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EVALUATION OF THE IMPACT OF CLIMATE CHANGE ON THE INFLOW TO LUBOVANE RESERVOIR IN USUTU CATCHMENT, SWAZILAND

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ABSTRACT
According to IPCC global average temperature is predicted to increase by 1.4-5.8°C by year 2100. Carbon concentration is expected to increase from 377ppm to 490-1260 ppm by the end of the century. In as much as global precipitation is expected to increase however in some regions especially in Southern Africa precipitation is expected to change by ± 20%. The Lubovane Reservoir has been constructed to address water shortage for low income subsistence farmers during the dry season when Usutu River flows are minimal. Therefore a 218m ogee shaped weir across the Usutu River was constructed to harvest flood water during the wet season to fill an off river 155 MCM Reservoir along Mhlatuzane River. This development is aimed at providing irrigation water for 11500 hectares for mainly sugarcane production. There is no evidence that the impacts of climate change on stream flows were considered and it is uncertain whether the reservoir will fill up under climate change or not. Three GCMs (CCMAD2, ECH5D2 and IPSLD2) in Magicc/Scengen5.1 version 2 were used to simulate year 2075 rainfall and temperature. Future stream flows were then simulated using a calibrated rainfall runoff model (Watbal). Inputs to the Watbal model were year 2075 rainfall and potential evapotranspiration and current runoff. Simulation results revealed an average of 4.83% and 4.13% decrease in annual runoff for dry and wet-year conditions respectively compared to present situation. With initial reservoir storage of 0 to 10 % in year 2075, the reservoir will not fill up and the irrigation of 11500 ha will face challenges. This is however not attributed to expected climate change but mainly due to the limiting size of the diversion canal.

Keywords: Climate Change, GCMs Stream Flow Simulation, Wet and Dry Year Conditions, Irrigation, Rainfall

INTRODUCTION
The Lower Usutu Smallholder Irrigation Project (LUSIP) is a poverty alleviation initiative situated in the Lowveld of Swaziland. The main goal of LUSIP is to improve the standard of living of the people in the project area, who are currently the poorest in the country. The project will achieve this goal by transforming the local economy from subsistence farming into sustainable commercial agriculture. The project is significantly the efforts of the Government of Swaziland in alleviating poverty in the country and meeting the millennium development goals (MDGs).

The Lower Usutu Smallholder Irrigation Project commenced in December 2003 and is scheduled to be completed in 2015. The project was founded to address the lack of irrigation water for poor farmers as the dry season river flow of the

Lower Usutu River has already been fully allocated to existing irrigators. The LUSIP project will address this constraint by storing flood water in an off-river, 155 million m^3 reservoirs at Lubovane that will provide irrigation water for an overall 11500 ha after completion of the second phase in 2015. Three dams have been constructed at Mhlathuzane River, Golome River and Saddle dam to form an off river reservoir to store flood water diverted from wet season flows from the Usutu River.

Climate will always change due to the natural forcing of centricity. However, it has been argued that climate change in the next hundred years will be due to anthropogenic activities. Human interventions are causing the earth to change too fast and this affects adaptability of many living organisms. According United Nations Environmental Program (UNEP) (2007) the earth temperature has increased by 0.6^o C and this is attributed to increase in green house gases exacerbated by emission from human activities. Green house gases control energy flow in the atmosphere by absorbing infrared radiation emitted by the earth. Green house gases act like a blanket to keep the earth some 20^{o}C warmer than it would be if atmosphere contained only oxygen and nitrogen (UNEP, 2007). However water vapor is a largest natural contributor of green house gas not attributed to human activities. Global average temperature is predicted to increase by 1.4-5.8^{o}C by year 2100 (UNEP, 2007). The 2001, IPPC report on climate change reveals an increase in mean sea level by 10-20cm and further predicts a further increase by 9-88cm by year 2100.

Carbon dioxide is a major contributor to climate change as a result of human interventions. In 2001, the carbon concentration in the atmosphere was 367ppm and it is predicted to increase to 490-1260ppm by year 2100 (UNEP, 2007). Carbon dioxide is currently responsible for over 60% of enhanced green house effect. This is promoted by the burning of fossil fuels such as coal, gas and oil. Power stations release aerosols which are microscopic particles from sulphur dioxide and nitrous oxides released from agriculture also contribute as green house gases.

The impacts of climate change will involve an increase in droughts in some regions especially in the African continent and floods, hurricanes and monsoons will be experienced in other regions especially in the northern hemisphere (Al Gore's 2006). Africa and Asia is likely to experience reduction in rainfall and increase in severe droughts. Globally, the green house gases effect is expected to increase average precipitation by 5-15% and Evapotranspiration by 10-20% World Meteorological Organization (WMO, ICSU and UNEP, 1989).

DESCRIPTION OF STUDY AREA

The Lower Usutu Smallholder Irrigation Project (LUSIP) is found in the Lower Usutu river basin which is the largest river basin in Swaziland with an area of 12559 km^2. The study area (Sphofaneni) is located in the lowveld agro-climatic region of Swaziland, between latitudes 26° 40' 60" S and longitudes 31° 40' 60" E with an altitude of 164m above sea level Central Statistical Office (CSO, 2008).

Climatic and Hydrological Setting

Usutu River originates from South Africa cuts through Swaziland to the sea in Mozambique. Upper main tributaries found in Swaziland include: Lusushwana River and Mkhondvo and other minor ones. The basin annual rainfall ranges between 600 to 1000mm. The basin inflow is about 696 x 10^6 M^3/ annum and an outflow of 2357 x 10^6 M^3/annum. The region is endowed with two climatic seasons. The summer-wet and winter- dry season. The average temperatures range between 19^{o}C to 30^{o}C (Swaziland Meteorological Department, 2009). The Usutu Basin cuts through three agroecological zones, with tributaries from the highveld, middleveld and lowveld. Usutu River Basin is the third basin of economic significance in Swaziland; it supports sugar cane irrigation, hydro power generation and industry. The direct beneficiaries of the LUSIP project include 2600 farm households (15300 persons) situated only around Sphofaneni Area, Swaziland Water and Agricultural Development Enterprise (SWADE, 2010).

Figure 1 Map of Swaziland Showing LUSIP Project Location and Lubovane Reservoir (Source: SWADE, 2010)

METHODOLOGY

Data Collection and Processing

For the purposes of evaluating the effect of climate change on the stream flow in the Usutu River basin requires hydro-meteorological data which includes: daily rainfall air temperature (minimum and maximum), potential evapotranspiration and stream flow for the Usutu River at the gauging station GS6, at Sphofaneni. Meteorological data was provided by the Swaziland Meteorological Department and stream flow data was provided by the Water Resources Department. Data was analyzed for data quality control due to existing gaps that needed to be filled before further use.

