HHD.1 Inception report

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Contents

1. Abbreviations and acronyms

CEO	Centres of Excellence
CSIR	Centre for Scientific and Industrial Research
NUST	Namibia University of Science and Technology
RBIS	River Basin Information System
SADC	Southern African Development Community
SANWATCE	Southern African Network of Water Centres of Excellence
SASSCAL	Southern African Science Service Centres for Climate Change and Adaptive Land Management
SUWI	Stellenbosch University Water Institute
SWAT	Soil and Water Assessment Tool
WACOZA	
WAFLEX	Spreadsheet-based model that can be used for analysis of dam/reservoir management rules, including upstream-downstream interactions, water allocation policies and development options.
ZAMCOM	Zambezi Watercourse Commission
ZRB	Zambezi River basin

2. Background

The Zambezi Watercourse Commission (ZAMCOM) as river basin organisation is faced with the tough task of "promoting the equitable and reasonable utilisation of the water resources of the Zambezi Watercourse, as well as the efficient management and sustainable development thereof" (ZAMCOM, 2018). It was established by the eight SADC countries that depend on the basin for diverse uses.

Population growth, industrialisation, increasing agriculture and climate change are just a few factors that are putting strain on the river, which traditionally was used mainly for three hydropower schemes. According to the World Bank (2010), "the Zambezi Watercourse is one of the most diverse and valuable natural resources in Africa. Its waters are critical to sustainable economic growth and poverty reduction in the region. In addition to meeting the basic needs of more than 40 million people and sustaining a rich and diverse natural environment, the river plays a central role in the economies of not only the eight riparian countries, but the region as a whole. It is an important water resources system in terms of energy generation, food production and ecosystems services". Finding a way for ZAMCOM and the nations dependent on this river basin to improve the management thereof, is therefore critical and urgent.

Southern African Network of Water Centres of Excellence (SANWATCE) members gathered in Kenya in November 2017 to plan the implementation of a project for improved management of competing demands on the Zambezi River. By developing a simulation model to optimise the management of three hydropower reservoirs, the researchers hope to improve the ability of the governments dependent on the river, to manage the competing demands on the resource.

This inception report outlines Stellenbosch University's tasks and planned interventions and associated methodologies for this project.

3. Objectives and activities

Stellenbosch University's role in the project relates to the development, or optimisation, of the simulation model and corresponding best-practice guidelines for applying such modelling.

Objectives:

- To provide a review of best-practice guidelines in modelling hydrology and hydropower production;
- To provide a hydrological-driven database for the ZRB (soils, geology, land cover, etc), including data from gauging stations, metadata and existing hydrological/flood modelling tools and assessments.

Main deliverables:

- HHD.1 Manual on guidelines in modelling hydrology and hydropower (due on 30/06/2018)
- HHD.2 Hydrological database (spatial): dataset, tools, assessments (due on 30/11/2018)

3.1 Proposed contributions from SUWI

Budget [Euro]	Institution	Major deliverables	Milestones	Research outcome			
				Manual	Report	Database	Model
10K	University of Stellenbosch South Africa	**HHD.1.1 Manual** on guidelines in modelling hydrology and hydropower based on case studies **HHD.1.2 Database**: hydrological-driven database for the ZRB (soils, geology, land cover, etc), including data from gauging stations, metadata and existing hydrological/flood modelling tools and assessments. (NB: this deliverable is developed in close cooperation/coordination with HHD.2.1, performed by NUST Namibia) **HHD.1.3 Capacity Building** material	**HHD.M1**: Manual and related presentation (due 30/06/2018) **HHD.M1.2**: Database on hydrology (due 30/11/2018). Ref.: HHD.1.1, HHD.1.2, HHD.1.3	X	X	X	X

4. Expected outcomes

4.1 The conceptual framework

This section of the research and development programme will aim to provide a solid base for water resource management and contribute to the Atlas on Water Cooperation. The mapping will be done to support hydrology and form the basis between water utilisation for human needs, for agriculture and hydropower energy. The research will log all data resources available, and where possible generate new mapped information for modelling. We also aim to indicate temporal resources that could be used in flood forecasting and similar needs. To some extent, a lot of this work is covered in the World Bank Report (2010).

