water affairs
Department:
Water Affairs
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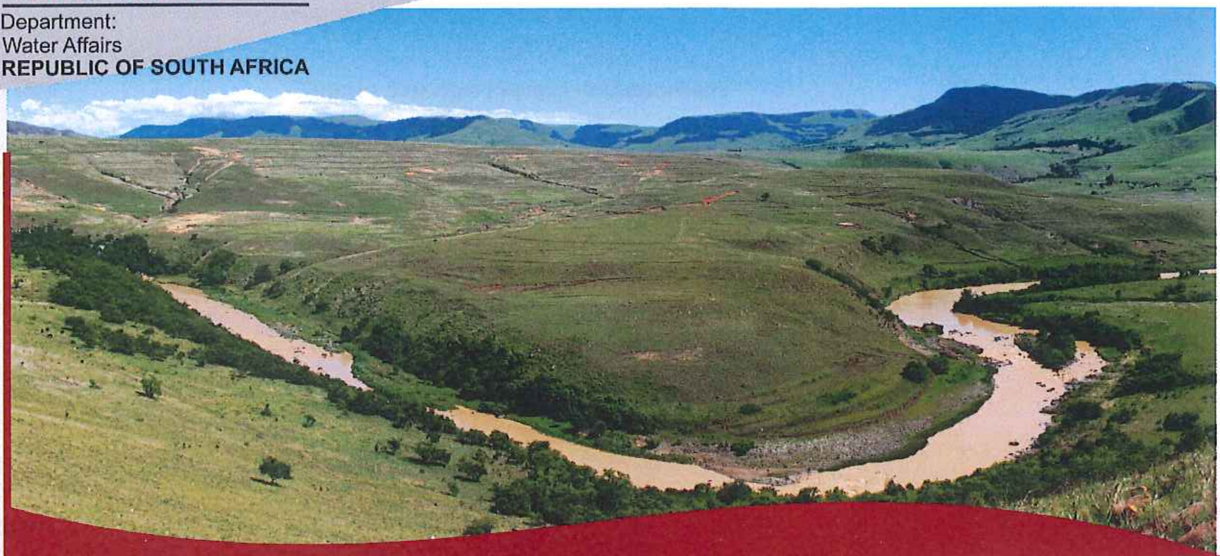

REPORT NO: P WMA 11/U10/00/3312/3/1/11

The uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water

ENGINEERING FEASIBILITY DESIGN REPORT

WRITE-UP 6: CLIMATE CHANGE IMPACT ASSESSMENT

FINAL

NOVEMBER 2015



W131_2013/J01763

Project name:	***The uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study Raw Water***
Report Title:	***Climate Change Impact Assessment***
Authors:	***M Summerton, HG van der Merwe and FGB de Jager***
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CONSULTANTS: AECOM (BKS*) in association with AGES, MM&A and Urban-Econ.

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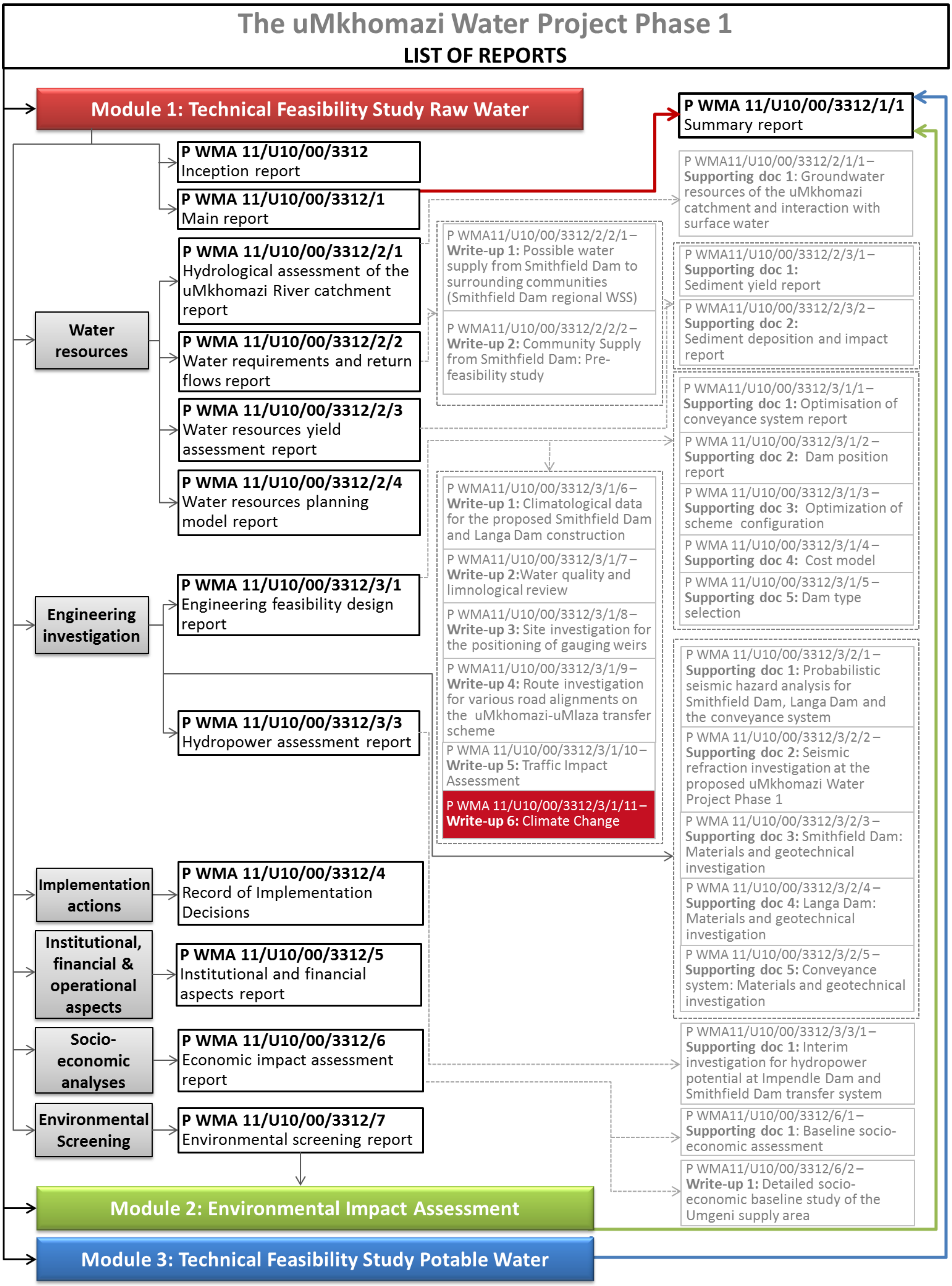
AGES

Mogoba Maphuthi & Associates (MMA)

PREAMBLE

In June 2014, two years after the commencement of the uMkhomazi Water Project Phase 1 Feasibility Study, a new Department of Water and Sanitation was formed by Cabinet, including the formerly known Department of Water Affairs.