Potential evapotranspiration (PET) is also required data for analysis purposes. Unfortunately there was no direct PET data provided therefore it had to be computed using meteorological variables. Due to the available data, the Thorn Waite method of computing PET was found to be ideal and easier to use. Runoff at the controlling station (GS6) for the

Lubovane reservoir was critical for analysis in this study. Stream flow records at the GS6 (Sphofaneni) was analyzed for quality control by filing the missing gaps using rainfall runoff modeling (Matondo and Misibi 2001).

Separation between Dry and Wet Years

Further analysis was done whereby rainfall data was separated into wet and dry years. This was achieved by averaging the 30-year period rainfall and all years above the average were considered wet years and those below as dry years. This enabled analysis to be divided into dry and wet year condition. This is very critical for analysis of future stream flows for abstractions to fill the reservoir.

Hydrological Modeling Using WatBal Model

WatBal is a lumped conceptual model which represents the water balance in the use of continuous functions of relative storage to represent surface outflow, sub-surface outflow and evapotranspiration (Yates & Strzepek 1994).

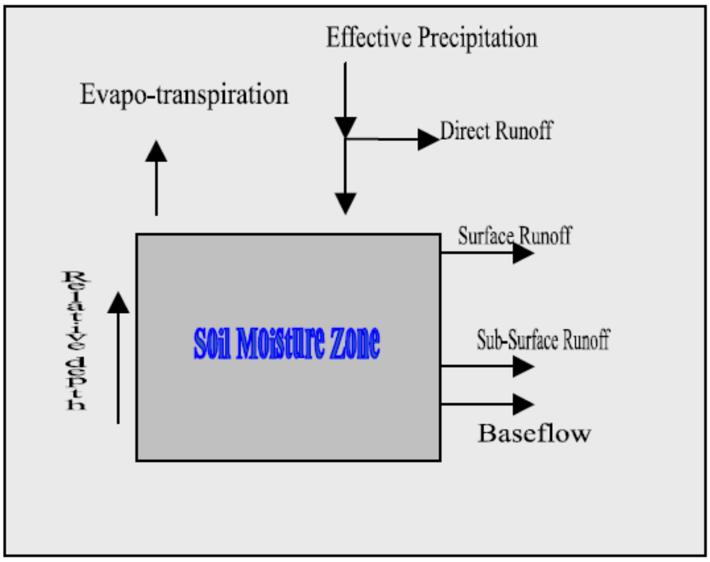

Figure 2 Conceptualization of the WatBal Model

It has essentially two main modeling components. The first is the water balance component that uses continuous functions to describe water movement into and out of a conceptualized basin (Figure 2). The second is the calculation of potential evapotranspiration.

Calibration of the WatBal Model Using Historic Monthly Data

The Watbal model was used for the generation of future stream flows of the Usutu River. In order to use this model for the prediction of future stream flows it had to be calibrated using historical data (1979-2009). During the calibration stage, the model parameters were adjusted by trial and error process until the model produced closely the observed stream flow. The Nash and Sutcliffe model efficiency was determined for simulation and observed flows after calibration. Only a coefficient above 0.5 was adopted as defined in the literature review.

Selection of Suitable GCMs

The Magicc/Scengen 5.1 version 2 was used for the prediction of climate change scenarios. The model consists of 19 GCM's that can be used to predict future climate data. All the 19 models were used to simulate 1979-2009 rainfall and temperature. Only three GCM models which simulated better the baseline rainfall and temperature were selected for use. Statistical analysis which involved the computation of Nash coefficient and model bias was used in selecting the three GCM's suitable for Swaziland.

Apart from the above process of selecting the models the following was also considered:

Model Vintage: This is related to the age of the GCM. It is assumed that recent models perform better than older models, since they use new knowledge about climate system behavior.

Model Resolution: The finer resolution of the model gives better climate process dynamics than coarser resolution models. Nevertheless in this study all models had the same resolution of 2.5°.

Running of GCMs for Swaziland

Having determined the three GCM's which are suitable for the Swaziland climatic conditions; they were then used to predict 2075 precipitation percentage change and mean temperature change in degrees Celsius. GCM's can only predict these two parameters which are input to the WatBal model.

Rainfall: to determine 2075 rainfall, the GCMs predicted percentage change for precipitation was added to the baseline precipitation to predict an increase or decrease in rainfall.

PET: Since the GCM's cannot predict future PET, temperature change was then used to compute the PET. Firstly, the change in temperature was added to the baseline temperature for Usutu Station to determine an increase or decrease in temperature for 2075. Having obtained temperature for 2075, Thornthwaite method was again used for calculating PET for year 2075 for average, wet and dry year conditions.

Application of the WatBal Model

After establishing the rainfall and PET for 2075 using the GCM's, the calibrated Watbal hydrological model was then used to simulate the 2075 stream flow of the Usutu River at Sphofaneni station (GS6). The model optimal parameters used during calibration were used for stream flow simulation for 2075.

RESULTS AND DISCUSSION

Calibration and Validation of the Watbal Rainfall Runoff Model

The Watbal model simulated well the observed runoff for both wet and dry years for the period of 30years (1979-2009) during calibration as shown in Figures 3 and 4 below respectively. The dry year's simulated runoff was a little bit higher than the observed from August to January. From February to July the observed runoff was higher than the modeled runoff. This can be attributed to sub-surface flow during the dry season. The total for observed runoff was 2.77mm/day against 2.78 mm/day for simulated. For the wet year's calibration, the observed runoff was higher than modeled runoff from September to November (Figure 3).