The model will need to take as many as possible pressures on the river basin into account in order to predict future scenarios. Agricultural production, for example, can lower the flows toward the Zambezi, but will ultimately lower dam levels and compete with power generation. Groundwater contributes greatly to the sustainability of flows in the Zambezi, therefore surface-groundwater interaction is a large source of concern towards future water quality of the Zambesi system. Climate change may also impact negatively on the sustainability of the Zambezi as a system and any model developed will need to have the ability to reflect future scenarios. Furthermore, the information generated in this work is aimed at enhancing good governance. Without this ability to have early warning information and specific scenario developments, the decision base for future development will be absent. Therefore, scenarios must come from the governments in terms of long-term development goals.

The framework for the guidelines and report on database development will entail the following:

- Accessibility of data and resources
- Various types of data needed and their uses
- Data manipulation processes and their presentation
- Modelling flows with SWAT
- Reflecting on hydropower generation using the SWAT model results
- Use the modelled results to instruct the economic assessment

For this work, we would like to refer to the article by Black *et al*., (2014) regarding “best practice implementation and application of models for analysis of water resources management scenarios”. Figure 1 is a graphical explanation of the modern concepts related to modelling and the guidelines to ensure the best possible quality in modelling. The full extent of the proposed procedure is, however, not the aim of this project and not achievable as it requires the input from all stakeholders.

From the work of (Cohen Liechti, Matos *et a*l. 2012) a critical look is provided regarding the influence of hydropower development on flow regime in the Zambezi River Basin for different scenarios of environmental flows. This study will form a key guideline towards the goals with in this project. Rensgaard *et al.,* (2004) provides a perspective towards the necessary modelling guidelines, terminology description and guiding principles necessary for the research.

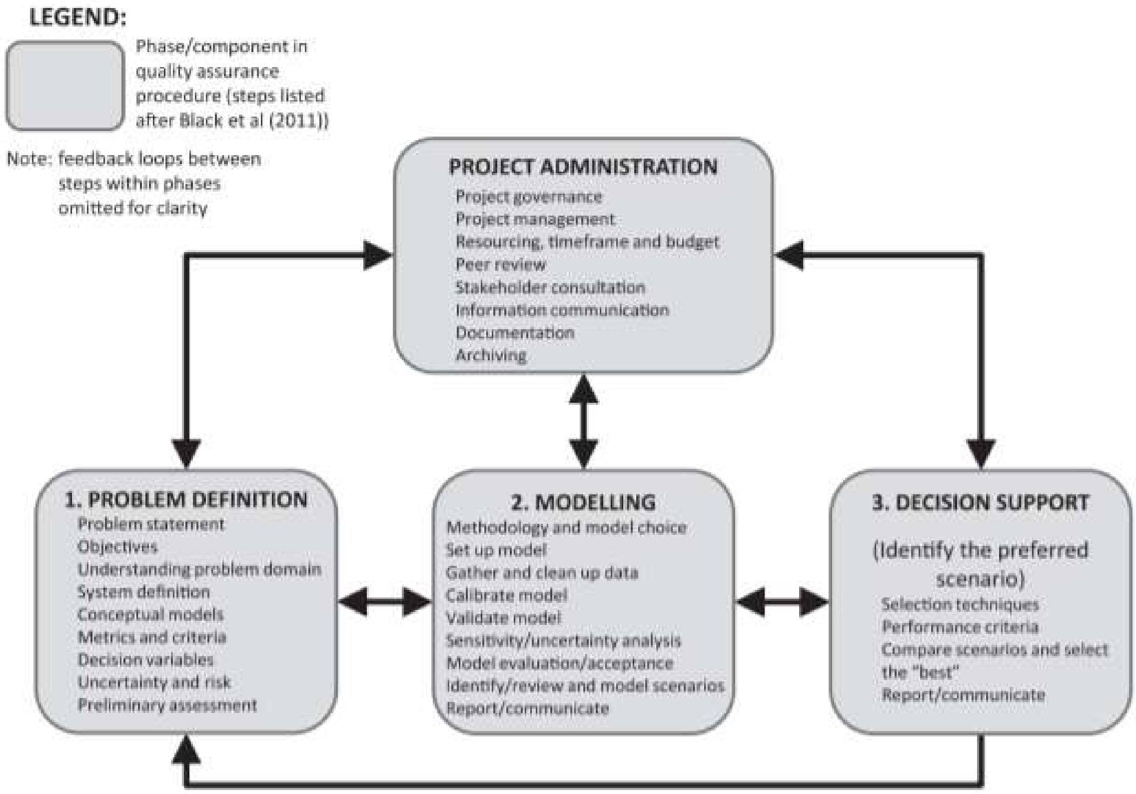

Figure 1: Procedure for quality assured model implementation and application for scenario analysis.

