CHAPTER 2 METEOROLOGY AND HYDROLOGY

2.1 Meteorology

2.1.1 Meteorological Network

Meteorological data of Namibia are collected and maintained by the Namibia Meteorological Service. They have six (6) well equipped offices (stations) scattered all over the country. Apart from these six offices, there are nine (9) first order stations managed by part-time observers. The locations of these stations are shown in the Fig. 2.1-1. Regarding rainfall stations, Namibia has about 250 stations functioning as present. All operated by the volunteers. It was reported that in the early 90s there were about 400 stations in the country. This decrease in number is due to the unavailability of volunteers. The rainfall is measured by a standard rain gauge supplied by the Department of Meteorological Services.

2.1.2 General Climate

Due to the geographical location, the climate of Namibia is classified as subtropical. The rainfall of the country is greatly influenced by the ocean currents, air circulation and topography. High-pressure system in the Ocean hinders the influx of moisture that supposes to occur the rainfall. As a result, most of the Namibian territory falls under semi-arid to arid zone. The annual rainfall varies from 50mm to 700mm. The evaporation is much higher than the rainfall. There are two distinct seasons; the rainy season starts in October and continue until end of April. However, most of the rainfall occurs between end of December and the middle of April. The average temperature is 25℃, the highest may rise up to 40℃ in the dry season and lowest could be below freezing point over most of the country during the winter.

Description of meteorological parameters such as, rainfall, temperature, wind speed, sunshine hours, evaporation and humidity are presented as follows.

1) Rainfall

Namibia is an arid country. Therefore, rainfall is very scarce. In order to know the rainfall pattern in the study area, especially over the river catchments (Nossob and Auob), 21 stations were selected for data collection. However, data of four stations had discrepancies and were not considered for analysis. The locations of the stations are shown in Fig. 2.1-2. The list of the stations is presented below.

i)	Otjisororindi	x)	Leonardville
ii)	Lorette	xi)	Gochas
iii)	Okuje	xii)	Owingi
iv)	Hofmeyr	xiii)	Kalkrand
v)	Aranos	xiv)	Mariental
vi)	Kous	xvi)	Stampriet
vii)	Olive	xvi)	Gochas
viii)	Kanonschoot	xvii)	Windhoek
ix)	Krumhuk		

With few exceptions, monthly data of latest 20 years were collected and analysed. Within this period highest annual rainfall was found to be 774mm in Owingi (1977-78), which is located in the upstream of the catchment. Rainfall is higher in the north and gradually decreases towards the south. The isohyetals of annual average rainfall are presented in Fig. 2.1-3. The study area approximately falls within the annual average rainfall area of 150 - 300mm.

2) Temperature

As Namibia is an arid to country, the maximum temperature may rise up to 40℃ in the southern part of the country. On the other hand, temperature may fall down below freezing during the winter months. Most of the study area has a maximum average temperature of 30℃ and minimum average temperature of 2℃. The averages of maximum and minimum temperature recorded at Windhoek, the capital is presented in Fig. 2.1-5.

3) Evaporation

The overall climatic conditions and long sunshine hours make evaporation rate is very high. The lowest value of annual Pan evaporation, which is about 2500 to 2600mm per year, is recorded in the northeastern part of the country. Extreme value is usually recorded in the south central part, which is about 3700mm per year. Yearly evaporation in the study area is over 3200mm per year. Department of Water Affairs (DWA) prepared a map showing annual evaporation rate from Class-A Pan along with rainfall isohyetes. The map also regionalized the country according to the amount of annual evaporation as shown in Fig. 2.1-4. It can be used as a handy tool for calculating monthly distribution of evaporation for a site of interest by multiplying the annual gross (of the region) with the percent-factor tabulated below.

Unit: %

Region*	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
A	12.0	9.5	8.3	7.8	7.4	8.3	7.6	7.2	6.2	7.0	8.6	10.1
B	11.3	10.9	11.3	10.3	7.9	7.3	6.6	6.1	5.9	5.4	7.5	9.5
C	8.8	9.6	10.1	10.1	8.6	9.2	8.0	7.5	6.6	6.8	7.0	7.7
D	10.0	11.4	12.5	12.2	9.6	8.6	6.7	5.4	4.6	5.0	6.1	7.9

Source: Water Affairs Department, * : Refer to Fig.2.1.4 on Page 2-7

Using the above factors and Pan evaporation data measured at Hardap dam site (70% of actual value), daily evaporation rate for the study area has been calculated and tabulated below. As the study area falls within the regions of B and D, factor that has been used in the calculation is an average of the two regions.

Unit: mm/day

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
8.7	9.4	9.7	9.2	7.9	6.5	5.6	4.5	4.4	4.2	5.5	7.3

4) Sunshine

Namibia enjoys a great deal of sunshine all over the country. In general, southern part has longer hours than the north. The average sunshine hours that Namibia enjoys may be calculated as 10 hrs/day. The study area has more sunshine hours than the national average. The longest and shortest sunshine hours at Mariental are measured 11.4 hours/day in December and 9.3 hours/day in March respectively.

