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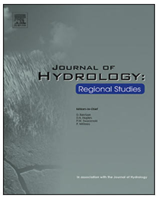

Facing a future water resources management crisis in sub-Saharan Africa

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ABSTRACT

Study region: Sub-Saharan Africa.
Study focus: Water resources availability assessments are highly uncertain due to inadequate observation networks, and this is expected to get worse into the future. This uncertainty is expected to increase in the future due to climate, environmental, population and other socio-economic development changes.
New hydrological insights for this region: This paper argues for a coordinated effort to provide improved water resources information by water scientists both within the region and from outside. It further proposes a unified approach based on hydrological modelling that incorporates realistic measures of uncertainty and that can be applied to the region as a whole using a common methodology. The concept is designed to make the best use of all available data sets, including local observations as well as emerging global data. The suggested approach has scientific credibility (based on previous studies), is technically feasible and offers a range of long-term benefits. The overall conclusion is that without a project of this type, water resources planning and management decisions in the region will continue to be based on inadequate information and unquantified uncertainties.

1. Introduction

According to the UN, the population of sub-Saharan Africa could rise from approximately 1 billion people in 2015 to almost 2.2 billion in 2050 (UN, 2017). Coupled with anticipated increases in temperature and uncertain changes in rainfall patterns (Conway et al., 2015), there is a high potential of future threats to water security for people, agriculture (Schuol et al., 2008), power generation and the environment (Vörösmarty et al., 2010). The region as a whole may appear to have adequate water resources based on indicators that use long-term mean annual runoff data. However, there are large differences in access to adequate water resources across the region, and there are parts of the region where the degree of inter-annual variability (Conway et al., 2009; Ngcobo et al., 2013) is so high that mean values are of little use in estimating the real availability of water resources. For example, the baseline water stress index from WRI Aqueduct (https://www.wri.org/applications/maps/aqueduct-atlas/; accessed on 31 Jan. 2019) uses mean annual runoff data from GLDAS (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120010316.pdf; accessed on 31 Jan. 2019). However, WRI Aqueduct also includes information on inter-annual variability which improves the value of the total information package. One mitigating factor noted by Bonsor et al. (2011) is that some parts of the sub-continent are reliant on groundwater supplies that are less vulnerable to climate change. However, increased pressure on these supplies for domestic and subsistence agriculture purposes due to population growth could increase the level of vulnerability. During early 2018 Cape Town faced a potential water supply disaster, partly associated with a long-term drought (possibly climate change related: Otto et al.,

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2018), but also caused by population growth and a lack of foresight in the planning of water supply infrastructure. Arguably, many other cities and rural areas of sub-Saharan Africa could face similar crises in the future (https://news.nationalgeographic.com/2018/02/cape-town-running-out-of-water-drought-taps-shutoff-other-cities/; accessed on 31 Jan. 2019).

Added to the threats related to the availability of water, now and into the future, is the fact that large parts of the region are poorly monitored in terms of both hydro-climate variables (rainfall, evaporation, surface and ground waters, etc.) as well as water use information, and this situation is worsening as hydro-meteorological networks continue to decline worldwide (Stewart, 2015). Even where, for example, stream flow gauges do exist there are frequent problems with rating curves, gaps in the data, or there is little quantitative information about the extent of water use during the period of gauging (Jarsjö et al., 2012). Thus, many water resources development decisions are necessarily taken with data that are either unreliable, inaccurate, or just simply absent. Some of these problems are caused, or exacerbated, by the limited technical capacity (largely associated with inadequate funding) within many of the regions national and regional water management agencies (Hughes, 2012). One of the consequences is that the technical designs for a large proportion of water resources development schemes are undertaken by consultants from outside the region, which does little to develop local capacity and does not improve the future sustainability of water management as the local agencies are generally unable to build on, or modify the development designs to cater for future changes in demand, climate, or any other factors affecting the schemes.

There have been a number of initiatives in the quite recent past that have been designed to improve the water management capabilities of parts of the region. These include the establishment of the SADC (Southern Africa Development Community) Water Sector (http://www.sadc.int/sadc-secretariat/directorates/office-deputy-executive-secretary-regional-integration/infrastructure-services/sadc-water-sector/) as well as a number of transboundary water commissions, such as the Orange-Senqu River Commission (ORASECOM; http://wis.orasecom.org/; accessed on 29/01/2018), the Limpopo Watercourse Commission (LIMCOM; http://www.limpopo.riverawarenesskit.org; accessed on 29/01/2018), the Okavango River Basin Water Commission (OKACOM; http://www.okacom.org/; accessed on 29/01/2018) and the Zambezi Watercourse Commission (ZAMCOM; http://zambezicommission.org/newsite/; accessed on 29/01/2018). ORASECOM represents an example of where the importance of adequate data to support management decisions has been clearly recognized and this is clearly evident by the inclusion of a water information system as part of their web site. This represents a very comprehensive package of water management related data and the hydrology data are a combination of observed records and simulated data. Arguably, the wealth of information for the ORASECOM example is related to the long history of regional water resources assessments in South Africa (also covering Lesotho and Swaziland), starting as long ago as 1977 and culminating in the most recent assessment (WR2012; http://waterresourceswr2012.co.za/; accessed on 29/01/2018). One of the strengths of this approach is the use of a hydrological model (the Pitman model; Pitman, 1973) to simulate natural stream flows for 1 946 sub-basins varying in size from less than 100 km^2 to over 5 000 km^2 covering the total area covered. Existing model setups were therefore available to support the information requirements for the majority of the Orange-Senqu basin. What is not clear is whether or not ORASECOM has the capacity to update these simulations, and the information content of its water information system into the future when many changes (land use, water use and climate) are expected to occur.

