Plate 2 Sub-zone AS1 Soil Profile

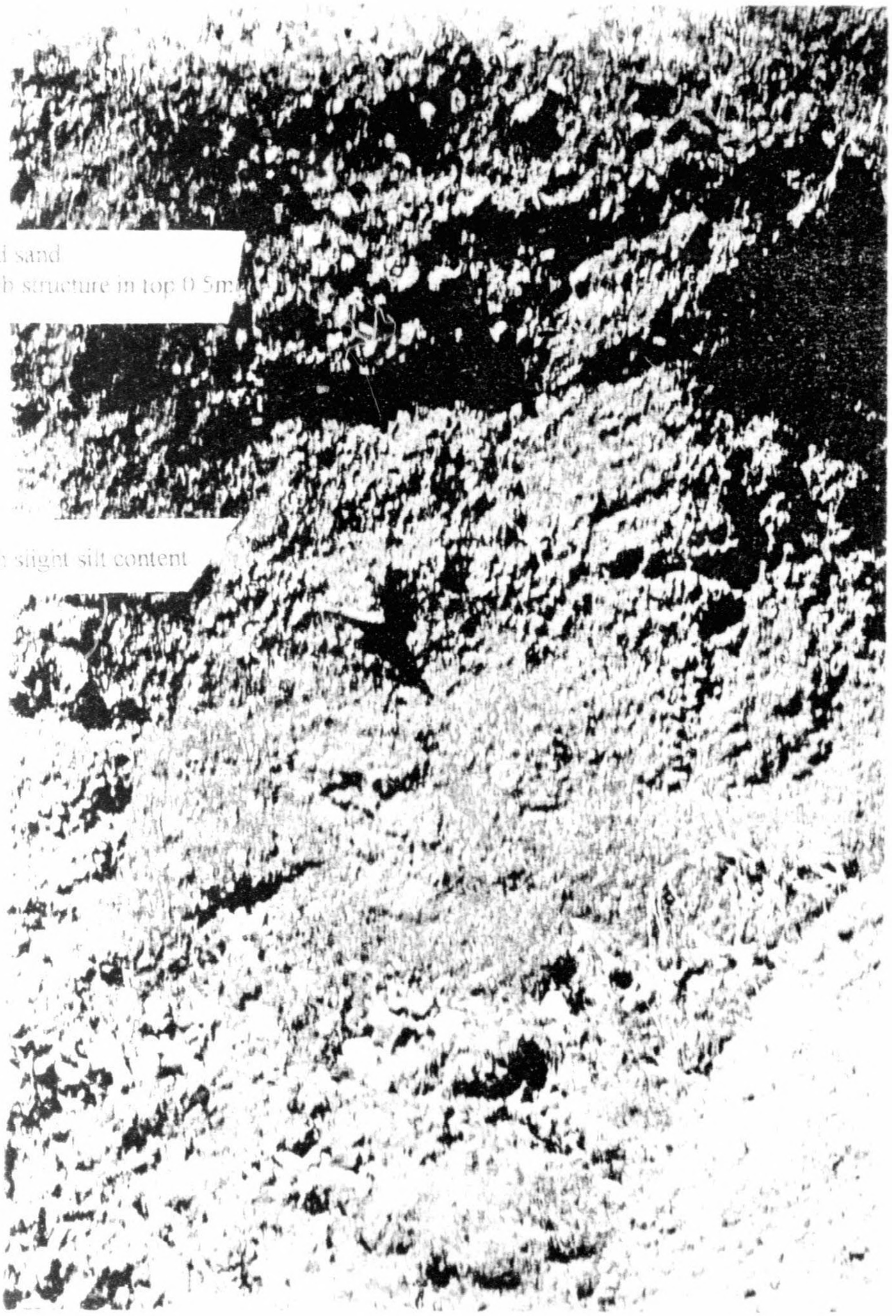


Plate 3 Sub-zone AS1 Kana River Basin

Sub-zone AS1

The relative position of this sub-zone is shown in Figure 2. The terrain is rather flat with a general slope to the Kana river valley. Figure 4 shows some of the topographic features. The vegetation cover can be described as woody grassland with a canopy cover of between 2% and 20%. The most common tree species is the Mopane tree. Another commonly associated species is *Brachystegia Speciformis*. The land use and vegetation cover are shown in figure 4.1.

Plate 1 shows the change in slope and details of the vegetation in the sub-zone. Plate 2 shows the soil profile at one location in the sub-zone. Coarse sand and gravel occupies most of the profile, but the top layer is much looser than the lower layers and it contains some organic matter. According to Anderson *et al* (1993) there are two predominant land classification units in this sub-zone referred to as K1 and KM1. Plate 1 shows a typical profile in land unit K1. This soil profile shows very little variation either chemically or physically. Clearing of vegetation in areas with this profile can lead to sheet erosion under high intensity rainfall. Land unit KM1 is prevalent within 2 to 5km either side of the Kana river. They consist of moderately deep coarse-grained sands with proportion of fine particles reaching 14% by weight on average. Relatively impermeable horizons may occur with depth. Erosion is locally severe with gully development in some areas. The predominant tree species is the Mopane [Anderson *et al* 1993].

A rural community occupies this sub-zone. It is in one of the driest parts of the country and it is in a low-lying area which is typically hot. There is limited crop production because of the low rainfall received. A few dams provide water for irrigated cropping. Where there is no irrigation most people keep cattle and goats.

Plate 3 shows the Kana river bed. The whole bed is covered with clean sand which could indicate that most of the catchment is sandy.

The location of runoff observation station used for this study is indicated on Figure 4.