Unit: hr/day

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
10.3	10.9	11.4	10.1	10.1	9.3	9.6	9.9	9.6	9.9	10.2	10.3

5) Wind Speed

Along the coast line wind is very high, especially south western part has higher speed than the central-east and north-west. Prevailing wind blows from the south or southwest. Average wind speed in the southwest is more than 10 m/sec. And higher is in the months of November through January. In Mariental, which is located in central eastern part of the study area and may represent the study area, has prevailing wind from southeast and the average speed through out the year is about 1m/sec. Daily wind speed measured at Mariental is tabulated below.

Unit: m/sec

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1.1	1.3	1.3	1.0	1.0	0.8	0.7	0.8	0.7	0.8	0.8	0.8

6) Relative Humidity

Humidity levels are monitored through monthly mean values and are very low throughout the year. Even during the rainy season, the mean monthly values very rarely exceed 70%. During the dry season the values are found to be around 30 percent. At the coast, humidity levels are high, above 80% throughout the year. Average monthly values of few selected stations are presented in the table below.

Unit: %

	O	N	D	J	F	M	A	M	J	J	A	S
Odangwa	31	41	45	58	62	66	58	44	41	36	31	45
Windhoek	22	28	30	39	47	51	44	35	34	29	22	30
Mariental	24	25	27	33	38	44	42	41	41	37	24	27
S. mund	88	88	90	89	89	90	90	82	78	81	88	90

