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ASSESSING VULNERABILITY TO DROUGHT AND POSSIBLE EFFECTS OF CLIMATE CHANGE ON WATER RESOURCES IN A SEMI-ARID COUNTRY

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ABSTRACT

Namibia, being the driest sub-Saharan country, is characterised by semi-arid to arid climatological and hydrological conditions. Rainfall is erratic and comes in short convective showers in a rainy season from October to April. The variability of the seasonal rainfall is high, with some seasons totalling half or double the nominal "normal" rainfall.

Due to the mountainous and hilly character of the terrain and the hard and impermeable surfaces, runoff occurs almost exclusively as a short and immediate response to rainfall, resulting in typical flash floods that may last only a few hours. Even more than rainfall, riverflow is unreliable. Droughts occur in different forms, and runoff, grazing and rainfed crop droughts are regular phenomena.

As a signatory to the United Nations Framework Convention on Climate Change, Namibia is investigating the vulnerability of its society, environment and economy to the potential effects of climate change. Vulnerability is measured by sensitivity to climate and by the ability to adapt to new environmental conditions. Water is the most constraining factor on any development in Namibia and the possible effect of climate change on the availability of water resources therefore needs careful assessment.

It is customary to extend short riverflow records over a longer period by means of a calibrated rainfall/runoff model and the longer rainfall records. The rainfall/runoff model applicable for Namibia incorporates two specific features of the physical process:

- An initial loss which reflects the non-linear relation between rainfall and runoff.
- An antecedent season index which reflects the negative effect of vegetation persistence, meaning that after one or two good rainy seasons vegetation will be abundant resulting in a lower runoff potential, while after poor rainy seasons the absence of vegetation will cause a higher runoff potential.

The latter factor results, in the absence of serial correlation for the annual rainfalls, in a negative serial correlation in annual flows in Namibia.

The calibration of the model is done for records that include both wet and dry cycles, and it is therefore thought that a calibrated model could be used to simulate the effect of lower rainfall, as it implicitly takes vegetation changes into account. The driest periods may now have rainfall below the lowest level for which the model was calibrated, but these periods have zero runoff and remain therefore correct in any case.

The methodology was applied for possible dam sites on the Kuiseb River, situated in the central part of Namibia. Typical runs show that a reduction by 5 % in rainfall would reduce runoff and safe yield from a dam by between 5 and 10 %. Although this reduction is more than proportional, due to the non-linear relation between rainfall and runoff, it is also not exponential, because the model incorporates that lower rainfall will mean less vegetation and a higher runoff potential.

INTRODUCTION

A rainfall/runoff model was run to determine safe yields for two possible dam sites, Donkersan and Gaub, in the middle Kuiseb River, of which the catchment is situated in the central western part of Namibia. Refer to **FIGURE 1** for orientation of the Kuiseb catchment in Namibia and to **FIGURE 2** for the upper and middle Kuiseb catchment. Following this, possible climate change characteristics were run via a simulation model to determine the effect of reduced rainfall on runoff and yields for the possible dams.