There have also been previous studies that have attempted to provide water resources estimates for the region as a whole based on a combination of modelling and observed data (UNESCO, 1997 and 2004; Schuol et al., 2008; McNally et al., 2017), but these typically fall short of the requirements for future water management for different reasons. The model setups may not be available (for updating and future scenario planning) to the practitioners in the region, the spatial resolution of the data may be too coarse, or not orientated towards basin management units, or they simply do not account for some aspects (e.g. details of existing water use) of the present day hydrology of the sub-basins.

The inescapable conclusion is that the current situation with respect to future management of water resources for large parts of the region is very uncertain, and that interventions are required to both quantify and reduce this uncertainty and to establish a sustainable basis for improved water management. This uncertainty stems from the lack of one or more of the following prerequisites that are considered necessary to be able to quantitatively understand the availability of water resources and to make decisions into the future:

i Lack of integration of the data necessary (climate, stream flow, land and water use data, etc.) for assessing water availability in both gauged and ungauged sub-basins.
ii Lack of familiarity with, or ability to access and process, global data sets that can be useful in supporting the relatively scarce local data in water resources assessment studies.
iii Lack of an installed water resources modelling system to be able to estimate water resources availability in ungauged sub-basins, both now and into the future.
iv Lack of capacity, or lack of access to the expertise required, to update modelling systems and interpret the results.

This paper therefore offers a perspective on how these ‘lacks’ can be addressed and proposes a regional water resources assessment based on a common water resources assessment modelling approach. This perspective is based on many years of experience of hydrological modelling and water resources assessment in the region, as well as many discussions with scientists and practitioners from within, and outside, the region. One of the key issues that will be highlighted is that water resources assessments in data scarce regions will always be uncertain, even if one of the future focus areas is to improve monitoring and data collection and reverse the general decline in observation networks (Stewart, 2015). It can take many years before new hydro-meteorological stations can provide enough data to adequately represent patterns of variability, particularly when the variability is non-stationary (Milly et al., 2008). It is therefore important that the common approach includes measures of uncertainty (Pappenberger and Beven, 2006;

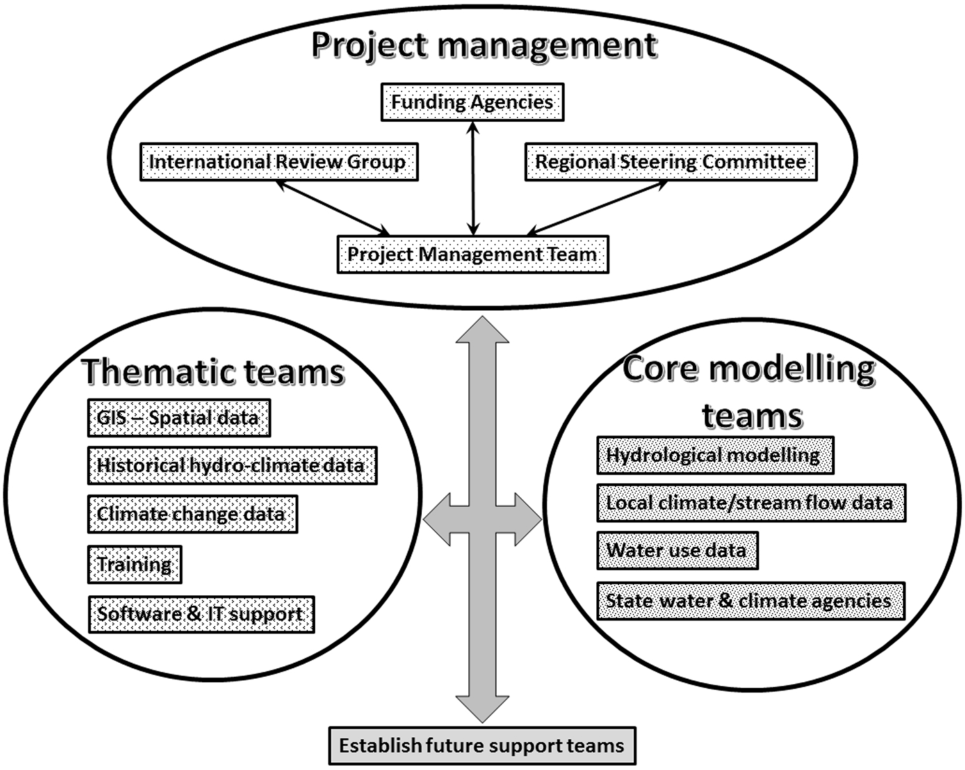

Fig. 1. Basic structure of the proposed intervention.