For this task, the focus is hydrology and hydropower, and therefore, as indicated in Figure 1, the need for hydrological modelling must be decided based on a systems approach. The needs that exist in the other parts of the research project must be harmonised with the decision base for hydrological modelling. Hydrologically modelled results form a key driver required in the other sections of this project.

In summary, the tasks in this part of the research will rely heavily on making use of existing information. Secondly, the work will utilise existing models, which are shared freely. The model that will be used will be adapted to each scenario defined for this research. The most important aspect of having a running model for this research is the fact that the model was already calibrated and that the input data was already defined. For this purpose, access to an existing SWAT model was already acquired and SWAT is the preferred platform.

5. Methods

5.1 Remote sensing

Remote sensing forms an important part of hydrological research. The basic building blocks are elevation models, land use maps and soil maps also derived from remote sensing (Meier, Frömelt *et al*. 2011; Cohen Liechti, Matos *et al*. 2012; Michailovsky, McEnnis *et al*. 2012).

The European Space Agency generated data for the Zambezi, as can be seen on their shared website: http://tethys.eaprs.cse.dmu.ac.uk/RiverLake/info/zambezi_modelling).

The specific products that will be used are the following:
- Digital elevation models, specifically the SRTM 90 and 30 m products (USGS).
- For land-use mapping, there are already land-use maps available. Where we will need to update information, data will be acquired using mainly the Landsat thematic mapper information and/or Sentinel information from the EU space agency.
- Bathymetric data from remote sensing to support hydrological modelling and long-term modelling (ESA).

5.2 Architecture of the database

The database will consist of imagery and maps, climate data, flow data and dam level information.
The primary demands on a system relates to the data type and the size of files. The format that is used by the models:
- Text files
- Shape files
- Raster files

The River Basin Information System (RBIS) is indicated as an example. RBIS is an online database system, of which the dashboard and functionality is demonstrated in Figure 2. It can also be viewed online at http://rbis.uni-jena.de/. The SASSCAL data for the Zambezi catchment is already available in this format (http://www.sasscal.org/). The project will, however, make use of the database system currently constructed on the JRC website for this project.