FIGURE 1: LOCATION MAP OF UPPER KUISEB CATCHMENT IN NAMIBIA

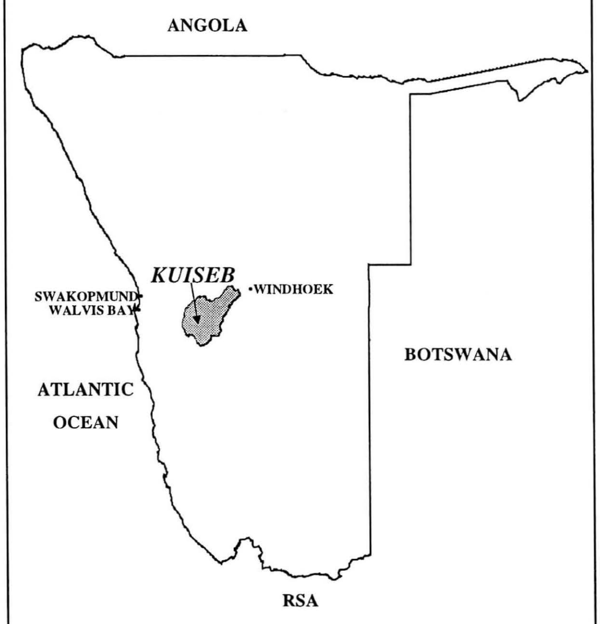
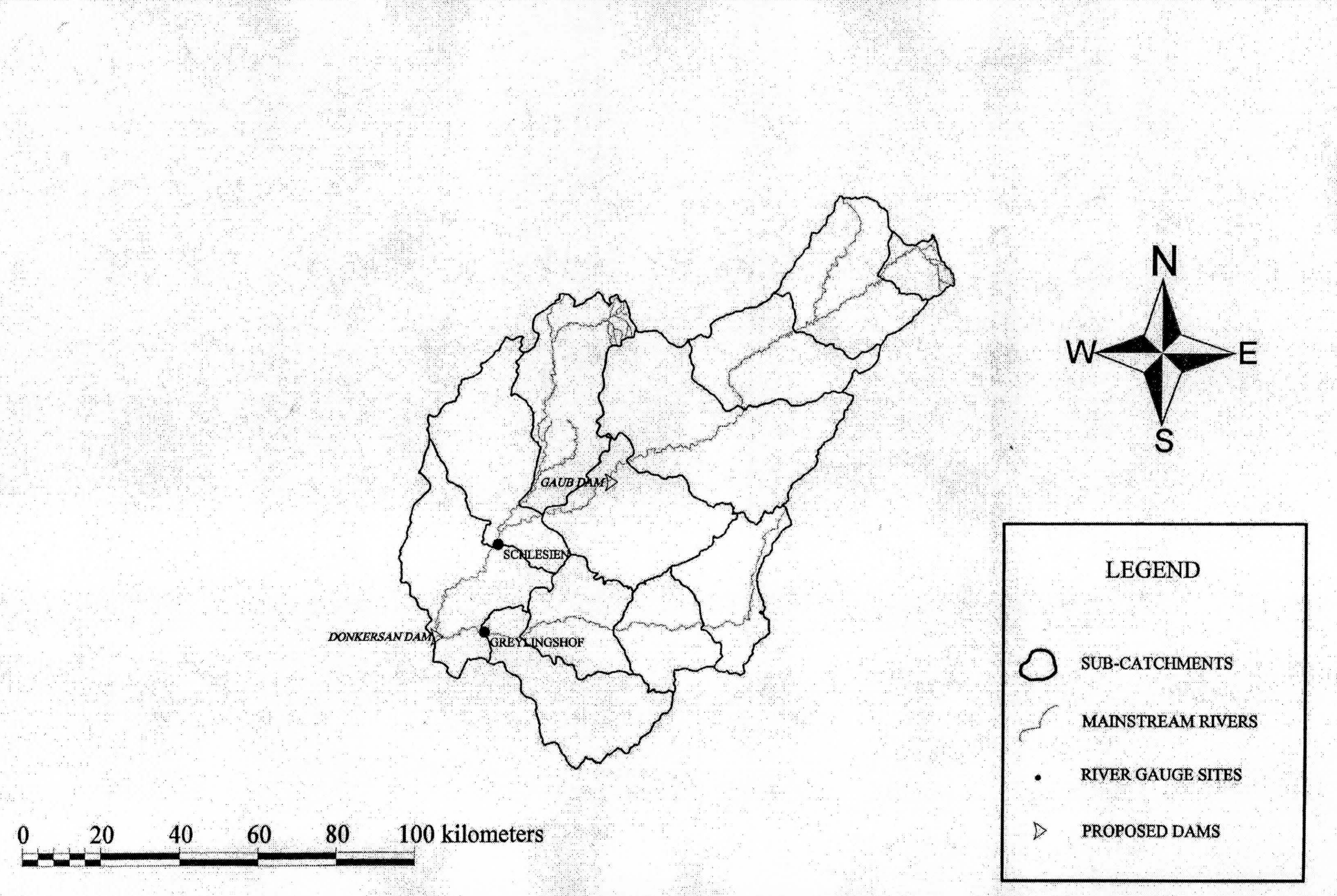