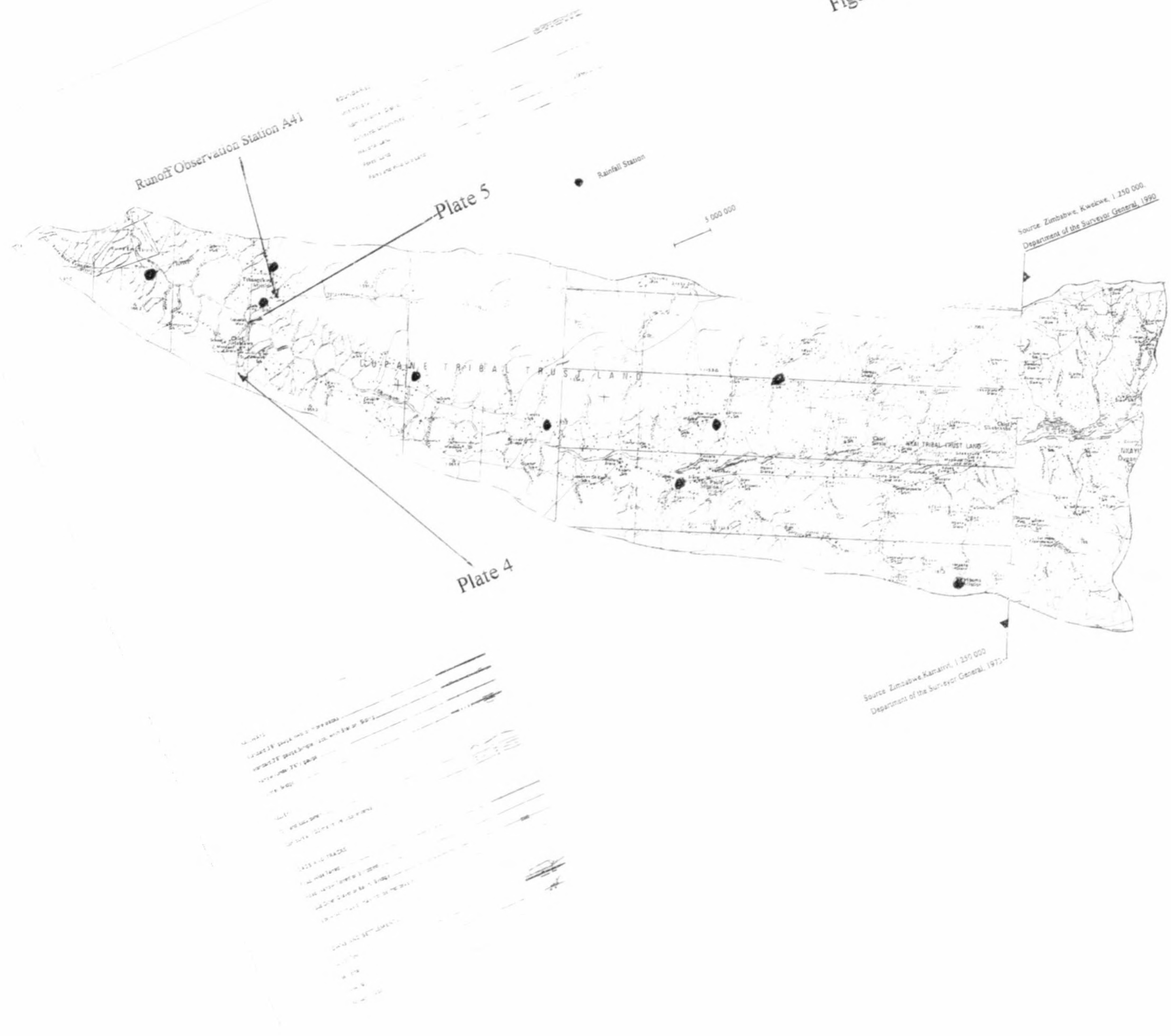


Figure 5 Sub-zone AS2 Topographic Features

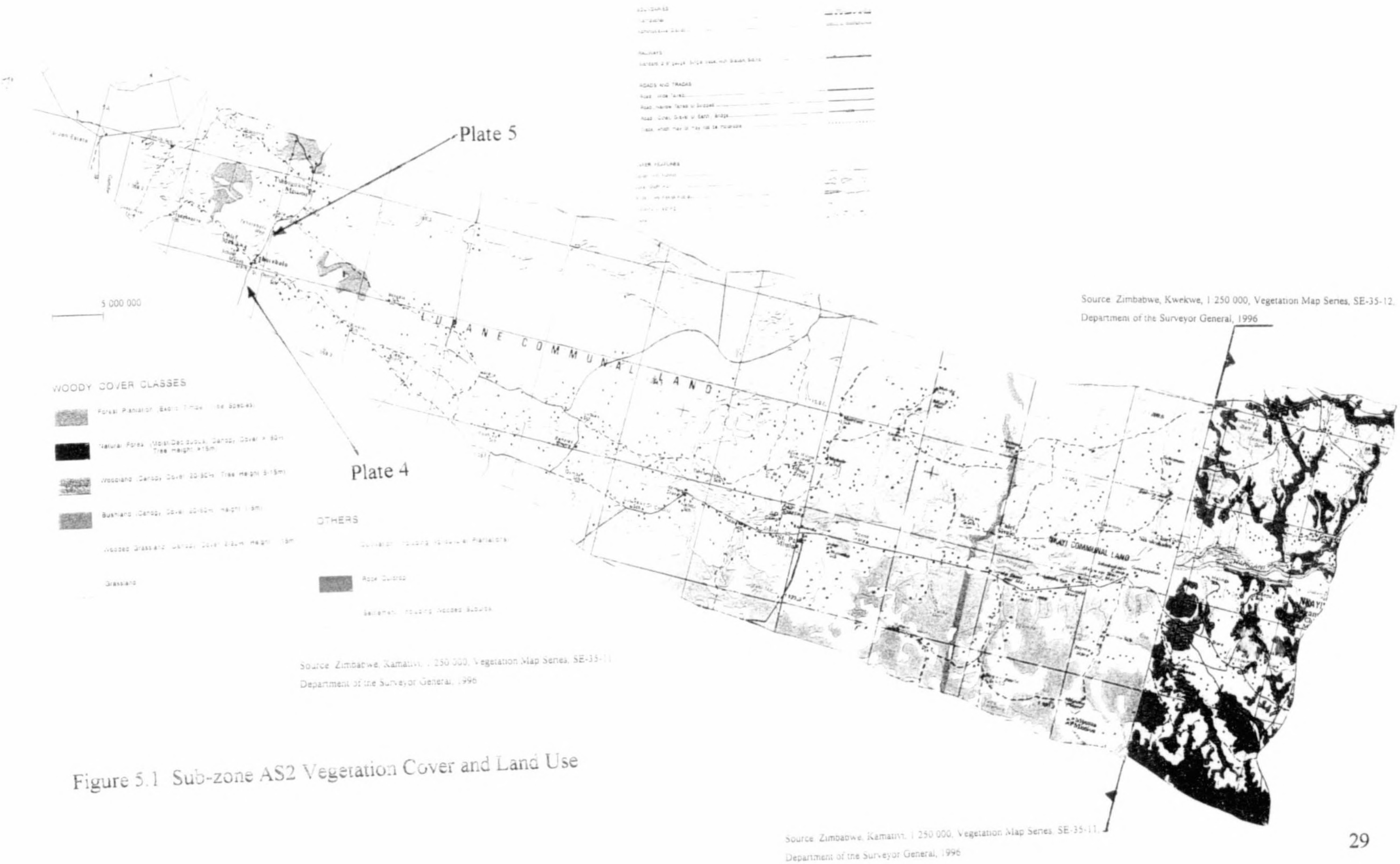


Figure 5.1 Sub-zone AS2 Vegetation Cover and Land Use

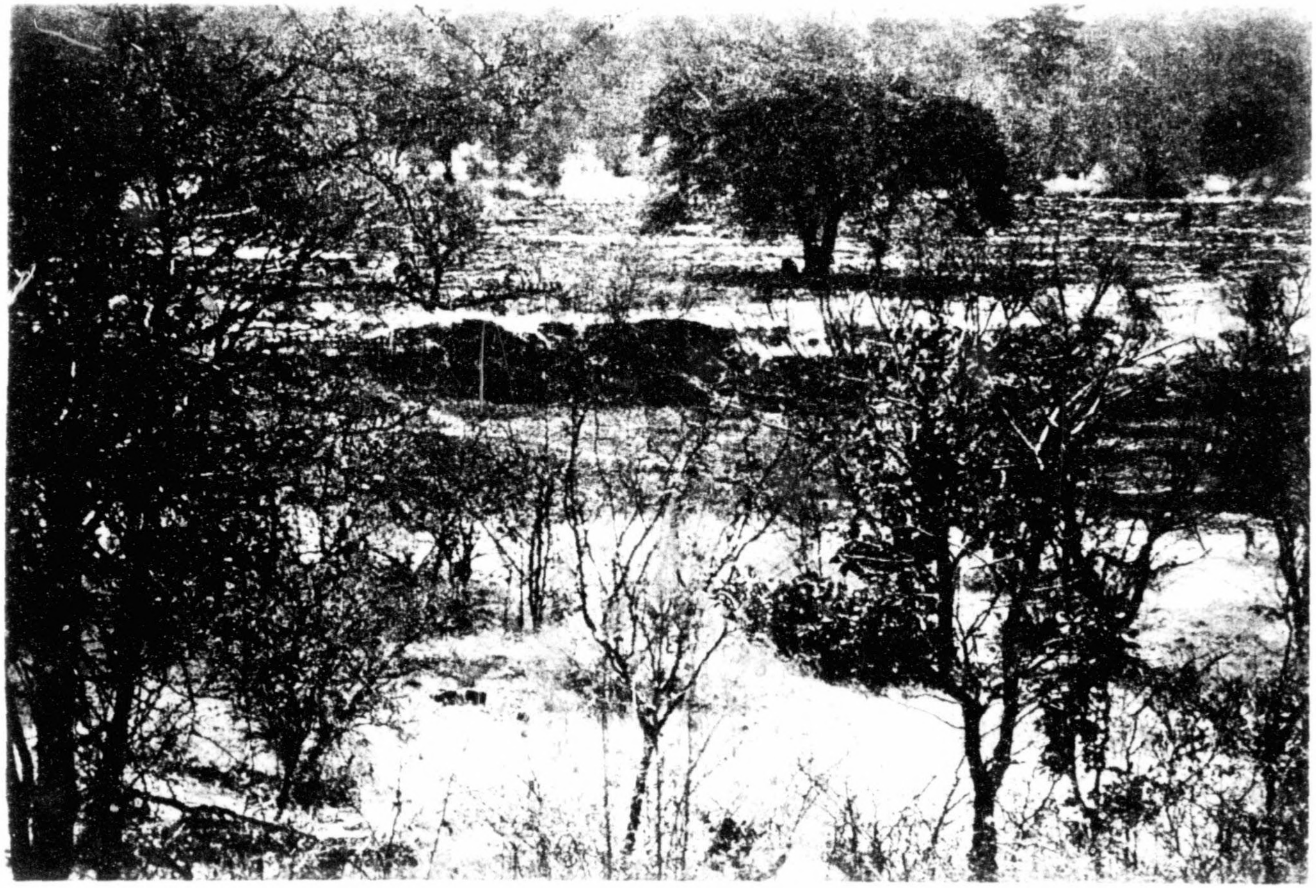


Plate 4 Sub-zone [illegible] Vegetation Cover and Land Use

Sub-zone AS2

This is adjacent to sub-zone AS1 as shown in Figure 2. The land slopes rather sharply into the Shangani river valley from the south but from the north the slopes are more gentle. The vegetation in the sub-zone is both wooded grassland and bush-land as shown in Figure 5.1.

The canopy cover is between 2% and 20% in the west and between 20% and 80% in the east. The bush-land, which is mainly in the west, has a canopy cover of between 20% and 80% but in some parts it has been harvested off without replacement. Anderson *et al* (1993) shows that there are four predominant land units described as K1, KM1 and M7 and M9. Land units K1 and KM1 have already been described under sub-zone AS1. Land unit M7 is variable owing to lateral changes in lithology of Karoo sediments and cycles of erosion and deposition. Land unit M9 is predominantly sandy with less than 20% clay by weight. According to Anderson *et al* (1993) 35% of the soils in this land unit are coarse grained. As in sub-zone AS1 there is limited crop production, most people keep cattle and goats. Plate 4 shows the vegetation cover and cultivated land.

The location of runoff observation station used for this study is indicated on Figure 5. Plate 5 shows the Shangani river bed at the location indicated in Figure 5.1. It is composed of rock but further downstream there is some evidence of flow. This could be coming in from beneath this rock.

Sub-zone AS3

This sub-zone joins the eastern parts of sub-zones AS1 and AS2 as shown in Figure 2.Its northern part is occupied by communal farmers while most of the south is both large and small scale commercial farmland. The city of Gweru occupies the south eastern tip of this sub-zone. Most of the land in the commercial farms is used for cattle ranching and limited crop production. The communal land there is both cattle keeping and crop production. The land demarcations are shown in Figure 6. The runoff observation station used for this study is indicated on the same figure.

