



# **FINAL REPORT**

## **Climate Change Impacts on Water Resources in the Pungwe Drainage Basin**

In cooperation with



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Author:

SMHI, Losjö et al.

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# Climate change impacts on water resources in the Pungwe drainage basin

Katarina Losjö, Lotta Andersson, Patrick Samuelsson

Author SMHI 601 76 Norrköping Sweden	Project Leader Katarina Losjö Tel: +46 11 495 8291 Fax: +46 11 495 8001 E-mail: katarina.losjo@smhi.se
client UNOPS, GLO/INT 11-13 Chemin des Anemones 1219 Châteleine -Genève Schweiz	Contact Cecile Collas Tel: +4122 917 8288 E-mail: CecileC@unops.org
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## LIST OF USED DEFINITIONS AND ABBREVIATIONS

ACRU	Agrohydrological Modeling System, developed at Kwa-Zulu Natal University, South Africa.
CCSM3	GCM (Community Climate System Model) from National Center for Atmospheric Research (NCAR), USA
CV	Coefficient of Variation; a statistical measure of the dispersion of data around the mean in a time series.
CVI	Climate Vulnerability Index
ECHAM4	GCM from the Max-Planck-Institute for Meteorology, Germany
ECMWF	the European Centre For Medium-Range Weather Forecasts
ENSO	El Niño Southern Oscillation
ERA40	ECMWF Re-Analysis ERA-40
Forcing data	Input data to a particular numerical model
GCM	General Circulation Model (also called. Global Climate Model)
HBV	A hydrological catchment model, developed at the Swedish Meteorological and Hydrological Institute
IHMS	Integrated Hydrological Modeling System; in addition to the HBV model, it includes systems for database management, presentations, and various tools for, e.g., hydrological forecasting and statistical analyses.
IPCC	Intergovernmental Panel on Climate Change, established by WMO and UNEP ( <a href="http://www.ipcc.ch">www.ipcc.ch</a> )
ITCZ	Intertropical Convergence Zone
LAM	Legal Assessment Model
MSLP	Mean Sea Level Pressure
RCM	Regional Climate Model
RCA	Rosby Centre Regional Atmosphere Model
SRES	Special Report on Emission Scenarios
SST	Sea Surface Temperature
Transient simulations	Simulations with some of the forcing (input) data being subject to an ongoing change. This is contrary to a steady-state climate change, where the forcing data lacks a trend during the simulated period.

## Foreword

Scientists and world leaders agree that the threat from climate change attributed to human activities is real, serious and that it could have a significant impact on human society and the natural environment. Climate change will lead to an intensification of the global hydrological cycle and will have major impacts on regional water resources. The present scientific consensus is that those areas of the world that are already experiencing water stresses are also those in which rainfall is likely to be even more variable as the climate changes. Climate change is also likely to lead to increased magnitude and frequency of precipitation related disasters, such as floods, mudslides, typhoons and cyclones. Flows in rivers are likely to decrease at low flow periods, as a result of increased evaporation, and runoff increase with high rainfall events and waste overflows, both of which will degrade water quality. Increased temperatures and changes in precipitation are projected to accelerate the retreat and loss of glaciers, impacting on the timing of stream flow regimes and thereby downstream agriculture. The semi-arid regions of the developing world, which are already poor and face major water resource management and food security problems, are likely to be the most severely impacted.

UNDP proposes that an essential first step is to understand the potential effects on water availability and flow regimes for particular regions and identify appropriate response measures. Identifying vulnerability and potential adaptation needs is a high priority task for UNDP. In brief, our role is to:

- Raise awareness of water and climate issues and mainstream climate change issues into water governance;
- Enhance national capacities in the developing countries to integrate climate change considerations into water resource management and decision making processes;
- Identify and implement appropriate adaptation strategies;
- Support pilot project activities that may offer suitable frameworks and techniques, particularly those that can be replicable in other countries and assist in coping with existing climate variability;
- Develop knowledge products from on the ground lessons learned to help guide decision making and promote replication in other countries.

It is against this background that UNDP, in close collaboration with key counterparts, initiated the project “*Climate change impacts on water resources in the Pungwe drainage basin*” in Moçambique and Zimbabwe. The current report describes the findings of the important first phase of the project which was directed at evaluating the merits of integrating hydrological and climate modeling expertise to identify possible changes in water availability and extreme hydrological events. It is hoped that the results would form valuable input to continued work with relevant stakeholders to identify, interpret and prioritize potential environmental and socioeconomic impacts for the region so that a range of possible adaptation, risk minimization and coping strategies could be formulated and form the basis for informed decision making for the Pungwe River basin and beyond!

New York in October 2006



Joakim Harlin  
Water Resources Specialist



Brian Dawson  
Climate Change Advisor

UNDP Bureau for Development Policy  
Environment & Energy Group

# **1 Executive summary**

The aim of this project has been to use a combination of climate and hydrological models to assess the possible consequences of future global warming on the water resources in the Pungwe catchment up until 2050. By generating information on future trends in water resource availability in the basin, the project seeks to identify possible adaptation needs over the coming years.

## ***Deriving the modeling results***

The hydrological calculations have been made with the HBV model, using the previous model setup by SWECO & Associates, (2004).

The modeling report, SMHI Report 2006 – 41, is to be found as Appendix 1 to this report.

Input to the HBV model calculations have been obtained through climate modeling. Global climate models have been used to project possible future climates, based on scenarios of greenhouse gas emissions. The scales of the global models are however too coarse to be useful for regional or river basin applications. Therefore the regional climate model, RCA3, has been set up for the Southern African region, using output boundary conditions from the global modeling as input data. Finally, monitored climatological data from various parts of the basin were used to adjust outputs from the regional climate model in order to assure that they correspond. The output from the regional model simulations have been used as input to the hydrological model, for simulations of consequences on the water resources.

## ***The modeling scenarios***

The model results were evaluated for present climate conditions, and three different model scenarios of possible future climate have been simulated for the period up to 2050. These three scenarios are based on combinations of two different global models, the ECHAM4 and the CCSM3, and two of the emission scenarios in the IPCC Special Report on Emission Scenarios.

- The first emission scenario (A2) describes a continued increase in the world's population, moderate growth of GNP and high (but not extremely high) emission of greenhouse gases.
- The second emission scenario (B2) describes the same GNP growth and a slower increase in the world's population as in the first, and lower emissions, but still higher than the situation today.

Altogether, the three different scenarios of future climate are as follows:

- 1) The ECHAM4 GCM combined with the A2 emission scenario
- 2) The ECHAM4 GCM combined with the B2 emission scenario
- 3) The CCSM3 GCM combined with the B2 emission scenario

### *Model results*

The regional climate simulations show satisfactory results both for temperature and precipitation in the present climate, as compared to available observations. The differences between simulations and observations are larger on the local scale than for the whole Southern African region. The modeling activities undertaken in this project have produced results that are broadly consistent with other modeling results produced for southern Africa.

The present climate and river flow is expressed as the control period 1961-1990, which is the standard normal period according to WMO (World Meteorological Organization). The results are mainly presented as differences between the values simulated for future and for present climate conditions. Changes were considered significant when deviations between historical (1961-1990) and future conditions exceeded 10%.

In most analyses, the control period was compared to the 1991-2020 and 2021-2050 periods, respectively. In most cases, changes are more pronounced for the latter period.

There has not been room for analyses of the frequency of tropical storms within this project.

The balanced results from the three scenario experiments indicate:

- A higher air temperature in all seasons, but most pronounced in September – November.
- Approximately a 10% reduction of annual rainfall, with no significant variability between sub-basins.
- Indications of later start of the rainy season
- A decrease of river flow and available water for the entire Pungwe River basin over the period to 2050. The reason for this is a decrease in precipitation and an increase in evaporation. The reduction is significant also in the drier sub-basins, and could imply severe consequences for agricultural production.
- The annual period favorable for agricultural production (expressed as positive difference between rainfall and the demand for water from the atmosphere) is reduced by approximately one month for the period 2021 – 2050.
- Interannual variability of rainfall, as well as of dry season runoff will increase significantly, whereas the interannual variability of mean annual runoff seems to be less affected.
- A reduction of the frequency of high floods.
- An increased number of days with critically low flow at Bué Maria, with consideration to the freshwater intake to the city of Beira.
- For present climate conditions, it is notable that there is a pattern of higher inter-annual variability between years of streamflow in the drier sub-basins than in the wetter headwater (upstream) area.

Apart from these general conclusions, Scenario 1 indicates a slight increase of precipitation and river flow for some of the wet months, and in some sub-basins an increase of extreme floods. The results from Scenario 1 do not indicate any increase of days with critically low flow at Bué Maria.

Further, the general rise of sea water level with 5-30 cm till 2050, with a mean value around 16 cm (IPCC 2001), has to be taken into consideration.



*Key impacts of the modeled possible future climate:*

- Problems in several aspects for the city of Beira. Rising sea level will influence the infrastructure and the intake of freshwater. Due to more days with critically low flow in the river, the freshwater availability will be more straitened, which also alerts the needs for cutting transmission losses in the urban water supply network.
- Less water available in general, for e.g. water supply, irrigation and hydropower production.
- A decrease in crop yield for rain-fed agriculture and an increased demand for irrigation.
- The choice of suitable crops to cultivate, as well as availability for live stock fodder could be affected.
- Less runoff implies less dilution of pollutants, which can aggravate the problems in areas with poor water quality. This will have direct consequences for people using river water for washing and drinking, as well as for fish and other organisms living in the water.
- Consequences for the road network in low altitude areas.
- Probably less often problems caused by the very high floods.
- An increased competition for water resources implies a potential source for conflict, but also a possibility of closer cooperation between water users.

It is recommended that the results of this project are incorporated in the development of the joint, transboundary IWRM strategy for the Pungwe basin, which needs to consider the possible impacts of climate change.