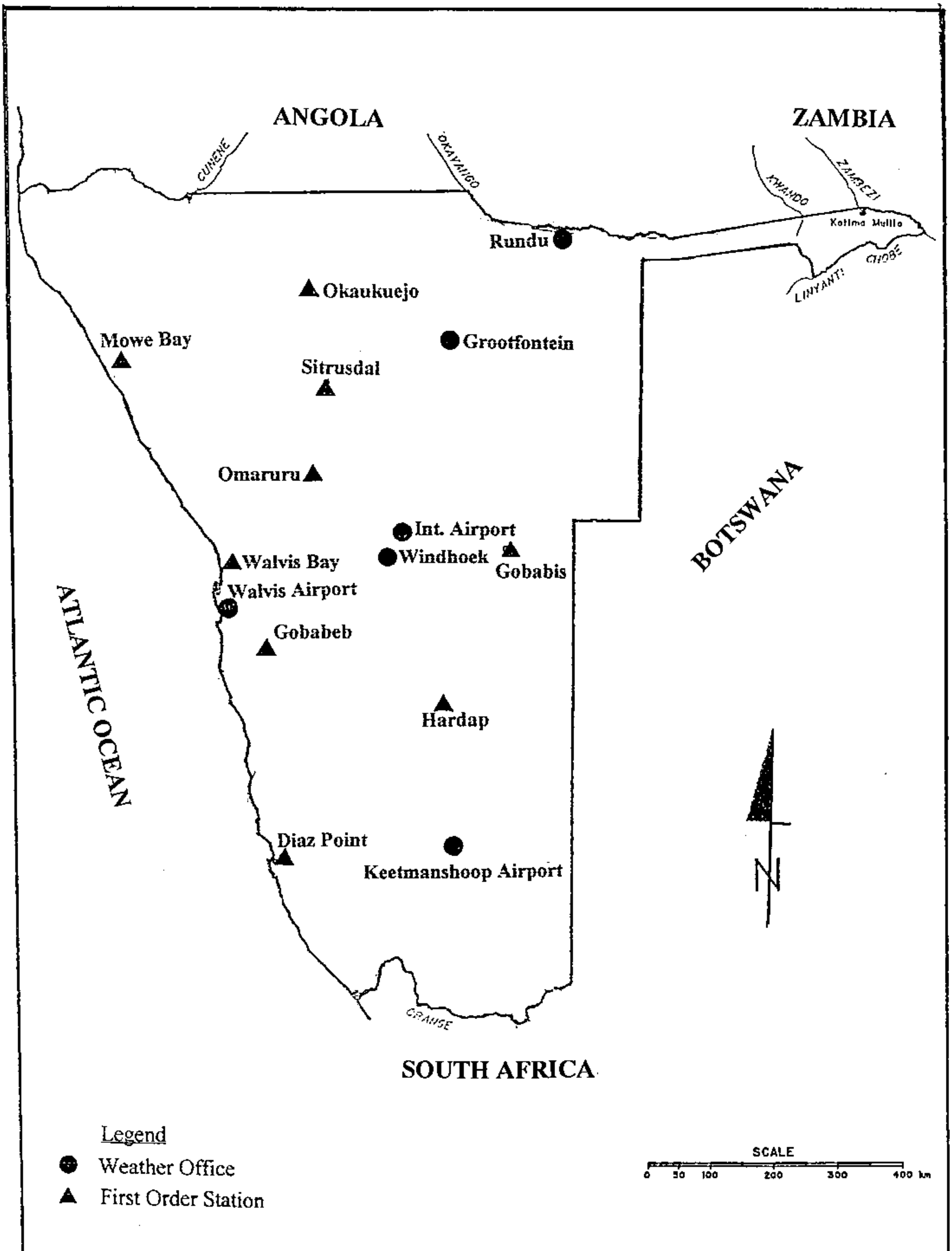


Fig. 2.1-1 Location of Meteorological Stations

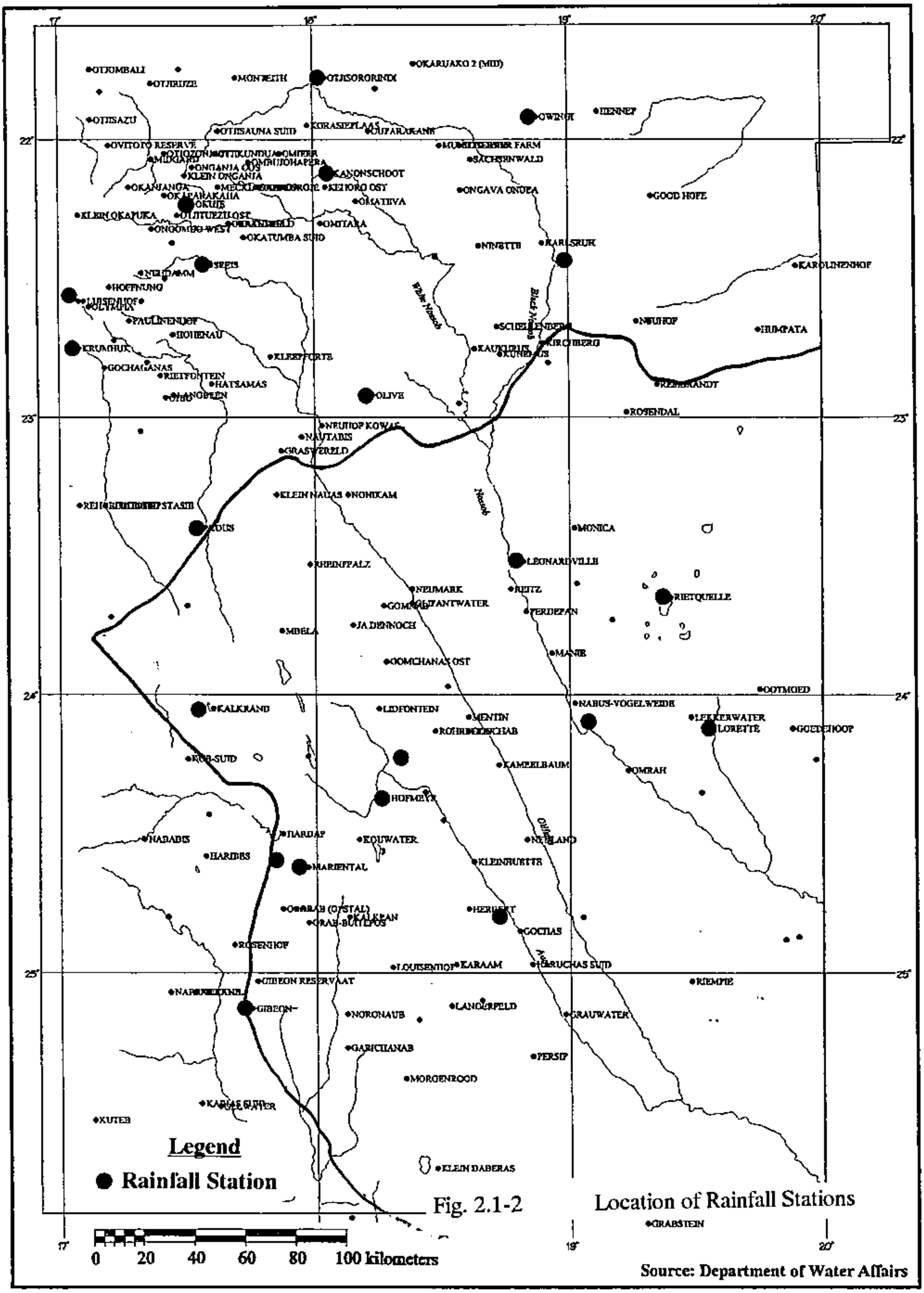


Fig. 2.1-2 Location of Rainfall Stations

Source: Department of Water Affairs

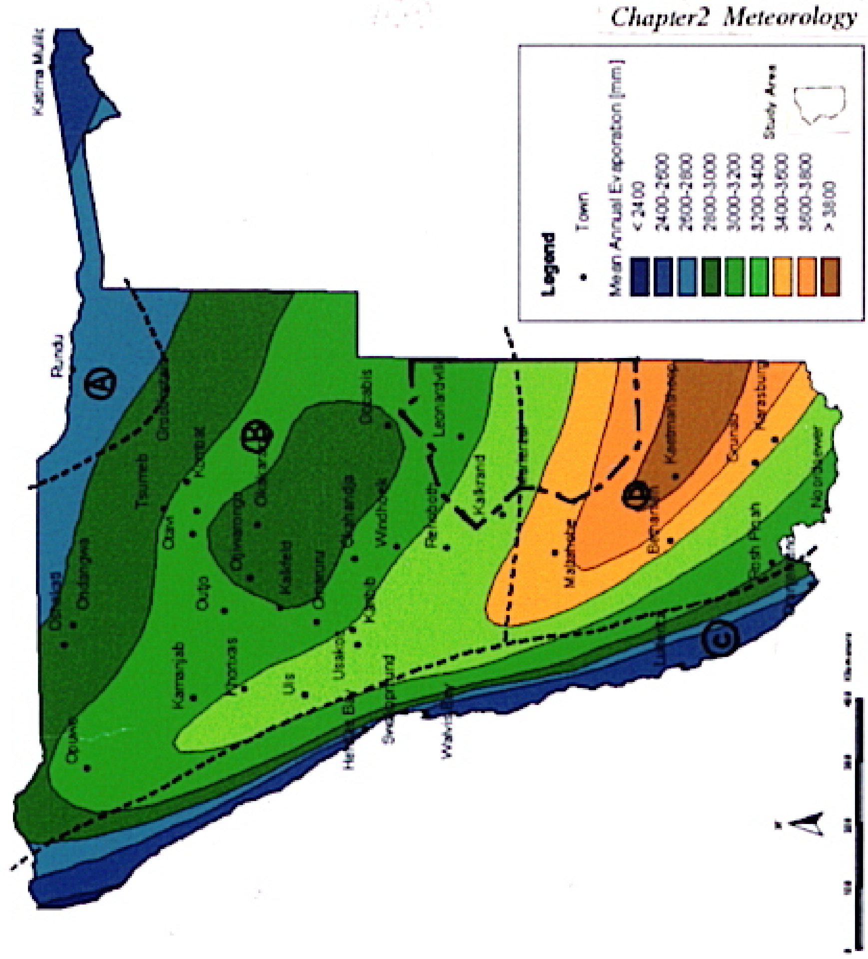


Fig. 2.1.4 Annual Evaporation

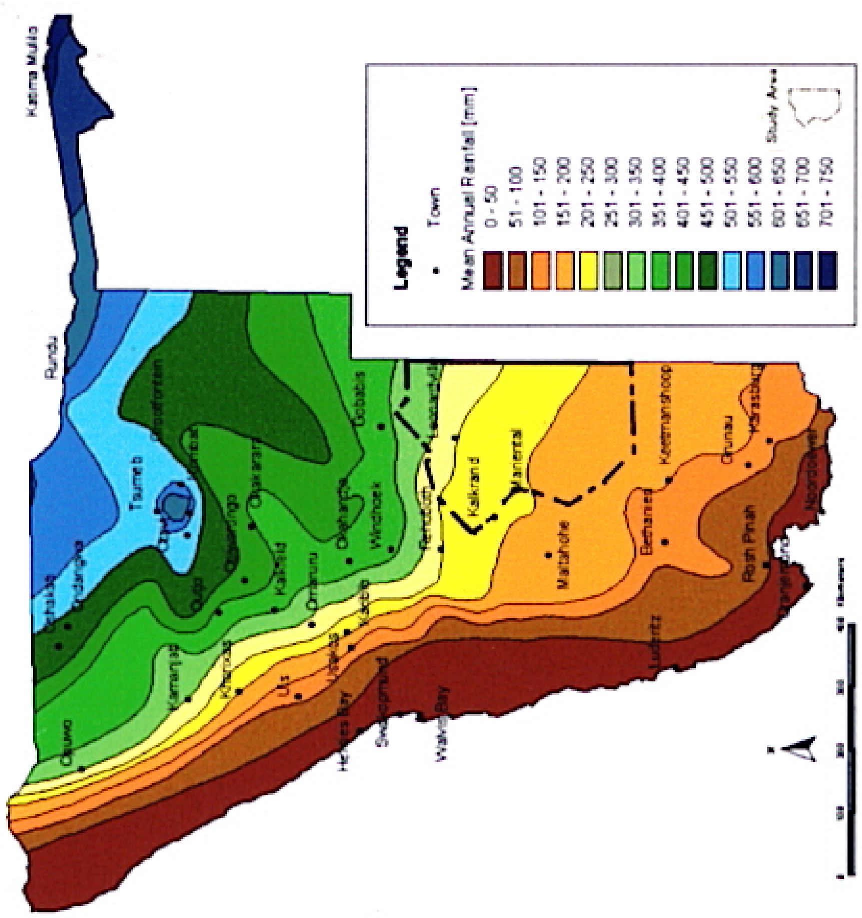


Fig. 2.1.3 Average Annual Rainfall

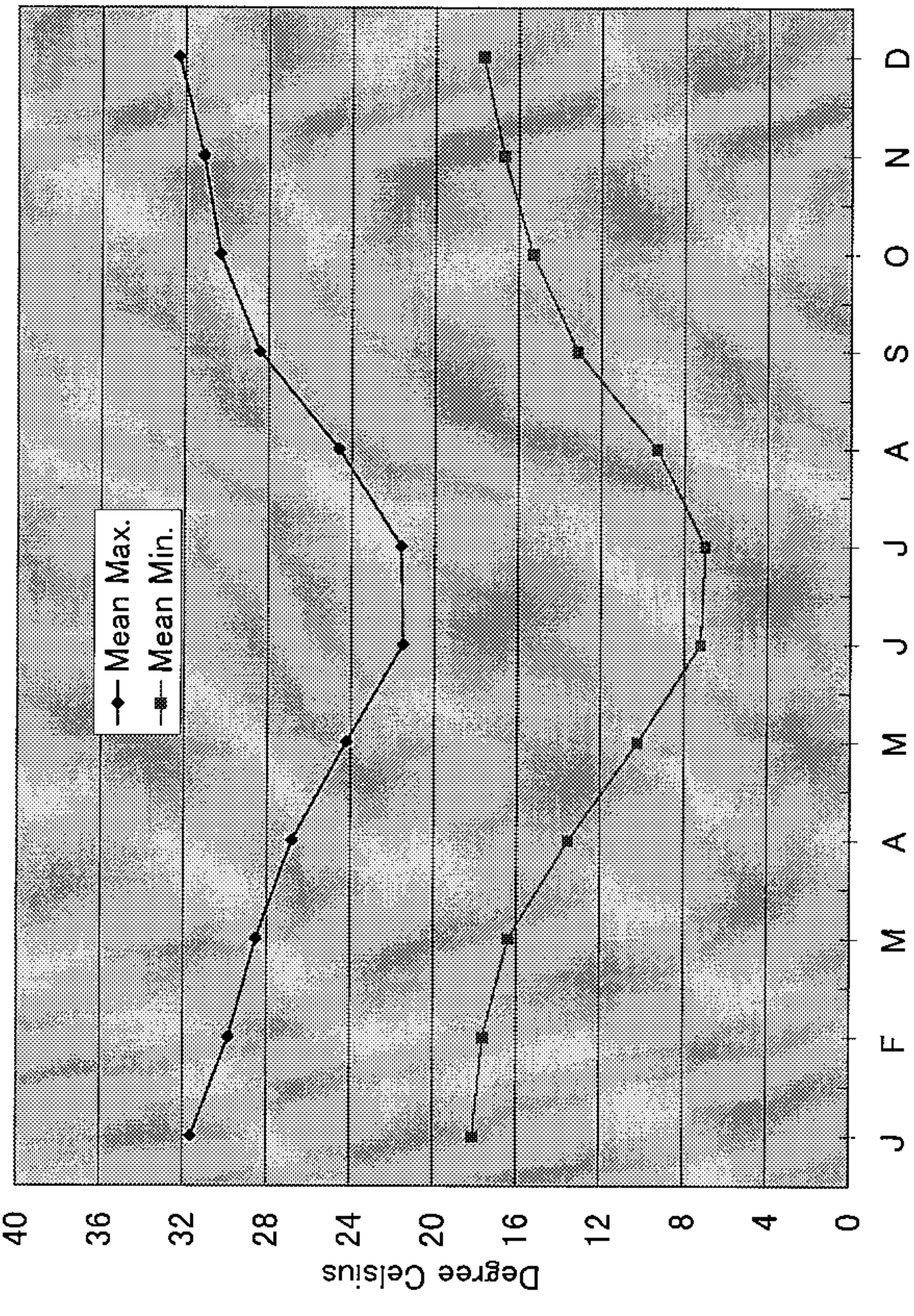


Fig. 2.1.5 Monthly Means of Maximum and Minimum Temperature

2.2 Hydrology

2.2.1 General

Except the international rivers such as the Kunene, the Okavango and the Zambezi in the northern border, and the Orange in the southern border, Namibia does not have any perennial river within its territory. The northern part of Namibia is blessed with some depressions where water may be found all year round. One of them, in fact the biggest one is Etosha Pan. Although all of the internal rivers are intermittent, notable ones are Eiseb, Nossob, Olifants/Auob, Fish, Omaruru, Swakop, Kuiseb and Omatako rivers. Depending on the rainfall amount these rivers can generate flush floods. There are as many as 18 dams constructed in the river systems of Namibia and these are used as irrigation, drinking and recharge purposes. Accumulated capacity of these dams is about 706 million m^3.

As a theoretical basis, it is believed that only 2% of the rainfall of the country is available as runoff. However, it does not mean that the whole country will have the same distribution of runoff. From the records and information it was found out that a central strip with an average width of 200km has a relatively high runoff potential. This is due to the presence of little or no topsoil, an underlying impermeable layer and mountainous terrain with moderate vegetation.

The remainder of the country has no potential to generate runoff due to the presence of sand dunes and or flat terrains covered by soils with a high water absorption capacity.