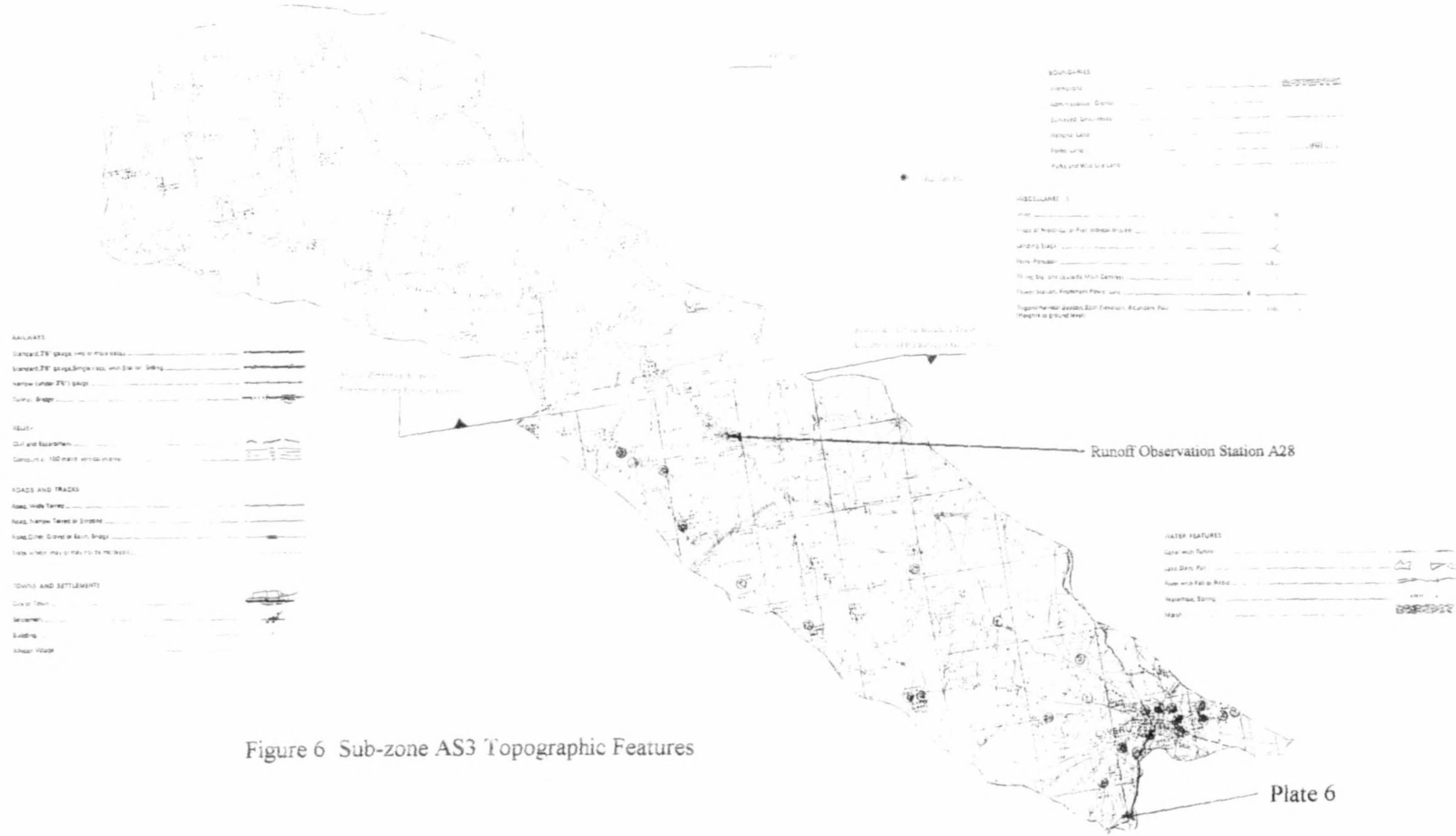


Figure 6 Sub-zone AS3 Topographic Features

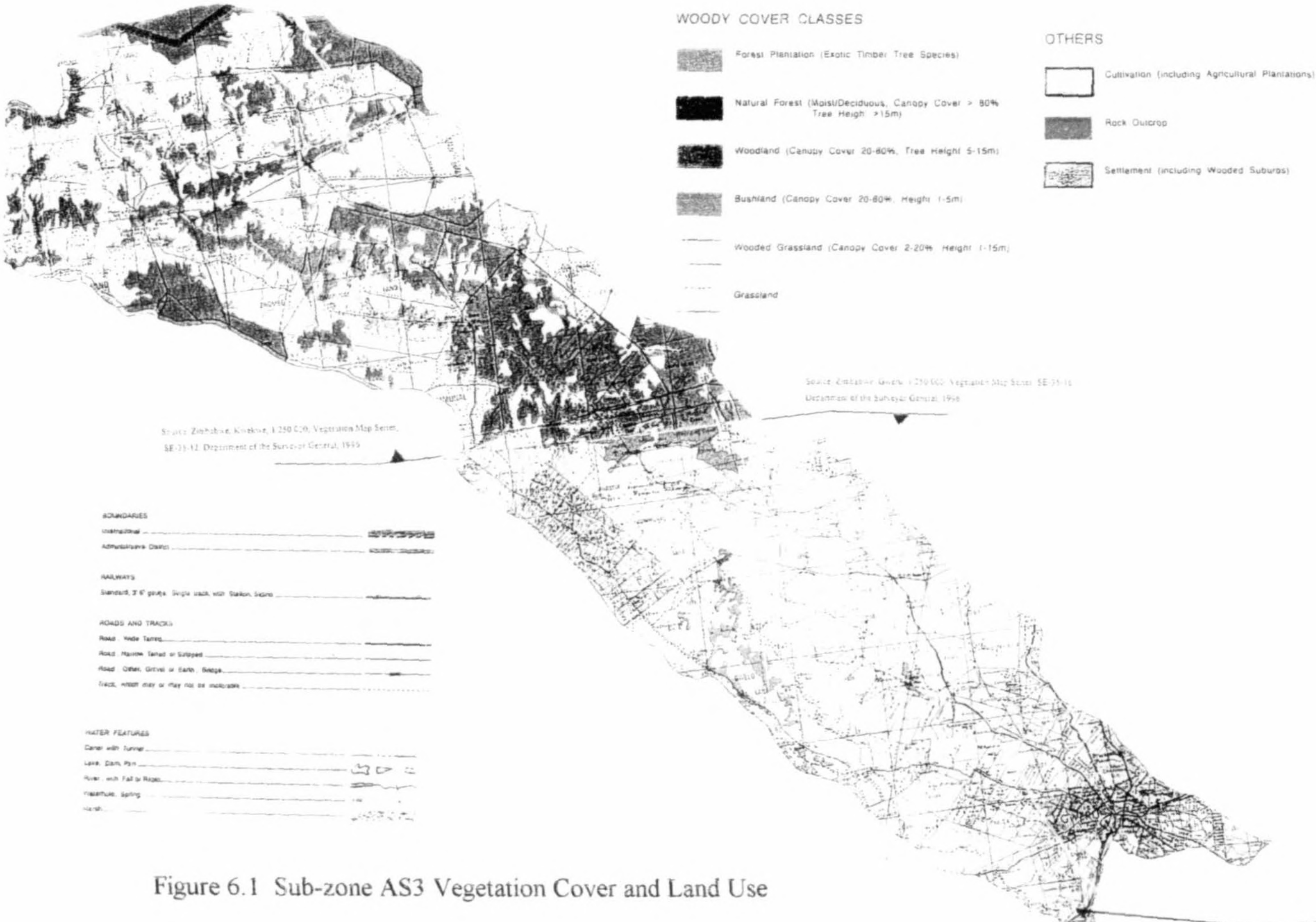


Figure 6.1 Sub-zone AS3 Vegetation Cover and Land Use

Plate 6

Plate 6 Sub-zone AS3 Vegetation Cover

Figure 6.1 shows the vegetation and land use patterns. According to Anderson *et al* (1993) most of the communal lands in this sub-zone fall into two land units namely KM1 and G6. KM1 has already been described under sub-zone AS1. Land unit G6 consists of shallow sands poorly drained in some areas. Much of this land unit is affected by severe sheet erosion [Anderson *et al* 1993].

Most of the southern part up to the middle is grassland. The typical appearance of this grassland is shown in Plate 6. From the picture the soil is generally sandy and the terrain has a very gentle slope. In the middle of the sub-zone there is a large area of bushland with a canopy cover of between 20 and 80%. The middle to northern half is both woodland and cultivated land.

Sub-zone AS5

This sub-zone is to the west of and adjacent to sub-zone AS3 as shown in Figure 2. It is divided into communal land, small and large-scale commercial land as in sub-zone AS3. This is shown in Figure 7.

According to Anderson *et al* (1993) most of the communal lands fall into two land units namely KM1 and G6. KM1 has already been described under sub-zone AS1. Land unit G6 has been described under sub-zone AS3.

Most of the land is divided into grassland, woodland, bushland and cultivated land as shown in figure 7.1. Plate 7 shows the typical grassland cover in the commercial farming areas of this sub-zone. Some trees are also noticeable in the background.

The location of the runoff station used in this study is indicated in Figure 7.