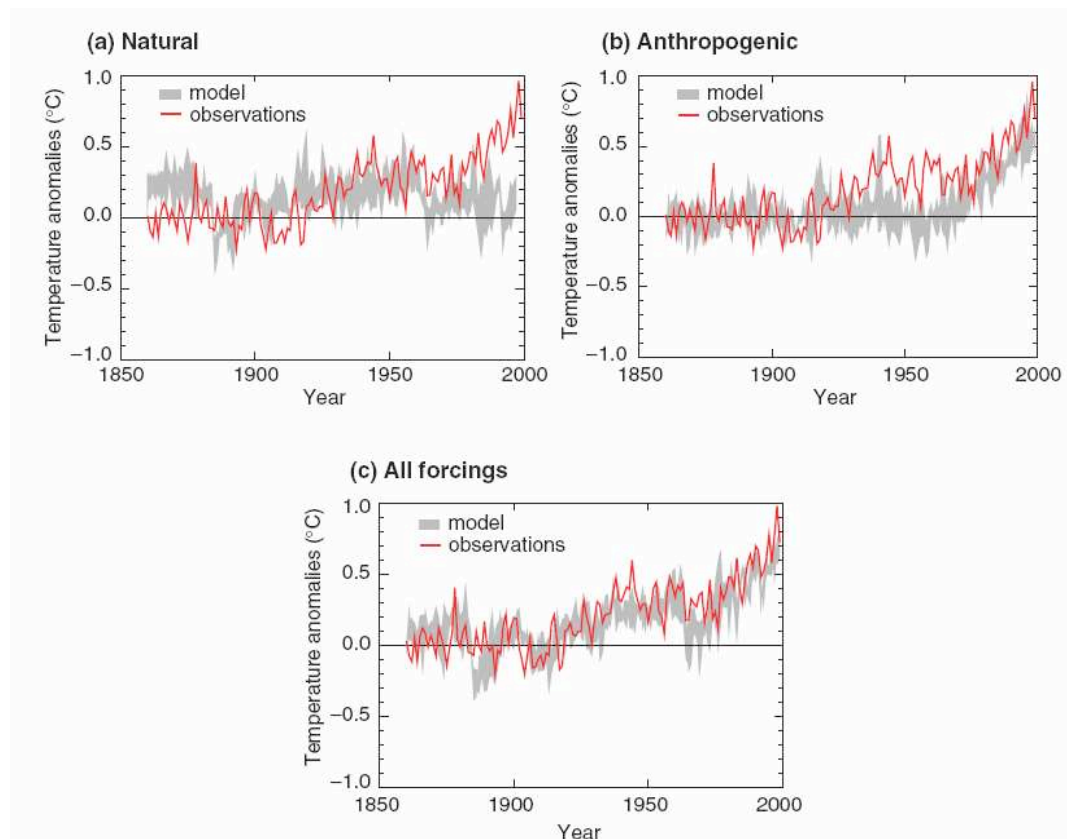
## **2 Background**

Climate varies naturally, and even extremes are normal events. Observations and analyses, however, indicate that the climate is now changing. This is especially evident on the global scale. The extent and pattern of regional changes vary more. As also the natural variability of climate is often larger on regional scale than on global scale, it is more difficult to detect regional climate change with the same degree of significance as for the globe as a whole.

The reasons for the ongoing global climate change are thought to be a combination of natural and anthropogenic factors. However, whereas natural factors provide a sufficient explanation for the observed variations and changes during the early part of the 20<sup>th</sup> Century and earlier, they no longer seem to be able to explain the observed variations and changes during the last 30-50 years. This is evident in climate model simulations in which both natural and/or anthropogenic factors have been studied for the period with a globally representative instrumental record, i.e. the last 140 years. A combination of natural and anthropogenic climate forcing factors provides the best fit between observed and simulated global mean temperature changes. The evident warming since the second half of the 20<sup>th</sup> century is only explained by considering anthropogenic factors, i.e. the emission of greenhouse gases and their accumulation in the atmosphere causing an imbalance in the radiative balance known as the enhanced greenhouse effect. See Figure 2.1.

The climate system is very complex, and climate models are useful tools for providing consistent climate change scenarios that can be used as a basis for estimating the impacts of climate change. Global climate models do not provide sufficient details for regional and local applications, and regionalization is needed to bridge the gap between global models and these applications. The most consistent method of regionalization is to use regional climate models.

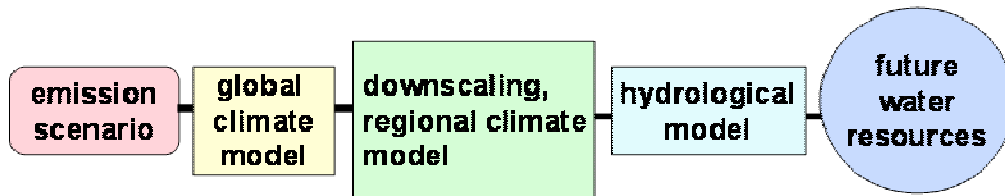
Changes in water resources are one of the major foreseen impacts of climate change. To provide useful scenarios of water resources changes, results from climate simulations can be applied as input in hydrological models to identify climate change impacts on river basin scale in terms suitable for practical decision-making support by local and regional actors.



**Figure 2.1.** Measured (red) and simulated (grey) global mean surface temperature anomalies. The simulated data encompass an ensemble of four global climate model runs forced with natural (a) or anthropogenic (b) forcing as well a combination of both (c). The natural factors considered are solar and volcanic forcing. The anthropogenic factors include greenhouse gases, ozone changes and sulphate aerosols. [With permission from the Intergovernmental Panel of Climate Change, IPCC 2001. SPM, WGI, Figure 15.]

SMHI was entrusted with the task of providing regionally detailed climate change scenarios for the southern Africa region for the period up to 2050, and to apply these in hydrological modeling for the Pungwe River basin, in dialogue with local actors. The modeling results were a prerequisite for elaborating climate change in terms of its impacts to the local and regional actors, so that they can better prepare and, if needed, take precautionary action to re-

spond to possible consequences. The modeling work in this project consisted of a chain of activities starting with global emissions and global climate scenarios, followed by regionalization and impact studies (Figure 2.2). The regional and hydrological models employed were, however, first evaluated for present climate conditions.



**Figure 2.2.** Modeling changing future water resources, due to climate change involves a chain of activities.

***Important steps in this work have included:***

- 1) The Inception report, including a detailed work plan, was submitted in August 2005.
- 2) On the 25-26 of August 2005 a group of representatives of the reference group visited SMHI, in connection with the World Water Week in Stockholm, under guidance of SWECO. The visitors received information about the work at SMHI in general and most of the time was spent meeting and discussing with the staff working with the climate and hydrological modeling within the project.
- 3) A progress meeting was held in Maputo on 8-9 November 2005, aiming at facilitating the dialogue between the modelers and the reference group, as well as consisting of part of the capacity building within the project. Lotta Andersson and Patrick Samuelsson participated from SMHI.
- 4) The modeling report contains descriptions and results of the modeling work and forms a basis for discussions within the reference group and with stakeholder representatives. Due to unexpected technical problems, the finishing of this report has been delayed, compared to the work plan in the inception report. During a Reference Group Workshop in the end of August 2006, stakeholder views, consequences and possible risk adaptation measures were discussed and outcomes of the workshop were incorporated in this report.

### **3 Climate modeling**

This chapter describes briefly how the climate modeling has been performed and some main results. A detailed description is given in the modeling report (Appendix 1), where also results for the whole model domain (Southern Africa) are shown. The results from the climate modeling were used as input to the hydrological modeling of the Pungwe River basin.

### 3.1 Scenario experiment description

The Rossby Centre Regional Climate model (RCA3) was used as the regional climate model, and four different scenario simulation experiments were made.

The control period (present-day climate, 1961-1990) was simulated, using forcing (input data) from a reanalysis experiment, (ERA40, Uppala *et al.*, 2005), performed by the European Centre for Medium Range Forecasts (ECMWF). The results were compared to observations in an effort to evaluate the model performance for Southern Africa.

For the future climate, results from simulations with global climate models (GCM:s) were used as input. To partly cope with the uncertainties of the possible future climate, three different scenarios were made for the period 1991-2050. Two of the simulations use forcing data from the global model ECHAM4/OPYC3 (Roeckner *et al.*, 1999) and two different scenarios of greenhouse gas emissions. The two chosen emission scenarios have been taken from a report from the Intergovernmental Panel on Climate Change (Nakićenović *et al.*, 2000) and follow the SRES (Special Report on Emission Scenarios) A2 and B2.

Scenario A2 describes a continued increase in the world's population, moderate growth of GNP and high (but not extremely high) emission of greenhouse gases.

The B2 scenario describes the same GNP growth and a slower increase in the world's population as in A2, and lower emissions, but still higher than the situation today.

In the third future scenario, forcing data from the Community Climate System Model (CCSM3, Collins *et al.*, 2006) was used, together with the B2 emission scenario.

In this report, we simplify the denominations of the future climate scenarios as the following:

**Scenario 1** is RCA3 driven by the GCM ECHAM4, using the A2 emission scenario

**Scenario 2** is RCA3 driven by the GCM ECHAM4 using the B2 emission scenario

**Scenario 3** is RCA3 driven by the GCM CCSM3, using the B2 emission scenario.

### 3.2 Regional climate modeling results

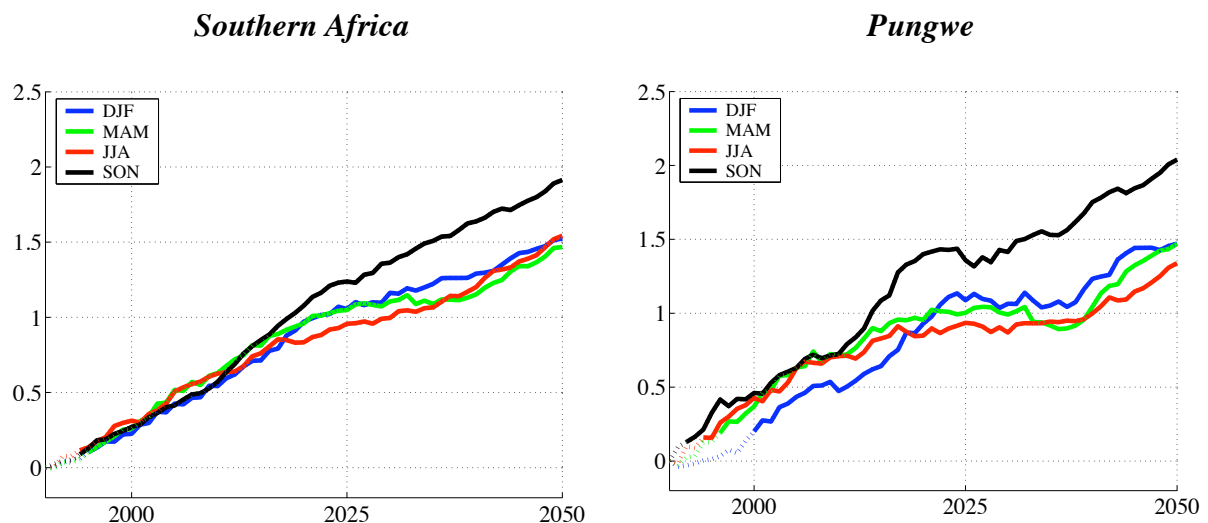
#### 3.2.1 Control period (present climate)

The evaluation of RCA3 in Southern Africa shows that the model, given appropriate boundary conditions, is capable of simulating the most important aspects of the climate on a regional scale. This includes the pronounced seasonal cycles of temperature and precipitation. Generally the temperature is simulated to within  $\pm 1^\circ\text{C}$  as an average over the domain while regional biases, as in the Pungwe drainage basin, are somewhat larger and occasionally exceed  $\pm 2^\circ\text{C}$ . The precipitation climate is also captured to a high degree of realism both on continental, regional and local scales. The results for Southern Africa were considered to be of sufficient quality to allow the model system to be used for scenarios simulations.

### 3.2.2 Future climate scenarios

The results are shown in maps and graphs, often representing the 30-year periods 1991-2020 and 2021-2050, respectively, and compared with the modeled results for the control period. In this way it is possible to compare the climate change signal of each scenario, regardless of the variations between the used models in describing the present climate.