In order to maintain consistent reporting, all reports emanating from Module 1 of the study will be published under the Department of Water Affairs name.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Executive summary

The possible impacts of climate change on the proposed Smithfield Dam were assessed at a desktop level, based on available stream flow scenarios and results from previous studies. The investigation involved two separate components, namely (i) to assess the flood design capacity of the dam to accommodate future flood peaks; and (ii) to assess the possible impact of climate change on the water supply potential (or "yield") of the dam. The outcomes and conclusions of the investigation can be summarised as follows:

- *The design stream flow and magnitude of flood peaks at the Smithfield Dam site are projected to increase by approximately 30% in the* **Intermediate Future** *(2046 to 2065), requiring a non-overspill crest level of 935.8 m. Since this is well within the originally proposed level of 936.0 m (which included a 1.0 m allowance for unknown climate change impacts and possible embankment settlement), it can be concluded that the crest level provides adequate resilience to the possible impacts of climate change.*
- *While the projected impact of climate change on yield produced a wide range of results, from a decrease of 15% to an increase of 20%, the majority of scenarios occur within a +/- 10% range, which was considered acceptable. It can be concluded that, in the* **Intermediate Future**, *climate change is unlikely to have a significant impact on the yield of Smithfield Dam.*

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LIST OF ABBREVIATIONS

AMSL	Above Mean Sea Level
CCCma	Canadian Centre for Climate Modelling and Analysis
CCSR	Centre for Climate System Research
CNRM	Meteo-France / Centre National de Recherches Meteorologiques
CSAG	Climate Systems Analysis Group (UCT)
CSIR	Council for Scientific and Industrial Research
CV	Coefficient of Variance
DM	District Municipality
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EVD	Extreme Value Distribution
FRCGC	Frontier Research Centre for Global Change
FSL	Full Supply Level
GCM	Global Circulation Model
GISS	Goddard Institute for Space Studies
IPSL	Institut Pierre Simon Laplace
KZN	KwaZulu-Natal
LM	Local Municipality
MAR	Mean Annual Runoff
MIUB	Meteorological Institute University of Bonn

MMTS	Mooi-Mgeni Transfer Scheme
MOL	Minimum Operating Level
MPI-M	Max Planck Institute for Meteorology
NIES	National Institute for Environmental Studies
NOAA	Geophysical Fluid Dynamics Laboratory
NOC	Non-overspill Crest
PMF	Probable Maximum Flood
PSP	Professional Services Provider
RDF	Recommended Design Flood
RMF	Regional Maximum Flood
SEF	Safety Evaluation Flood
SMHI	Swedish Meteorological and Hydrological Institute
UCT	University of Cape Town
UKZN	University of KwaZulu-Natal
uMWP	uMkhomazi Water Project
WRYM	Water Resources Yield Model
WSS	Water Supply System

1 INTRODUCTION

The Department of Water Affairs (DWA) appointed **BKS (Pty) Ltd** in association with three sub-consultants **Africa Geo-Environmental Services, MM&A and Urban-Econ** with effect from 1 December 2011 to undertake the **uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study Raw Water** study.

On 1 November 2012, BKS (Pty) Ltd was acquired by **AECOM Technology Corporation**. The new entity is a fully-fledged going concern with the same company registration number as that for BKS. As a result of the change in name and ownership of the company during the study period, all the final study reports will be published under the AECOM name.

In 2010, the Department of Arts and Culture published a list of name changes in the Government Gazette (GG No 33584, 1 October 2010). In this list, the Mkomazi River's name was changed to the **uMkhomazi River***. The published spelling will thus be used throughout this technical feasibility study.*

1.1 BACKGROUND TO THE PROJECT

The current water resources of the integrated Mgeni Water Supply System (WSS) are insufficient to meet the long-term water requirements of the system. The Mgeni WSS is the main water source that supplies about five million people and industries in the eThekwini Municipality, uMgungundlovu District Municipality (DM) and Msunduzi Local Municipality (LM), all of which comprise the economic powerhouse of the KwaZulu-Natal Province.

The Mgeni WSS comprises the Midmar, Albert Falls, Nagle and Inanda dams in KwaZulu-Natal, a water transfer scheme from the Mooi River and the newly constructed Spring Grove Dam. The current system (Midmar, Albert Falls, Nagle and Inanda dams and the MMTS-1) has a yield of 334 million m^3/a (measured at Inanda Dam) at a recurrence interval (RI) of failure of 1:100 years (or an annual assurance of supply of 99%). The short-term augmentation measure, Phase 2 of the Mooi-Mgeni Transfer Scheme (MMTS-2), currently being implemented with the construction of Spring Grove Dam, will increase water supply from the Mgeni WSS by 60 million m^3/a. However, this will not be sufficient to meet the long-term requirements of the system.

Pre-feasibility investigations indicated that Phase 1 of the uMkhomazi Water Project (uMWP-1), which entails the transfer of water from the undeveloped uMkhomazi River to the existing Mgeni WSS, is the scheme most likely to fulfil this requirement. The uMkhomazi River is the third-largest river in KwaZulu-Natal in terms of mean annual runoff (MAR).