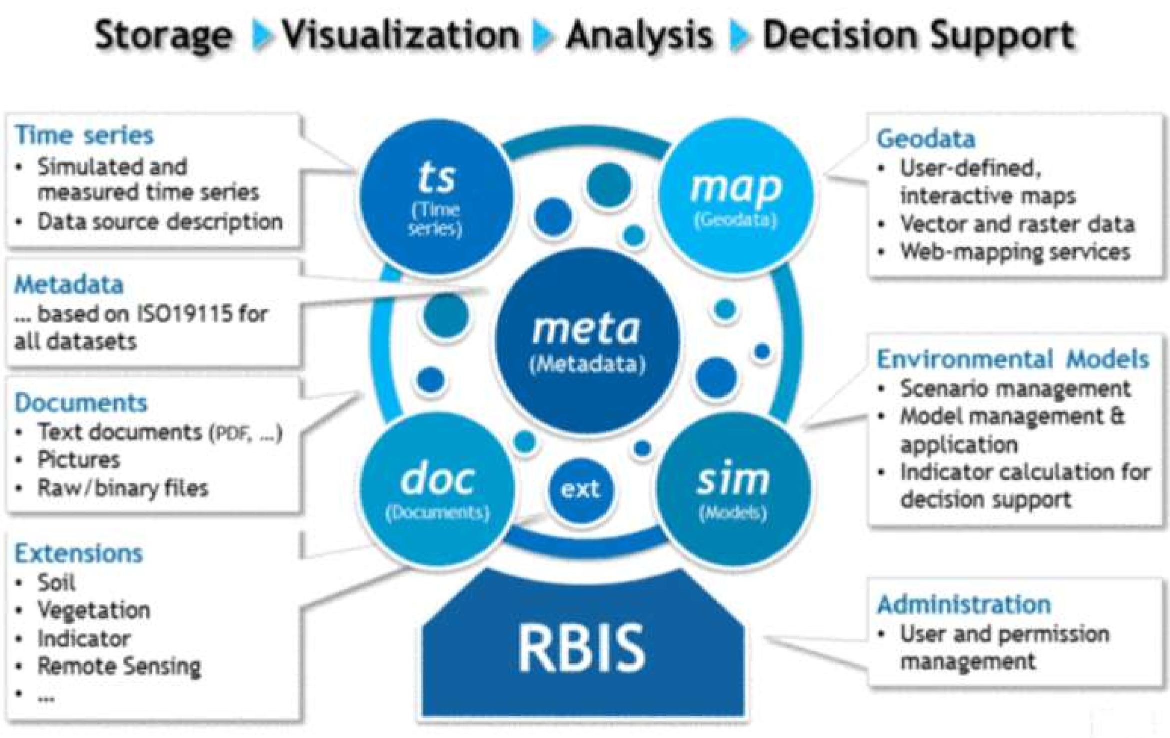

Figure 2. The RBIS system as an example of river basin information archiving (http://rbis.uni-jena.de/).

5.3 Data types, availability and concerns

Various data types will need to be built into the simulation model to ensure its usability. These include:

- Long term climate data: one will need access to all weather station within the Zambezi catchment. The modelled climate data for the catchment from various sources needs to be accessible as they reflect the climate change predictions from various sources and research groups.
- Dam level data: this data also reflect the flows and water use, balanced by water flows needed for power generation.
- Weir data: Also reflect flow.

The data needed for this project is available from the following resources:

a) The MESA database (http://www.mesasadc.org/): the data products can be viewed at http://www.mesasadc.org/data-products. Two of the pillars of this work relates to the ACE-Water programme, namely Agriculture and Flood risk.

b) Sentinel imagery: https://sentinels.copernicus.eu/web/sentinel/thematic-areas/land-monitoring/bio-geophysical-variable-mapping . The Sentinel information is key in defining land-use, and deriving soils related information for hydrological modelling. The information is also used in relation to Geological mapping and defining of groundwater recharge zones.

c) USGS for various products, including elevation models and LANDSAT information. The information can be acquired from the Earth Explorer platform. https://earthexplorer.usgs.gov/ .

d) SWAT model website is also a repository for modelled climate data, for instance the Global weather data for SWAT, accessible from http://swat.tamu.edu/ and https://earthexplorer.usgs.gov/
e) Climate data from the SASSCAL system: http://www.sasscalweathernet.org/
f) Flows measurable in a number of spots including dam levels, is archived with ZAMCOM.
g) CSIR for climate data and Land Cover data can be found at http://gsdi.geoportal.csir.co.za/projects/sadc-lc-metadata .

Data can also be accessed on the following websites:
http://swat.tamu.edu/
http://zambezi.epfl.ch/
http://www.fao.org/docrep/W4347E/w4347e0o.htm
http://www.zaraho.org.zm/hydrology
Climate data: http://www.sasscal.org/; https://www.csir.co.za/developing-african-based-earth-system-model
Runoff data: http://www.bafg.de/GRDC/EN/Home/homepage__node.html ;
http://tethys.eaprs.cse.dmu.ac.uk/RiverLake/info/zambezi_modelling; http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/; http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/

Data concerns

The Zambezi catchment has a huge rainfall gradient in an East-West direction and also in a North-South direction. This may not be adequately represented through individual climate stations, which will force the project to make use of modelled climate data for the project.

A unified Geo-referencing system is needed for the project. Hydrology makes use of projected data. The best resolution in terms of mapped information (rasters) are needed. This may be a specific problem related to hydrology, but information like land-use, generated by another team, will affect the hydrology and model output.

The temporal resolution still to be decided between modellers, but is normally done on a daily basis.

5.4 Existing models

The hydrology of the Zambezi has been a research focus area for many groups worldwide. The fact is that a number of models, already set up for the Zambezi, do exist (Winsemius, Savenije *et al*. 2005). One such model is available online and the developers are still busy building aspects of the online SWAT version. This SWAT modelling attempt can be viewed at http://zambezi.epfl.ch/. This is the preferred product for this work (Gerrits, Savenije *et al*. 2005). The aim of this study therefore is to, as far as possible, make use of procedures and models already developed and used. The risks of not being able to do so, is however rather low and the data used in these existing models (also for calibration purposes) are available at ZAMCOM. Setting up SWAT from scratch, making use of the WeatherNet data may be possible within the timeframe of the project. This include making use of the modelled climate data from the CSIR in South Africa.