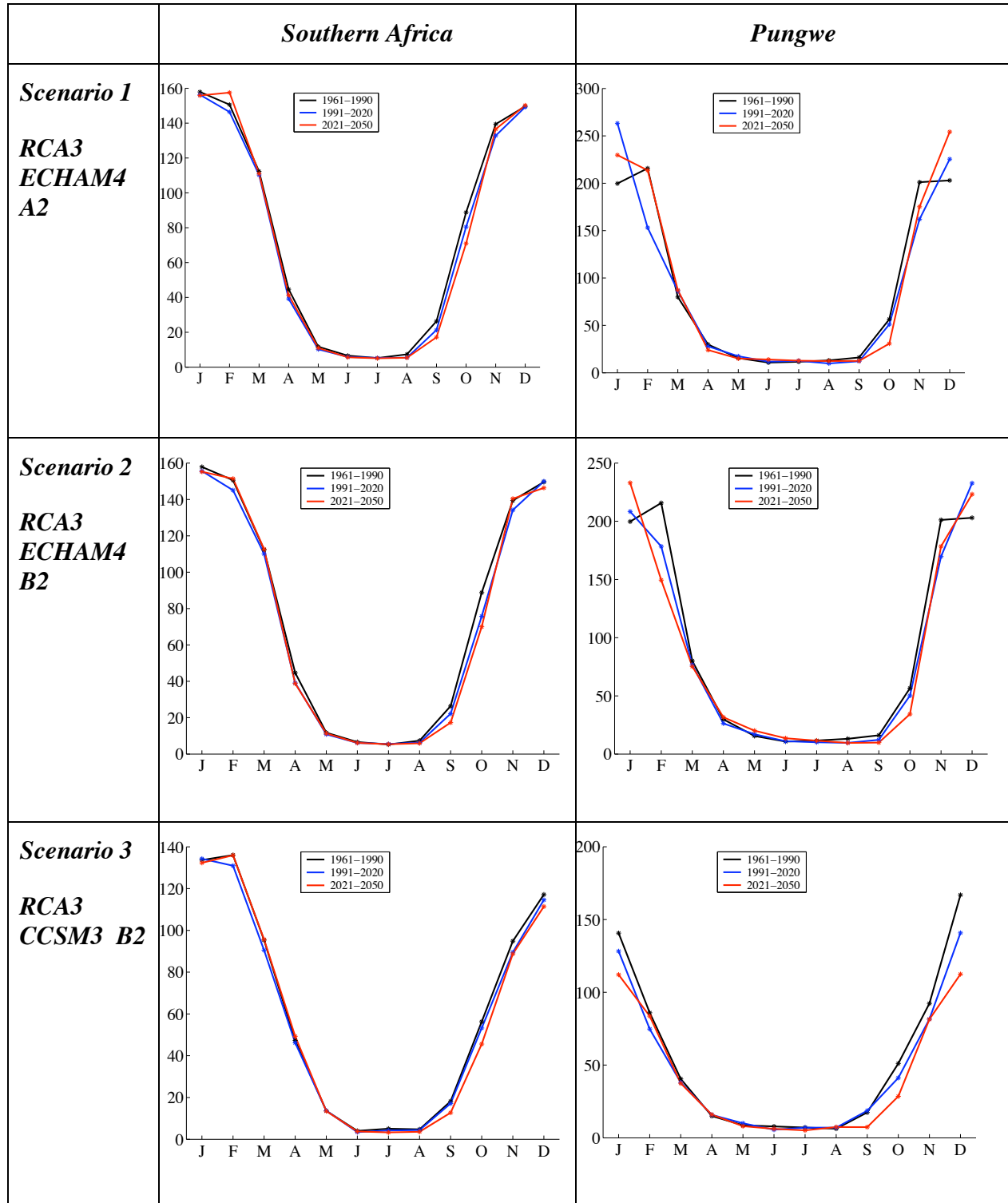
- A general feature of the scenario simulations is a significant increase in temperature during all seasons. The signal is larger over the continent than over the adjacent oceans, which is a widely observed feature in climate change simulations (Cubasch et al., 2001). The temperature increase for all seasons is statistically significant (in the sense that it exceeds the variability during the control period) already during the first decade of the simulation on a continental scale, see an example from one scenario in figure 3.1. Taken as an area average over Southern Africa the increase lies between 1.5 and 2.2 degrees for all seasons and all scenarios. In smaller areas the variability is larger but still the signal becomes statistically significant already during the first decade, as illustrated for the Pungwe drainage basin in Figure 3.1. From the figure it can also be noted that the change is strongest for southern hemisphere spring (September-November). Over the Pungwe drainage basin the summer wet season (December-February) shows less warming than the other seasons for the first part of the period but higher warming than autumn-winter for the second part of the period. More details and figures can be found in Appendix 1.



**Figure 3.1.** 30-year running means of area averaged 2m-temperature in Scenario 1 Shown are the anomalies from the 1961-1990 mean. Full (dashed) lines denotes 30-year periods that are (not) significantly different from the control period. Unit: °C.

- There is a tendency of a decrease of precipitation in all three future climate scenarios. None of the climate simulations give precipitation changes larger than  $\pm 5\%$  in total precipitation amount integrated over the entire model domain during December-May, while they give decreases of the order of 10-20 % during June-November. Also, these results lie within the ranges as based on output from several climate models under different emission scenarios as presented by Ruosteenoja et al. (2003). For the Pungwe River basin it is clearly seen that there is a delay in the onset of the wet season in all

three scenario experiments, and that there is a decrease in the total amount of precipitation, with exception from scenario 1 and 2 showing an increase during December and January. The climate change signal is in most cases stronger in the second period (2021-2050) compared to the first (1991-2020). See fig 3.2.

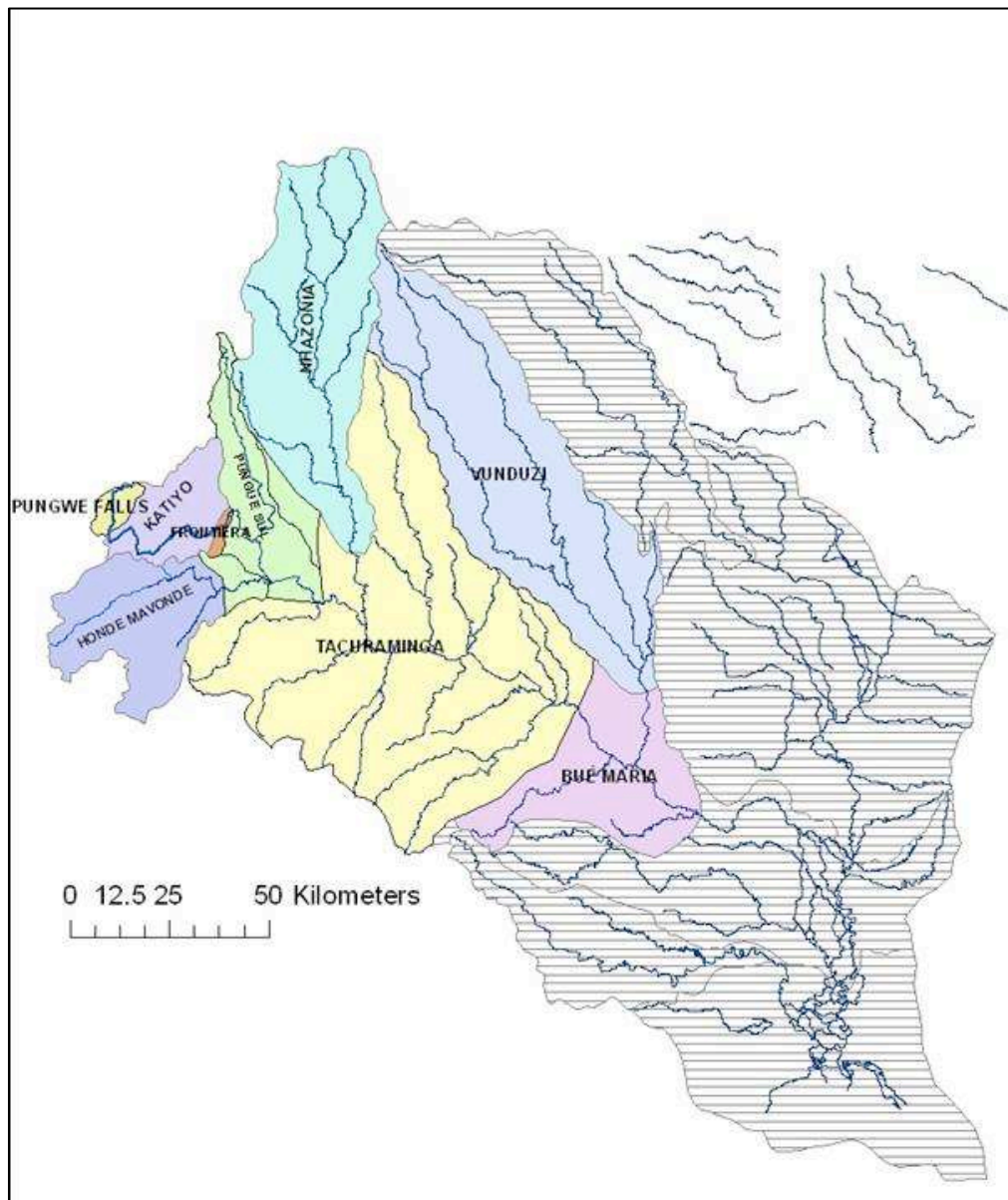


**Figure 3.2.** Monthly mean precipitation for 1961-1990 (black), 1991-2020 (blue), and 2021-2050 (red) in the three transient climate change simulations





basin. The aim of using a hydrological model is to identify plausible changes of water availability, droughts and floods in time and space. The used setup of the HBV model was kindly made available from the project “*The Pungwe River Basin Joint Integrated Water Resources Management Strategy*”, (SWECO & Associates, 2004), hereafter called “the SWECO project”. Calculated precipitation and potential evaporation values from the three Regional Climate Models (RCM:s), as described in Section 3 and Appendix 1, have been scaled against monitored data in order to assure that modeled corresponds to monitored time series (1961-1980) on a sub-basin scale.



**Figure 4.2** The Pungwe River basin upstream of Bué Maria, divided in sub-basins used in the setup of the HBV model within the SWECO project and within the climate change project presented in this report.

Due to limited availability of climatic and hydrologic databases with daily resolution in some parts of the basin, and due to the influence of sea water levels high up in the river, the HBV model was only set up for nine sub-basins in the upper and central parts of the basin, down to



the Bué Maria site, see Figure 4.2. A model with a daily time step, like the HBV model, is needed in order to catch floods. However, for other hydrological assessments, a monthly time step is often sufficient.

In the SWECO project, a setup of the Pitman model was made for the entire basin with a monthly time resolution, and it was decided by the reference group that, adjustment (delta) factors (see Appendix 1) should be delivered in the present project, making it possible for local participants to run the Pitman model for the entire basin for the various climate scenarios. Such delta factors on a sub-basin scale have been delivered, but due to practical constraints, model runs with the Pitman model have not yet been carried out.