FIGURE 2: UPPER KUISEB RIVER CATCHMENT

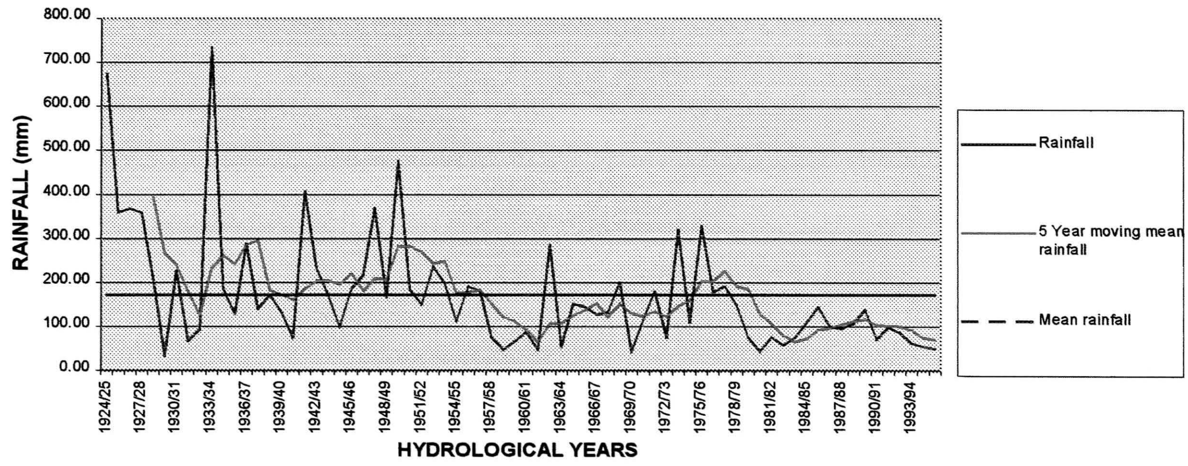


RAINFALL

Fifty-two (52) Weather Bureau daily read rainfall stations cover the upper and middle Kuiseb catchment area. Rainfall data have been recorded in parts of this area since as early as 1903, and although the records for the area have gaps at some of the stations, all fifty-two were chosen for this investigation.

The average annual rainfall for this catchment varies from approximately 275 mm in the eastern area to 170 mm in the south-west. (Data obtained from the multiquadric results). Refer to **FIGURE 3** and **4** for the graphical representation of the rainfall obtained from the multiquadric surface fit for the sub-catchment closest to the proposed Donkersan and Gaub dam sites. The five-year moving mean rainfall is also presented as a time series for the period 1924/25 to 1995/96. Presented in **TABLE 1** are the wet and dry periods detected from the graphs.

FIGURE 3: SCHLESIEN MULTIQUADRIC MEAN RAINFALL



FIRURE 4: GREYLINGSHOF MULTIQUADRIC ANNUAL RAINFALL

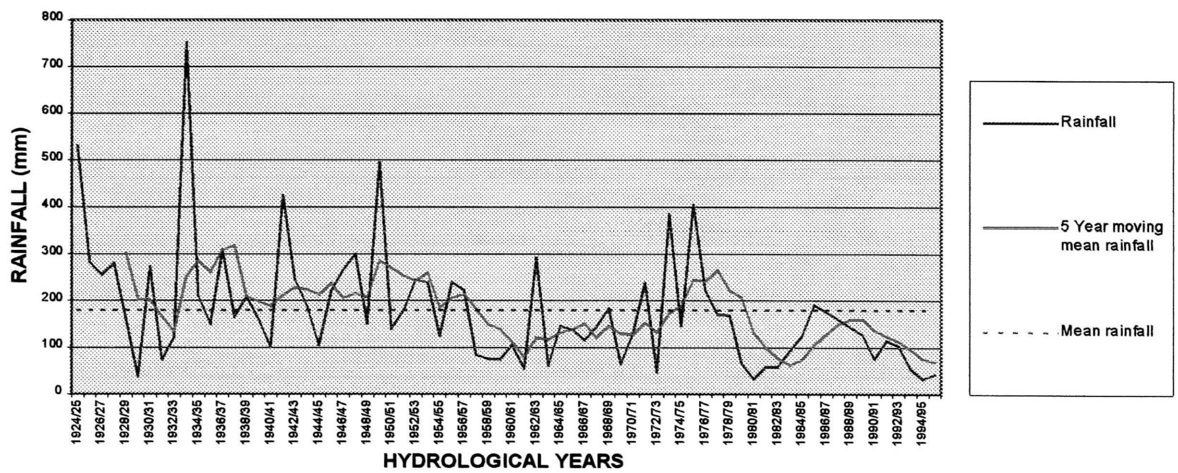


TABLE 1: IDENTIFIED WET AND DRY RAINFALL PERIODS FOR THE 1928/29 TO 1995/96 HYDROLOGICAL YEARS

WET RAINFALL PERIODS FOR		DRY RAINFALL PERIODS FOR	
SCHLESIEN	GREYLINGSHOF	SCHLESIEN	GREYLINGSHOF
1928/29 to 1931/32	1928/29 to 1930/31	1932/33 to 1932/33	1931/32 to 1932/33
1933/34 to 1939/40	1933/34 to1957/58	1940/41 to 1940/41	1958/59 to1973/74
1941/42 to 1956/57	1974/75 to 1979/80	1956/57 to 1974/75	1980/81 to 1995/96
1975/76 to 1979/80	-	1980/81 to 1995/96	-

