact on human survival, economic development and environmental sustainability through loss of life and significant economic loss as a consequence of the failure of structures (e.g. dams and culverts). Estimates of design floods are required for the design of hydraulic structures and to quantify the risk of failure of the structures. Information on flooding is also essential for the development of safe human settlements, particularly in low lying areas.

Historical records of floods are used to both directly estimate design floods from the observed gauged data and to develop methods to estimate the design floods at ungauged sites. The longer the period of available gauged flow data, the more reliable the design floods and methods. Most of the methods currently used for design flood estimation in South Africa were developed in the late 1960s and early 1970s and are in need of updating with more than 40 years of additional data currently available and with new approaches used internationally. In addition, climate change is expected to influence the magnitude and frequency of flooding, and hence this increased variability in flows need to be accounted for when determining flood risk.

Given the above, the South African National Committee on Large Dams identified the urgent need to update the data and methods used for design flood estimation in South Africa and, in conjunction with the Water Research Commission, initiated a National Flood Studies Programme (NFSP) to update these. This paper will briefly summarise the performance of empirical, event-based deterministic and regional approaches currently used in South Africa and will provide an overview of new developments to date. This will include updates to design rainfall and probable maximum precipitation estimation, the identification and recommendation of the best probability distribution to use in flood frequency analyses, the development of regional quantile regression and index flood approaches, the determination of locally derived Curve Numbers for the SCS model using both observed and simulated flows, the development of an ensemble approach for the SCS-SA model, and the development of a continuous simulation approach to flood estimation on a national scale.

Keywords: Updated design flood estimation, South Africa

Soil Erosion Risks and their Patterns in a Peri-Urban Catchment of the Lake Victoria Basin

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Understanding patterns of soil erosion and hotspots in catchments is critical in devising mitigation measures for deteriorating water quality and increasing sedimentation. This study was conducted in the Inner Murchison Bay (IMB) catchment on the northern shores of Lake Victoria, since most soil erosion studies in Sub-Saharan Africa have been focused on rural landscapes with limited attention given to urban catchments. The study sought to identify sediment sources by mapping erosion hotspots using the Revised Universal Soil Loss Equation (RUSLE) model in appendage with field walks. RUSLE model was built in a GIS environment using ArcGIS 10.5 software and a GISUS-M plugin with factors including rainfall erosivity, soil erodibility, slope length and steepness, land cover and support practices. The GIS model was run, producing an erosion hotspot map for the entire catchment. Field assessments were conducted in the catchment to ground-truth the hotspots identified by the model in addition to locating other potential erosion sources. The percentage areas for RUSLE modelled erosion rates were: 66.7% for 0-2 t.ha−1.yr−1; 10.8% for 2-5 t.ha−1.yr−1; 10.1% for 5-10 t.ha−1.yr−1; 9% for 10-50 t.ha−1.yr−1 and 3.3% for 50-100 t.ha−1.yr−1. The average erosion risk was 7 t.ha-1.yr-1 and total watershed erosion risk was 197,400 t.ha−1.yr−1, with croplands and steep areas (LS-factor >20) the major hotspots (>5 t.ha−1.yr-1). Field walk assessments showed that bare (exposed) soils, marrum (gravel) roads and drainage channels are other major erosion sources. Results from this study unveiled a wide range of soil erosion hotspots, which are potential contributors of the overall sediment yield from the catchment into the Inner Murchison Bay (IMB) of Lake Victoria. We therefore recommend that tailored soil and water conservation measures should be integrated into urban physical planning, focusing on non-conventional hotspots like drainage channels and exposed (bare) soil surfaces to ameliorate sediment pollution into Lake Victoria.