Eight alternative schemes were initially identified as possible alternatives, and the Impendle and Smithfield scheme configurations have emerged as suitable for further investigation. The pre-feasibility investigation, concluded in 1998, recommended that the Smithfield Scheme be taken to a detailed feasibility-level investigation as its transfer conveyances would be independent of the existing Mgeni WSS, thus reducing the risk of limited or non-supply to eThekwini and some areas of Pietermaritzburg, and providing a back-up to the Mgeni WSS.

The ***Mkomazi-Mgeni Transfer Pre-feasibility Study*** concluded that the first phase of the uMWP would comprise a new dam at Smithfield on the uMkhomazi River near Richmond, a multi-level intake tower and pump station, a water transfer pipeline/tunnel to a balancing dam at Baynesfield Dam or a similar in-stream dam, a water treatment works at Baynesfield in the uMlaza River valley and a gravity pipeline to Umgeni Water's bulk distribution reservoir system, below the reservoir at Umlaas Road. From here, water will be distributed under gravity to eThekwini and possibly low-lying areas of Pietermaritzburg. Phase two of the uMWP may be implemented when needed, and could comprise the construction of a large dam at Impendle further upstream on the uMkhomazi River to release water to the downstream Smithfield Dam. Together, these developments have been identified as having a 99% assured stochastic yield of about 388 million m^3/a.

The DWA aims to have this scheme implemented by 2023.

1.2 OBJECTIVE OF THE STUDY

According to the Terms of Reference (November 2010), the objective of the study project is to undertake a feasibility study to finalise the planning of the proposed uMkhomazi Water Project (uMWP) at a very detailed level for the scheme to be accurately compared with other possible alternatives and be ready for implementation (detailed design and construction) on completion of the study.

The feasibility study has been divided into the following modules, which will run concurrently:

- Module 1: Technical Feasibility Raw Water (DWA) (*defined below*).
- Module 2: Environmental Impact Assessment (DWA).
- Module 3: Technical Feasibility Potable Water (Umgeni Water) (*ranging from the Water Treatment Plant to the tie-in point with the eThekwini distribution system*).

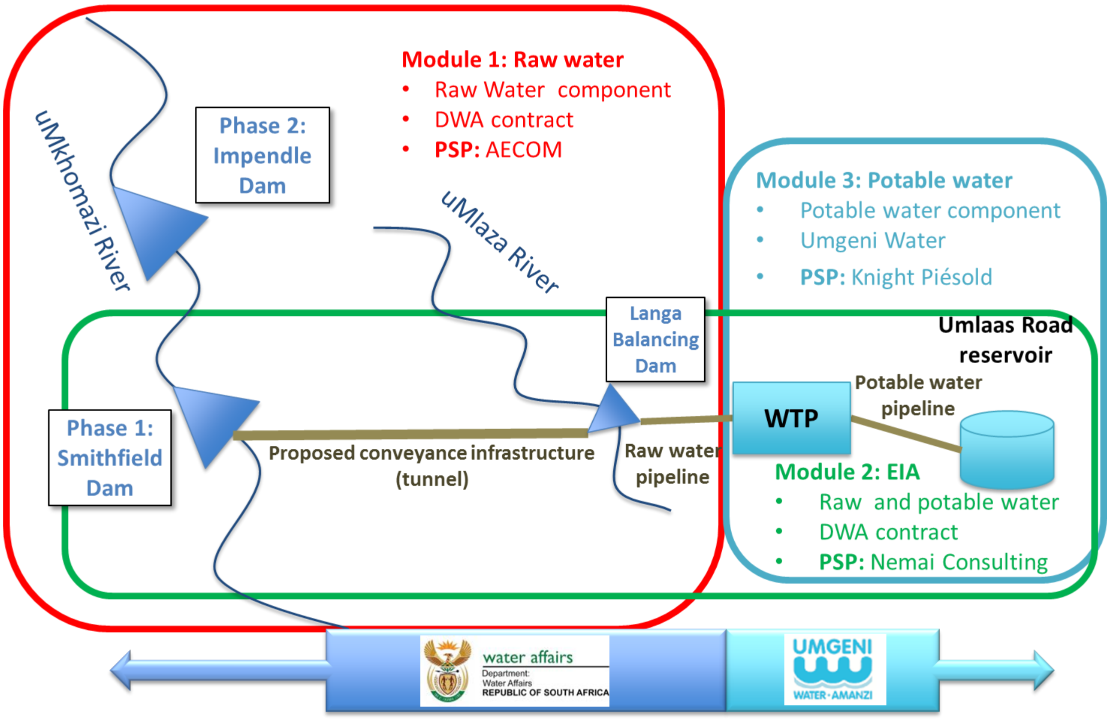

Figure 1.1: uMWP-1 feasibility study modules

This module, the raw water technical feasibility study, considers water resources aspects, engineering investigations and project planning and scheduling and implementation tasks, as well as an environmental screening and assessment of socio-economic impacts of the proposed project.

Some specific objectives for this study, recommended in the *Mkomazi-Mgeni Transfer Scheme Pre-feasibility* study are listed below:

- Smithfield Dam (Phase 1) to be investigated to a detailed feasibility level.
- Investigate the availability of water from Impendle Dam (Phase 2) as a future resource to release to Smithfield Dam, and refine the phasing of the selected schemes.
- Optimise the conveyance system between Smithfield Dam and the proposed Baynesfield Water Treatment Plant.
- Undertake a water resources assessment of the uMkhomazi River Catchment, including water availability to the lower uMkhomazi.
- Evaluate the use of Baynesfield Dam as a balancing dam.

- Investigate the social and economic impact of the uMWP.

This one of three studies was undertaken in close collaboration with the DWA, Umgeni Water and the Professional Services Providers (PSPs) of the other modules.

1.3 STUDY AREA

The study focus and key objective is related to the feasibility investigation of the Smithfield Dam and related raw water conveyance infrastructure. However, this is a multi-disciplinary project with the study area defined as the uMkhomazi River catchment, stretching to the north to include the uMngeni River catchment, refer to **Figure 1.2**.

The various tasks have specific focus area, defined as:

- Water Resources: uMkhomazi and uMngeni river catchments.
- Water requirements: Water users in the existing Mgeni WSS and the uMkhomazi River catchment.
- Engineering Investigations: Proposed dams at Impendle (only for costing purposes) and Smithfield, and the raw water conveyance infrastructure corridor between Smithfield Dam and the Water Treatment Plant of Umgeni Water.
- Environmental screening as input for the Environmental Impact Assessment.
- Socio-economic impact assessment: regional, provincial (KwaZulu-Natal (KZN)) and national.