## **4.2 Results**

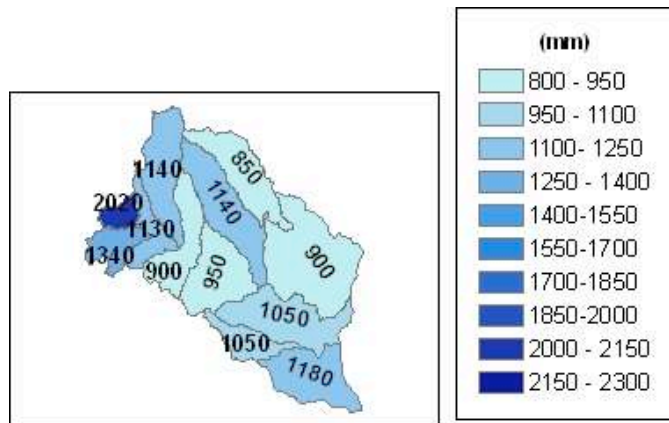
The HBV model uses the precipitation and potential evaporation (the atmospheric demand of water) for calculation of streamflow in each sub-basin. The time series provided by the RCA3 regional climate model were adjusted before they could be used as input to the HBV model. The adjustments were made with the objective to provide a satisfactory agreement between observed and RCA3 model generated input data to the HBV model for the control period. These adjustments give as a result a geographically and temporally distribution of precipitation and evaporation that, on a sub-basin scale, is more in correspondence with observations, compared to the direct output from the RCA3 model. The adjustment procedures, named Delta Change and Scaling approach, respectively, are described further in Appendix 1. After these adjustments, however, the relative changes between the control and scenario periods are still of the same magnitude as the results from the RCA3 scenario experiments, described in Section 3 above.

### **4.2.1 Results for the entire Pungwe basin**

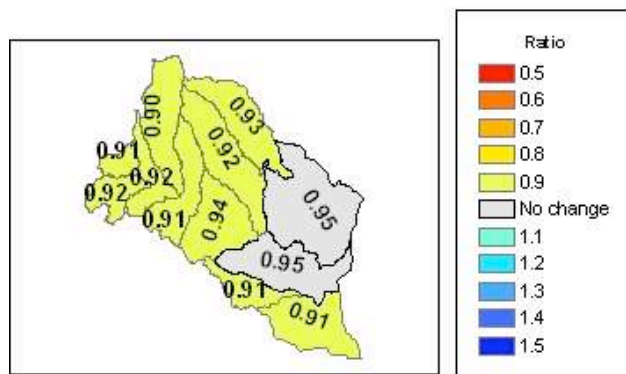
The HBV model was only set up down to Bué Maria (Figure 4.2). However, results for the entire basin are also presented in several figures in Appendix 1, and illustrate precipitation, potential evaporation and available water (water balance, calculated as precipitation minus potential evaporation), in comparison to a control period with observations for the years 1960-80. It should be noticed that these results are based on multiplying the observed time series (1960-1980) with the relative change of precipitation and potential evaporation between the reference and the scenario periods.

#### Precipitation:

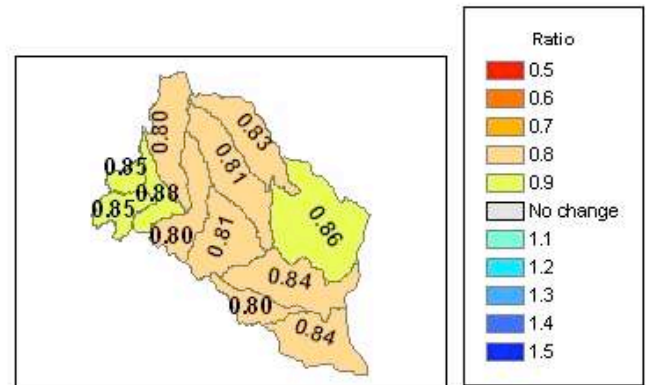
- The results indicate an average of 10% decrease in mean annual precipitation with no significant variability between sub-basins, and a slight larger decrease of rainfall for the period 2021-2050, compared to the 1991-2020 period. See Figure 4.3, and results for all sub-basins in Appendix 1.
- An analysis of the annual precipitation cycle shows a delay in the start of the rainy season, with indications of more rain concentrated to the month of January.



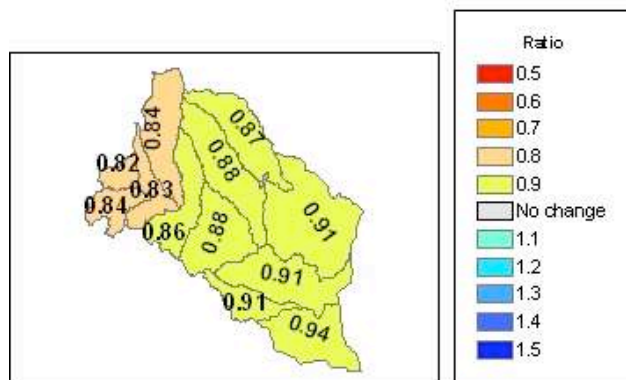
Mean Annual Sub-Basin Precipitation (mm) (1960-1980)



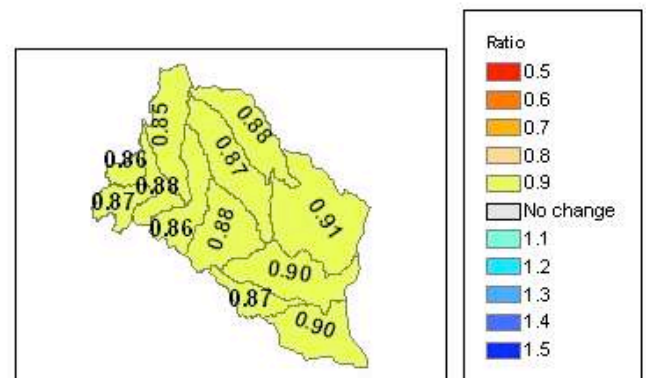
Echam A2 - Ratio of Future (2021-2050) to Present (1960-1980) Mean Annual Sub-Basin Precipitation



Echam B2 - Ratio of Future (2021-2050) to Present (1960-1980) Mean Annual Sub-Basin Precipitation



CCSM B2 - Ratio of Future (2021-2050) to Present (1960-1980) Mean Annual Sub-Basin Precipitation



Mean of Ratio of Future (2021-2050) to Present (1960-1980) Mean Annual Sub-Basin Precipitation

**Figure 4.3.** Monitored annual sub-basin rainfall (1960-1980) and mean ratio of simulated sub-basin rainfall for 2021-2050, compared to that simulated for 1961-1990 by RCA3, driven by ECHAM4-A2, ECHAM4-B2, and CCSM3-B2 respectively .

### Potential evaporation:

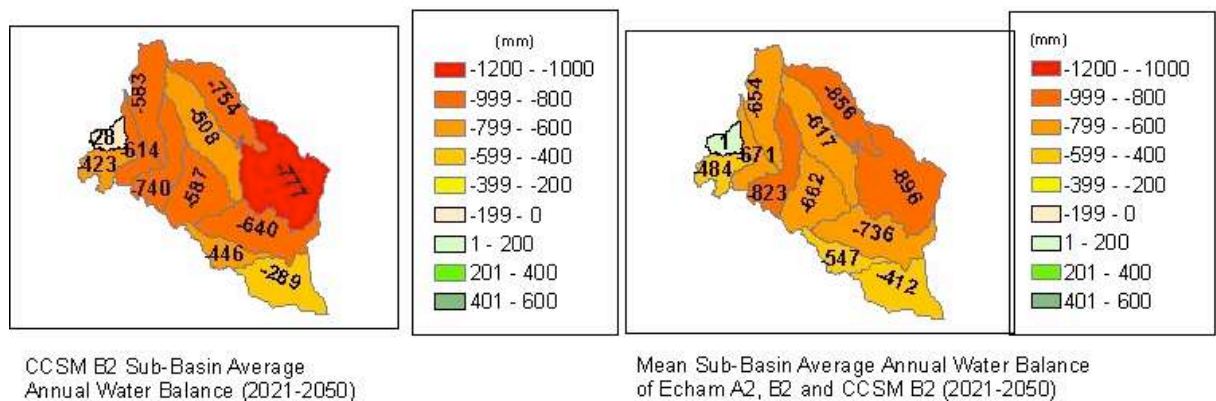
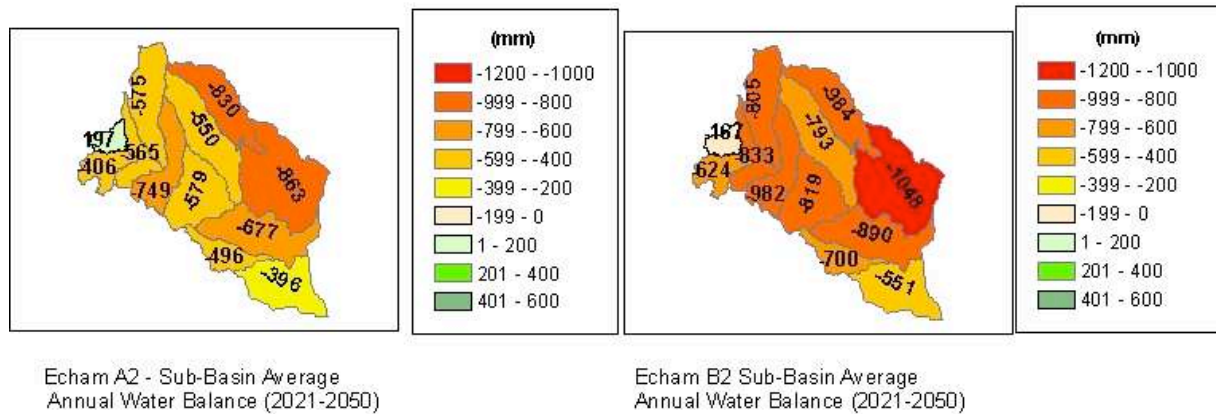
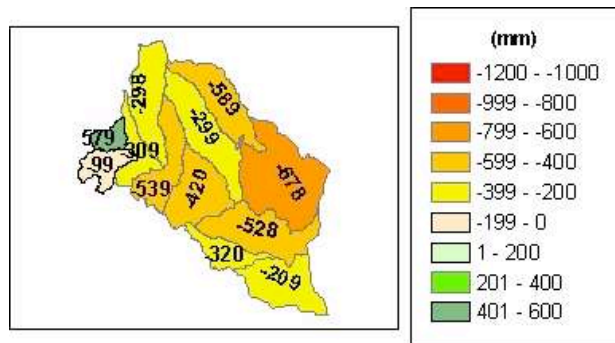
- The increase in temperatures, indicated by the RCA3 simulations should result in an increase of the potential evaporation. The model results show no significant increase for the period 1991-2020, except for the Pungwe Zimbabwe sub-basin. For the period 2021-2050 the evaporation increases by 20 % in the three headwaters, i.e. sub-basins Pungwe Zimbabwe, Honde and Upper Pungwe, and with 10% in the rest of the basin.
- An analysis of the annual potential evaporation cycle show that the largest increase of potential evaporation will occur in the dry season, when there is not much water available anyway, but it will have an impact on dam evaporation. This means that the possibility for growth during the dry season is even less than today.