Keywords: Land Use Land Cover, Inner Murchison Bay (IMB) Catchment, GIS, RUSLE, Erosion

Assessment of Impacts of Climate Change and Variability on Water Resources: The Case of Kimani River Catchment, Tanzania

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In many regions, increased climatic extremes have adversely impacted food security and terrestrial ecosystems. As a result of climate change and increased development, Tanzania's water supplies are under serious strain. Climate change studies have indicated that rainfall intensities and temperature will increase while annual streamflow are predicted to decrease in the future under Representative Concentration Pathways (RCPs) emission scenarios. Kimani River at the upstream of Rufiji Basin is an important water source for large and small scale agriculture, small hydropower plant as well as inflow to the Ruaha National Park. The catchment is currently experiencing significant water stress as a result of escalating river water abstractions due to population growth, economic development initiatives and climate change. Consequently, low river flows and an elongated dry season have been observed downstream of the catchment in the Ruaha National Parks since the mid-1990s. This research aims to assess the impact of climate change and variability on water resources in the Kimani river catchment and evaluate its implication on water availability for economic and environmental requirements using the CMIP6 climate scenarios under Shared Socioeconomic Pathways (SSP2-4.5 and SSP5-8.5). The WEAP model has been used to carry out a hydrological assessment of water resources for baseline and future climates. The analysis at catchment level has highlighted the impact of climate change on water availability for economic activities and ecological systems. The impacts of the Kimani river low flows and increased dry season length on the sustainability of the Ruaha National Park downstream of the catchment were significant.

Keywords: Climate change; Climate Variability; Environmental flow; Kimani River Catchment; Water security

Innovative Uses of Water from a Raised Clanwilliam Dam

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Construction is underway to raise the existing Clanwilliam Dam by 13m, with a resultant increase in the capacity of the dam from 122 million m3 to 344 million m3. This will provide an incremental yield of 82.1 million m3/a, at a 91% assurance of supply. The additional yield will be used to meet ecological flow requirements, improve the assurance of supply of the existing 12 500 ha of scheduled irrigators, allow for new irrigation development, and increase water supply to rural towns and communities. The project aims to alleviate poverty in a semi-desert region and to promote water allocation reform.

For suitable bulk water conveyance options, new irrigation development supplied from the existing canal system are constrained by the capacity and poor condition of the extensive canal conveyance system that is almost 100-years old, when compared to the identified potential new irrigable areas. Innovative approaches to supply and store water for new irrigation development, either expanding existing farms, more intensive farming or greenfield development were identified and assessed.

Solutions include:

• Keeping a portion of the incremental yield in reserve to cater for the uncertainty of climate change and changing hydrology.

• Using spare capacity in existing canals to supply restitution farms and a historically disadvantaged community.

• 'Best approaches' for the uptake of water on private land, including strategic partnership / mentorship agreements.

• A mechanism for the identification and screening of emerging farmers, to assist with the assessment of water licence applications.

• Socio-economic evaluation proving that the inclusion of a 'betterment' component for the scheme will have a positive socio-economic impact on the area.

Successful planning was achieved by following an integrated and highly inclusive approach, using an innovative approach to the use and development of bulk water infrastructure, to benefit existing and prospective farmers, improve water supply to rural communities, reduce water losses while improving scheme operation, and ensuring socio-economic security for the entire region.

Keywords: Clanwilliam Dam; innovative water use; canal spare capacity; new irrigation development; emerging farmers.

The Water Research Observatory: Developing a cloud-based data platform for water research and hydrological modelling in South Africa

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South African water-related information is being collected in an un-coordinated way across many institutions, and there are risks of losing valuable data because of hard- and software redundancies. The increasingly heterogeneous sources and sizes of datasets are also becoming a major challenge. To address this the Water Research Commission (WRC) is building a Water Research Observatory (WRO) that will consist of a cloud-based data storage platform (Google Cloud Platform) that will enable data discovery, further data processing, big data analytics, and water-related information visualisation. The WRO will also digitise data and reports from past WRC projects and provide guidelines for the future archiving of data according to international standards and privacy requirements. Special attention is being given to enable inter-operability with other databases, data democratisation to ensure access by people with a wide range of technical skills, and a risk-based data access management system to ensure that data is used in a fair and ethical manner. South African standardised layers required to run the Soil and Water Assessment Tool (SWAT) model were recently developed in a WRC project, and an online user-friendly version of the SWAT model (called HAWQS-ZA) is being built to increase access to hydrological modelling and cloud computing across the country. This paper will describe functionality in the WRO that has been developed to date and that could be of interest to hydrologists.