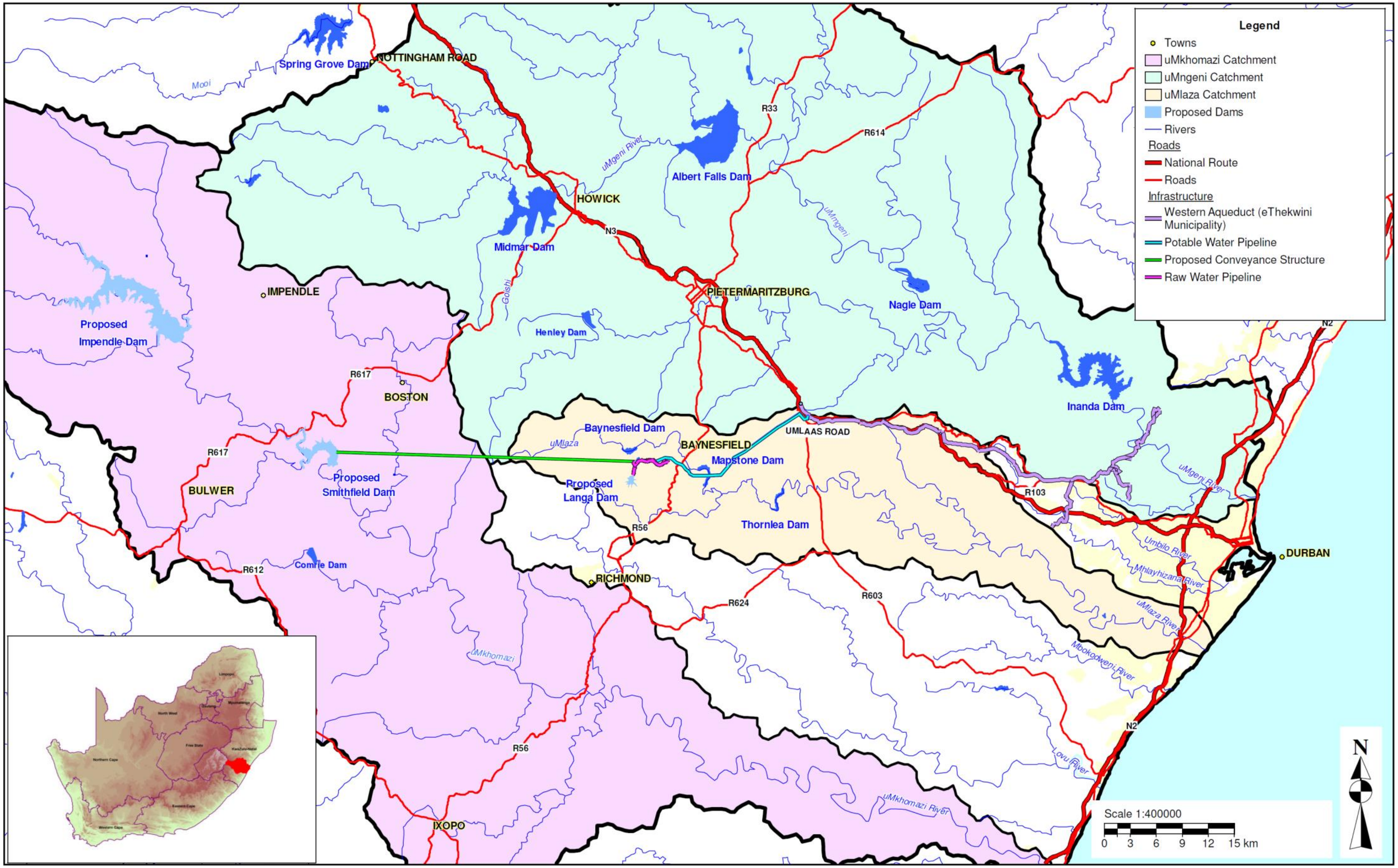

Figure 1.2: Study area of the uMWP

1.4 SCOPE OF THIS REPORT

The purpose of this report is to discuss the investigation undertaken to assess the possible impacts of climate change on the proposed Smithfield Dam. The investigation involved two separate components, namely:

- Assessing the flood design capacity of the dam to accommodate future flood peaks.
- Assessing the possible impact of climate change on the water supply potential (or "yield") of the dam.

2 DAM CHARACTERISTICS

The proposed Smithfield Dam will consist of an 84 m high earth core rock fill dam with a side channel spillway discharging into a plunge pool. The design includes two intake towers, with one of the diversion tunnels used for the dam outlet and with the transfer tunnel intake located up-stream in the dam reservoir. A summary of the characteristics of selected dam at Smithfield is provided in **Table 2.1** *(AECOM, 2015)*.

Table 2.1: Characteristics of the selected dam at Smithfield

Parameter	Main dam	Saddle dam
Type of dam	Zoned earth core rock-fill dam	Zoned earth-fill embankment dam
DWA classification	Category III	
Natural MAR(1) (million m³/a)	725.9	
Full supply level (FSL, m AMSL(2))	930.0	
Minimum operating level (MOL, m AMSL)	887.2	
Gross storage capacity at FSL (million m³)	251.4	
Live storage capacity at FSL (million m³)	226.2	
Live storage volume (as % of MAR)	31%	
Surface area at FSL (km²)	9.53	
Catchment area (km²)	2 058	
Non-overspill Crest level (m AMSL)	936.0	
Maximum wall height (m)	81.0	26.0
Crest length of wall (m)	1 200	1 090
Spillway type	Main side channel	Fuse plug
Spillway shape	Ogee	Broad-crested
Spillway length (m)	150.0	100.0
1:100 yield(3) (million m³/a)	220	

Notes: (1) Mean annual runoff.
(2) Above mean sea level.
(3) At 2050 in-catchment development levels.