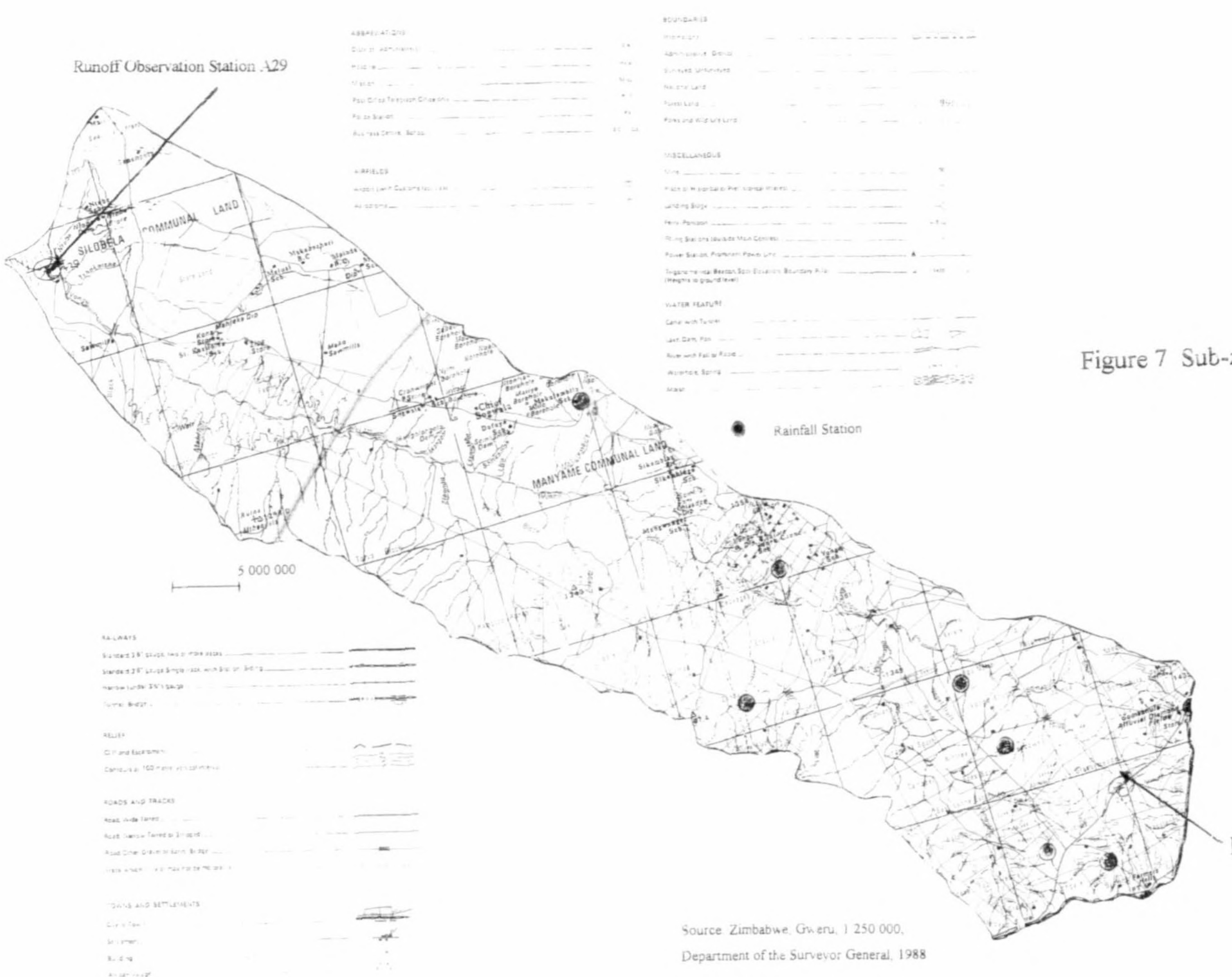


Figure 7 Sub-zone AS5 Topographic Features

Source: Zimbabwe, Gweru, 1:250 000, Department of the Surveyor General, 1988

Source: Zimbabwe, Gweru, 1:250 000 Vegetation Map Series, SE-35-16, Department of the Surveyor General, 1996

Figure 7.1 Sub-zone AS5 Vegetation Cover and Land Use

Plate 7 Sub-zone AS5 Vegetation Cover

Sub-zone AS6

This sub-zone is to the west of and adjacent to sub-zone AS5 as shown in Figure 2. It is composed mainly of large scale commercial farms as shown in Figure 8. The land cover consists mainly of bushland and grassland a few pockets of cultivated land as shown in figure 8.1. The main activity is cattle ranching. Plate 8 shows typical grass cover and terrain. The terrain is generally gently slopping. The runoff observation station used for the study is shown in Figure 8.

3.3 Selection of Rainfall Stations

The MET department maintains that of the 2500 rainfall stations in the country only 41 have reliable record: 12 in zone A, 9 in Zone B, 10 in Zone C, 4 in Zone D, 4 in Zone E and 2 in Zone F. These are shown as dots in Figure 9 on the rain-days map. For each selected sub-zone the nearest reliable rainfall station was selected. Table 3.1 shows the nine stations. Each sub-zone was allocated the nearest reliable rainfall station as shown. Out of these nine rainfall stations only data for the four was actually available from MET namely Lupane, Gweru Thornhill, Kezi and Filabusi. Details of the four rainfall stations are shown in Table 3.2. These stations were allocated according to shortest distance to runoff observation station and located in the same climatic zone. For sub-zones AS3, AS5 and AS6 the rainfall stations used were in the same major catchments as those of the runoff stations. In the case of sub-zones AS1, AS2 and BNC rainfall stations in major catchments different from those of the runoff stations were selected to test the response of the model. In fact the same rainfall station was used for AS1 as for AS2.

According to MET a review of a number of studies done on the incidence, distribution, reliability and variability of rainfall in Zimbabwe they have concluded that 'the stability of the mean annual rainfall increases markedly when the period is 20years or more' [Climatological Summaries 1978]. A period of 30 years is generally acceptable. For this assignment a period of 30 years was used in screening off rainfall stations for deriving runoff from rainfall.