Keywords: Big data, data democratisation, hydrological modelling, SWAT

Application of hydropedological interpretations in hydrological modelling

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Capturing internal catchment hydrological processes in hydrological models is important for accurate predictions of the impact of climate and land-use change on water resources. Characterising and quantifying these processes are however difficult and expensive due to their dynamic nature and spatio-temporal variability. Hydropedological interpretations of soils and soil distribution patterns can be used to characterise key hydrological processes, especially in areas with no or limited hydrometric measurements. Here we applied a hydropedological approach to reflect flowpaths through detailed routing in SWAT+ for a 157 ha catchment (Weatherley) in South Africa. The hydropedological approach and a standard (no routing) approach were compared against measured streamflow (two weirs) and soil water contents (13 locations). The models were not calibrated against hydrometric measurements to establish the direct contribution of hydropedological interpretations on modelling efficiency. Streamflow was predicted well (NSE > 0.8; R2 >0.82) for both approaches at both weirs. The standard approach yielded slightly better streamflow predictions. The hydropedological approach resulted in considerable improvements in the simulation of soil water contents (R2 increased from 0.40 to 0.49 and PBIAS decreased from 40 to 20%). The routing capacity of SWAT+ as employed in the hydropedological approach reduced the underestimation of wetland water regimes drastically and resulted in a more accurate representation of the dominant hydrological processes in this catchment. We concluded that hydropedology can be a valuable source of ‘soft data’ to reflect internal catchment processes and, potentially, for realistic calibrations in other studies, especially those conducted in areas with limited hydrometric measurements.

Keywords: Hydrological processes, Soil information, SWAT+

Developing conceptual-perceptual model to assess groundwater recharge dynamics in the upstream of Uitenhage Artesian Basin, South Africa

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A conceptual model is one that describes what is known, assumed, how water flows through the landscape, processes and connections involved and usually represented in the form of diagrams, flow charts, and texts. In this study, a conceptual model is one which forms the basic idea of how the system works, not the one in which algorithms are on the more "conceptual" or empirical side of the spectrum. Some numerical models rarely capture micro scale processes yet they are likely to predominate the entire modelling structure. This therefore necessitates the integration of conceptual models with numerical models to account for processes like localized recharge which are key in understanding groundwater recharge dynamics. Groundwater recharge is a key and most difficult hydrological variable to be measured, particularly in dry areas where recharge fluxes are low compared to annual precipitation. Uitenhage Artesian Basin (UBA) is South Africa's largest and most important artesian basin supplying water for various uses. As a result of increasing water demand, more boreholes have been drilled in the basin and this has led to increase in the Piezometric depth levels thus affecting the artesian pressure conditions. Although the basin has been locally studied, there remains insufficient understanding of upstream groundwater recharge dynamics. The upstream consists of Table Mountain Group Sandstones (TMS) which are highly folded, fractured, known for high recharge volumes and deep groundwater flow. Thus, understanding the dynamics of the upstream is key in assessing the longer term impacts of extensive groundwater use in the downstream artesian area of the basin and this is possible through a conceptual model. Therefore, this study aims at building a better picture of the upstream recharge area of the UAB by developing a conceptual model to assess groundwater recharge dynamics in the area using previous area studies, GIS techniques and other published information.