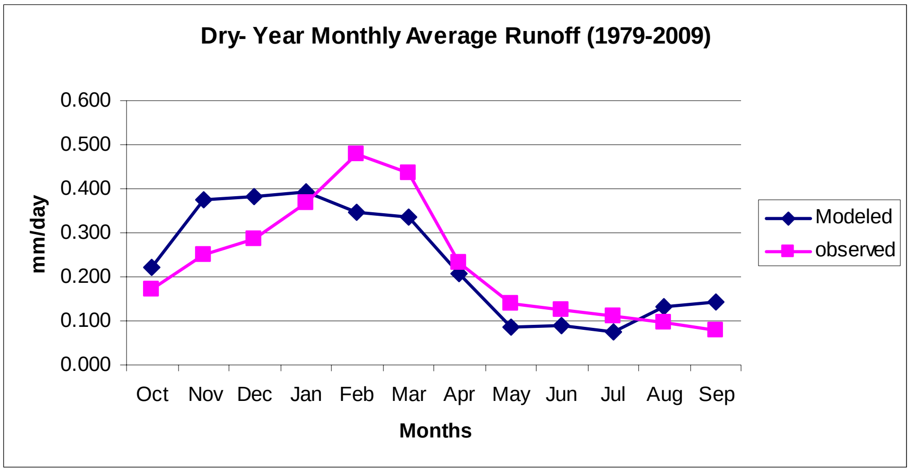

Figure 3 Observed and Simulated runoff after calibration for dry years

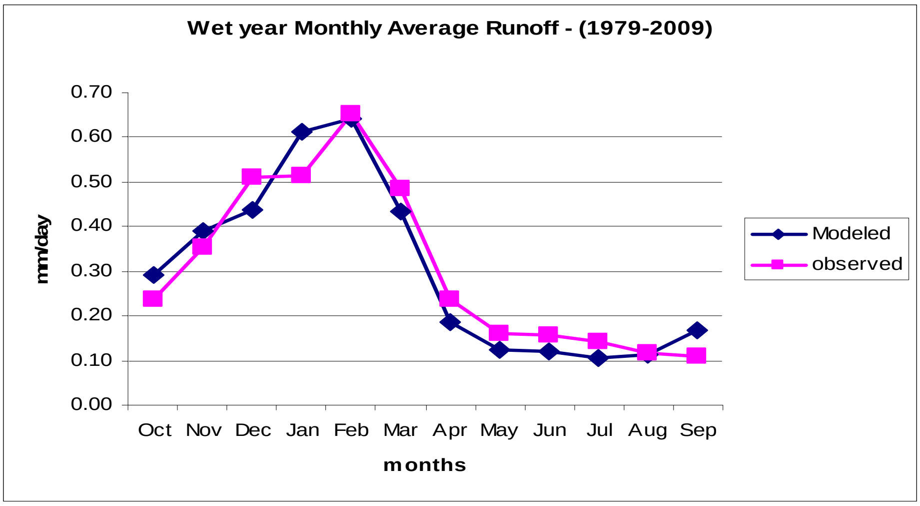

Figure 4 Observed and simulated runoff after calibration for wet years

Thereafter the modeled runoff is higher than observed for January. From February to August observed runoff was a little bit higher than the simulated. The calibration was good hence the total for observed was 3.66mm/day against 3.61mm/day for simulated. Nevertheless statistically the wet year calibration was better than the dry year calibration. The NASH coefficient for wet-year condition was higher than that of dry year condition with 0.972 and 0.678 respectively. This means that wet year's calibration was 97.2% efficient and dry years was 67.8%. Out of the 30 years used 18years were considered dry and 12 years considered wet. This also shows that more years have been dry and this can be due to the changing climate. Table 1 show the optimal parameters after calibration of the WatBal model.

Table 1 Optimal Parameters between Observed and Simulated Stream Flow for Usutu River during Calibration of Wet and Dry Year Conditions

Model Parameters	Wet Year	Dry Year
Surface Runoff Coefficient, ε	1.9	1.9
Ground Water Coefficient, α	1.0	1.0
Maximum Basin Holding Capacity, S_{max}	5594	7643
Base Flow, R_b	0.007	0.006
Direct Runoff Coefficient, DRC	0.1	0.1
Sub Surface Runoff, SSRC	1.9	1.9
Initial Storage, Z_i	0.1	0.1
Epsilon	2.375	2.425
Error	0.0322	0.06544
NASH coefficient	0.972	0.678
% Biase	1.52	-0.45

The Magicc/Scengen contains 19 GCM models from which climate change modeling can be performed. Three Models that simulated precipitation very well were selected for use in this study. Selected models are CCMAD2, IPSLD2 and ECH5D2. Figure 5 shows the comparison between simulated and observed precipitation. Models with higher NASH coefficient closer to 1 were considered to be better models. The NASH coefficient for the selected models in their descending order were 0.855, 0846 and 0.782 for ECH5D2, CCMAD2 and IPSLD2 respectively. Other models were discarded because they did not statistically simulate observed precipitation properly and through observation. These results were not in line with previous studies of similar nature in Swaziland. Previously GCM models found to be suitable for Swaziland in a similar study included UKTR, CCC-EQ and GFDL (Matondo, *et al*, 2004). These results show that model vintage has an effect. The models used here were more recent than the later ones hence they simulated better, the observed flows.

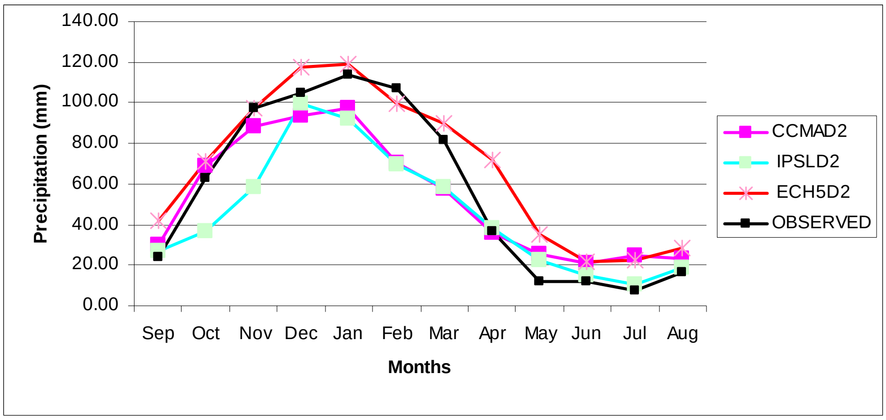

Figure 5 Baseline Simulated and Observed Precipitation using 3 Selected GCM's

Running of Selected GCM's

The selected GCM's were then used to simulate 2075 change in precipitation and temperature for both dry and wet years (Table 2 and 3).