Due to a lack of sufficient rainfall data prior to 1924 the rainfall could not be extended further back than 1924/25 with the use of the multiquadric program. The results clearly indicated that from 1956/57 to 1995/96 this area has experienced below mean rainfall for two extended periods.

RAINFALL/RUNOFF MODELING

The **NAMROM** model (Namibian Rainfall/Runoff Model) used for the analyses has proven to provide the best results for Namibian conditions, particularly because it is able to accommodate negative seasonal serial correlation evident in most Namibian runoff records.

The procedures followed for the model were:

- Identify and divide the catchment into sub-catchments that correspond to sites of hydrological significance.
- Run a monthly multiquadric model to fit a continuous surface for all point rainfall values for each month. The monthly rainfall depths can then be evaluated for any point or delineated area of the catchment. Station rainfalls are in this manner implicitly utilized to fill gaps in the record which eliminates time consuming patching of rainfall records.
- An observed runoff record at or nearby the outlet of the catchment is utilized for calibration purposes. The runoff record can be modified if necessary by considering rainfall events at the end of the month that produce runoff in the next month.
- Having derived the regression equation, it is used to generate a synthetic runoff record from the weighted historic rainfall record followed by the generation of stochastic rainfall and runoff record(s) of 1 000 years with the use of the program **NAMREC**.

NAMROM attempts to model as many as possible of the physical processes involved in the generation of runoff in Namibia, which is done in an indirect manner due to the absence of quantifiable data concerning soil cover, vegetation, grazing conditions and land use. Weighting is carried out by introducing the following parameters:

- Antecedent weighting factor
- Initial loss
- Sub-catchment loss factor
- Loss exponent

Refer to **TABLE 2**, which provides a summary of the annual runoff statistics, rainfall/runoff calibration for the Schlesien and Greylingshof record and to **TABLE 3** for the regression results. **FIGURE 5** and **FIGURE 6** present the graphical outlook of the actual synthesised annual runoff records versus the observed runoff records.

TABLE 2: ANNUAL STATISTICS OF FLOW DATA FOR SCHLESIEN AND GREYLINGSHOF

	SCHLESIEN FLOW			GREYLINGSHOF FLOW		
PERIOD	1961/62-95/96	1961/62-95/96	1927/28-95/96	1980/81-95/96	1980/81-95/96	1927/28-95/96
STATISTICS	OBSERVED	SIMULATED	SIMULATED	OBSERVED	SIMULATED	SIMULATED
AVERAGE (Mm^3)	15.19	15.20	18.91	1.89	1.88	3.63
ST. DEV. (Mm^3)	20.93	21.78	42.52	1.78	1.77	6.53
CV	1.38	1.43	2.25	0.94	0.94	1.80
MEDIAN (Mm^3)	8.69	7.62	7.09	1.26	1.40	1.54
ZEROS	1	1	8	2	0	5
YEARS	35	35	69	16	16	69

TABLE 3: REGRESSION RESULTS

SCHLESIEN	Regression Equation : Runoff = 0.124 * Weighted Precipitation + 0.00
SCHLESIEN	Correlation Coefficient = 81.10 %
GREYLINGSHOF	Regression Equation : Runoff = 0.046 * Weighted Precipitation + 0.00
GREYLINGSHOF	Correlation Coefficient = 73.56 %