Ivanović and Freer, 2008) and guidelines for incorporating them into the overall decision making process (Korteling et al., 2012; Matrosov et al., 2013; Pienaar and Hughes, 2017). This is by no means the first time a project of this nature has been proposed (WRC, SADC, 2001), but unfortunately previous proposals were not implemented.

2. Structure of a possible intervention

While it may be somewhat presumptuous to suggest a project structure without inputs from likely funding agencies or the national hydrological services and water management agencies, Fig. 1 provides one possible structure that is largely based on the technical requirements of the project, discussed later. The top (management) part of the structure is therefore only loosely defined, but includes two main elements that are considered essential to the credibility and success of a project of this type. The first is the need for an independent international review team who can assess the scientific credibility of the project, while the second is the need for a regional steering committee whose task would be to ensure that the needs and interests of the national water management agencies, as well as the trans-boundary basin commissions, are being addressed by the project.

The second level of the proposed structure is made up of a number of teams, divided up into thematic teams focused on key technical issues common to all countries, and core modelling teams focused on generating the model simulation results for individual countries (or groups of countries). The thematic areas include data collection, collation and processing (spatial, historical hydro-climate data and climate change data), and these teams are expected to facilitate access to global data to assist the country teams in quantifying the required model forcing and validation data. The other thematic areas are focused on training (other project members and future users of the project outputs) and IT/Software support. The core modelling team responsibilities would be the main modelling tasks, plus facilitating access to local hydro-climate, water use and water infrastructure (reservoirs and transfer schemes) data. It is essential that the core modelling teams should work as closely as possible with the national hydrometric services. One possible approach to achieving the latter objective, as well as to include a training component, is to offer short-term (3–6 months) internships during the project duration that targets individuals employed in state or transboundary water management agencies. The internships would be designed to offer training in both the details of the modelling approach, and the use of the outputs for practical purposes.

The final level of the structure refers to the teams that will provide future support (technical, training, etc.) to the national and regional water management agencies. It is assumed that the establishment of these teams will be a key issue right from the start of the project, as they will be critical to the future sustainability of the project outcomes. It is also assumed that they will be established within the region (i.e. university research groups, state research agencies or local consulting companies). This implies that the level of local participation in all of the technical implementation teams, but particularly the country teams, should be as high as possible. The balance between local and non-local participation in the various technical teams is difficult to prescribe. It is inevitable that the project will benefit from contributions from highly experienced groups and individuals located outside the region and that these will be essential to the success of the project. However, the key point is that all of the data, techniques, methods, models and software (whether existing or developed as part of the project) that are utilized to achieve the aims of the project, should be properly established, and remain, within the region. This should be a fundamental, non-negotiable principle underlying the project terms of reference and will inform the way in which all of the technical teams will need to be structured.

3. A proposed methodology

The basis of the proposed methodology is the use of a common hydrological model to simulate time series of hydrological data (primarily stream flow and ground water recharge) under natural and impacted conditions that are long enough to represent inter-annual variability. The model should have been previously demonstrated to be appropriate for simulating the natural hydrology and water resources availability of the region, should be able to incorporate uncertainty assessments and should use software that is freely available. An additional consideration is the amount of existing experience of the use of the model within institutions located in the region. The motivation for a common modelling approach is related partly to the benefits of shared experience and understanding, and partly with the efficiency advantages associated with using common data input procedures. The proposed model is a version of the Pitman monthly time step, semi-distributed, rainfall-runoff model (Pitman, 1973), that has been updated on a regular basis and has seen wide use within the region over the last several decades (summarized in Hughes, 2013). One version of the model is currently implemented as a flexible uncertainty model within a more general water resources modelling framework (SPATSIM; Hughes and Forsyth, 2006; https://www.ru.ac.za/iwr/research/software/, accessed on 209/01/2018) that includes a GIS interface, a generic database structure for storing all types of information relevant to water resources analysis and modelling, some standard data analysis and summary facilities and links to several models. The main justification for proposing this specific model is based on the frequency and geographical area over which it has been applied (in one form or another) within the region, the fact that the original structural design and subsequent modifications have all been orientated towards the conditions found within the sub-Saharan Africa region, as well as the fact that some of the technical developments (e.g. uncertainty approaches) have been motivated by the extensive research and practice emanating from more developed parts of the world (Hughes, 2016). The full details of the model and a complete review of its application can be found in the citations included with this paper, however, the following two sub-sections provide some further details of the proposed approach.

3.1. Scientific credibility

Fig. 2 illustrates the structure of the version of the Pitman model used by the Institute for Water Research (Rhodes University,