3 FLOOD PEAK CAPACITY

Flood estimations have traditionally used historical rainfall or stream flow-based methods to make predictions of possible future flows. Examples are the Regional Maximum Flood (RMF) and Probable Maximum Flood (PMF) methods. These indicators play a key role in the design and notably the sizing of a dam wall to accommodate possible floods.

From recent studies, clear evidence exists that the climate is changing globally and that this will have an amplified impact on water resources and therefore on floods. Recently, the reliability of Global Circulation Models (GCMs) has improved and they are being used to provide a scientifically-based indication of potential future climates.

The possible impacts of a changing climate on the flood peak capacity of the proposed Smithfield Dam were assessed at a desktop level. The assessment involved four main aspects as discussed in the following subsection. These are:

- The collation and interpretation of data from climate change models.
- Hydrological modelling to provide scenarios of future climate stream flows.
- Applying modelled future climate stream flows to estimate the possible impact of climate change on future flood peaks.
- Assessing the flood design capacity of Smithfield Dam to accommodate future flood peaks.

3.1 CLIMATE CHANGE MODELS

The climate change impact assessment was largely based on rainfall data from the quinery (sub-quaternary) catchment climate change database developed by (Schulze, 2012). The database incorporates daily rainfall outputs obtained from five selected GCMs as summarised in **Table 3.1**. In each case data sets were obtained for three distinct 20-year time periods, as follows:

- The *Present* climate (1971 to 1990).
- The *Intermediate Future* climate (2046 to 2065).
- The *Distant Future* climate (2081 to 2100).

Table 3.1: Climate change models used for the flood peak assessment

No.	Institute	GCM[(1)]
1	Canadian Center for Climate Modelling and Analysis (CCCma), Canada	Name: CGCM3.1(T47) First published: 2005 Website: http://www.cccma.bc.ec.gc.ca/models/cgcm3.shtml
2	Meteo-France / Centre National de Recherches Meteorologiques (CNRM), France	Name: CNRM-CM3 First published: 2004 Website: http://www.cnrm.meteo.fr/scenario2004/indexenglish.html
3	Max Planck Institute for Meteorology (MPI-M), Germany	Name: ECHAM5/MPI-OM First published: 2005 Website: http://www.mpimet.mpg.de/en/wissenschaft/modelle.html
4	NASA / Goddard Institute for Space Studies (GISS), USA	Name: GISS-ER First published: 2004 Website: http://www.giss.nasa.gov/tools/modelE
5	Institut Pierre Simon Laplace (IPSL), France	Name: IPSL-CM4 First published: 2005 Website: http://mc2.ipsl.jussieu.fr/simules.html

Notes: (1) Global Circulation Model.

3.2 STREAM FLOWS

The daily time-step "ACRU" agro-hydrological model (Schulze, R.E., 1995 and updates) was used to re-model daily stream flows for the *Present* and *Intermediate Future* time periods, based on result outputs from the five GCMs shown above. The modelled results were then post-processed to:

- Develop annual maximum series of multiple duration stream flows, namely 1-day, 2-day, 3-day and 7-day.
- Using the above, to calculate multiple duration design rainfall and stream flow events for the 2-year, 5-year, 10-year, 20-year, 50-year and 100-year recurrence intervals, using the log-Normal Extreme Value Distribution (EVD).

Based on the results from the above analysis, ratios were calculated of both the *Intermediate Future*-to-*Present* and *Distant Future*-to-*Present* design stream flow characteristics. The resulting averages were then averaged across the five selected GCMs, based on the motivation that this would ensure any uncertainties inherent in the respective models would be largely self-cancelling (Schulze, 2012). The results of this assessment are presented in **Table 3.2** and show that, for all recurrence intervals considered, 1-day design stream flow events are projected to increase by approximately 30% in the *Intermediate Future* (refer to values highlighted in red).

Table 3.2: Summary of design stream flow impacts

Design stream flow event		Average increase over indicated time period (as a % compared to *Present* climate)	
Duration (days)	Recurrence interval (years)	*Intermediate Future* climate	*Distant Future* climate
1	2	**23**	31
	5	**25**	27
	10	**27**	26
	20	**29**	26
	50	**32**	26
	100	**34**	26
2	2	24	32
	5	26	28
	10	29	27
	20	31	27
	50	35	28
	100	39	29
3	2	26	33
	5	28	29
	10	30	28
	20	33	28
	50	37	29
	100	40	30
7	2	33	41
	5	35	36
	10	36	36
	20	38	36
	50	41	37
	100	43	38

3.3 FLOOD PEAKS

The flood peaks that are relevant to the design of the freeboard and the spillway design of the proposed Smithfield Dam are the Recommended Design Flood (RDF, at a recurrence interval of 1:200-years) and the Safety Evaluation Flood (SEF). These were calculated based on the historical hydrological characteristic of the catchment upstream of the dam site *(AECOM, 2015)* and are provided below:

- RDF: 2 620 m^3/s.
- SEF: 5 650 m^3/s.

For the purpose of this climate change assessment it was assumed that the projected increase in design stream flows (as discussed in the previous section) could be used as a pseudo indicator of the possible impact of climate change on flood peaks – which was therefore taken to be 30% in the *Intermediate Future*. Although this is acknowledged not to be entirely scientifically robust, the approach is considered plausible. This is especially true when one accepts the inherent inaccuracies associated with climate-water modelling of this nature which often results in highly variable results (as discussed later in **Section 4**).

3.4 DAM FLOOD CAPACITY

(a) Historical analysis

The dam flood capacity is generally determined by routing an inflow hydrograph with RDF and SEF peaks, through different spillway lengths to determine the height of the water level in the reservoir at each spillway length. This water level is then compared to an empirical determined freeboard height to verify if it can pass without overtopping the Non-overspill Crest (NOC) of the dam (AECOM, 2015).

Using the historically-based flood peaks shown in a previous subsection, it was found that an Ogee spillway with a length of 150 m and a broad-crested weir fuse plug with an additional length of 100 m will be required to safely pass the SEF. This spillway length requires a total freeboard (the difference between the NOC level and the Full Supply Level, or FSL), of 5 m. Based on the selected FSL of 930.0 m (as shown earlier in **Table 2.1**) this resulted in an NOC level of 935.0 m, which was then increased by 1.0 m to 936.0 m to allow for climate change impacts and possible embankment settlement *(AECOM, 2015)*.