JAMS modelling has been applied in SASSCAL research, making use of the SASSCAL WeatherNet data. Application was, however, only focussed on the SASSCAL participating countries, and did not include modelling of the whole Zambezi catchment. Information can be found at http://www.sasscal.org/ and http://jams.uni-jena.de/.

European Space Agency: Derivation of Bathymetric information from space, which in itself reflect on flows in the Zambezi, but can also be used in the modelling of river flows or runoff. This information is available on web sites like http://tethys.eaprs.cse.dmu.ac.uk/RiverLake/info/zambezi_modelling; http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/; http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/;

The prospect of real-time modelling can only be accomplished using timely remote sensed information as the drivers for hydrology. One often finds that instrumentation and the data stream they produce, is not reliable and data is collected in the field once in 6 months (Meier, Frömelt *et al*. 2011). Bathymetric information derived from remote sensing provides a good source of timely information needed for water management.

The idea of topographic driven conceptual modelling is also a possibility (Savenije 2010). As an example, we will in this project use this concept together with the agricultural water use information to reflect on runoff and recharge. This may generate good insight into the groundwater flows towards the Zambezi.

5.5 Table of contents of the manual on guidelines

a) Introduction
b) Methods and guidelines towards securing data also reflecting on the quality of data.
    a. Temporal data
        i. Climate data
        ii. Land-use change
    b. Mapped information
        i. Soils
        ii. Geology
        iii. Land-use and land-use change
    c. Models
        i. SWAT
        ii. Land-use based runoff generation
    d. Risks and economic indicators
    e. A reflection on the quality of data sources and resources
        i. Data collection in the field

ii. Data sampling from remote resources
iii. Field verification
iv. Instrumentation calibration and control.

f. Discussion and synthesis
g. Reflecting on the optimum data needs, to adequately manage the Zambezi water.

6. Planning

Most of the data sources are accessible and we started accumulating data for the project. We are in the process of finding and setting up of existing hydrological models and water planning information.
The main deliverables and milestones are as follows:

- An inception report, due 31/12/2017
- Manual on guidelines in modelling hydrology and hydropower (due on 30/06/2018)
- Hydrological database (spatial): dataset, tools, assessments (due on 30/11/2018)
- Capacity building materials will be gathered through the course of the work.

The outputs of the model can be used in response modelling from the other pillars of the research – especially an interaction with agriculture and land-use. This information will have to feed into other work packages.

7. Possible risks and solutions

The resolution of information for the upper Zambezi basin may be too high using the 30 or 90 m resolution available in the SRTM database. Furthermore, the trade-off between resolution used for the whole catchment in hydrological modelling and the loss in definition could be a problem. There are defined and calibrated models available for the whole catchment and they will be used in the first approximation of the task (Cohen Liechti, Matos *et al*. 2012).

Satellite data for the Zambesi basin is in the form of a mosaic, implying multiple images is needed to cover the basin. For the temporal information needed, it would imply storing a multitude of images per year. Archiving will need to be selective and decisions need to be taken regarding what to store. In this task, the optimum information will be carefully described, and resampling procedures and validation procedures will be described.

The largest problem foreseen is the calibration of the models used in absence of an existing calibrated model. This assessment will be fully described and comparisons will be made to other model output (Güntner 2008) and data resources (Güntner 2008; Savenije 2010; Cohen Liechti, Matos *et al*. 2012).
The aim of this study therefore is to, as far as possible, make use of procedures and models already developed and used, as the re-engineering of models and model input will be a task beyond the scope of the project. The risks in this regard are however rather low and the data used in these existing models are available at ZAMCOM.

8. Conclusion

The two major components of this work entail the availability of data and the access to a calibrated running model for the Zambezi catchment. Both seem to be possible and the secondary mayor task would be to secure the information and apply the modelling for the project. A third challenge is to have this information available for the other tasks of this project. The links between tasks in this project necessitates the timely interaction between the pillars of the research to secure the successful timely completion of the work.

The hydrological database that will be developed, will contribute special information to the Atlas on Water Cooperation. The contribution will further be in terms of tools and assessments, highlighting some key scenarios.

9. References

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