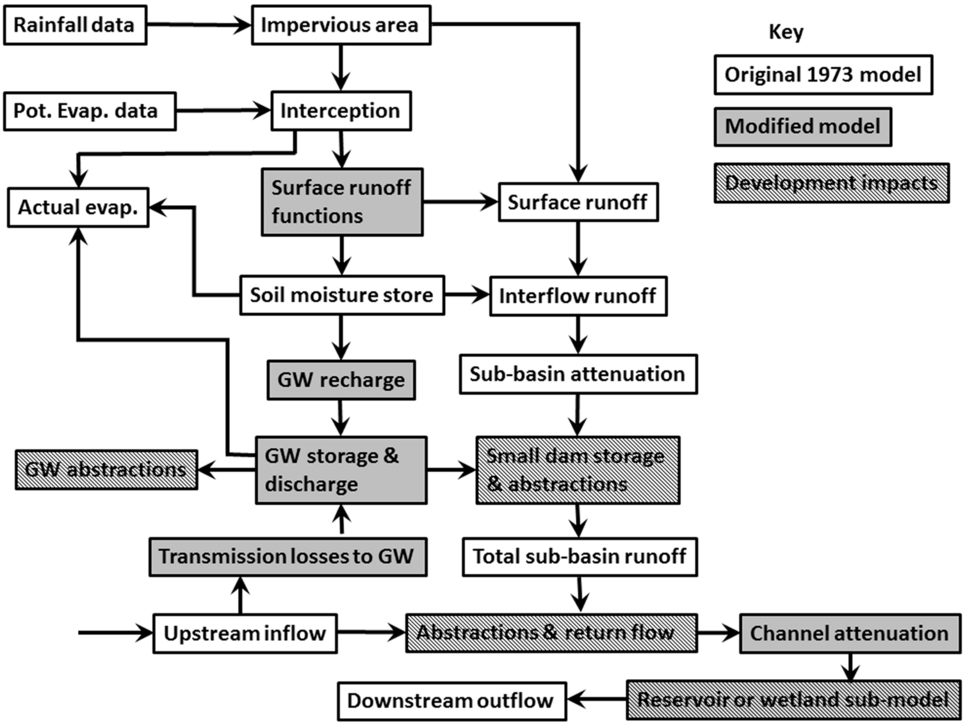

Fig. 2. Structure of the Pitman model.

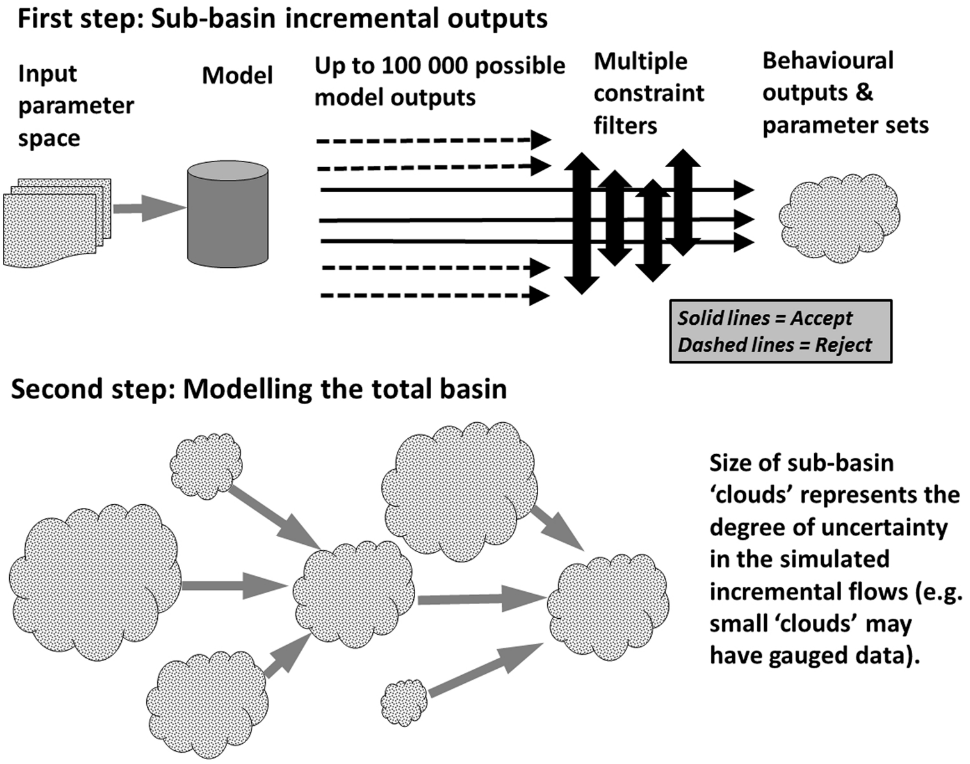

Fig. 3. The two-step uncertainty approach.

South Africa) and implemented as part of the SPATSIM framework. It represents a compromise between structural complexity and practical value, is semi-distributed (based on sub-basins) and uses a monthly time step. However, it has a relatively large parameter space so that the parameters and outputs reflect the full range of hydrological processes expected to occur in sub-Saharan river basins. This includes not only the main catchment runoff processes typically included in hydrological models, but also additional components that are important for understanding water resources availability under natural and modified conditions such as surface water–-groundwater interactions (Hughes, 2004), river-wetland interactions (Hughes et al., 2014), and the impacts of small (Hughes and Mantel, 2010) and large reservoirs. This large parameter space, although frequently criticized (Jakeman and Hornberger, 1993; Perrin et al., 2001), is justified to ensure that the parameters are explicitly associated with the way in which different runoff generation and stream flow propagation processes might be modified by environmental (Hughes, 2015a) and development changes in a basin (Hughes, 2013).