Table 2 Data for dry-year scenario for Usutu Catchment

Month	Rainfall Now (mm/day)	CCMAD2 (% change 2075)	CCMAD2 Rainfall 2075 (mm/day)	IPSLD2 (% change 2075)	IPSLD2 Rainfall 2075 (mm/day)	ECH5D2 (% change 2075)	ECH5D2 Rainfall 2075 (mm/day)
Oct	1.70	8.493	1.84	-42.357	0.98	-50.552	0.84
Nov	3.08	-4.179	2.95	-20.323	2.45	-11.767	2.72
Dec	3.22	11.723	3.59	2.204	3.29	-0.121	3.21
Jan	3.11	9.823	3.41	-2.92	3.02	-19.191	2.51
Feb	2.51	-9.884	2.26	-17.737	2.07	11.214	2.79
Mar	2.43	-13.624	2.10	17.36	2.86	-8.928	2.22
Apr	1.33	-54.232	0.61	-14.67	1.13	2.32	1.36
May	0.24	-22.964	0.18	-14.596	0.20	19.237	0.28
Jun	0.28	-24.1	0.21	14.491	0.32	2.39	0.28
Jul	0.13	-7.431	0.12	-76.237	0.03	-18.534	0.10
Aug	0.63	-26.41	0.46	-7.426	0.58	-20.45	0.50
Sep	0.73	-32.109	0.50	-1.181	0.72	-2.078	0.71

Month	Temp Now °C	CCMAD2 Temp change 2075 °C	CCMAD2 Temp 2075 °C	IPSLD2 Temp change 2075 °C	IPSLD2 Temp 2075 °C	ECH5D2 Temp change 2075 °C	ECH5D2 Temp 2075 °C
Oct	21.22	1.503	22.7	2.128	23.3	1.811	23.0
Nov	21.22	1.349	22.6	1.584	22.8	1.349	22.6
Dec	21.22	1.141	22.4	1.765	23.0	1.52	22.7
Jan	25.30	1.05	26.4	1.341	26.6	1.71	27.0
Feb	24.48	1.327	25.8	2.128	26.6	1.525	26.0
Mar	24.22	1.502	25.7	1.549	25.8	1.479	25.7
Apr	22.00	1.214	23.2	1.196	23.2	1.541	23.5
May	19.06	1.222	20.3	1.51	20.6	1.496	20.6
Jun	16.58	1.512	18.1	2.013	18.6	1.916	18.5
Jul	16.39	2.016	18.4	1.376	17.8	1.788	18.2
Aug	18.25	1.564	19.8	1.338	19.6	1.328	19.6
Sep	20.72	1.402	22.1	1.83	22.6	0.843	21.6

Month	PET Now (mm/day)	CCMAD2 PET 2075(mm/day)	IPSLD2 PET 2075(mm/day)	ECH5D2 PET 2075(mm/day)
Oct	2.81	3.15	3.34	3.25
Nov	3.05	3.38	3.43	3.37
Dec	3.04	3.29	3.49	3.39
Jan	4.42	4.88	4.97	5.16
Feb	4.32	4.85	5.24	4.94
Mar	3.66	4.16	4.20	4.16
Apr	2.85	3.12	3.10	3.21
May	1.86	2.01	2.06	2.07
Jun	1.36	1.51	1.58	1.58
Jul	1.30	1.54	1.39	1.48
Aug	1.84	2.01	1.99	2.03
Sep	2.58	2.86	3.00	2.69

Model results were added to the baseline figures to get year 2075 rainfall and temperature. The results show a decrease in precipitation and an increase in temperature and PET for both wet and dry years. These results are similar to what Matondo, *et al*., (2004) obtained in a similar study in other catchments in Swaziland whereby rainfall was decreasing and temperature increasing due to climate change. The temperature for the year 2075 is expected to increase by an average of 1.5 degrees Celsius as predicted by the three models. Model CCMAD2 predicted an annual change of 1.4^{o}C, followed by ECH5D2 with a predicted annual change of 1.5^{o}C then finally model IPSLD2 with an annual change of 1.6^{o}C.

Table 3 Climatological data for wet-year scenario for Usutu Catchment

		CCMAD2	CCMAD2	IPSLD2	IPSLD2	ECH5 D2	ECH5D2
	Rainfall Now (mm/day)	% change 2075	Rainfall 2075 mm/day	% change 2075	Rainfall 2075(mm/day	% change 2075	Rainfall 2075 mm /day
Oct	2.49	8.493	2.70	-42.357	1.43	-50.552	1.23
Nov	3.44	-4.179	3.30	-20.323	2.74	-11.767	3.04
Dec	3.57	11.723	3.99	2.204	3.65	-0.121	3.57
Jan	4.89	9.823	5.37	-2.92	4.75	-19.191	3.95
Feb	5.59	-9.884	5.04	-17.737	4.60	11.214	6.22
Mar	3.21	-13.624	2.77	17.36	3.76	-8.928	2.92
Apr	1.27	-54.232	0.58	-14.67	1.09	2.32	1.30
May	0.60	-22.964	0.46	-14.596	0.51	19.237	0.72
Jun	0.55	-24.1	0.42	14.491	0.63	2.39	0.57
Jul	0.43	-7.431	0.40	-76.237	0.10	-18.534	0.35
Aug	0.56	-26.41	0.41	-7.426	0.52	-20.45	0.44
Sep	1.02	-32.109	0.69	-1.181	1.01	-2.078	1.00

Month	Temp Now °C	CCMAD2 Temp change 2075 °C	CCMAD2 Temp 2075 °C	IPSLD2 Temp change 2075 °C	IPSLD2 Temp 2075 °C	ECH5 D2 Temp change 2075 °C	ECH5D2 Temp 2075 °C
Oct	21.4	1.503	22.9	2.128	23.6	1.811	23.2
Nov	22.9	1.349	24.2	1.584	24.5	1.349	24.2
Dec	24.1	1.141	25.3	1.765	25.9	1.52	25.7
Jan	24.9	1.05	25.9	1.341	26.2	1.71	26.6
Feb	24.6	1.327	25.9	2.128	26.7	1.525	26.1
Mar	23.9	1.502	25.4	1.549	25.5	1.479	25.4
Apr	21.2	1.214	22.4	1.196	22.4	1.541	22.8
May	18.5	1.222	19.7	1.51	20.0	1.496	20.0
Jun	16.0	1.512	17.6	2.013	18.1	1.916	18.0
Jul	16.0	2.016	18.0	1.376	17.3	1.788	17.7
Aug	18.0	1.564	19.6	1.338	19.4	1.328	19.3
Sep	20.3	1.402	21.7	1.83	22.1	0.843	21.2

Month	PET Now (mm/day)	CCMAD2 PET 2075(mm/day)	IPSLD2 PET 2075(mm/day)	ECH5D2 PET 2075(mm/day)
Oct	2.85	3.21	3.45	3.31
Nov	3.61	4.01	4.12	4.00
Dec	4.04	4.47	4.74	4.65
Jan	4.26	4.64	4.78	4.97
Feb	4.36	4.89	5.29	4.99
Mar	3.54	4.04	4.07	4.03
Apr	2.61	2.84	2.82	2.96
May	1.73	1.85	1.89	1.91
Jun	1.24	1.39	1.46	1.46
Jul	1.22	1.44	1.28	1.37
Aug	1.74	1.99	1.83	1.95
Sep	2.45	2.72	2.82	2.55