### Available water:

No hydrological modeling was made for the entire basin, due to lack of possibilities to run the Pitman model before this report was compiled. The HBV model has only been set up for the basins upstream of Bué Maria. Therefore, only calculated values of available water are obtainable for all sub-basins.

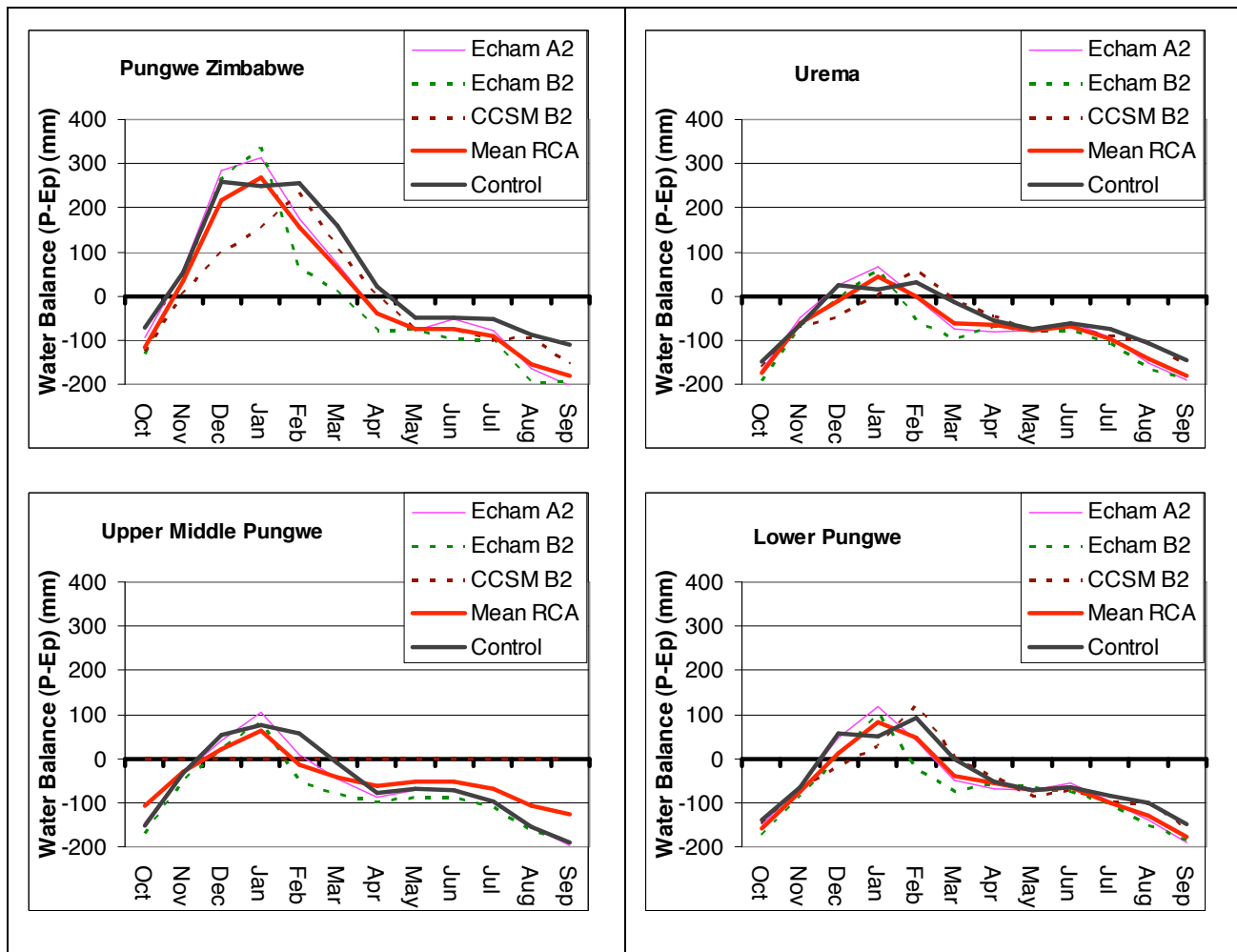
Changes of the available water, or water balance, expressed as rainfall minus potential evaporation, can e.g. be used as an indicator for possible impacts on agricultural production.

- In mm of water, the available water is most reduced in the headwaters, but the reduction can have more severe consequences in drier basins, where the conditions for agricultural production are already constrained. See Figure 4.4.



**Figure 4.4** Observed average annual sub-basin water balance (mm rainfall - mm potential evaporation), based on data from rainfall gauges and class A-pans (1960-1980) and sub-basin average annual water balance as predicted for 2021-2050 by RCA3, driven by ECHAM4-A2, ECHAM4-B2, and CCSM3-B2, using the “Delta Change” approach. A negative water balance indicates that the annual rainfall is smaller than the annual atmospheric demand of moisture.

- An analysis of the annual cycle shows that the period with water available for agricultural production (a positive water balance), is reduced by approximately 0,5 months for the 1991-2020 period and 1 month for the 2021-2050 period. See examples in Figure 4.5, and results for all sub-basins and periods in Appendix 1.



**Figure 4.5** Mean monthly water balance 2021-2050 in the sub-basins Pungwe Zimbabwe, Upper Middle Pungwe, Urema and Lower Pungwe (cf. Figure 4.1). The control period is based on monitored rainfall and potential evaporation 1960-1980. The reduced period with water balance above zero (available water) is clearly seen.

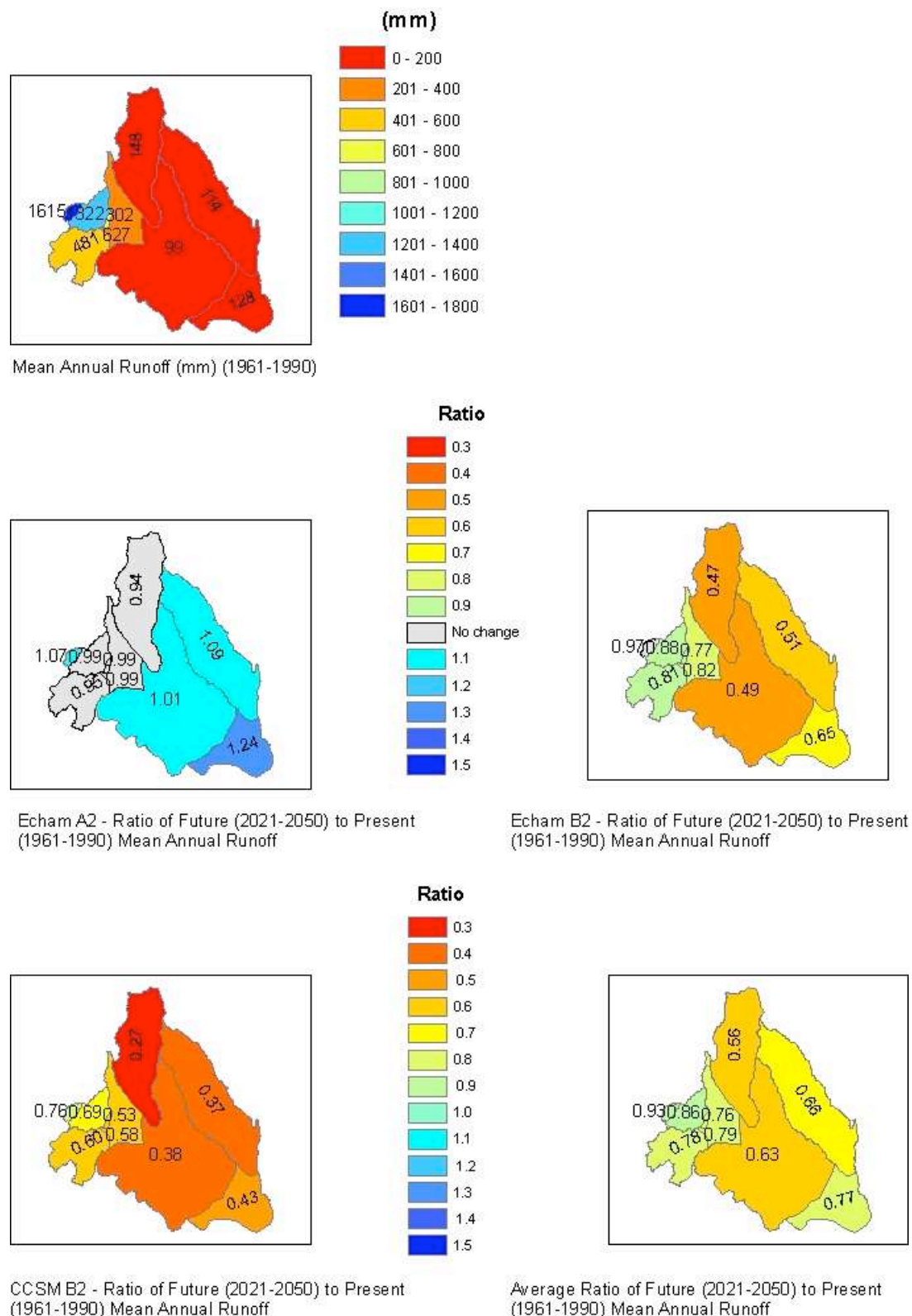
#### 4.2.2 Results for the sub-basins upstream of Bué Maria

The HBV model was run for the sub-catchments in the Pungwe basin upstream of Bué Maria (cf. Figure 4.2). The methodology is further described in Appendix 1.

Scenarios of changes in mean annual runoff (MAR) indicate:

- For the 1991-2020 period, the runoff in the drier parts of the basin will decrease to about 55-75% of MAR during the control period (1961-1990). In the wetter parts the runoff will be approximately 90% of MAR during the control period.
- For the 2021-2050 period, scenarios 2 and 3 show a decrease of the mean annual runoff to a value corresponding to 30-65 % of the control period MAR in the drier sub-basins, and 50-95% in the wetter sub-basins. Scenario 1 does not indicate any significant change, and even an increase of runoff in some sub-catchments.

See example in Figure 4.6 and for both future periods in Appendix 1, Fig 4.16.



**Figure 4.6:** Mean Annual Runoff (mm) (1961 - 1990) and Ratios of future (2021-2050) to present Mean Annual Runoff in the Pungwe basin, upstream Bué Maria. A ratio above one indicates increased MAR whereas a ratio below one indicates decreased MAR.

#### **4.2.3 Variability of precipitation and streamflow in the Pungwe basin down to Bué Maria**

A relevant question concerning climate change is how the variation of dry and wet years will vary in the future. For this type of calculations, it is necessary to use the scaling approach (c.f. 4.2 and Appendix 1, pp 30-32), as this gives the possibility to capture also changes in dynamics, and not only in averaged values. In this section we therefore mainly show results linked to changes of dynamics, such as coefficients of variance, duration of flows and frequency of high floods.