Figs. 3 and 4 illustrate the uncertainty framework that is used within the SPATSIM implementation of the Pitman model (Hughes, 2015b), and which is broadly based on the Generalised Likelihood Uncertainty Estimation (GLUE) approach (Beven and Binley, 2014) and consists of 2 steps in setting up and running the model. The first step is concerned only with the simulation of the natural (no development effects) incremental sub-basin stream flows and is based on generating multiple model outputs (typically 5 000) using random samples from the initial parameter range space, but constraining the outputs using ranges of hydrological response signatures (such as mean monthly discharge, groundwater recharge and some percentage points on the flow duration curve). This approach has become standard practice amongst many hydrologists worldwide (Yadav et al., 2007; Euser et al., 2013; Westerberg et al., 2014; Nijzink et al., 2016) in attempts to ensure that all parts of a basin are simulated in a behavioural way (Beven, 2012). Fig. 3 illustrates that the saved parameter sets from the first step are then used in the second step to simulate uncertainty ensembles (typically 10 000) for the total basin and all of the sub-basin linkages. The second step can be applied under natural conditions, or under developed conditions where the model components that simulate anthropogenic impacts are included. One of the key messages is that, from a practical water management perspective, the uncertainty range should be realistic and this range is always expected to vary within a basin. Gauged and well understood sub-basins would therefore have low uncertainty, while others would realistically have much higher uncertainty ranges (reflected in the size of the 'clouds' in the lower part of Fig. 3). The method accommodates these expected differences which will be reflected by the way in which the hydrological response constraints are quantified. Fig. 4 suggests that the processes of setting up the model and validating the results using any observed information is expected to be iterative (Fenicia et al., 2008) and indicates that future scenarios, related to either climate or water use (or both), can then be generated with the model that was established with historical data. Two key issues (addressed in the next sub-section) in the application of this approach to different regions of the sub-continent are the methods and the data that are available to quantify the hydrological response constraints.

The Pitman model has been applied throughout sub-Saharan Africa in the past, while the specific uncertainty approach discussed

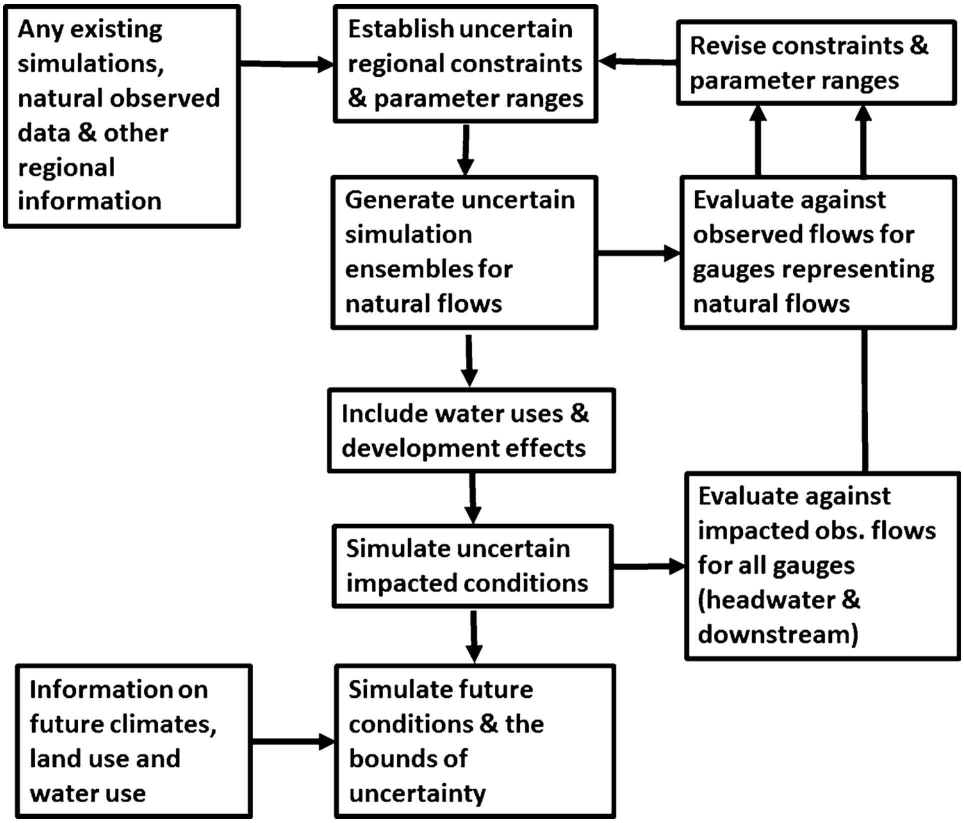

Fig. 4. Iterative approach for validating the results of the two-step uncertainty approach.

above has been recently applied in several data scarce areas and has been peer reviewed (Tumbo and Hughes, 2015; Hughes and Gray, 2017; Ndzabandzaba and Hughes, 2017; Hughes and Mazibuko, 2018)). It is also being applied in a current Royal Society (UK) project designed to update the model simulations for the whole Congo River basin (Tshimanga and Hughes, 2014). Table 1 summarises some of the best model performance statistics that have been achieved across these various studies and includes some recent results for the Zambezi River. Apart from sub-basins with suspect gauging data (often associated with rating curve problems), the worst results are found in semi-arid areas with complex spatial variations in both climate and runoff response, as well as areas with poorly quantified (and often non-stationary) upstream water or land use impacts. Identifying such basins is important for the effective allocation of the limited funds that are typically available in the countries of the region for improving hydro-meteorological data collection.