Keywords: Conceptual Model; Groundwater Recharge Dynamics; Uitenhage Artesian Basin

Development of homogeneous climate zones for evaluation of climate change impacts on water resources in South Africa

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The current National Climate Change Response Strategy for the Water Sector in South Africa describes six hydro-climatic zones that are "going to be impacted differently by climate change", but the origin and rationale of these zones is not clear. This paper describes the process of delineation of broad hydro-climatic zones intended for synthesizing climate change information at the national scale. The process combines a) data-centric analyses including clustering of co-variabilty of rainfall and PET at interannual timescales, in multiple gridded "observational", historical datasets as well as in CMIP5 climate projections with b) review of existing, published, regionalizations of hydro-climate based on criteria such as seasonality or co-variability and c) understanding and review of main drivers and mechanisms underlying the nature of local and regional hydro-climates. Data-centric analyses objectively support only three zones that capture the dominant types of climate drivers over South Africa, and align with rainfall seasonality zones. Segmentation into a larger number of zones is warranted, however, by a) differences between coastal and interior climates, separated along the escarpment, b) differences in the role of rainfall delivery mechanisms such as tropical cyclones, cut-off lows, and tropical temperate troughs. Final segmentation distinguishes seven zones that partly align with Water Management Areas

Keywords: climate change, homogeneous zones, water resources

Evaluating the socio-economic impact of water restrictions in different sub-sectors of an agricultural catchment

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Climate change projections flag long-term reductions in available supply, seasonal hydrological variability leading to intra-annual shifts in assurance, upstream economic efficient allocations may result in downstream shortfalls, and socially optimal water allocations may wear away economic efficiency. Therefore, to meet the objectives of the National Water Act of 1998 (i.e. efficiency, equity and sustainability), future water-sharing strategies must consider the different levels of decision uncertainty and complexity presented by different sources of restrictions. Grounded in the socio-hydrology narrative, and working with different water user groups (including the reserve) in the upper Koue- Bokkeveld region, we provide guidelines for a reformed method that can play a role in improving our understanding of water use decision-making under uncertainty and contribute to optimally robust policies at local scales. A 3-step integrated modelling approach is adopted (previously presented in literature based on hypothetical cases), combining uncertain hydrology, reserve requirements, and water use values based on multi-criteria decision analysis. The approach presented here is systematic and consistent, can be useful for diverse group stakeholder engagement to evaluate socio-economic impacts of water-use authorisation or rejection, and can handle different water value systems.

Keywords: Decision-making under uncertainty, hydrological uncertainty, National Water Act, Socio-hydrology

Workshops

Workshop 1: Future Update of the Baseline Hydrology for South Africa

Convenors: Water Research Commission - Wandile Nomquphu

South Africa's water resource planning and development is largely dependent on the baseline hydrology, which is provided in the web-based database popularly known as the Water Resources 2012 (WR2012) system. The WR2012 system is the fifth appraisal of the water resources of South Africa, Lesotho and Swaziland. It stores and maintains a series of reports, models and hydrological data that include climate, stream flows, groundwater, land use, water use, water storage in dams, inter-basin transfers, and water abstractions for urban, industrial and agricultural use, etc. The time span of these data is up to the 2009/2010 hydrological year.

More than 10 years have passed since the launch of the WR2012 study. In the intervening period, South Africa experienced extreme droughts and devastating floods, population growth and hence increased water requirements, and changes in land use/cover. These changes may have significant implications for the baseline hydrology. Additionally, the WR2012 system highlights the decline in observation networks and the deteriorating quality of data as well as restrictions on data access as impinging on the precision of the water resource assessments. However, technical and scientific advances over the last 15 years and the availability of alternative sources of data (e.g. remote sensing, radar data) could prove useful in broadening the assessments and improving the precision in appraisals.

The main aim of this Workshop Session is to provide scope for the future update of the WR2012 system and to explore the best mechanisms for undertaking South Africa's baseline hydrology. Speakers will set the scene by providing some background to the current water resource assessment approaches in South Africa (and/or WR2012 system) followed by a moderated interactive session.