Simulated Stream Flows for Wet and Dry Years Using WatBal Model

Figures 6 and 7 show year 2075 results of the simulated runoff for dry and wet years compared to currently observed runoff. For the dry year's runoff is expected to increase in October to December when compared with current situation and thereafter decline (Figure 5). Current peak in runoff is experienced around February, while it is observed in December for GCMs inputs. The peak for current runoff for dry-years in February is 0.478 mm/day compared to models average of 0.33 mm/day for the same month in 2075. The models predicted almost the same flows for the wet year condition. The peak for current runoff for wet-years in February is 0.651mm/day compared to models average of 0.661 mm/day for the same month in 2075. This shows that runoff will increase during the rainy season of the wet year condition but not with a high magnitude. A peak runoff of 0.692 mm/day is depicted by model ECH5D2 in February. For wet-year condition peak runoff is expected in February following the currently observed trend, while for dry-year condition peak runoff is expected in December rather than February as currently observed. More runoff during the dry season of the dry years will be as a result of base flow contribution and this will be experienced from May to September, during the dry season.

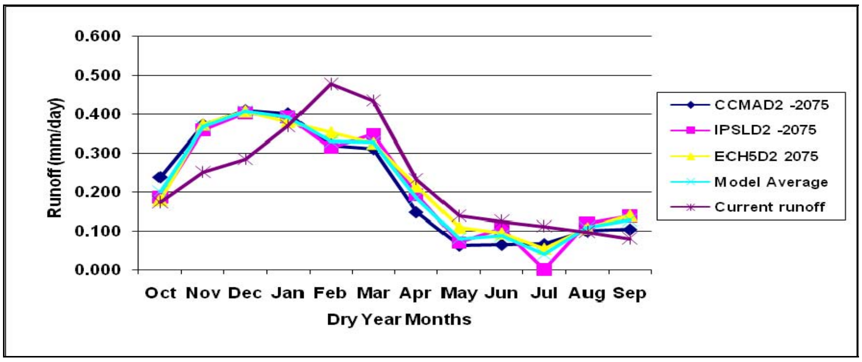

Figure 6 Simulated Usutu River stream flow for dry years

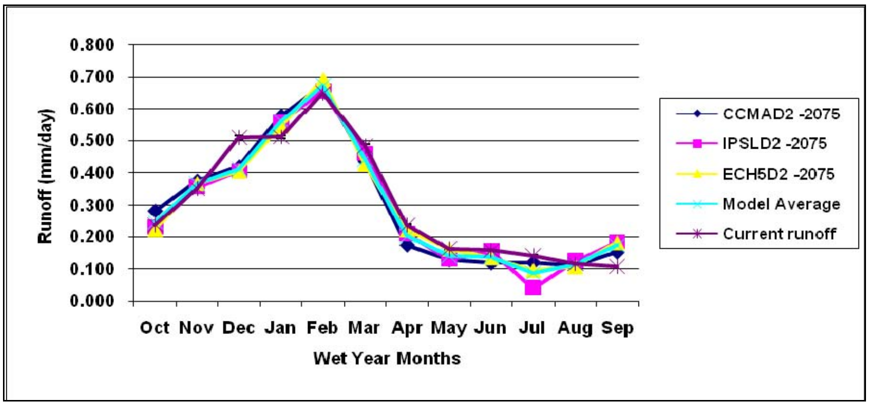

Figure 7 Simulated Usutu River stream flow for wet years

The Table 4 below show Usutu River Stream flows with and without the effect of climate change for both wet and dry-year conditions. The results shows that total flow will reduce during the dry and wet-year condition due to the effect of climate change.

Table 4 Monthly Stream Flow With and without Climate Change for Wet and Dry Years

Month	Without Climate Change		With Climate Change	
	DRY year Flows Current (MCM)	Wet year Flows Current (MCM)	Dry Year Flows 2075 (MCM)	Wet Year Flows 2075 (MCM)
Oct	67.33	99.26	69.91	79.10
Nov	89.92	136.14	122.53	121.04
Dec	110.65	226.47	163.22	166.21
Jan	139.12	210.63	144.07	208.92
Feb	186.09	274.10	125.26	257.41
Mar	163.71	190.03	123.17	169.30
Apr	90.39	91.69	69.06	76.90
May	53.82	66.55	33.01	55.64
Jun	47.00	56.05	33.81	52.25
Jul	43.18	57.64	26.56	41.15
Aug	36.75	45.80	43.83	46.99
Sep	31.24	45.44	51.11	68.25
Total	1059.20	1499.81	1005.53	1343.14

When comparing the monthly flows of dry and wet years without climate change and with climate change, during the wet season, flows will vary. Sometimes it will increase or decrease. Each month has its own model effect, either decreasing or increasing flows. In overall during dry-year condition annual flows will decrease by 4.43% and 3.23% for wet-year condition when compared to the currently observed flows.

Lubovane Reservoir Storage Analyses

Table 5 show LUSIP gross water demand as calculated during a water demand study. Downstream users with existing allocations are Tambuti Estate, Ubombo Sugar, W57J reservoir and W57E reservoir and the flow into South Africa according to the tripartite agreement between Swaziland, Mozambique and South Africa on shared water courses. This demand will be experienced after the completion of the second phase in year 2015. This includes mainly water for irrigation, potable water and livestock. The reservoir design capacity is 155 MCM. The critical research question this section tries to answer is that ‘would the 2075 stream flows are enough to fill the reservoir especially during the dry year condition whereby a 4.73% decrease in flows is expected?

The notion towards the construction of the Lubovane Reservoir is that it will only capture flood flows from the Usutu River. The Bulungapoort weir is allowed to capture floods only if the stream flow is higher than 20 m^3/s (53.57 MCM), per month due to existing downstream users. Another point to note is the maximum design capacity of the diversion canal which is 13.5 m^3/s (36.16 MCM), per month.