3.2. *Technical feasibility*

Technical feasibility covers a range of issues associated with the spatial scale at which the model should be applied, the availability of model forcing climate data and regional hydrological response data to implement the 2 step approach summarized in Figs. 3 and 4, the structure of the project designed to cover the whole region, as well as the availability of expertise both within and outside the region to contribute to the project. The latter two issues were covered in the previous main section.

Table 1
Summary of results obtained using the Pitman model in data scarce areas based on the Nash-Sutcliffe coefficient of efficiency (CE).

Region/basin	Sub-region	Citation	Range of CE values
Dem. Rep. Congo/ Congo River		Tshimanga and Hughes (2014)	0.6 to 0.79
Tanzania/Great Ruaha River	All sub-basins	Tumbo and Hughes (2015)	−0.77 to 0.75
	Excluding suspect gauge data.		0.54 to 0.75
Swaziland/ several river basins.		Nzabandzaba and Hughes (2017)	Typically > 0.5
Okavango River		Hughes and Gray (2017)	0.56 to 0.93
Various basins in sub-Saharan Africa		Hughes and Mazibuko (2018)	0.53 to 0.91
Zambezi River	Headwater sub-basins	Not published	0.56 to 0.82
	Main river		0.20 to 0.65

Table 2
Total country areas, suggested mean sub-basin sizes and number of sub-basins.

Country	Total Area (km^2)	Mean Sub-basin size (km^2)	No. of Sub-basins
Angola	1 247 000	4000	312
Botswana	600 370	2000	300
Burundi	27 834	500	56
DRC	2 345 000	5 800	404
Gabon	267 667	800	335
Kenya	580 367	800	725
Lesotho	30 355	320	68
Malawi	118 484	500	237
Mozambique	801 590	650	1 233
Namibia	825 615	1 500	550
Rep. Congo	342 000	800	428
Rwanda	26 338	500	53
South Africa	1 215 049	650	1 824
Swaziland	17 364	320	54
Tanzania	945 087	800	1 181
Uganda	241 038	800	301
Zambia	752 618	2 500	301
Zimbabwe	390 757	650	601
Totals	10 774 533	1 255 (Mean)	8 964

Table 2 lists all of the countries, and their total areas, that are considered to be part of sub-Saharan Africa for the purposes of the proposed project. The last two columns list the proposed mean sub-basin size and the number of sub-basins that would be modelled. These are based largely on the South African, Swaziland and Lesotho experience, where a regional approach has already been successfully applied (WR2012: http://waterresourceswr2012.co.za/). The WR2012 data cover a range of sub-basin sizes from < 100 to > 5 000 km^2, with the size largely determined by topographic, climate and vegetation cover variability. The Royal Society (UK) funded CRuHM project (https://www.researchgate.net/project/Congo-River-user-Hydraulics-and-Morphology-CRUHM) is updating previous Pitman model simulations (˜90 sub-basins) of the whole Congo basin and this will involve some 400 sub-basins. The total number of sub-basins is therefore expected to be about 9 000, and based on the experience of the Institute for Water Research (through staff and student involvement with the application of the model), it is likely that a reasonably experienced model user could achieve the initial model set-ups and validation against observed data for 2 sub-basins a day, or 4 500 person-days for the whole region. This suggests that a total of 8 well-trained individuals could complete this part of the project in approximately 3 years. Table 3, however, indicates that some existing model set-ups (using either the current model version or earlier versions) are available and could reduce the total resources needed for the whole region. The final number of sub-basins in the different countries of the region would clearly need to be informed by the requirements of the national and regional water management agencies, but Table 2 at least provides an initial guideline.

Part of the above time calculation assumes that the data to force and validate the model (rainfall, potential evaporation and observed stream flow data) have been previously prepared and made available to the modelling team. This then becomes an important part of the project technical plan, where all available sources of data are compiled prior to starting the model setups for any part of the region. These data can include local data from the national hydrometric agencies, as well as global data sets of climate, groundwater recharge and stream flow (as well as supporting information such as topography, geology, soils and vegetation).

Table 3
Existing model set-ups.

Country	Basin	Total Area	No. of Sub-basins
Using current version of the uncertainty model			
Angola, Namibia & Botswana	Okavango	228 798	23
DRC & others	Congo	3 700 000	400
Swaziland	All rivers	38 950	122
South Africa	Caledon	15 266	31
Tanzania	Great Ruaha	85 628	48
Totals		4 068 642	624
Totals as % of region		37.8	7.0
Using earlier versions of the model (will need updating)			
South Africa	All rivers	1 215 049	1 824
Lesotho	All rivers	30 355	68
Zambia	Kafue	150 247	21
Zambia	Luangwa	148 174	24
Namibia	Fish River	84 288	17
Totals		1 628 113	1 954
Totals as % of region		15.1	21.8

Fortunately, there is an ever expanding body of experience of global data sets and their applicability in any given region, or for specific purposes (UNESCO, 1997 & 2004; Kim and Jackson, 2012; Beck et al., 2015; Beck et al., 2017; Martens et al., 2017; McNally et al., 2017). These data products and this experience will be invaluable for rapidly generating the necessary forcing data in countries where local data are lacking, too short, unreliable or inaccessible.