The results are summarized below, and more details and figures are found in Appendix 1.

##### Precipitation:

A division has been made between dry and wet season rainfall, and assessments have been made for wet, medium and dry years.

- The results show that precipitation is mainly decreased during the wet season (October – March), with a magnitude of 10-13% for all three types of years. Scenario 1, though, indicates a small increase of rainfall during wet years.
- No significant change of dry season rainfall is found.

The coefficient of variation (CV) is a statistical measure of the spread of data around the mean in a time series. A high CV indicates a high variability around the mean, i.e. higher occurrence of extreme years. CV can be expressed as:

$$CV = \frac{\text{standard deviation}}{\text{mean}} \times 100$$

- An analysis of the CV indicates an increased inter-annual variability of precipitation in the future.

##### Monthly discharge at Bué Maria:

- Scenarios 2 and 3 show decreased flow during wet, medium as well as dry years. This is due to the increased potential evaporation and decreased precipitation foreseen in the climate model results.
- Scenario 1, however, shows a small increase in wet-season flow during wet years (due to increased precipitation), but for medium and dry years this scenario also indicates decreased monthly streamflow.
- The scenarios indicate a slightly decreased dry-season flow, with exception for wet years with scenario 1, which indicate unchanged conditions.



#### Inter-annual variability of streamflow:

Coefficients of variance (CV) were calculated for the mean annual runoff and for the dry season runoff (April – September). As described above, a high CV indicates a high inter-annual variability, i.e. a high occurrence of extreme years (N.B. both wet and dry years).

- Results for present climate situation (the period 1961-1990) show higher CV in the drier, downstream, subbasins than in the wetter headwater part of the Pungwe basin.
- The three future climate scenarios do generally not indicate that inter-annual variability of mean annual runoff will increase in the future.
- For dry-season flow, scenarios 2 and 3 show a significant increase of inter-annual variability for the period 2021-2050, indicating that streamflow can become less consistent during the dry season. Scenario 1, however, indicate a general decrease of the variability of dry season streamflow.

#### Flow durations curves:

Based on the HBV simulations, driven by the simulations of climatological time series, flow duration curves were computed for all sub-basins used in the model setup of the Pungwe River basin upstream Bué Maria. A flow duration curve is a graph, representing the time during which the value of the discharge in a river is equal to or exceeded during a certain period of time.

The flow duration curves are presented in three different graphs, to enable a visualization of the results at the different flow magnitudes. The curves are divided in:

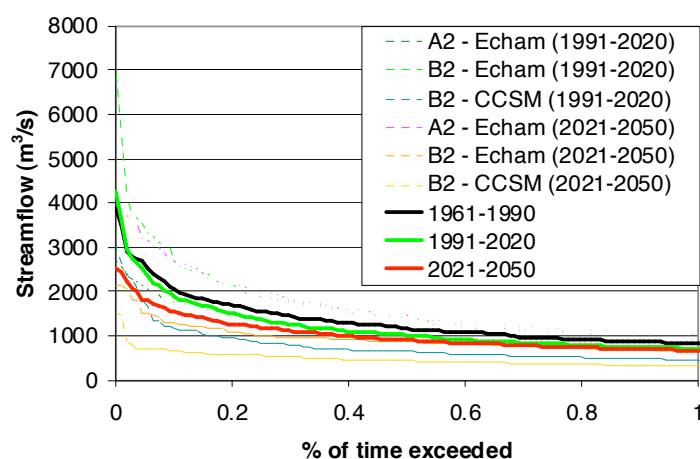
- the highest flows, exceeded not more than 1% of the time,
- the flows exceeded between the 1% and 30% of the time,
- and the low flows, exceeded 30-100 % of the time.

The graphs for Bué Maria are shown in Figure 4.7 and the graphs for all sub-basins upstream of Bué Maria are shown in Appendix 1

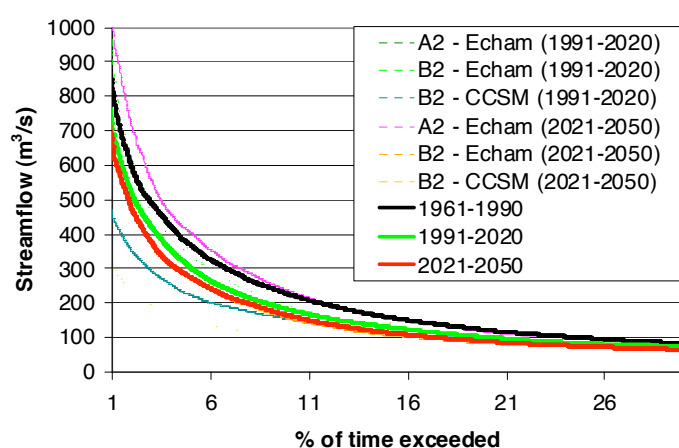
- For the highest flows, the results show a general trend towards lower flows for the periods 1991-2020 and 2021-2050, when comparing with the 1961-1990 period. The trend is more pronounced for the 2021-2050 period. The only exceptions from this are the results of Scenario 1 for the 2021-2050 and for Scenario 2 for the 1991-2020 periods, which indicate increased high flows.
- All scenarios indicate a reduction of the low flows.



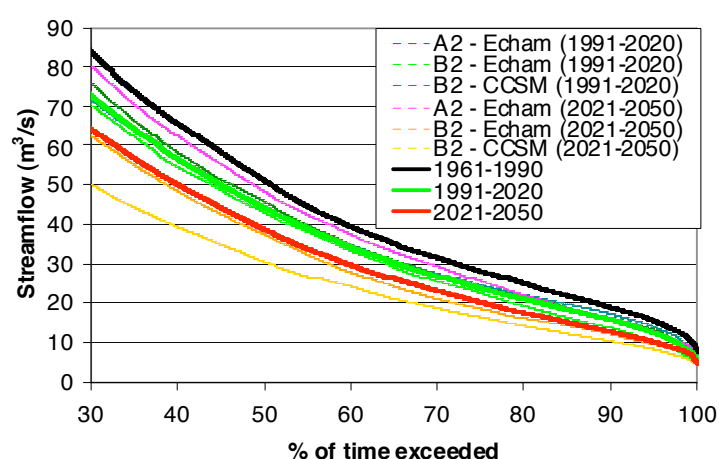
### Bué Maria. Highest flows



### Bué Maria. Medium flows



### Bué Maria. Lowest flows



**Figure 4.7** Flow duration curves, showing percentage of time when daily streamflow of various magnitudes are exceeded at Bué Maria. The black, green and red lines show the average from the simulations based on three climate change scenario experiments

### Changes of flood peaks calculated by frequency analysis:

Frequency analysis is a statistical method to assess the magnitude of extreme floods, expressed as return period of the flood peak. The method uses annual maximum peak values as input. Model outputs from the HBV model, driven by data from the three RCA3 scenarios, were used to assess possible changes of extreme floods over time in four selected subbasins. Similar procedures as in the SWECO project (SWECO and associates, 2004) were used. The results are presented for the gauging stations at the outlet of the sub-basins Fronteira, Pungwe Sul, Nhazonia, and Bué Maria. Although the modeled flood peaks differ from the recorded peaks and the peaks modeled by SWECO and associates (2004), it is possible to make comparisons between the results for various periods, in order to see relative changes over time.

- Most of the scenarios of future climate indicate that high floods will be significantly reduced. The effect is more distinct for the period 2021-2050. The highest reduction is indicated for the sub-basin Nhazonia (extreme floods reduced by about 80%), whereas the lowest reduction is shown for the headwater sub-basin Fronteira (extreme floods reduced by about 30%).
- Only Scenario 2 shows an increase of high floods for the 1990-2021 period, and this only for Bué Maria.
- Only Scenario 1 shows an increase of high floods for the period 2021-2050 and this only for the sub-basins Fronteira and Pungwe Sul, whereas this scenario does not show any significant change of extreme floods for the sub-basins Nhazonia and Bué Maria.

#### **4.2.4 Summary of the results**

The conclusion that “dry conditions will get drier” is rather robust, since all three scenarios point in that direction. It is thus indicated by all three scenario experiments that:

- Annual rainfall will decrease by ca 10%
- There will be a later start of and less rainfall in the early part of rainy season
- The atmospheric demand of moisture (evaporation) will increase, especially in the dry season
- The water balance will be shifted towards increased water deficit
- There will be a shorter period with a positive water balance (rainfall minus potential evaporation)
- During dry years, both rainy season and dry season flow will decrease.
- During wet, as well as dry years, low flows will be decreased.

It is, however, more uncertain if high flows will increase or decrease in the future. In general, scenario experiments 2 and 3 (ECHAM3-B2 and CCSM3-B2) indicate that also high flows will be decreased, whereas scenario experiment 1 (ECHAM3-A2) points in the opposite direction (Table 4.1).

**Table 4.1.** Comparison of indications from the three scenario experiments of whether wet conditions will become even wetter or drier in the future.

	Scenario 1	Scenario 2&3
Wet season rainfall during wet years	<i>Increased</i>	<i>Decreased</i>
Wet season river flow during wet years	<i>Increased</i>	<i>Decreased</i>
The 1% highest flows	<i>Increased</i>	<i>Decreased</i>
Flood peaks in the driest sub-basins	<i>Unchanged</i>	<i>Decreased</i>
Flood peaks in wetter sub-basins	<i>Increased</i>	<i>Decreased</i>