(b) Climate change impact assessment

For the purpose of testing the flood design capacity of Smithfield Dam to accommodate future climatic conditions, a range of flood peaks were routed through the spillway arrangement, from the historically-based SEF up to a maximum flood of SEF plus 30% (in 5% increments).

The results are shown in **Table 3.3** and indicate that an increase of 30% in the SEF would result in a water level of 935.8 m (highlighted in red), well within the originally proposed NOC level of 936.0 m.

Table 3.3: Results of future flood peak routing analysis

Assumed increase in flood peak	Inflow flood peak (m^3/s)	Outflow flood peak (m^3/s)	Stage (m AMSL)
5%	5 907	5 679	935.1
10%	6 188	5 938	935.2
15%	6 469	6 201	935.4
20%	6 750	6 473	935.5
25%	7 032	6 747	935.7
30%	7 313	7 020	**935.8**

4 WATER RESOURCES

The possible impact of climate change on the yield of the proposed Smithfield Dam was undertaken at a desktop level. The assessment was based largely on the results of an earlier study by Umgeni Water to assess the impact of climate change on the neighbouring uMngeni River catchment (Umgeni Water, 2012). The proximity of the uMngeni catchment means that its results can be used to infer possible impacts in the uMkohomazi catchment. Details in this regard are provided in the following subsection.

4.1 STREAM FLOWS

Climate change induced stream flow time-series were obtained from the University of KwaZulu-Natal (UKZN). These long-term stream flow time-series were simulated using the daily time-step "ACRU" agro-hydrological model, at a quinary (sub-quaternary) catchment level, based on climate change data for three distinct 20-year time periods, as follows:

- The *Present* climate (1971 to 1990).
- The *Intermediate Future* climate (2046 to 2065).
- The *Distant Future* climate (2081 to 2100).

Umgeni Water used the results from a total of 31 scenarios (including the five used for the flood peak assessment discussed earlier in **Section 3.1**), comprising of 14 different GCMs from 12 different institutions and with five different CO_2-emission scenarios, as summarised in **Table 4.1**. These scenarios were all derived at a large geographical scale and then downscaled using so-called empirical (or statistical) methods as applied by the Climate Systems Analysis Group (CSAG) of the University of Cape Town (UCT) and the Council for Scientific and Industrial Research (CSIR), or physical methods used by the Swedish Meteorological and Hydrological Institute (SMHI), in order to obtain corresponding results that are representative of specific areas (i.e. at a smaller scale).

Table 4.1: Climate change models used for the water resources assessment

Acronym	GCM	Institution	CO_2-emission scenarios	Sources
CC1	CCMA_CGCM3_1	Canadian Centre for Climate Modelling and Analysis (CCCma), Canada	B1	CSAG
CC2	CCMA_CGCM3_1	Canadian Centre for Climate Modelling and Analysis (CCCma), Canada	A2	CSAG
CN1	CNRM_CM3	Meteo-France / Centre National de Recherches Meteorologiques (CNRM), France	B1	CSAG
CN2	CNRM_CM3	Meteo-France / Centre National de Recherches Meteorologiques (CNRM), France	A2	CSAG
CS1	CSIRO_MK3_5	Centre for Australian Weather and Climate Research: A partnership between CSIRO & Bureau of Meteorology	B1	CSAG
CS2	CSIRO_MK3_5	Centre for Australian Weather and Climate Research: A partnership between CSIRO & Bureau of Meteorology	A2	CSAG
E11	MIUB_ECHO_G	Meteorological Institute University of Bonn (MIUB), Germany	B1	CSAG
E12	MPI_ECHAM5	Max Planck Institute for Meteorology (MPI-M), Germany	B1	CSAG
E21	MIUB_ECHO_G	Meteorological Institute University of Bonn (MIUB), Germany	A2	CSAG
E22	MPI_ECHAM5	Max Planck Institute for Meteorology (MPI-M), Germany	A2	CSAG
G11	GFDL_CM2_0	Geophysical Fluid Dynamics Laboratory, NOAA, USA	B1	CSAG
G12	GFDL_CM2_1	Geophysical Fluid Dynamics Laboratory, NOAA, USA	B1	CSAG
G21	GFDL_CM2_0	Geophysical Fluid Dynamics Laboratory, NOAA, USA	A2	CSAG
G22	GFDL_CM2_1	Geophysical Fluid Dynamics Laboratory, NOAA, USA	A2	CSAG
Gi1	GISS_MODEL_E_R	Goddard Institute for Space Studies (GISS), NASA, USA	B1	CSAG
Gi2	GISS_MODEL_E_R	Goddard Institute for Space Studies (GISS), NASA, USA	A2	CSAG
IP1	IPSL_CM4	Institut Pierre Simon Laplace (IPSL), France	B1	CSAG
IP2	IPSL_CM4	Institut Pierre Simon Laplace (IPSL), France	A2	CSAG
MR1	MRI_CGCM2_3_2A	Meteorological Research Institute, Japan Meteorological Agency, Japan	B1	CSAG
MR2	MRI_CGCM2_3_2A	Meteorological Research Institute, Japan Meteorological Agency, Japan	A2	CSAG
CSIRO	CSIRO_MK3_5	Centre for Australian Weather and Climate Research: A partnership between CSIRO and the Bureau of Meteorology	A2	CSIR
GFDL20	GFDL-CM2.0	Geophysical Fluid Dynamics Laboratory, NOAA, USA	A2	CSIR
GFDL21	GFDL-CM2.1	Geophysical Fluid Dynamics Laboratory, NOAA, USA	A2	CSIR