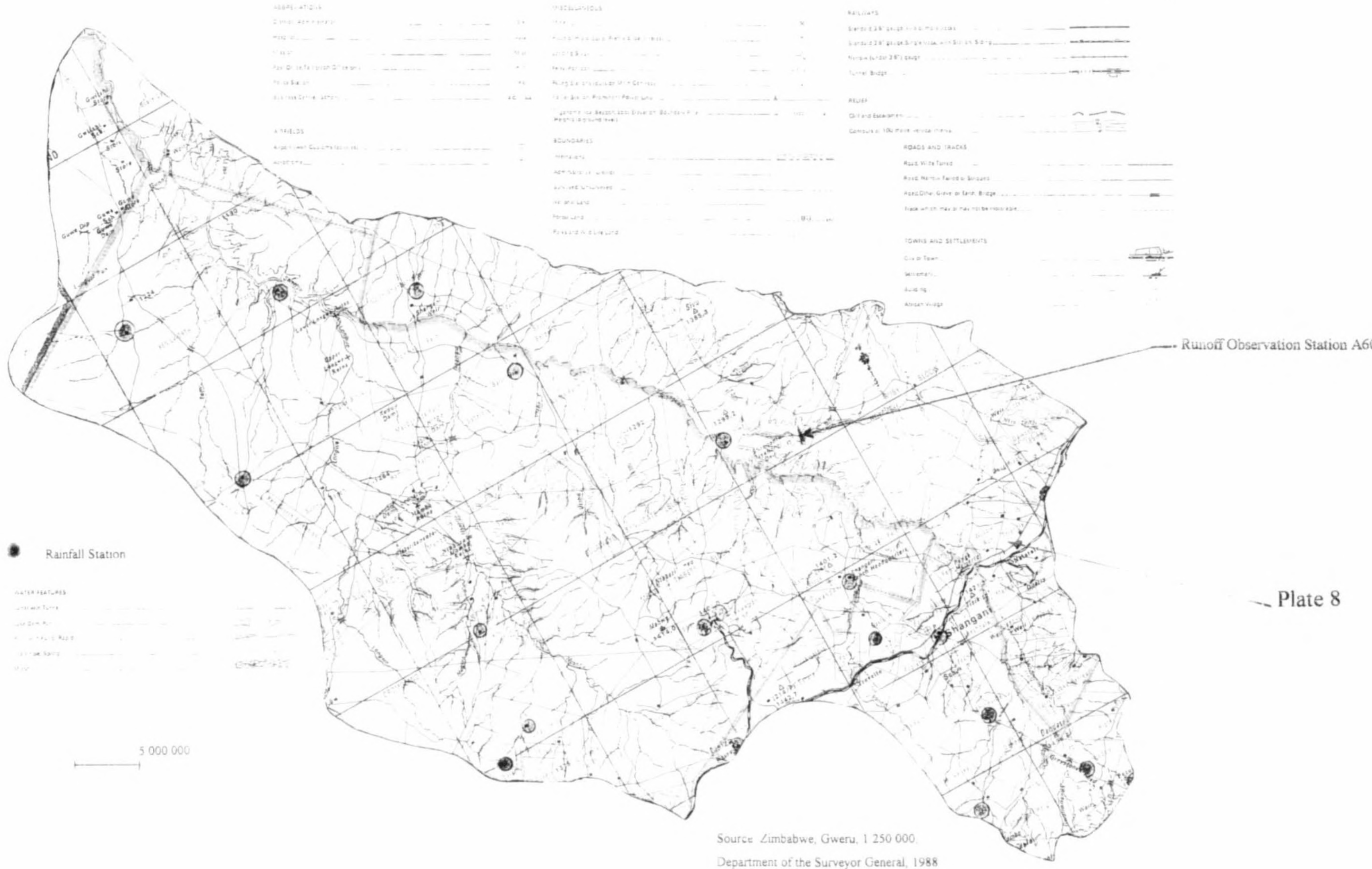
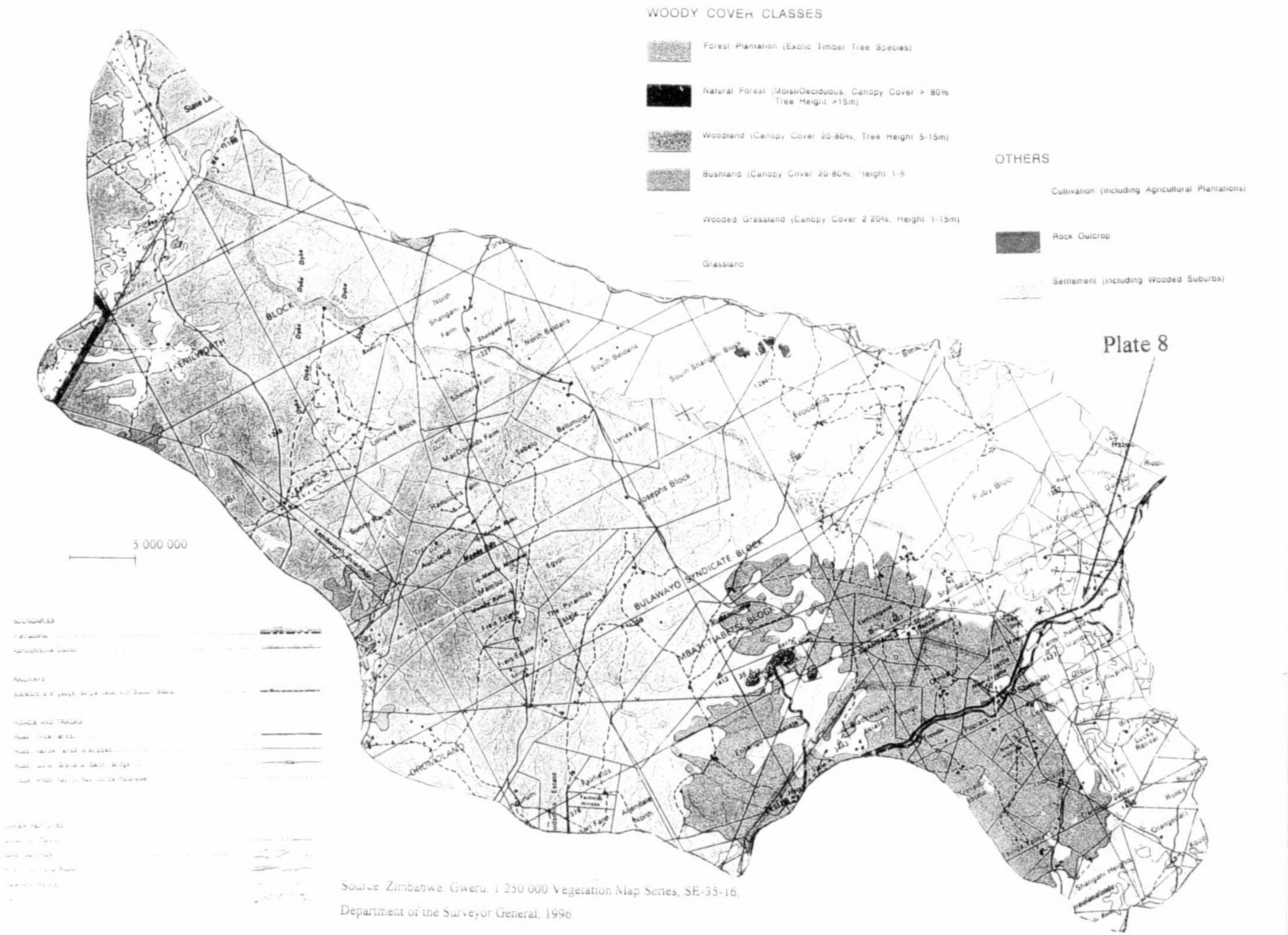


Figure 8 Sub-zone AS6 Topographic Features

Figure 8.1 Sub-zone AS6 Vegetation cover and Land Use



Source: Zimbabwe. Gweru. 1:250 000 Vegetation Map Series, SE-35-16, Department of the Surveyor General, 1996

Plate 8 Sub-zone AS6 Vegetation Cover

Mean Rain-days Per Year for Zimbabwe

Figure 9

Table 3.1 Nearest Reliable Rainfall Stations to Hydrological Sub-zones

Hydrological Sub-zone	Nearest Reliable Rainfall Station
AT	Plumtree
AM	Victoria Falls Airport
AS3	Gweru Thornhill
AS5	Gweru Thornhill
AB3	Bulawayo Airport
AS1	Lupane
AS2	Lupane
AL	Hwange Airport
AS6	Gweru Thornhill
AD	Hwange Airport
BS6	Kezi
BNC	Filabusi
BT4	Matopos