Table 5 LUSIP Monthly Gross Water Demand

Month	Gross Water demand (m^3/s)	Monthly demand (MCM)
January	7.909	21.18
February	7.446	18.34
March	6.731	18.03
April	5.555	14.40
May	5.220	13.98
June	4.597	11.92
July	4.828	12.93
August	5.802	15.54
September	6.304	16.34
October	6.362	17.04
November	6.800	17.63
December	7.515	20.13
Total		197.45

Source: SWADE (Water Management Study)

The Tables 6 a-d below show monthly simulated stream flows, actual amount of water that can be diverted controlled by canal capacity and downstream users and the cumulative reservoir balance after subtracting all downstream water demands. The gross water demand for the LUSIP Project is subtracted from the balance and reservoir cumulative storage is then determined.

Table 6a Current Dry Year Condition Monthly Cumulative Reservoir Storage after Meeting all Other Demands

Current Year Dry Month	Available water (MCM)	Downstream users (MCM)	Available for diversion (MCM)	Canal Capacity monthly MCM	Actual Amount diverted MCM	LUSIP Monthly Demand MCM	Reservoir cumulative increase MCM	Reservoir storage (%)
Oct	67.33	53.57	13.76	36.16	13.76	21.18	-7.43	-4.79
Nov	89.92	53.57	36.35	34.99	34.99	18.34	9.23	5.96
Dec	110.65	53.57	57.08	36.16	36.16	18.03	27.36	17.65
Jan	139.12	53.57	85.55	36.16	36.16	14.40	49.12	31.69
Feb	186.09	53.57	132.52	33.24	33.24	13.98	68.38	44.12
Mar	163.71	53.57	110.14	36.16	36.16	11.92	92.63	59.76
Apr	90.39	53.57	36.82	34.99	34.99	12.93	114.69	73.99
May	53.82	53.57	0.25	36.16	0.25	15.54	99.40	64.13
Jun	47.00	53.57	0.00	34.99	0.00	16.34	83.06	53.59
Jul	43.18	53.57	0.00	36.16	0.00	17.04	66.02	42.59
Aug	36.75	53.57	0.00	36.16	0.00	17.63	48.40	31.22
Sep	31.24	53.57	0.00	34.99	0.00	20.13	28.27	18.24
Total	1059.20	642.84	472.46	426.32	225.72	197.45	679.13	

Table 6b Current Wet Year Condition Monthly Cumulative Reservoir Storage After Meeting all Other Demands

Current Year Wet Month	Available water (MCM)	Down-stream users (MCM)	Available for diversion (MCM)	Canal Capacity monthly MCM	Actual Amount diverted MCM	LUSIP Monthly Demand MCM	Reservoir cumulative increase MCM	Reservoir storage (%)
Oct	92.46	53.57	38.89	36.16	36.16	21.18	14.97	9.66
Nov	126.22	53.57	72.65	34.99	34.99	18.34	31.63	20.41
Dec	198.68	53.57	145.11	36.16	36.16	18.03	49.76	32.10
Jan	193.06	53.57	139.49	36.16	36.16	14.40	71.52	46.14
Feb	253.45	53.57	199.88	33.24	33.24	13.98	90.78	58.57
Mar	182.40	53.57	128.83	36.16	36.16	11.92	115.03	74.21
Apr	92.00	53.57	38.43	34.99	34.99	12.93	137.09	88.44
May	63.05	53.57	9.48	36.16	9.48	15.54	131.03	84.53
Jun	59.37	53.57	5.80	34.99	5.80	16.34	120.49	77.73
Jul	55.19	53.57	1.62	36.16	1.62	17.04	105.06	67.78
Aug	43.68	53.57	-9.89	36.16	0.00	17.63	87.44	56.41
Sep	42.11	53.57	-11.46	34.99	0.00	20.13	67.31	43.43
Total	1401.67	642.84	758.83	426.32	264.76	197.45	1022.11	

Table 6c Year 2075 Dry-year Condition Monthly Cumulative Reservoir Storage After Meeting all Other Demands

Dry Year Month	Available water 2075 (MCM)	Down stream users (MCM)	Available for diversion (MCM)	Canal Capacity monthly MCM	Actual Amount diverted MCM	LUSIP Monthly Demand MCM	Reservoir cumulative increase MCM	Dry year reservoir storage (%)
Oct	78.09	53.57	24.52	36.16	24.52	21.18	3.34	2.15
Nov	131.71	53.57	78.14	34.99	34.99	18.34	20.00	12.90
Dec	158.33	53.57	104.76	36.16	36.16	18.03	38.13	24.60
Jan	147.39	53.57	93.82	36.16	36.16	14.40	59.89	38.64
Feb	128.11	53.57	74.54	33.24	33.24	13.98	79.15	51.06
Mar	123.50	53.57	69.93	36.16	36.16	11.92	103.39	66.70
Apr	71.71	53.57	18.14	34.99	18.14	12.93	108.60	70.07
May	31.27	53.57	0.00	36.16	0.00	15.54	93.06	60.04
Jun	33.24	53.57	0.00	34.99	0.00	16.34	76.72	49.50
Jul	15.47	53.57	0.00	36.16	0.00	17.04	59.68	38.50
Aug	40.83	53.57	0.00	36.16	0.00	17.63	42.06	27.13
Sep	49.42	53.57	0.00	34.99	0.00	20.13	21.93	14.15
Total	1009.08	642.84	463.85	426.32	219.38	197.45	705.94	

Table 6d Year 2075 Wet- Year Condition Monthly Cumulative Reservoir Storage after Meeting all Other Demands

WET Year Month	Available water 2075 (MCM)	Downstream users (MCM)	Available for diversion (MCM)	Canal Capacity (monthly) MCM	Actual Amount Diverted	LUSIP Monthly Demand MCM	Reservoir cumulative increase MCM	Reservoir storage (%)
Oct	95.38	53.57	41.81	36.16	36.16	21.18	14.97	9.66
Nov	131.28	53.57	77.71	34.99	34.99	18.34	31.63	20.41
Dec	159.86	53.57	106.29	36.16	36.16	18.03	49.76	32.10
Jan	211.59	53.57	158.02	36.16	36.16	14.40	71.52	46.14
Feb	262.47	53.57	208.90	33.24	33.24	13.98	90.78	58.57
Mar	166.25	53.57	112.68	36.16	36.16	11.92	115.03	74.21
Apr	78.50	53.57	24.93	34.99	24.93	12.93	127.02	81.95
May	54.59	53.57	1.02	36.16	1.02	15.54	112.50	72.58
Jun	51.65	53.57	-1.92	34.99	0.00	16.34	96.16	62.04
Jul	33.54	53.57	-20.03	36.16	0.00	17.04	79.12	51.05
Aug	43.12	53.57	-10.45	36.16	0.00	17.63	61.50	39.68
Sep	67.05	53.57	13.48	34.99	13.48	20.13	54.84	35.38
Total	1355.28	642.84	712.44	426.32	252.29	197.45	904.85	