Workshop 2: Catchment Hydrology Model-a-thon: discussion and briefing session

Convenors: *MURRA project team* - Julia Glenday (South African Environmental Observation Network, Fynbos node, and Rhodes University, Institute for Water Research), Shaeden Gokool (University of KwaZulu-Natal, Centre for Water Resources Research), David Gwapedza (Rhodes University, Institute for Water Research), Petra Holden (University of Cape Town, African Climate and Development Initiative), Faith Jumbi (South African Environmental Observation Network & University of Western Cape, Department of Earth Sciences), Penisoh Metho (University of Cape Town, Environmental & Geographical Sciences Department), Alanna Rebelo (Stellenbosch University, Conservation Ecology & Entomology Department & Agricultural Research Council, Natural Resources and Engineering, Water Science Unit) and Jane Tanner (Rhodes University, Institute for Water Research)

This will be an interactive session aimed at those engaged in hydrological modelling. The session will introduce a 'model-a-thon' activity, and allow those who want to participate to start getting their feet wet! Catchments are complex systems and there are many reasonable approaches to modelling them. One can use any number of software tools, each with its own options for representing hydrological processes, or custom-build a new model. Even when using the same software tool, and the same information, individual modellers can make different decisions about how best to represent a catchment in the model set-up. To take a first look at what this means in practice, the 'model-a-thon' will be a collective exploration of modelling strategies across our community and the influence on model prediction. Participants will be given the same data and information about a case study catchment and model it using any tool they are familiar with. The task is to model this catchment under a baseline condition, for which there is observed streamflow data, as well as under a scenario of change, to assess the impacts predicted by different models. The case study will be kept simple to reduce the time needed for the activity. Submissions will be kept anonymous in all analyses shared. Prizes and recognition will be awarded for high performing models in student and professional categories. This activity is part of a WRC supported project, Modelling uncertainty and reliability for water resource assessment in South Africa. Model-a-thon participants will be given certificates of participation, acknowledged in publications, and offered the opportunity to co-author a publication conditional on engagement in manuscript preparation. Further details will be publicised and discussed in the session. The session will include a briefing on the case study, the data provided and how to access it, and how to submit models and output, with time for questions and discussion. There will be time for participants to download the data and start modelling. Participants are advised to attend with their laptops.

Keywords: hydrological modelling, model-a-thon, community of practice, structural uncertainty, model intercomparison

Workshop 3: Refocusing South Africa hydrology research for the upcoming international hydrology decade

Convenors: Jean-Marc Mwenge Kahinda (Council for Scientific and Industrial Research, Water Centre), Evison Kapangaziwiri (Council for Scientific and Industrial Research, Water Centre) and Denis Hughes (Institute for Water Research, Rhodes University)

Hydrology in South Africa faces an uncertain future as it grapples with challenges of declining capacity, dwindling hydrological data and unreliable funding. A strategy for hydrology research is needed to accelerate and focus research that improves the delivery and use of hydrologic data, information and services and directly responds to projected socio-economic trajectories, demand and need patterns and changes in climate and weather patterns.

It is anticipated that the 23 Unsolved Problems in Hydrology (UPH) will be central to the upcoming scientific hydrological decade. The UPHs revolve around seven themes: Time variability and change, Space variability and scaling, Variability of extremes, Interfaces in hydrology, Measurements and data, Modelling methods, and Interfaces with society.

It is critical to align the country's hydrology research with international trends while keeping it relevant to national requirements or demands and policy imperatives. To this effect, the relevance of the UPH to South African hydrology is explored and national perspectives are emphasised. A systematic literature review was used to objectively analyse available studies to determine the state of hydrology research in South Africa. Under the identified themes, scientific searches were performed 2000 and 2021 using relevant search terms. Science questions are asked under each of the themes, which comes from the 23 UPH, and appropriate research questions are identified.

The newly formed South African Hydrological Society is the best body to finalise and implement the South Africa Hydrology Research Strategy. This will however require close collaboration with the relevant government department and research entities at the level of the working groups addressing the relevant themes.

South Africa's domestic research, development, and innovation (RDI) expenditure is less than 1 % of the gross domestic product. Nevertheless, the Water Research Commission remains the main funding body supporting water research, with 20 to 30% (estimate) of its total RDI expenditure funding hydrology and water resources research. Hydrology is primarily funded nationally through the Water Research Commission and there is a potential to improve the funding mix by targeting stakeholders' needs, particularly corporations.

Keywords: International Hydrological Decade, South Africa hydrology research, research funding, Unsolved Problems in Hydrology.

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