Table 3.2 Reliable Rainfall Stations with Available Observed Data

Name of Station	Latitude	Longitude	Altitude (m)	Years of Record
Lupane	18° 57' S	27° 48'E	1010	58
Gweru Thornhill	19° 27' S	29° 51'E	1430	100
Kezi	20° 55' S	28° 27'E	1020	85
Filabusi	22° 03' S	29° 17'E	1070	90

Table 3.3 Available Reliable Rainfall Stations for the Selected Sub-zones

Runoff Observation Station	Nearest Reliable Rainfall Station With Available Records	Hydrological Sub-zone for Rainfall Station	Distance Between Rainfall and Runoff Station (km)
A37	Lupane	AB1	45
A41	Lupane	AB1	38
A28	Gweru Thornhill	AS3	69
A29	Gweru Thornhill	AS3	95
A60	Gweru Thornhill	AS3	58
B36	Filabusi	IN1	38
B26	Kezi	T3	52

Table 3.4 Details of Rainfall Stations in Selected Sub-zones

Runoff Observation Station	Rainfall Stations	Years of Continuous Record	Hydrological Sub-zone for Rainfall Station	Distance Between Rainfall and Runoff Station (km)
A28	Lower Gweru	40	AS3	40
A29	Somabula Rail	65	AS5	94
A60	Shangani Rail	80	AS6	20
	Shangani Ranch	44	AS6	44

For some rainfall stations some months of records were not available. For these stations to get the rainfall for a particular month the ratio of the mean of the entire record for that station to that of the nearest reliable station was multiplied by the rainfall of the same month for the reliable station. On a sample of observed and estimated values the observed mean, standard deviation, variance, maximum and minimum values were compared to determine whether to accept or reject the estimated record.

Sub-zones AS5 and AS6 were used to explore the sensitivity of RAFLER to the use of different rainfall stations to estimate runoff for a given location.

3.4 Mean Annual Evaporation

Annual evaporation was estimated from the nearest reliable climatic station with evaporation records.

3.5 Application of RAFLER on Micro Catchments

The BASIC program RAFLER was run to generate runoff for the micro catchments draining to runoff stations A28, A29, A37, A41, A60, B26 and B36. As pointed out in section 3.2.1, for each of the runoff stations A29 and A60 two rainfall stations were used. Average sub-zone input parameters were applied in all cases as stated in section 3.1 but for each micro catchment the respective width and length were used.

Table 3.5 Input Parameters for RAFLER

Runoff station	Sub-zone	Area of Micro Catchment (km^2)	Length (m)	Width (m)	Slope	Mannings n	Rill Ratio	Cover Factor	Saturated permeability (m/hr)	Soil Suction (m)	Direct Runoff Fraction
A37	AS1	1370	107857	12702	0.00168	0.1	0.3	0.3	5	0.3	0.006
A41	AS2	502	49807	10079	0.00088	0.1	0.3	0.3	6	0.3	0.006
A28	AS3	1630	100412	16233	0.00139	0.1	0.3	0.2	5	0.3	0.06
A29	AS5	1840	102873	17886	0.00235	0.1	0.3	0.2	7	0.3	0.03
A60	AS6	137	27710	4944	0.00295	0.1	0.3	0.2	7	0.3	0.03
B36	BNC	21	7387	2843	0.00295	0.1	0.3	0.2	7	0.2	0.003
B26	BS6	189	34023	5555	0.00453	0.1	0.3	0.4	14	0.1	0.01

The estimated run-off was imported into a spreadsheet where analysis was then performed to compare it with observed runoff. Instructions on the spreadsheet are given in Appendix II. Using the spreadsheet, the mean, maximum, minimum, variance and standard deviation of both the observed and estimated data were calculated for each case on both the monthly and total annual runoff. The parameters were slightly adjusted to get better agreement between these statistical values. The final values of the parameters are shown in Table 3.5.

For RAFLER to calculate the average rain hours per month factors of 6 and 16 were used in lines 98 and 100 respectively. For each of the micro catchments observed and estimated runoff were plotted on one graph for trend analysis as shown in Figures 10 to 19 in Appendix I of this report. The same results were also plotted on scatter diagrams to check for linearity. The results are shown in Figures 10.1 to 19.1 in Appendix I. The mean, maximum, minimum, variance and standard deviation of both the observed and estimated data for the monthly and annual runoff are shown in Tables 3.6 and 3.7 respectively.

3.6 Sensitivity Tests with RAFLER

About two hours of data entry time was required per rainfall station on RAFLER. However after estimation of the geophysical and climatic parameters and the computational time to derive the runoff and the calculations on the spreadsheets were insignificant. Therefore sensitivity tests on the parameters on RAFLER were undertaken relatively quickly. In fact each rainfall-runoff conversion was accompanied by at least two sensitivity tests on the parameters. Additionally the consistence of the model was tested by use of different rainfall stations to estimate runoff for sub-zones AS5 and AS6 and their micro catchments.

It was observed that overall RAFLER was sensitive to the estimated values of the coefficients in lines 98 and 100. Table 3.8 shows the results of sensitivity tests on slope factor, rill ratio, cover factor, saturated permeability, soil suction and direct runoff fraction, for sub-zone AS1.

Table 3.6 Estimated Runoff Statistics – Monthly Runoff for Micro Catchments

Runoff Observation Station	Rainfall Station	Monthly Data									
		Mean		Variance		Standard Deviation		Maximum		Minimum	
		Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated
A37	Lupane	2371	2570	2096745	1659706	4597	4074	24800	31847	0	127
A41	Lupane	599	857	1377496	1778778	1174	1334	7950	10422	0	42
A28	Lower Gweru	7972	8807	$5.03x10^8$	$2.82x10^8$	23003	16799	191057	113162	0	129
A29	Gweru Thornhill	2865	3297	51501317	24430872	7176	4943	42100	33186	0	65
	Somabula		3889		49510280		7036		54947		124
A60	Shangani Rail	464	474	1541889	1102710	1242	1051	10400	8241	0	0
	Shangani Ranch		432		1026819		1013		9105		0
B36	Filabusi	67	71	43910	46551	210	216	1610	1213	0	0
B26	Kezi	276	270	1009287	428250	1005	654	10700	6106	0	1

Table 3.7 Estimated Runoff Statistics – **Annual Runoff for Micro Catchments**

Runoff Observation Station	Rainfall Station	Annual Data									
		Mean		Variance		Standard Deviation		Maximum		Minimum	
		Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated
A37	Lupane	5601	2717	$3.38x10^8$	$1.72x10^8$	18375	13099	60714	51677	5697	9096
A41	Lupane	7183	9865	$2.67x10^7$	$4.50x10^7$	6705	5166	19600	23494	305	4601
A28	Lower Gweru	80444	101070	$4.43x10^9$	$2.58x10^9$	66531	50752	219380	193576	219380	29288
A29	Gweru Thornhill	44288	46100	$7.01x10^9$	$8.84x10^8$	83755	29738	350604	147552	4116	19118
	Somabula		52387		$5.94x10^8$		24364		107988		16987
A60	Shangani Rail	5159	5014	$2.44x10^7$	$8.76x10^6$	4939	2959	14400	12391	448	2058
	Shangani Ranch		4915		$1.22x10^7$		3496		14701		1387
B36	Filabusi	776	847	$3.63x10^5$	$5.72x10^5$	603	756	1812	2075	83	123
B26	Kezi	3380	2789	$1.82x10^7$	$3.46x10^6$	4265	1860	17050	5840	270	5740