Special focus has been given to the dry-year condition where an average of 4.73 % annual decrease in stream flows is expected from currently observed. Figure 8 show 2075 monthly percentage reservoir storage given assumed initial reservoir storage at the end of the dry season prior to year 2075. Lubovane reservoir storage is expected to increase from October and maximum storage will be reached in April thereafter storage will decrease. The reservoir will not fill to capacity even at 25% initial storage is assumed. This will be due to the optimum size of the diversion canal. The diversion canal has an optimal capacity of, 13.5 m^3/s above which water is allowed to pass downstream. This canal size was designed for the 155 Mm^3/s of Lubovane Reservoir. The storage in the reservoir is based on what is available for diversion and what the canal can handle. Table 6 a-d show the amount of water currently and that will be lost in year 2075. If this water can be harvested at any initial storage the reservoir will fill up. The limitation to harvesting all this water is brought by the 13.5 m^3/s optimum capacity of the diversion canal. This canal capacity can meet the LUSIP gross demand though the reservoir will not fill up especially at 0-25% initial storage in a dry year. The gross annual demands is constantly at 197.46 MCM but currently water harvested in a wet year is about 264.76 MCM as compared to 252.29 MCM in year 2075. Currently in a dry year about 225.72 MCM is diverted but this will decrease to 219.38 MCM.

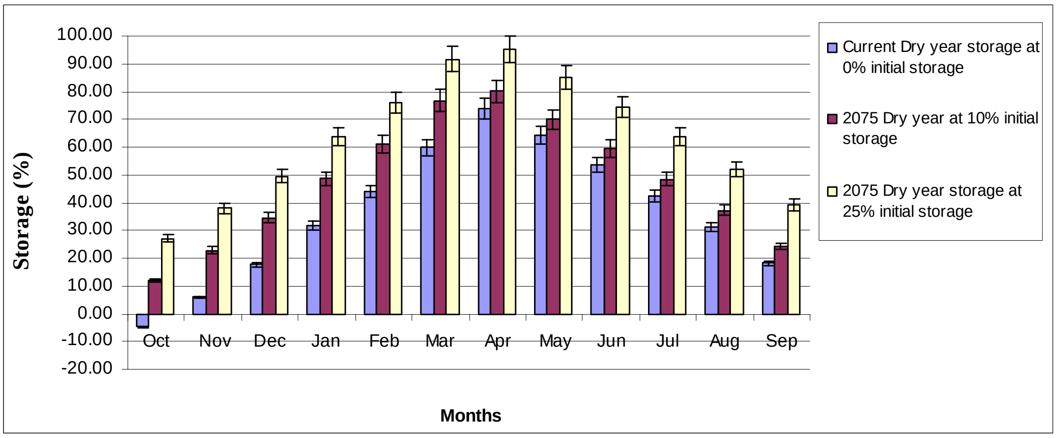

Figure 8. Dry-Year Percentage Reservoir Storage at Varying Initial Storage Levels after Meeting all Monthly Demand

Figures 9, 10 and 11 show year 2075 reservoir levels at varying initial storages given under expected climate change. Conditions with an assumption that at the beginning of the wet season the level of the reservoir is zero (Figure 9) which is less likely to happen, the reservoir will not fill up even on a wet-year condition. The project gross demand for October and November will not be met on a dry-year condition since no water is released below dead storage. Nevertheless on a wet-year condition only demand for October will not be met. The current situation shows a negative storage in October. This means that water will not meet the demand and that shows the deficit. At the end of a dry-year condition, the reservoir level will be close to the dead storage and any delays of rainfall will cause demand problems in the following month. With this assumption the LUSIP project will be affected since some months gross demand will not be met. Water management options would have to be developed for this scenario. Any further development (increasing irrigation land) is not possible for this scenario.

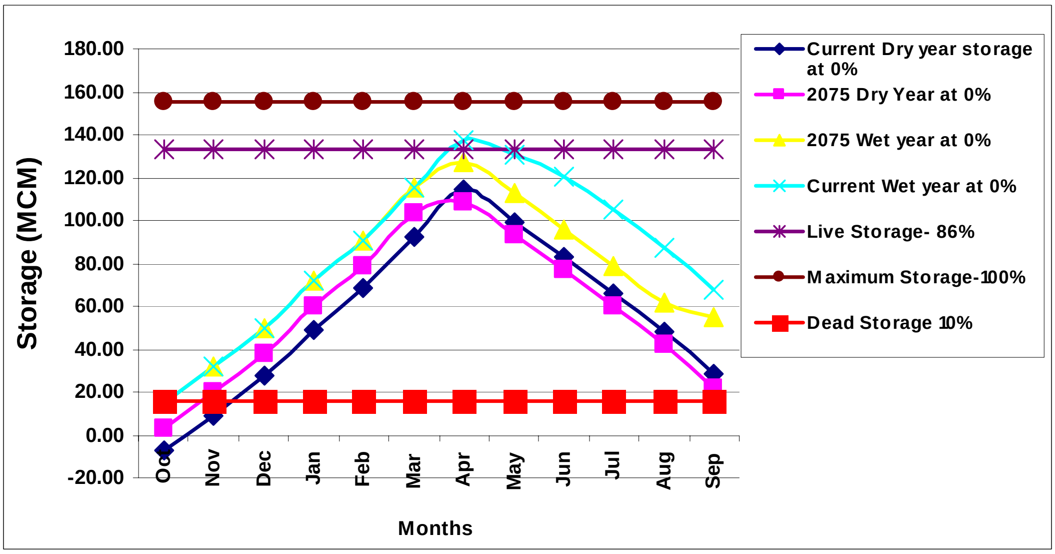

Figure 9. 2075 Wet and Dry-Year Conditions Reservoir Storage Levels at 0% Initial Storage

With a 10 % initial storage currently on a wet year the reservoir will be full in April while in year 2075 storage will exceeded slightly the live storage (Figure 10). Currently on a dry year at 10% initial storage October demand is not met but still live storage is reached in April. In the year 2075 on a dry year all demand will be met but the storage will not reach the live storage. This is mainly due to the fact that due to climate change the wet season will be more we and the dry season will be drier, such that in April of year 2075 rainfall will be less than what is currently observed. This is in line with literature on climate change impacts and modeling.