Ndzabandzaba and Hughes (2017) and Tumbo and Hughes (2015) represent published examples of where the 2-step method has already been applied and illustrate that the methods used to establish the model constraints will be different across the sub-continent. Previous regional modelling studies (UNESCO, 1997; Schuol et al., 2008; Beck et al., 2015) may not provide complete regional coverage, or do not provide stream flow information at an appropriate resolution for local water management, but the outputs from these are expected to be very useful for establishing the regional constraints. One of the key advantages of the proposed method is the inherent flexibility in the approaches used to quantify the constraints. However, this also means that the most suitable approach that leads to the most realistic levels of uncertainty will not always be immediately evident, and will require further testing and assessment across the region.

4. Perceived benefits

The primary benefit is a database of hydro-climate and water management information combining local and global data, based on a combination of observed (where it exists) and modelled data, and incorporating realistic estimates of the uncertainty in this information. Given the combined effects of changes in population, socio-economic conditions, environment and climate, information generated at any one time will become out-of-date very quickly. The proposed project would overcome this problem by providing model set-ups that can be updated with either new known forcing information, or with information on expected future conditions (scenario planning). Almost all of this model forcing information is currently uncertain and this situation is not likely to change into the future. It is therefore essential (Pappenberger and Beven, 2006; Ivanović and Freer, 2009) that realistic estimates of the uncertainties involved are included as part of the database and that water managers are trained to incorporate these uncertainties into policy, planning and management (Matrosov, 2013). The additional benefit of realistic uncertainty estimates is that they can identify the key sources of uncertainty in different parts of the region and therefore target where investments in data collection or method development should be prioritized.

In a region where there are many trans-boundary river basins and shared water resources (Saruchera and Lautze, 2016; Tilleard and Ford, 2016), the benefits of a common approach should be self-evident. Assuming that no countries feel that they have been coerced into using an approach that they do not agree with, the common approach suggested here should encourage the development of trust in shared information and allow bordering states to focus on the real policy issues of water sharing, rather than arguing over the amounts of water that they have to share between them.

It is likely that arguments will be presented that a single model (and particularly one that uses a monthly time step), applied at the spatial scales suggested in Table 1, cannot address all of the water management needs of a country. This includes issues related to flood management, well-field design, water quality (Dabrowski, 2014) and sediment management (Ndomba et al., 2008), irrigation scheduling, hydro-power design, quantifying environmental flow requirements (Hughes and Louw, 2010), etc. These arguments are fully accepted and it is not suggested that the Pitman model can provide all of the necessary information. However, it can provide the foundation or baseline information on water availability under natural and developed conditions, against which the outputs from more specialized models can be compared in the absence of observed data. Recent studies have also demonstrated that it is possible to use daily rainfall data to disaggregate monthly simulations (from any model) to daily time steps for use with such as water quality or sediment yield models (Hughes and Slaughter, 2015; Slaughter et al., 2017). The key benefits of the project are therefore associated with generating this baseline information in a region where a very large proportion of the sub-basins are ungauged and therefore where there is currently no information against which to compare the outputs of specialized models.

The section on project structure (Fig. 1) places a great deal of emphasis on training, specifically for scientific and technical staff within the region. While, there have been successful training initiatives in the region in the past and some of these remain active (Van der Zagg, 2005; Hughes, 2012), most of these have focused on educational qualifications or water and sanitation services delivery skills, while this proposed project offers opportunities for highly focused vocational training in water resources assessments, as well as future employment in the regions water management sector. Hughes (2012) noted that the skills of well-trained post-graduates in the region are often under-utilised after they complete their degrees, and this is partly related to the continued reliance on expertise from outside the region for water availability assessment projects. One of the perceived benefits to the region is therefore the further use and development of this cadre of water engineers and scientists, as well as to increase the size of this pool of local expertise. The benefits of a common modelling approach also plays a role in this regard, as this cadre of specialists will be able to share expertise and experiences and further strengthen the water resources estimation capabilities for the region as a whole.

5. Potential crticisms, risks and failures

The greatest risk is almost certainly an inability to attract funding for the project, while a related risk is that the region's national governments fail to support the project concept due to competing priorities and a lack of appreciation of the potential value of the project outcomes. Clearly, the funding (from whatever source) is unlikely to be forthcoming without the latter support. A further risk to initiating a project of this type lies in the potential for a lack of acceptance of the benefits of a common approach by the national water management agencies of the region. This could stem from suspicions that they are being coerced into adopting methods that they had no part in developing, or that they have a preference for other methods that they have previously used. A related risk is that some of the national hydro-climate data collection agencies are reluctant to fully participate in the project and refuse to release their data for use. This will not always be a critical risk, as these local data may be replaced with global data. However, it is likely to increase the level of uncertainty in the model setups and final results.