FIGURE 5: SCHLESIEN SYNTHESISED RUNOFF VS OBSERVED RUNOFF

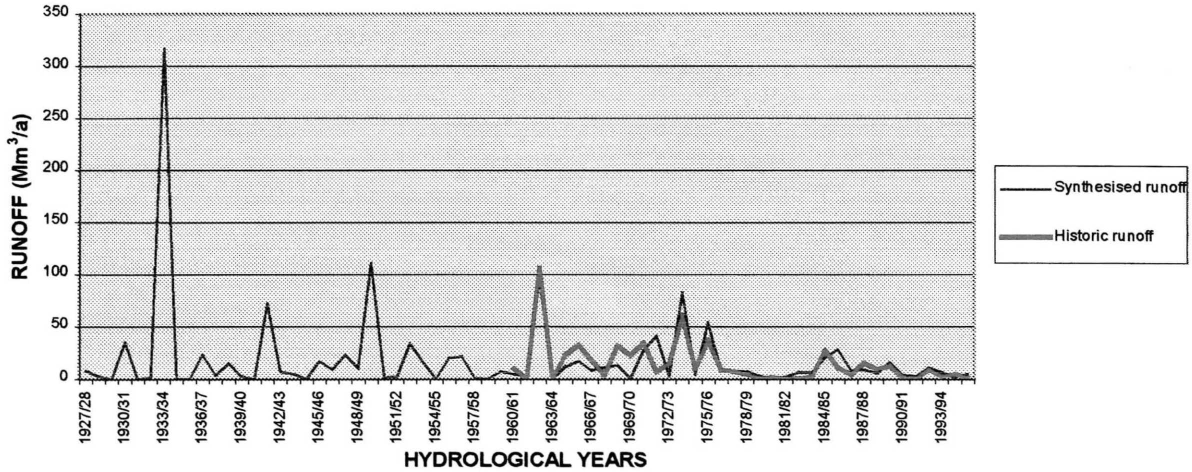
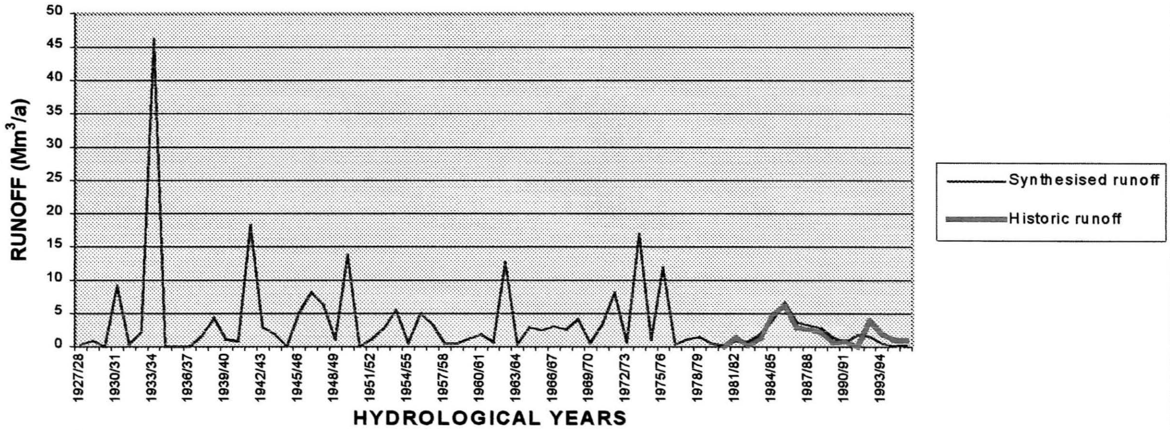


FIGURE 6: GREYLINGSHOF SYNTHESISED RUNOFF VS OBSERVED RUNOFF



DONKERSAN DAM RUNOFF RECORD

No runoff record exists for the proposed Donkersan Dam site. The Schlesien runoff record was however taken to be representative for the Donkersan Dam site. The dam site is 55 km upstream of the Schlesien station. An assumption was made that the loss of flow between the Schlesien station and the Donkersan Dam site would be approximately equal to the flow generated by local runoff.

This observed runoff record for the period 1961/62 to 1995/96 was used to produce a synthesised runoff record and the synthesised runoff record was used to generate a stochastic runoff record for the proposed Donkersan Dam site, which was used in the yield analyses.

GAUB DAM RUNOFF RECORD

No runoff record exists for the proposed Gaub Dam site. The assumption was made that the loss of flow from Greylingshof and Schlesien stations to the Kuiseb/Gaub confluence would be approximately equal to the flow generated by additional runoff. Hence the observed runoff records for the corresponding years (1980/81 to 1995/96) of the Schlesien and Greylingshof stations were added together to produce a runoff record for the proposed Gaub Dam site. The distances from the Greylingshof and Schlesien stations to the Kuiseb/Gaub confluence are approximately 20 km and 40 km respectively.