2.2.2 Drainage Systems

As it is mentioned earlier that the rivers within the Namibian territory are intermittent, however, during the rainy season all become active according to the amount of rainfall in the catchment. On the basis of the drainage pattern, the country has been divided into ten major drainage catchments as shown in Fig. 2.2-1. The main drainage catchments are as follows:

Catchment Name	Area (km^3)	Rivers	Direction of Drainage
Zambezi	924	Zambezi	To Indian Ocean
Kwando	15,525	Kwando	To Zambezi
Okavango	89,484	Okavango	To Botswana
		Cuito	
		Omatako	
Etosha	103,369	Distributaries of Kunene	To Etosha Pan
Kunene	14,327	Kunene	To Atlantic Ocean
North Coast	186,430	Nadas	To Atlantic Ocean
		Khumib	
		Hoarusib	
		Unjab	
		Koichab	
		Huab	
		Ugab	
		Omaruru	
		Khan	
		Kuiseb	
South and Central Namib	80,436	Tsondab	
		Tsauchab	
		Koichab	
Fish and Other River	121,665	Fish	To Orange
		Lowen	
Nossob-Auob	124,131	Nossob	To Molopo
		Olifants	
		Auob	
NE part	8,8139	Otjozondjou	To Botswana
		Eisab	
		Epukiro	

2.2.3 Study Area Related Rivers

1) River Catchments

The Stampriet Artesian Basin is situated within the catchments of the Nossob-Auob Rivers. The rivers are ephemeral and only flow for short periods during the rainy season. Both of the rivers originate northeast of Windhoek, within the Khomas Region, a highland savannah with an elevation of about 2,000m ASL.

The upper part of the Nossob River has two tributaries namely, the Black Nossob and the White Nossob. Both of these tributaries flow eastwardly from their origin and then turn in a southerly direction. They merge at a point approximately 20km north of Leonardville in Gobabis District of the Omaheke Region. Another tributary of the Nossob, the Klein Nossob joins the Nossob at a point about 10km before the Nossob crosses the Namibian border with Botswana. The Nossob also merges with the Auob in Botswana and continues as the Molopo River. The catchment area of Nossob within Namibia is 50,050 km^2.

The Auob River originates northwest of Stampriet at an elevation of about 1,200 mASL. This area is also known as southern Kalahari where the vegetation consists of mixed tree and shrub savannah. On the other hand, the main tributary, the Olifants originates in the highland savannah southeast of Windhoek and meets the Auob in the southeastern corner of the Mariental District, approximately 40km from the border with Botswana. The catchment area of the Auob River within Namibia is 74,081 km^2.

Both catchments, operational runoff gauging stations and rainfall stations considered for the average basin rainfall calculations are shown in Fig. 2.2-2.

2) Network

There are seven runoff measurement stations in the rivers of the study area. Flow measurements commenced in the 1970s. Two of the stations are not functional at present. The measurements are recorded with automatic recorders. The charts are collected three times in a year and processed to determine the discharge. The names of the runoff gauging stations are as follows:

Item	River/Station Name	Type	Year Established
1	Black Nossob at Henopsrus	Weir	1970
2	Black Nossob at Mentz	Weir	1973
3	White Nossob at Amasib	Weir	1973
4	Auob at Stampriet	Open Section	1977
5	Auob at Gochas	Open Section	1973

3) Evaluation of Runoff Data

Namibia is an arid country. Therefore, rainfall is very scarce and only occurs during the months of October through April. The average rainfall within the study area ranges between 150 ~ 300mm per year. The runoff of the rivers is, therefore, seasonal, erratic and very low. A general evaluation of the collected data is presented below.

(1) Henopsrus

Data were available for the period from 19778-79 to 1997-98. Three hydrological years (80-81, 84-85 and 89-90) did not have any runoff. Data of four hydrological years (90-91, 91-92, 92-93 and 97-98) have many missing or lost data particularly for the months of January, February and March. Therefore, the available data that can be used for analysis is for about 10 rainy seasons.

(2) Mentz

In case of Mentz, data for 24 years (1973-74 to 1996-97) were available. However, no runoff was observed for two hydrological years, i.e. 89-90 and 94-95. The data of seven hydrological years were lost/estimated and is treated as incomplete. Therefore, the data of 15 years were taken into consideration.

(3) Amasib

For Amasib, data of 16 years were available. However, among them six years have lost/estimated data and is treated as incomplete. Therefore, data of a 10 year period will be considered for analysis.

(4) Stampriet

For Stampriet, data for 20 hydrological years (1977-78 to 1996-97) were available. No data was recorded in 1989-90. There are years where data were estimated or accumulated. The years under this category are eight. Therefore, data of 11 years have been used for the analysis.

(5) Gochas

For Gochas, data for 23 years (1973-74 to 1995-96) were available. A review showed that data for three hydrological years have been lost. Data for five hydrological years have been estimated or accumulated. Therefore, data of 15 years have been considered for analysis.

4) Observed Runoff

On the basis of the above evaluation, the observed runoff was reviewed and an annual average was calculated. The average was then expressed in terms of runoff depth.

Name of Station	Name of River	Catchment Area (km^2)	Annual Average Runoff (m^3)	Runoff Depth/ Unit Runoff (mm)
Henopsrus (10 years data)	Black Nossob	4,530	2,459,000	0.54
Mentz (15 years data)	Black Nossob	8,160	1,689,000	0.21
Amasib (11 years data)	White Nossob	9,250	2,165,000	0.23
Stampriet (11 years data)	Auob	19,200	4,646,000	0.24
Gochas (15 years data)	Auob	19,600	9,249,000	0.47

The values of runoff depth/unit runoff are very small. For an arid region, one may take these values as normal. However, it should be noted that the calculation is based on the annual average, which can vary considerably over the numbers of years taken into consideration and whether extreme values were included or excluded.