## 5 Consequences of simulated future climate effects

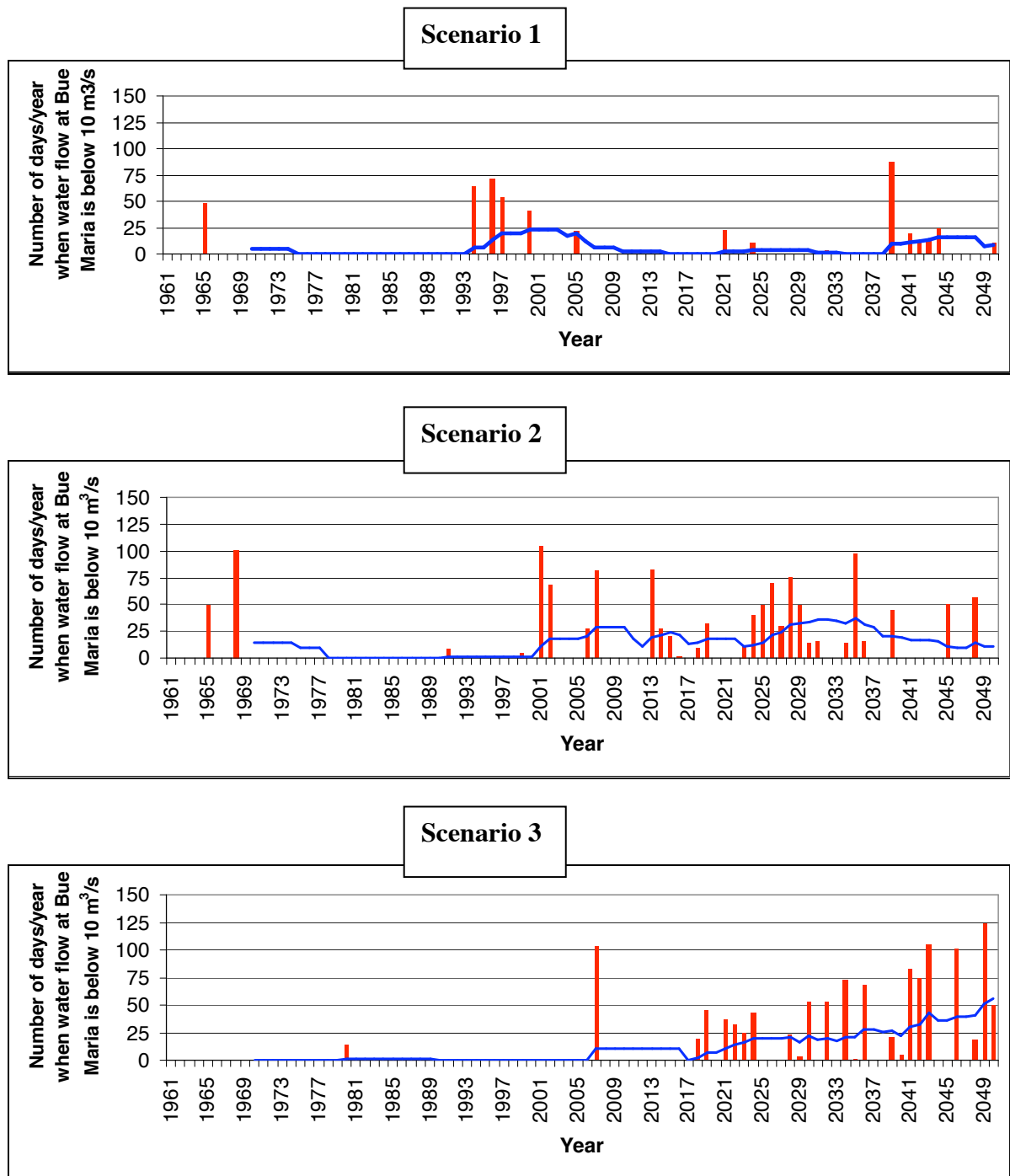
This chapter was elaborated after the final workshop in Maputo 30-31 of August 2006, using the results from group work performed and comments from the reference group sent after the workshop.

### 5.1 Rise of sea water level

According to IPCC (2001) a number of global climate models implicate a general rise of sea water level with 5-30 cm till 2050 with a mean value around 16 cm. This process will have severe consequences for the Lower Pungwe basin in general and for the city of Beira in particular. Beira has always had drainage problems, due to being situated close to sea level, and precautions should be taken to cope with the rise of sea level in the future.

### 5.2 Needs for the intake of freshwater to the city of Beira

Low streamflow in Pungwe at Bué Maria is of concern to the intake of freshwater to the city of Beira, the second largest city of Moçambique, with about one million inhabitants. The flow to safeguard the intake of freshwater for Beira has been considered as 10 m<sup>3</sup>/s (Chamuco, 1997). An assessment was made of the number of days per year when water flow was below this limit. Two of the three simulations (based on scenario 2 and 3), showed increased number of days with flow below 10 m<sup>3</sup>/s, with a highly significant upward trend from about 2020 and forward for Scenario 3. See figure 4.8. This is an example of how results related to determined thresholds can be presented.



**Figure 4.8.** Number of days/year (1961-2050) when water flow in Pungwe at Bue Maria simulated with the three different scenarios, is below  $10 \text{ m}^3/\text{s}$ , which is considered as the minimum flow to safeguard the intake of freshwater for Beira (Chamuco, 1997). The blue line is the 10-years running average.

The present capacity of the intake to Beira city is about 350 l/s. The intake is shared with Mafambisse Sugar Estate, who has permission to capture  $5 \text{ million m}^3/\text{months}$  (equaling about 1 900 l/s each day of a month). During low flow competition of water already has

occurred. Presently a supplementary intake for freshwater to Beira is under construction some kilometers upstream, which will double the capacity for Beira water supply.

The implications from the models, with decreased mean annual runoff and dry season flow in the river, alert the needs for a salt water intrusion barrier downstream the intakes, to prevent salination of Beira drinking water.

With decreasing availability of freshwater, the need for refurbishment of urban water supply network is highlighted, in order to cut transmission losses.

### **5.3 Needs for the intake of freshwater to the city of Mutare and other water demands in the basin.**

Presently, about 700 l/s is abstracted from Pungwe to a dam supplying freshwater to the city of Mutare in Zimbabwe. The intake is situated just upstream the discharge station F14 Pungwe Falls. At present, no increase of this abstraction is planned, but needs might appear in the future.

However, the modeled gradual reduction in runoff (see. e.g. Figure 4.4) indicates a decrease in the amount of water available for use (yield) and consequently an increased security on water supplies. A decrease in recharges will also imply a possible reduction in groundwater yield. This in turn means that there is a need for more water demand management.

### **5.4 Harmonization of national water law**

In the light of the possibilities for increased disputes of conflicts due to water shortage, it is recommendable to review existing water laws. The revised SADC protocol places water for human consumption as first priority, and this should be highlighted on a national scale.

### **5.5 Future dams for irrigation and rural water supply**

Decreased flow in the rivers augments the need for water storage and will probably increase the plans for construction of dams.

Feasibility studies for large and small dams for irrigation or/and rural water supply should take into consideration the implications from the models of decreased mean annual runoff and dry season flow, as well as increased potential evaporation during the dry season, due to increased temperatures. These factors might have severe impact on the viability of the dams. Today several dams are planned, for example two dams upstream the intake to Mutare in Zimbabwe, dams in the tributaries of Muda, Nhazonia, Missumbize and Metuchira in Moçambique and feasibility studies are being prepared for a large dam in the main river, either at Pavua or Bué Maria.

### **5.6 Agriculture and water quality**

A combination of higher temperature and lower precipitation implies a decrease in crop yield for rain-fed agriculture and an increased demand for water for irrigation. A higher potential evaporation affects the dam storage of water. The choice of suitable crops to cultivate, as well

as the availability of live stock fodder, could be affected. A changing climate will also impact on issuing of water permits and environmental flow assessment.

Less runoff implies low dilution factors, both for sediments and polluting agents. This can give a poor water quality and aggravate the situation in areas where there are problems already today.

A drier environment can give an increase in bush fires.

There is a need for deeper analyses of the impacts for the agricultural and forest sectors, as not enough representatives for these areas were present at the workshop.

### **5.7 Water needs for tourism and the Gorongosa National Park**

The mountainous region of upper Pungwe and the Pungwe Falls in particular, are a spectacular view and an area of high interest for tourism. It is also considered as a candidate for World Heritage (SWECO and Associates), and hence special attention has to be paid to the requirements of water to maintain the levels of discharge required.

The Gorongosa National Park was before the terrorist war considered as one of the best in Africa. Presently, work is in progress to develop the infrastructure of the park, including water supply and construction of small dams. These plans will require a minimum amount of discharge in the Pungwe River, and the modeled future water resources might have an impact on the development of the plans for the park.

### **5.8 Requirements for the aquatic ecology**

The changing flow pattern may have consequences for water living organisms, and the needs for the aquatic life have to be considered within the future water resources. Fish is a very important protein source for the people living along the river.

### **5.9 Planned hydropower production**

Small hydropower dams are already planned in the basin and will probably increase during the next years. Mini hydro power plants are planned in the tributary of Dura in Zimbabwe and in the Manica province in Moçambique. The possible new dam in Pungwe, at Pavua or Bué Maria, will be a multi-purpose dam, i.e. also including hydro power production. The decrease of runoff in the river will probably influence severely on the profitability of hydropower production, and it is utterly important to take into consideration the future climate scenarios when making the calculations of feasibility for hydropower dams.

### **5.10 Health impacts**

Unfortunately no representative for the health sector was present at the workshop. The project results should be presented to relevant persons in this sector for evaluation. Both research and planning activities should take future climate scenarios into consideration. For example, the impact of increased temperature on the extension of malaria, the deterioration of water quality and the impacts on community based resource management have to be taken into considera-

tion. Knowing that river water presently is frequently used for as well washing as drinking, the consequences of lower discharge for dilution of pollutants has to be taken very seriously.

Attention should also be paid to the consequences for the drainage and sanitation situation in Beira in a situation of higher sea level.

### **5.11 The transport sector**

The vulnerability to flooding increases downstream in the river basin. The area downstream Bué Maria is situated below 50 m.a.s.l. and is already with present climate exposed to influence from high sea water level and rather frequent flooding. The rise of sea water level (see 5.1 above) will aggravate these problems. Attention should be paid to the harbor and the international airport in Beira.

The main road to Beira (EN 6) is downstream of Tica flooded during high floods in Pungwe River. The critical water level is 8.0 m at the limnigraph E67 at Pungwe Bridge. It should be investigated to which discharge at Bué Maria this level corresponds. With this information it will be possible to estimate the frequency of flooding of the main road. Rehabilitation of the main road to Beira has to take also climate change consequences into consideration in the prospecting work.

### **5.12 Industry and mining**

There are siltation problems in the river already today, due to increased gold mining in the upper parts of the river basin. This seems to be in a process of control from the environmental authorities, but the water quality problems will of course increase if the runoff decreases.

If industrial activities are planned to start, it is important to always include the long term perspective of water resources and water quality. Reduced runoff can prejudice production and will imply less water to dilute the waste water.

## **6 Conclusions**

Two of the three scenarios in this study (Scenario 2 and 3) point towards drastically reduced water availability in the Pungwe River basin. If these scenarios should indeed occur in the region during the coming decades, they would add to the already critical situation regarding water availability, and affect many aspects of regional everyday life, since not only extreme, but also average conditions would be characterized by less water than today.

However, can we be sure that the three climate change experiments performed give sufficient information about the uncertainties in the projections about the future? Obviously, only the future itself can reveal how large uncertainties we are dealing with. In general, however, also other climate studies for Southern Africa provide similar results as the Pungwe study – i.e., although various scenarios might differ, most of them indicate less water (c.f. Appendix 1).

Consequently, the results from this study point towards a need to prepare for reduced water availability. In order to lay the ground for advancing development goals in a sustainable way and release full potential of market-based and technical opportunities, it is necessary to integrate assessments of the impact of climate change with other aspects of IWRM in the Pungwe

basin. This challenge calls for an integrated effort, including both economical, legal and hydroclimatological aspects, driven by regional stakeholders with assistance from relevant national, as well as international experts.