The newly produced observed runoff record, a new synthesised runoff record based on a combination of the Schlesien and Greylingshof synthesised runoff records and a stochastic runoff record based on the newly produced synthesised runoff record for the proposed Gaub Dam site were used in the yield analysis.

STORAGE/DRAFT ANALYSES

The generated flow data for the Donkersan and the Gaub Dam sites were each utilized in storage/draft analyses. It was opted to perform the storage/draft calculations with dead storages equal to 5% of the full supply capacities. The 95% safe yield corresponds to the accepted reliability for domestic and industrial supply whereas the 80% safe yields assesses the feasibility of irrigation or compensatory releases for environmental purposes from the dam.

The recommended 95% safe yields for domestic supply and 80% safe yields for irrigation or for environmental purposes for the Donkersan Dam and the Gaub Dam are presented in **TABLE 4**. The stochastic record of Schlesien was found to be representative to both the proposed dam sites and hence the yields were calculated using the same records on both the dam sites.

TABLE 4: RECOMMENDED SAFE YIELDS FOR DONKERSAN AND GAUB DAM

DAM	FULL SUPPLY CAPACITY (Mm^3)	DEAD STORAGE CAPACITY (Mm^3)	80% RELIABLE SAFE YIELD (Mm^3/a)	95% RELIABLE SAFE YIELD (Mm^3/a)
DONKERSAN	35.00	1.75	13.207	8.713
GAUB	50.00	2.50	14.618	10.130

EVALUATION OF CLIMATE CHANGE

Namibia is signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and is hence obliged to be involved in Climate Change studies.

Climate change science is complicated and is not yet fully understood. However studies have revealed that:

(I) Global mean surface temperatures have warmed by 0.5°C over the past 100 years.

(II) During the past 100 years Africa has experienced an increase in temperature of between 1°C and 1.5°C.

Sensitivities of climate changes and aerosols climate models predict the possibility that:

(I) Mean annual global surface temperature might show an increase of 1°C to 3.5°C by the year 2100.

(II) Unfavourable changes in spatial and temporal patterns of precipitation might occur.

(III) The global sea level might rise by 0.15 to 0.95 m.

The southern African countries are concerned about adverse changes in water resource distribution, and developing countries located in arid and semiarid regions are considered to be particularly vulnerable to climate change. For southern Africa, average temperatures have risen by 0.5°C during the last century and the 1986 to 1995 decade has been the warmest and driest since 1900.

POTENTIAL EFFECTS OF CLIMATE CHANGE ON RUNOFF

To determine the possible effect of climate change the **NAMROM** model was modified. The new model **NAMRED** was used to produce new synthesised runoff records for the Schlesien station by incorporating a reduction factor while utilising the same catchment characteristics. The analyses followed were as follows:

(I) reducing the rainfall by 5%, 10% and 15% respectively,

(II) using these rainfall records to produce a new synthesised runoff record with the use of the **NAMRED** program and hence a stochastic runoff record,

(III) utilising the newly generated stochastic runoff records to determine new safe yields for the medium sized Donkersan and Gaub dams using 5%, 10% and 15% higher evaporation figures respectively.

The calibrated rainfall/runoff relation derived for **NAMROM** is considered to be valid for the **NAMRED** simulations for the following reasons:

(I) There is no extrapolation to higher rainfalls.

(II) The lowest historic rainfalls already resulted in zero runoffs, and the extrapolation to lower rainfalls is therefore acceptable.

(III) The historic sequence includes extended dry periods during which vegetation almost completely disappeared, and the long-term effect of enduring decreased rainfalls on vegetation and runoff potential is therefore thought to be correctly modelled.

With respect to the last argument, the simulation obviously not models the effect of other physiographic or other alterations that may result from climate change, for instance changes in temporal or areal distribution of rainfall.

RESULTS OF CLIMATE CHANGE ANALYSES ON DONKERSAN AND GAUB DAM RUNOFF

Refer to **TABLE 5** for the statistics of the observed Schlesien runoff record, the synthesised runoff record generated from this record as well as the statistics of this synthesised runoff records after the incorporation of a 5%, 10% and 15% reducing factor in rainfall on the runoff record for the Donkersan Dam.

Referring to the yield analyses, it would be noted that the runoff record of Schlesien was found to be representative for the Gaub Dam site. Therefore **TABLE 5** is also applicable for the Gaub Dam.