In this particular case, the catchment area covered by one measuring station is very large. Therefore, the recorded data has a very small chance of being representative of the whole basin.

5) Runoff-coefficient

The unit runoff and the runoff coefficient are the two parameters that can be used to determine the relationship between rainfall and runoff. From the review of the "Unit Runoff Map of Namibia" by DWA, one can easily understand that the value of the unit runoff is very small, mainly due to the fact that the observed runoff value is also very small. Moreover, the unit runoff is based on the annual average. Therefore, in order to know the relationship between rainfall and runoff, some sets of daily rainfall and corresponding runoff data have been analysed. For this purpose two gauging stations were selected i.e. Henopsrus for the Nossob, and Stampriet for the Auob.

The characteristics of the Henopsrus station are as follows.

River name = Black Nossob

Area covered = 4,530 km^2

Rainfall stations = Owingi and Otjisorindi

Type of section = Weir

Although there is quite a long period (19 years) of runoff data, the relationship between runoff and rainfall data was not found in many years. Therefore, only two hydrological years with good rainfall and runoff sets have been selected for consideration i.e. the 1985-86 and 1988-89 years.

In 1985-86, runoff was only observed in the months of January and February. In January, runoff was observed on the 29th day amounting only 2,650 m^3. On the other hand, in the same month, there were 10 rainy days totalling 116mm recorded at Owingi station and in the Otjisorindi, it was 11 days totalling 98mm. With this rainfall pattern the amount of observed runoff was very small and made it difficult to establish a relationship. Therefore this set of data was not considered.

In February there was another block of rainy days with corresponding runoff and using this set of data a relationship is calculated as shown below as Case-1.

Case-1

Year	Month/ Date	Observed Runoff ($x10^3$ m^3)	Rainfall (Owingi) (mm)	Rainfall (O.Rindi) (mm)	Average Rainfall (mm)	Runoff Coefficient
1985-86	Feb-3	0.54	-	5.0		
	Feb-4	-	-	-		
	Feb-5	-	-	13.5		
	Feb-6	-	25.0	3.0		
	Feb-7	0.30	19.5	6.5		
	Feb-8	120.5	-	1.0		
	Feb-9	1.21	-	-		
Total		**122.55**			**36.8**	**0.00073**

During 1988-89, there was another block of rainy days covering January and February with corresponding runoff. Relationship between them is attempted in Case-2.

Case-2

Year	Month/ Date	Observed Runoff (x 10^3 m^3)	Rainfall (Owingi) (mm)	Rainfall (O.Rindi) (mm)	Average Rainfall (mm)	Runoff Coefficient
1988-89	Jan -28	-	41.5			
	Jan -29	-		-		
	Jan -30	-	-	18.5		
	Jan -31	11.6	51.0	31.3		
	Feb-01	3.62	10.5	13.0		
	Feb-02	-	-	-		
	Feb-03	-	-	21.0		
	Feb-04	-	15.5	-		
	Feb-05	-	-	65.0		
	Feb-06	11.62	-	16.0		
	Feb-07	24.17	-	-		
	Feb-08	-	-	-		
	Feb-09	10.28	34.5	19.0		
	Feb-10	7.6	17.5	-		
	Feb-11	-	-	-		
	Feb-12	0.4	-	-		
	Feb-13	86.9	-	-		
	Feb-14	22.24	-	-		
Total		**178.43**			**177.2**	**0.00022**

In the calculation procedure, first, for a particular event, the total amount of runoff for the corresponding rainfall was calculated and then average basin rainfall was determined (for example 37 mm in case-1 and 177 mm for case-2). In the second step, using this average rainfall, runoff without any loss has been calculated. The ratio between the observed runoff and the runoff without loss is termed here as runoff coefficient. An example of calculation is presented below.

Case-1

Total observed runoff = 122,550 m^3
Average rainfall = 0.037m
Runoff without loss = 0.037m x Catchment Area (km^2)
= 0.037 x 4,530 = 167,610,000 m^3
Runoff coefficient = 122,550/167,610,000 = **0.00073**

In the same manner, two cases for Stampriet were also calculated. The hydrological years that were considered are 1983-84 (Case-1) and 1990-91 (Case-2).

The characteristics of the Stampriet station are as follows:

River name = Auob
Area covered = 19,200 km^2
Rainfall stations = Hofmeyr, Kous, Krumhuk and Stampriet
Type of section = Open section

In Case-1, three events of runoff with corresponding rainfall were considered. The first event is from December 02 to December 12, the second event is from December 25 to January 04 and the third event is from March 20 to April 21. The calculated averages rainfall for these events are 20, 47 and 65 mm respectively.

For Case-2, the two events were considered. The calculated average rainfall was found to be 36 and 49 mm respectively.

The calculated coefficients varied from 0.0004 to 0.0487 as shown below.