Acronym	GCM	Institution	CO_2-emission scenarios	Sources
MIROC	MIROC 3.2	Centre for Climate System Research (CCSR), University of Tokyo; National Institute for Environmental Studies (NIES); Frontier Research Centre for Global Change (FRCGC)	A2	CSIR
MPI	MPI_ECHAM5	Max Planck Institute for Meteorology (MPI-M), Germany	A2	CSIR
UKMO	UKHADcm3	Hadley Centre for Climate Prediction and Research Met Office, United Kingdom	A2	CSIR
C3A1	CCSM3	National Centre of Atmospheric Research, USA	A1B	SMHI
C3B2	CCSM3	National Centre of Atmospheric Research, USA	B2	SMHI
E4A2	ECHAM4	Max Planck Institute for Meteorology (MPI-M), Germany	A2	SMHI
E4B2	ECHAM4	Max Planck Institute for Meteorology (MPI-M), Germany	B2	SMHI
E5A1	MPI_ECHAM5	Max Planck Institute for Meteorology (MPI-M), Germany	A1B	SMHI

Results of the analysis are summarised in **Figure 4.1** and **Figure 4.2**, showing the mean annual runoff (MAR) and annual coefficient of variance (CV) of the *Intermediate Future* relative to that of the *Present* climate (as a %), for each of the 31 selected climate change scenarios. It is interesting to note that the results exhibit significant variability, ranging from a possible decrease in MAR of 44% to an increase of 89%. The variability of the impacts on CV is even more pronounced.