TABLE 5: STATISTICS OF DECREASING SIMULATED (1927/28 TO 1995/96) RUNOFF DATA FOR DONKERSAN AND GAUB DAM

ANNUAL RUNOFF STATISTIC	RAINFALL REDUCTION (%) FOR THE SYNTHESISED RUNOFF RECORD			
	0%	5%	10%	15%
AVERAGE (Mm^3)	18.91	17.87	16.70	15.43
ST. DEV. (Mm^3)	42.52	39.94	37.31	34.62
CV	2.25	2.24	2.23	2.24
MEDIAN (Mm^3)	7.09	6.36	5.83	4.92
ZEROS	8	7	7	7
YEARS	69	69	69	69

The percentage reduction in runoff is found in all cases to be higher than the rainfall reduction, because of the non-linear relation between rainfall and runoff.

DONKERSAN DAM YIELD

The **RESSIM2** program that calculates the yields was modified to incorporate a rainfall reduction factor. This program **(SPILL)** was then used to generate a 1000-year stochastic rainfall and runoff record for each of the reduced synthesised runoff records. Using these stochastic runoff/rainfall records as well as corresponding increase in evaporation, new 80% and 95% safe yields for the medium sized, 35 Mm^3 Donkersan Dam were calculated. The results obtained for the yields are presented in **TABLE 6**.

TABLE 6: YIELD REDUCTION AS A RESULT OF DECREASED RAINFALL AND INCREASED EVAPORATION FOR THE DONKERSAN DAM

ASSUMPTIONS FOR STORAGE VOLUMES			YIELDS OBTAINED FROM THE STOCHASTIC RUNOFF RECORD							
FULL SUPPLY CAPACITY (Mm^3)	INITIAL STORAGE (Mm^3)	DEAD STORAGE (Mm^3)	80% SAFE YIELDS (Mm^3/a)				95% SAFE YIELDS (Mm^3/a)			
			RAINFALL REDUCTION FACTOR %				RAINFALL REDUCTION FACTOR %			
			0%	5%	10%	15%	0%	5%	10%	15%
35.00	0	1.75	13.081	12.005	11.505	10.870	8.880	8.320	7.960	7.522
TOTAL PERCENTAGE CHANGE IN YIELD			0	8.22	12.05	16.90	0	6.31	10.36	15.29

GAUB DAM YIELD

The same procedure as for the Donkersan Dam was followed for the Gaub Dam while using the Schlesien runoff record. The results obtained for the yields are presented in **TABLE 7.**

TABLE 7: YIELD REDUCTION AS A RESULT OF DECREASED RAINFALL AND INCREASED EVAPORATION FOR THE GAUB DAM

ASSUMPTIONS FOR STORAGE VOLUMES			YIELDS OBTAINED FROM THE STOCHASTIC RUNOFF RECORD							
FULL SUPPLY CAPACITY (Mm^3)	INITIAL STORAGE (Mm^3)	DEAD STORAGE (Mm^3)	80% SAFE YIELDS (Mm^3/a)				95% SAFE YIELDS (Mm^3/a)			
			RAINFALL REDUCTION FACTOR %				RAINFALL REDUCTION FACTOR %			
			0%	5%	10%	15%	0%	5%	10%	15%
50.00	0	2.50	14.820	13.610	13.025	12.305	10.400	9.540	9.170	8.670
TOTAL PERCENTAGE CHANGE IN YIELD			0	8.16	12.11	16.97	0	8.27	11.83	16.63

It should be noted that the above predictive calculations incorporate many arbitrarily assumptions, and that the results are in the first place to provide guidance for long term planning for sustainable management.

CONCLUSIONS

Generation of longer synthesized runoff records by rainfall/runoff modeling using negative serial correlation is necessary in Namibia.

The **NAMROM** model is run to obtain a regression equation, which is used to extend the observed runoff record. The model is rerun with the **NAMRED** program with reduced rainfall factors to produce reduced synthesized runoff records. With the use of the **RESSIM** program safe yields were calculated for the different runoff and rainfall files to determine the effect of reduce rainfall on the yields of two potential dams in the middle Kuiseb River.

The results presented indicate that the percentage reduction of runoff is higher than the percentage reduction in rainfall, because of the non-linear relation between rainfall and runoff. The reduction of runoff is consequently reflected in reduced yields as well.

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