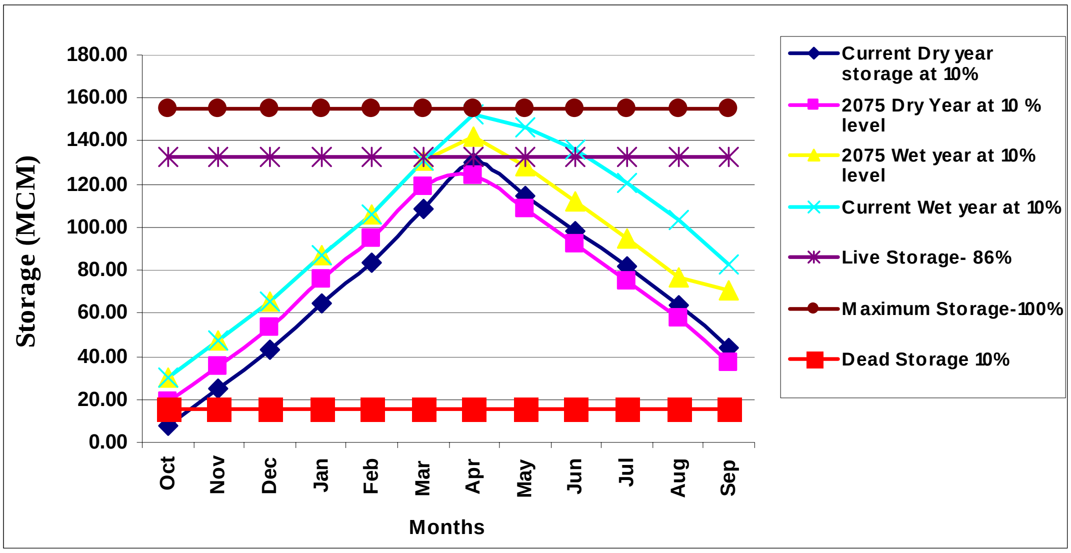

Figure 10. 2075 Wet and Dry Year Conditions Reservoir Storage Levels at 10% Initial Storage.

Assuming 25 % initial storage is available at the beginning of the year 2075 all monthly demands will be met without any problem as shown in Figure 11. Currently on a wet year the reservoir remains full to maximum capacity for three months (March to May) while in the 2075 it will be full to capacity only in April. We are receiving more rains in a wet year currently as compared to the future. Water level will be above live storage from (March to June) and the dry season of a wet year will be wet than the dry year situation.

Currently the reservoir will be full only in April and above live storage from March to May while in the year 2075 the reservoir will not fill up but will reach live storage from (March to May) as shown in Figure 11. For such a scenario no serious shortages will be experienced and irrigation expansion can be evitable.

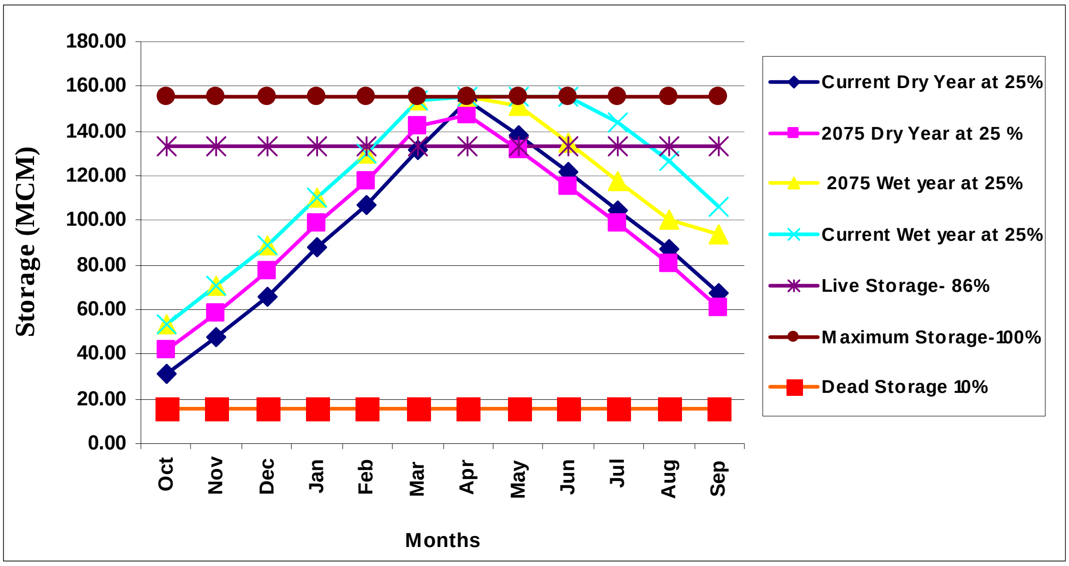

Figure 11 2075 Wet and Dry-Year Conditions Reservoir Storage Levels at 25% Initial Storage

CONCLUSIONS

In this study the evaluation of the impact of climate change on the Usutu River stream flows into the Lubovane reservoir using Watbal model was conducted. The calibration of the Watbal model yielded good results for wet and dry-year conditions. Statistically a Nash coefficient of 0.678 and 0.972 for dry and wet-year conditions respectively was obtained during the 1979-2009 calibration of stream flows. A model bias of -0.45 was obtained for dry-year condition against 1.52 model bias for wet year condition. Three GCMs found suitable for simulating baseline precipitation were selected. These GCM models were CCMAD2 with Nash coefficient of 0.846 and bias of 5.84, ECH5D2 with 0.855 Nash and -20.70 model bias and finally IPSLD2 model with Nash of 0.782 and model bias of 13.49.

Climate change will reduce year 2075 annual runoff of Usutu River by 4.83% and 4.13% on a dry and wet-year condition respectively. It is however noted that that this decrease will be more pronounced during the dry season when flows are already minimal. This will therefore not pose direct impact on the operations of the Lubovane reservoir which harvest floods during the wet season when high flows are experienced. More flood water than what is currently captured still expected to be lost downstream in year 2075. Any failure to meeting the project water demand and the filling of the Lubovane reservoir in year 2075 will not result from climate change but rather the limiting capacity of the diversion canal. Dry season flows are expected to decrease further and farmers depending on the river for their dry season irrigation will be affected.

The outcome of this study will be an eye-opener to the water management team of the LUSIP. Results from this study can be employed into decision making about the operation of the project. This study is expected to also provide more information to the feasibility study conducted by the Swaziland Government to construct an additional upstream reservoir on the Mkhondvo river (tributary to Usutu River) to capture more flood water. Moreover this study also provides insight to farmers depending directly on the river flows especially during the dry season on what to expect due to climate change.

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