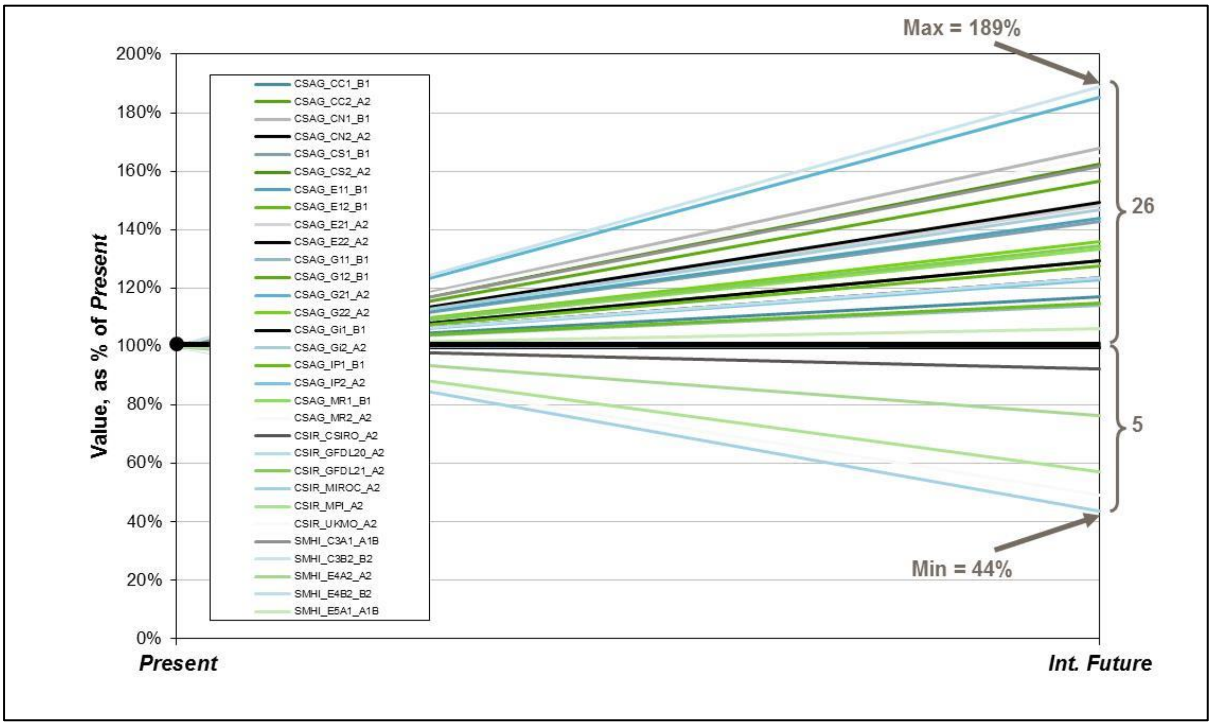

Figure 4.1: Modelled climate change impacts on MAR for selected scenarios

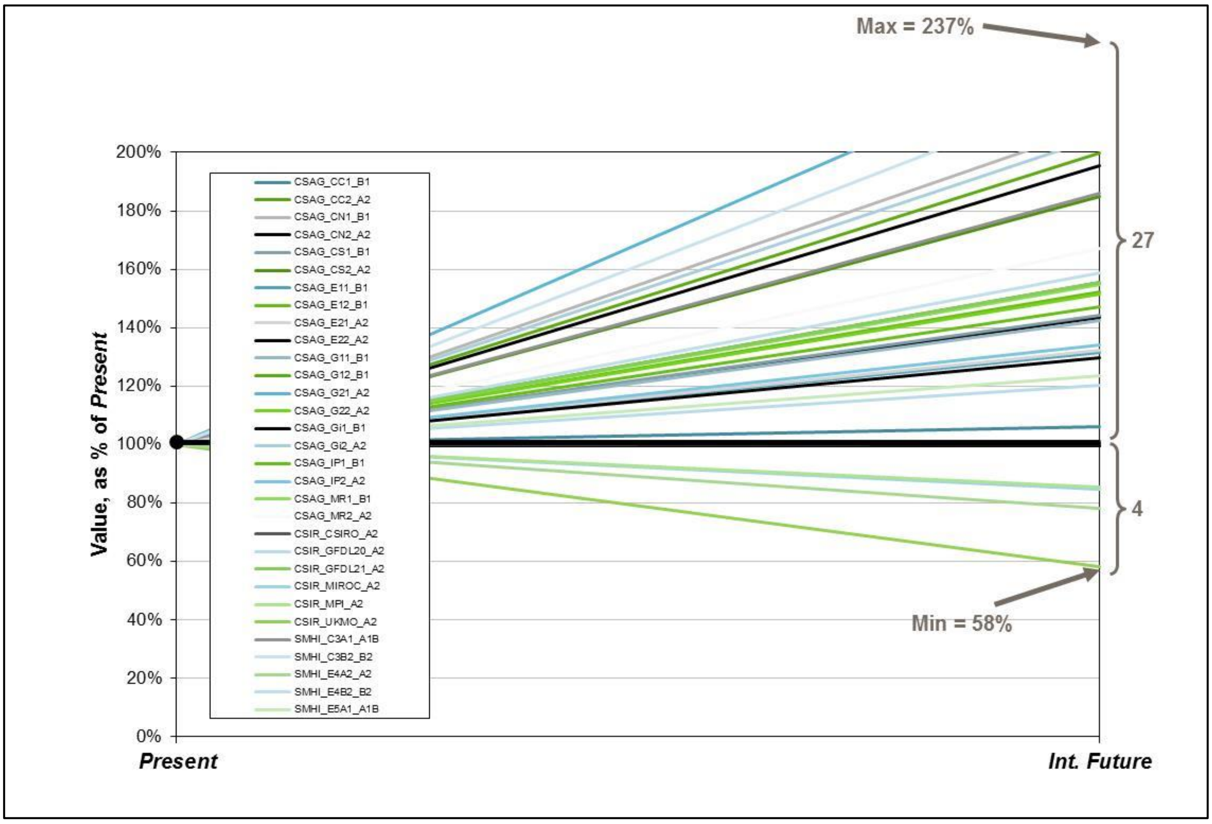

Figure 4.2: Modelled climate change impacts on CV for selected scenarios

4.2 YIELD ANALYSIS

Based on the long-term stream flow time-series discussed above, analyses were undertaken using the Water Resources Yield Model (WRYM) to assess the possible impacts of climate change on yield of the main dams in the uMngeni catchment. The results are shown in **Figure 4.3** in terms of yield at a recurrence interval of failure of 1:100 years (99% annual assurance of supply) as determined for the *Intermediate Future* relative to that of the *Present* climate (as a %), for each of the 31 selected climate change scenarios. The range of possible impacts on yields is large, ranging from an increase of 41% to a decrease of 55%.

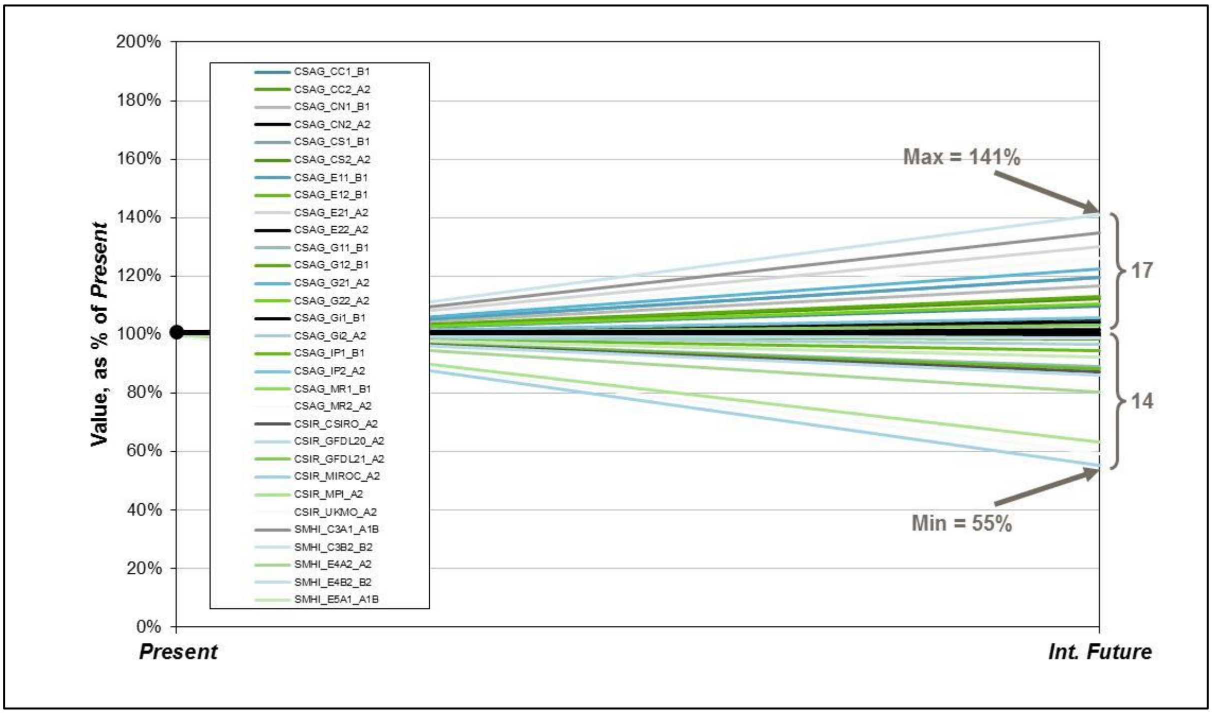

Figure 4.3: 1:100 yield results for selected scenarios

Unfortunately, the results shown above highlight the fact that the range of possibilities in the future remains large and unpredictable. However, the results also suggest that if the three highest and three lowest “outlier” scenarios are removed from the set of results, the climate change impact is limited to an envelope of possibilities from a decrease of 15% to an increase of 20%, with the majority of scenarios falling within the +/- 10% range. The 20% increase is in line with the 30% determined for an increase in flood peaks in the current study, giving a sense of confidence in the results. The water and climate systems are complex with numerous inter-related processes, the modelling of which is far from an exact science. Considering this and that water-climate assessments of this nature are contemporary, there is a paucity of other studies to which our results could be compared. Having considered this, the results presented here are intuitively acceptable.

5 CONCLUSIONS

Based on the climate change assessment and results presented in this reported, it is concluded that:

- The design stream flow and magnitude of flood peaks at the Smithfield Dam site are projected to increase by approximately 30% in the *Intermediate Future* (2046 to 2065).
- The projected increase of 30% requires a non-overspill crest level of 935.8 m. This is well within the originally proposed level of 936.0 m which included a 1.0 m allowance for unknown climate change impacts and possible embankment settlement.
- While the projected impact of climate change on yield produced a wide range of results, from a decrease of 15% to an increase of 20%, the majority of scenarios fell within the +/- 10% range.
- Based on the above outcome it can be concluded that in the *Intermediate Future* climate change is unlikely to have a significant impact on the yield of Smithfield Dam.
- Regardless of the impacts of a changing climate, indications are that the proposed Smithfield Dam is still required.

6 REFERENCES

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