## **7 Recommendations**

### **7.1 Recommendations for similar studies in other catchments**

Based on lessons learned from this project, the following recommendations are given for similar studies in other catchments:

- The uncertainties in the modeling results are to a large degree caused by the different combinations of GCM:s and IPCC emission scenarios used as forcing for the RCM. If the results are based on too few such combinations they can give a false impression of a “certain” future.
- The uncertainty cloud may be even better embraced by the use of a combination of dynamical and statistical downscaling. Which downscaling method to use depend partly on the questions asked but they can most probably complement each other.
- If the situation appears that there is a choice of performing a few high resolution simulations against the choice of performing several coarser simulations we would recommend the latter. Again, for the reason of embracing the uncertainty cloud from the perspectives mentioned above. High resolution simulations will give better distribution of precipitation but on the expense of the number of simulations in the case of limited computer resources.
- In order to ensure that hydrological modeling, based on climate scenarios will be operationally used in regional IWRM also after the finalization of the project, it is necessary to ensure that the project includes components that assure regional access to, including sustainable support of the use of, hydrological models, as well as interface tools between climate and hydrological models.
- A well covered representation of representatives from the basin is important to give rise to the relevant questions to be answered by the project, as well as to information needed in order to assess where and when modeled changes of water resources and extreme events are significant to IWRM. Consideration should therefore be given to including representatives from all relevant stakeholder groups within the studied basin. Steering group and stakeholder meetings should therefore preferably be arranged within the basin in order to ensure that as many basin representatives as possible can attend the meeting.

### **7.2 Recommendations for a follow-up with a second project phase**

In this report we talk about **scenarios** and not about forecasts, as there are large uncertainties in the assumptions of the future. Nevertheless, available assessments have to be used, because adaptation takes time, and the consequences might be very severe if nothing is done. There is a pedagogical challenge in learning to think and plan from a scenario perspective and to cope with uncertainties and probabilities in decision-making. This is sometimes referred to as



“adaptive management”, which, when applied on climate change impacts on water resources could be based on the following steps: (1) assessment of problems (which, where, for whom?); (2) design of mitigation strategies (both involving law, economics and technical aspects); (3) implementation of mitigation strategies; (4) continuous monitoring and evaluation of conditions in the basin, as well as updates of scientific knowledge; (5) adjustments of IWRM strategies based on the updates.

It is recommended by the regional counterparts of this project that the impact of climate change on water resources will be covered in a second phase of the “*Climate Change Impacts on Water Resources in the Pungwe Drainage Basin*”. However, since climate change only is one component that will impact future water resources, it is vital that this project is integrated in the overall development of the Pungwe Water Resources Management Strategy. Coping with climate change should, especially in a region like the Pungwe basin, where climate variability and the occurrence of extreme events is high, rather strengthen the significance of IWRM than provide a major change of how it is to be carried out.

A second phase of the project, with the aim of incorporating mitigations of identified consequences of climate change in IWRM, needs to be driven by regional and national stakeholders, assisted by national, as well as international experts. The aim of a second phase should thus be to contribute to the development of an IWRM plan, based on a synthesis of assessments of future development. This includes factors such as population growth, urbanization, agriculture, industrialization and health, as well as a possible climate change.

Below, some recommendations for a second phase of the project are given. However, we do not include a more specified proposal for the design of a second phase. We think it is necessary that the planning of a second phase is based on active participation of consultants from the region, together with relevant regional stakeholders. These should be responsible for the design and implementation of a possible second phase of the project, with assistance from national and international experts.

- A careful survey has to be made in order to ensure that stakeholders and other expertise from relevant sectors are included. The first phase would, e.g., have benefited from better representation from the health and agriculture sectors. For assessments of impacts and adaptations within the agricultural sector, it is advisable to incorporate an agrohydrological model in a possible follow-up project (e.g., the ACRU model (Schulze, 1995)).
- In the Pungwe basin, the Pungwe Basin Committee in Moçambique and the Pungwe Sub-Catchment Council in Zimbabwe have already been established and form a good base for stakeholder participation. In addition to the members of these groups, representatives from ministries and institutes on the national level, as well as from donors and international finance institutions, (African Development Bank, World Bank etc.) should be involved. Continued cooperation between Moçambique and Zimbabwe is of course also of great importance.
- Dialogues between stakeholder groups and external experts are vital in order to define critical thresholds (e.g., for floods implying overbank flow, amount of rainfall to define the start of the rainy season, definition of drought), as well as in prioritizing of the impacts and proposals for mitigation/adaptation measures that have to be made.

- Capacity building is an important part of the future activities. This expression can signify many different aspects; for example
  - awareness to local community on the extend they may be exposed to climate change
  - awareness to policy makers
  - knowledge transfer to locals institutions involved in research and applied IWRM work which should feed back into policy
- Tools are needed that provide guidance of where mitigation strategies are most needed, and how they can be best implemented. Such assessments need to be built from participatory consultation, encouraging a “buy-in” by stakeholders when needs for actions are identified. This could help policy makers and planners to build effective plans to cope with changed vulnerability – i.e. to take action to improve protection against increased disasters, water shortages, and drought. An example of such a tool is the Climate Vulnerability Index (CVI) (Sullivan and Meigh, 2005), which previously has been applied in Southern Africa. Based on such assessments, as a start, some mitigation demonstration projects could be developed on selected sites where livelihoods are likely to be significantly affected.
- For minimizing the impact of climate change, several strategies have to be considered on the river basin level. Some proposals are outlined by IPCC are presented in Table 7.1. In developments of policies, including the adaptation to changed hydroclimaticological conditions, it is necessary to recognize not only hydrological and technical components, but also policy, law and economics. This is especially critical when dealing with transboundary basins, in order to negotiating international water agreements and avoid international disputes. One way to address this is to use a legal assessment model (LAM), where all these components are considered (*e.g.*, Wouters and IWLRIKAR team, 2004).
- Also in a second phase, dialogues and the possible use of *e.g.* LAM and CVI need to be assisted by the use of catchment hydrological models, *e.g.* in order to relate scenarios to defined threshold values and to assess the impact of various mitigation strategies on water resources and extreme events. In this context, also design parameters for proposed and existing hydraulic structures *e.g.* spillways and bridges need to be assessed. In addition there might be a need for data collection activities with based on local involvement, with the aim of giving assistance in more in more accurate assessments on the impact of climate change.

SMHI is certainly interested in assisting in contributing to a follow-up study. In addition to continuation of catchment modeling linked to IWRM with consideration to climate change, we are willing to coordinate also possible incorporation of other international consultants. Interest for such cooperation within the field of water law and policy has been provided by Prof. Patricia Wouters, Director of the International Water Law Institute, University of Dundee, Scotland, as well as in the field of climate vulnerability assessments by Dr. Caroline Sullivan, Head of Water Policy and Management at the Centre for Ecology and Hydrology (CEH) in Wallingford, UK. Both have extensive previous experience of work in Southern Africa. When it comes to hydrological modeling and use of other tools, such as, *e.g.* LAM and WPI, transfer of knowledge is vital, and we suggest that all work within a second phase should be made in cooperation between national and international participants, in order to

ensure a transfer of knowledge (both from the South to the North and from the North to the South).

As previously expressed, we think it is of vital importance for the success for a second phase that regional consultants play a key role when it comes to coordination of stakeholders, as well as in the coordination of national as well as international experts.

**Table 7.1.** Selected recommendations from the IPCC for water resource managers (Modified from Table 4-13; TAR,2001).

Option	Comment	Option	Comment
<b>SUPPLY SIDE</b>		<b>DEMAND SIDE</b>	
<ul style="list-style-type: none"> <li>➤ Increase reservoir capacity</li> <li>➤ Extract more from rivers or ground-water</li> <li>➤ Alter system operating rules</li> <li>➤ Inter-basin transfers</li> <li>➤ Desalinization</li> </ul>	<ul style="list-style-type: none"> <li>➤ Expensive; potential environmental impacts</li> <li>➤ Potential environmental impacts.</li> <li>➤ Possibly limited opportunity</li> <li>➤ Expensive; potential environmental impacts</li> <li>➤ Expensive (high energy use)</li> </ul>	<ul style="list-style-type: none"> <li>➤ Incentives to use less (e.g. through pricing)</li> <li>➤ Legally enforceable water use standards (e.g. for appliances)</li> <li>➤ Increase use of grey water</li> <li>➤ Reduce leakage</li> <li>➤ Development of non-water-based sanitation systems</li> <li>➤ Seasonal forecasting</li> </ul>	<ul style="list-style-type: none"> <li>➤ Possibly limited opportunity; needs institutional framework</li> <li>➤ Potential political impact; usually cost-inefficient</li> <li>➤ Potentially expensive</li> <li>➤ Potentially expensive to reduce to very low levels especially in old systems</li> <li>➤ Possibly too technically advanced for wide application</li> <li>➤ Increasingly feasible</li> </ul>
<b>INDUSTRIAL AND POWER STATION COOLING</b>			
<ul style="list-style-type: none"> <li>➤ Increase source capacity</li> <li>➤ Use low-grade water</li> </ul>	<ul style="list-style-type: none"> <li>➤ Expensive</li> <li>➤ Increasingly used</li> </ul>	<ul style="list-style-type: none"> <li>➤ Increased water-use efficiency and water recycling</li> </ul>	<ul style="list-style-type: none"> <li>➤ Possibly expensive to up-grade</li> </ul>
<b>POLLUTION CONTROL</b>			
<ul style="list-style-type: none"> <li>➤ Enhance treatment works</li> </ul>	<ul style="list-style-type: none"> <li>➤ Potentially expensive</li> </ul>	<ul style="list-style-type: none"> <li>➤ Reduce volume of effluents to treat (e.g. charging discharges)</li> <li>➤ Catchment management to reduce polluting runoff</li> </ul>	<ul style="list-style-type: none"> <li>➤ Requires management of diffuse sources of pollution</li> <li>➤ Requires buy-in from farmers, e.g. incentives</li> </ul>
<b>FLOOD MANAGEMENT</b>			
<ul style="list-style-type: none"> <li>➤ Increase flood protection (levees, reservoirs)</li> <li>➤ Catchment source control to reduce peak discharges</li> </ul>	<ul style="list-style-type: none"> <li>➤ Expensive; potential environmental impacts</li> <li>➤ More effective for small than large floods</li> </ul>	<ul style="list-style-type: none"> <li>➤ Improved flood warning and dissemination</li> <li>➤ Curb floodplain development</li> </ul>	<ul style="list-style-type: none"> <li>➤ Technical limitations in flashflood areas and unknown effectiveness</li> <li>➤ Potential major socio-political problems</li> </ul>
<b>IRRIGATION</b>			
<ul style="list-style-type: none"> <li>➤ Increase irrigation source capacity</li> </ul>	<ul style="list-style-type: none"> <li>➤ Expensive; potential environmental impacts</li> </ul>	<ul style="list-style-type: none"> <li>➤ Increase water use efficiency</li> <li>➤ Increase drought-tolerant varieties</li> <li>➤ Change crop pattern</li> </ul>	<ul style="list-style-type: none"> <li>➤ Technology; increasing prices</li> <li>➤ Genetic engineering is controversial</li> <li>➤ Change to crops which need less or no irrigation</li> </ul>

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## **8 Appendix 1**

Appendix 1 is the Modelling report of this project ( SMHI Report 2006-41). This report contains a detailed description of the modeling work performed in the project and a presentation of the models used. A large amount of figures are included in the report.







Swedish Meteorological and Hydrological Institute  
SE 601 76 NORRKÖPING  
Phone 011-495 80 00 Fax 011-495 80 01