Table 3.8 Sensitivity of Monthly Runoff Estimates for Sub-zone AS1

Slope Factor	% Change	Mean	% Change	Minimum	% Change	Maximum	%Change	Standard Deviation	% Change
0.37	-10	2390	-7	131	3	28870	-9	3712	-9
0.39	-5	2480	-4	129	2	30309	-5	3893	-4
0.41		2570		127		31847		4074	
0.43	5	2658	3	126	-1	33382	5	4254	4
0.45	10	2746	7	124	-2	34915	10	4433	9

Rill Ratio	% Change	Mean	% Change	Minimum	% Change	Maximum	%Change	Standard Deviation	% Change
0.20	-33	4432	72	148	17	51885	63	7212	77
0.24	-20	3629	41	139	9	42833	34	5853	44
0.30		2570		127		31847		4074	
0.36	20	1575	-39	117	-8	20317	-36	2483	-39
0.40	33	1041	-59	113	-11	11485	-64	1474	-64

Cover Factor	% Change	Mean	% Change	Minimum	% Change	Maximum	%Change	Standard Deviation	% Change
0.15	-50	2570	0	127	0	31847	0	4074	0
0.24	-20	2570	0	127	0	31847	0	4074	0
0.3		2570		127		31847		4074	
0.36	20	2570	0	127	0	31847	0	4074	0
0.45	50	2570	0	127	0	31847	0	4074	0

Saturated Permeability	% Change	Mean	% Change	Minimum	% Change	Maximum	%Change	Standard Deviation	% Change
4.5	-10	2902	13	133	5	34418	8	4583	12
5		2570		127		31847		4074	
5.5	10	2910	13	121	-5	28512	-10	3516	-14
6	20	1743	-32	114	-10	23487	-26	2826	-31
6.5	30	1302	-49	109	-14	16713	-48	2035	-50

Table 3.8 Sensitivity of Monthly Runoff Estimates for Sub-zone AS1 - continued

Soil Suction	% Change	Mean	% Change	Minimum	% Change	Maximum	%Change	Standard Deviation	% Change
0.2	-33	3070	19	132	4	35000	10	4813	18
0.24	-20	2899	13	130	2	33977	7	4560	12
0.3		2570		127		31847		4074	
0.36	20	2148	-16	124	-2	28644	-10	3487	-14
0.4	33	1774	-31	120	-6	24606	-23	2940	-28

Direct Runoff Fraction	% Change	Mean	% Change	Minimum	% Change	Maximum	%Change	Standard Deviation	% Change
0.0048	-20	2499	-3	127	0	31381	-1	4000	-2
0.0054	-10	2534	-1	127	0	31614	-1	4037	-1
0.006		2570		127		31847		4074	
0.0066	10	2605	1	128	1	32078	1	4111	1
0.0072	20	2641	3	128	1	32308	1	4149	2

On the slope factor sensitivity was on the slope rather than Mannings coefficient because errors of estimate are more likely on the latter. RAFLER showed greatest sensitivity to estimates of rill ratio followed by saturated permeability, slope and then soil suction in that order. These parameters are of great importance to drought analysis, therefore their correct estimation is important. The computer programme was not very sensitive to small errors of estimate in the values of Mannings coefficient, direct runoff fraction and cover factor. This was agreement with Stephenson *et al* (1992).

As pointed out in section 3.3 at the sub-zone level the response of RAFLER to spatial variability of rainfall was tested in three ways as follows:

- by using rainfall stations in the same sub-zone as the runoff station,
- by using rainfall stations in different sub-zone but same major catchment as the runoff station and
- by using rainfall stations in different sub-zone and major catchment as the runoff station.

The results of these tests are discussed in chapter 4.

3.7 Brief Discussion of Results

At the micro-catchment level observed runoff data was available for statistical analysis which was important for the calibration and testing of RAFLER before its application to generate sub-zone runoff.

As shown in Tables 3.6 the statistical analysis on mean, variance, standard deviation and maximum values shows good agreement for the monthly runoff. Table 3.7 also shows good agreement on the same statistics for the annual runoff. In both cases there is significant difference on the minimum values. One possible explanation is that the gauging equipment at the runoff stations is not set to measure very low flows. Therefore the estimated low flows could present a more accurate scenario. However in the case of micro catchments draining to A60, B36 and B26 there is good agreement between estimated and observed minima.

These catchments are small hence this result is expected since in any case the gauge posts would be equipped to measure low flows. Low flows would be difficult to measure in sandy river-beds such as that shown in Plate 3 or where there is sub-surface flow as shown in Plate 5. Figures 10 to 19 show some agreement between the observed and estimated data. Where there is time shift this could be due to the time differences in occurrence of rainfall event and its runoff passing the point of measurement. The time shift would become more pronounced where the rainfall station is a long distance from the runoff observation station. In general Figures 10.1 to 19.1 show less scatter around low flows. This confirms the observations made from Figures 10 to 19 and Tables 3.6 and 3.7. Therefore the estimated runoff from RAFLER gives good estimates of low flows which are essential for drought analysis.

3.8 Calibration Problems with RAFLER

The flowchart for RAFLER was not available at the start of the assignment. The author had not used this programme before. However, with repeated use this minor problem was overcome.

The compatibility of the output from RAFLER with Microsoft Excel was of great help as data was then imported into this programme for statistical analysis. However the output from RAFLER was in a single column rather than an annual matrix of years of runoff by twelve months. It therefore required further work to make it compatible with the observed runoff data from DWRD. The data from DWRD was on a Microsoft Excel compatible spreadsheet of years of runoff by twelve months.

3.9 Application Of Rainfall Runoff Model On Sub-Zones

Using the concept of RDFA, for each micro catchment analyzed in chapter 3.0, the length and width parameters of the micro catchments draining to runoff stations A28, A29, A37, A41, A60, B26 and B36 were replaced in RAFLER by those of sub-zones AS3, AS5, AS1, AS2, AS6, BS6 and BNC. Runoff for the respective sub-zone was generated. Table 3.8 shows the catchment area, length and width of the sub-zones.

Table 3.9 Sub-zone Input Parameters for RAFLER

Sub-zone	Catchment Area (km^2)	Length (m)	Width (m)
AS1	3129	163000	19196
AS2	3966	140000	28329
AS3	4727	171000	27643
AS5	1851	102877	17992
AS6	3036	95000	31958
BNC	745	44000	16932
BS6	1045	80000	13063

From Tables 3.5 and 3.9 the ratios of sub-zone to micro catchment areas for AS1, AS2, AS3, AS5, AS6, BNC and BS6 were 2.28, 7.90, 2.90, 1.01, 22.16, 35.48 and 5.53 respectively. The generated sub-zone runoff was imported to a spreadsheet and adopted for drought frequency analysis.