Year	Period	Observed Runoff (x 10^3 m^3)	Average Rainfall (mm)	Runoff Coefficient
Case-1 (1983-84)	Dec 02～12 Dec 25～Jan 04 Mar 20～Apr 21	141.8 43,950.0 4,021.0	20.0 47.0 65.0	0.0004 0.0487 0.0032
Case-2 (1990-91)	Dec 01～11 Mar 15～15	553.7 944.8	36.0 49.0	0.0008 0.0010

It was anticipated that the above mentioned calculation procedure considering daily rainfall and runoff may produce a reasonable result and would be helpful for further analyses. The difficulty in this calculation procedure is how to select the average basin rainfall, where the basin is so wide. A small increase in rainfall would give a reciprocal small coefficient. Therefore, the calculated coefficient is so small that cannot be used as a representative one.

6) Review of 1999-2000 Rainfall and Runoff Data

A review of rainfall records revealed that the 1999-2000 hydrological year had an abnormally high rainfall over most of the country. This abnormally high rainfall caused huge amount of runoff in the rivers of the study area and it is believed that an unprecedented amounts of recharge occurred during this period. In some places, the piezometric heads rose up to 8m in several boreholes.

Although the year was a very important from a hydrogeological viewpoint, published research works were not available at this stage.

Monthly rainfall data for January and February were collected from the daily newspaper and daily rainfall for 1999-2000 hydrological year of some selected stations were collected from the Weather Bureau. A review showed that there was a wide discrepancy in the data of these two sources. After contacting the newspaper, data of the Weather Bureau was considered for analysis. It was found that most of the stations had very high amount of rainfall during the months of January, February and March. In some stations, January and February had more rainfall than February and March. In any case, almost all of the stations had much higher rainfall in only two months than their annual average.

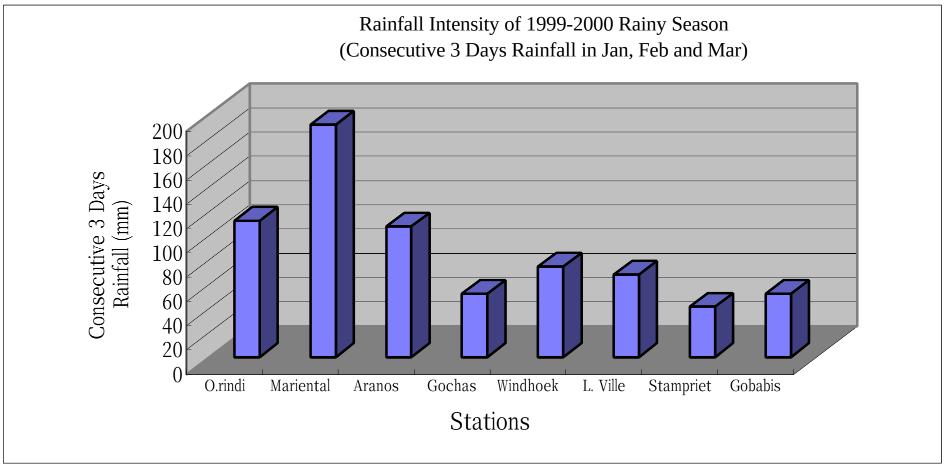
A field trip was made to find out more about this unprecedented event of rainfall. Interviewing farmers in the Mariental, Gochas, Stampriet, Aranos and Gobabis areas, it was learnt that Mariental has been badly affected by the event. Daily maximum rainfall was recorded as 94.5mm on the 18th of February. A total of consecutive four days (Feb 17 to 20) rainfall was recorded as 266mm, which is about 49% of seasonal total. This has caused severe flooding in the area for few days. In other places the damage was not significant.

The monthly rainfall (February and March) data of some selected stations in and around the area are presented below.

Station	Monthly Rainfall (mm)		Total (mm)	Annual Average (mm)
	February	March		
Stampriet	156.0	58.0	214.0	205
Leonardville	173.4	61.0	234.4	255
Gobabis	130.6	31.0	161.6	365
Aranos	224.5	41.0	265.5	230
Gochas	198.6	67.1	265.7	195
Mariental	349.6	106.3	445.9	198
Kalkrand	105.0	90.8	195.8	210
Otjisorindi	203.0	150.0	353.0	410
Windhoek	202.7	154.2	356.9	355

Note: Annual average has been estimated with Fig.2.1-3.

A graphical presentation of intensity of rainfall (consecutive 3 days rainfall) of eight selected stations surrounding the study area is presented below.



Runoff data of Gochas and Stampriet for the period of October through mid-January were available. Review of data revealed that October-November did not have any runoff. In December, Gochas had about 18,880 m^3 of runoff, whereas Stampriet had 430,300 m^3. When more discharge data are available, an attempt could be made to check the rainfall runoff relationship for this unusual event of rainfall.

7) Probability of Annual Rainfall

Although rainfall is scarce in the study area, in order to know the probable maximum annual rainfall, an analysis for few selected stations were performed. The results are as follows.

Unit: mm

Return Period (Year)	Station Name				
	Mariental	**Stampriet**	**Leonardville**	**Aranos**	**Gochas**
2	172	142	224	192	166
5	249	218	315	302	238
10	295	272	379	371	283
20	337	325	443	435	326
50	389	396	430	517	381
100	426	452	598	577	421