It is frequently noted that hydrological models cannot be used to replace monitoring data. It could be argued therefore that financial and human resources should be committed to improving the monitoring networks rather than a project designed to establish models. However, monitoring data can never cover all of the basins and sub-basins for which future water resource decisions need to be taken. Monitoring data alone cannot also account for projections of future conditions related to development effects or environmental change. Any sustainable water management system will therefore require a combination of monitoring data and established models. This paper does therefore not suggest that models can replace data, only that they can complement the limited data that is typically available in sub-Saharan Africa.

There is little doubt that the use of the uncertainty approach increases the time and effort required to complete the modelling tasks for the whole region and there is a risk that this component of the project plan could be rejected due to a lack of understanding and appreciation of the future benefits of such an approach (Ivanović and Freer, 2009). This risk would have to be over-come by targeted presentations that clearly outline the potential benefits and illustrate how uncertain information can be used in planning and management (Korteling et al., 2012), particularly for future conditions given the well-known uncertainties in projections associated with changes in climate, population growth and socio-economic growth.

There may be parts of the region where the initial modelling results may not be usable due to a high degree of uncertainty associated with inadequacies in one or more components of the model setup (e.g. forcing data, validation data or existing water use data). However, this does not mean that the model will not be useful in the future. In such situations the model results could highlight the need for further data collection and understanding of the local situation, which could then contribute to reducing future uncertainties. In these situations there is simply too little data or understanding to effectively manage the water resources and no model is likely to be of immediate use. However, attempts to establish a model will highlight these deficiencies and provide an incentive to improve the understanding through targeted data collection to provide the relevant national water agency with further information to improve the model in the future. This issue should be a key component of the training and capacity building components of the project to ensure that the models become a sustainable product that can support national and regional water resources assessments.

6. Conclusions

Sustainable water resources management in any region depends on many factors that cross several scientific, social, economic, political and engineering disciplines. One of the fundamental factors is the quantification of the available resources and the extent to which they can be exploited in a sustainable manner. There is currently no consistent approach used within the sub-Saharan Africa region for quantifying water availability. The information requirements for individual development projects tends to be generated on an ad hoc basis using many different approaches, and frequently by consultants from outside the region. This does not encourage the future development of regional expertise and shared experiences and has the potential to generate conflict in trans-boundary basins. This paper attempts to convince a wide audience of scientists and practitioners that an alternative approach of using a common methodology is not only scientifically credible and technically feasible, but also offers many benefits for the future.

The title of this paper refers to a future crisis in water resources management in sub-Saharan Africa and part of this crisis is likely to be associated with a lack of adequate information about the availability and variability of the resource. It is accepted that Information alone cannot avert a future crisis and that the ability to use information is as (if not more) important as the information itself. However, it is difficult to imagine how any wisely conceived water management policy can be implemented without adequate information and therefore the proposed approach is designed to supply the foundation upon which other developments can build. One issue that has been emphasized throughout the paper is that all information on water resources is and will continue to be uncertain (even after the proposed project is completed). One of the key aspects of the proposal is that this uncertainty must be appropriately quantified and accounted for during future water management practices (Ivanović and Freer, 2009; Korteling et al., 2012).

A personal observation is that many of the recent calls for proposals from international funding agencies for water related projects in sub-Saharan Africa relate to inter alia strengthening management and policy development skills, addressing some of the socio-economic imbalances in access to water and sanitation, or adapting to future climate or other environmental changes. While all of these are, of course, critical issues that need to be addressed for future water resources sustainability in the region, they also need to be supported by the availability of adequate information upon which to base policy and management decisions. Arguably, this information does not currently exist in a format, or at spatial scales, that is adequate to provide the necessary support. The key question is therefore whether or not the international and regional communities can be convinced that the proposed project is technically appropriate and that the investment required will provide a long-term return in terms of a contribution to sustainable water management. The paper has provided some suggestions about how the project could be structured, but further inputs are required from key role players in the region to ensure that any investment is justified and that the project outcomes are truly supportive of the needs of the region, both now and into the future.

No real attempt has been made to quantify the level of investment required, nor the source of the funding. However, a very rough estimate suggests that the technical/scientific components of the project (i.e. not accounting for some of the costs of project administration, the participation of the water management agencies of the 18 countries listed in Table 1 and their associated travel costs), could be completed over a period of 5 years for a total human resource cost of (very) approximately 5 million Euros. This sum includes many of the costs of training regional scientists or water managers in the use of the model and the application of the outputs for practical water resources planning or management purposes. Given the costs and value of some individual water resources development schemes that are known to be under current consideration, as well as the future socio-economic costs of unforeseen water supply failures, this seems like a relatively insignificant amount.

Data and software availability statement

The Institute for Water Research (IWR) version of the Pitman model is packaged as part of the SPATSIM generic model application framework which is available free of charge at https://www.ru.ac.za/iwr/research/spatsim/. The software installation includes some training material for both the main SPATSIM package as well as the implementation of the Pitman model. All of the software is written in Delphi code using SQLite databases (https://www.sqlite.org/) to store and access all of the data. While the IWR does not normally distribute the source code it can be made available on request. Example applications and model set ups can similarly be made available on request from the author of this paper. These example set ups will include all the input (climate and parameters) and results data associated with running the model (subject to any restrictions imposed upon the IWR by the original owners of the data).

Conflict of interest statement

There is no conflict of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ejrh.2019.100600.

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