CHAPTER 3
ENVIRONMENTAL CONSIDERATIONS OF DAMBO DEVELOPMENT

3.1 Dambo Classification

3.1.1 Introduction

Several definitions and classifications of Dambos have been developed by many research workers (Daka and Gondwe, 1998). McCartney ***et al***. (1998) alludes to the fact that Dambos are complex systems that do not fall easily into one discrete class. Many classification systems and definitions have been developed so far but not one has been universally accepted to date.

Many authors have defined Dambos on the basis of their biased perception but with certain attributes which fit common knowledge of what Dambos may be. This chapter presents chemical and physical properties as actually obtained by means of analyses. These characteristics, which are based on quantitative data, are applied according to the suggested key modifiers which eliminate subjective and professional biased interpretation of Dambos.

The following key modifiers as suggested by McCartney and Daka (1998) are applied to expand on Mackel's simplified definition of a Dambo which states that:

"Dambos are seasonally waterlogged, predominantly grass covered, depressions bordering headwater drainage lines".

The modifiers presented in Table 8 may be used to expand on the above definition to define individual Dambos with empirical scientific evidence. Thus Dambos would have a definition embracing vegetation type, chemical nature, wetness indication and present land use. Chemical data are used to decide on the acidity levels.

Two Dambos with greatly different characteristics, i.e. Fikolwa and Mudodo from the Central and Southern districs of Zambia respectively, were selected to illustrate the use of these criteria for the classification of Dambos.

3.1.2 Soil Chemical Properties and Fertility Status

3.1.2.1 Sampling and Analytical Procedures

Soil profile pits measuring 1m x 1m x 1 m were dug in each of the Dambo central/seepage zones where most vegetable growing activities take place. The month of August was chosen for sampling as this represents the peak dry month when it is expected that the antecedent soil moisture levels for most upland and Dambo areas will have dropped considerably and so would be the acidity levels. Soil profile descriptions were done and by cutting from the side walls of the pits with a knife, soil samples were taken from the following soil profile pit layers; 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm.

Samples for chemical analysis were packed in clean plastic bags and those in undisturbed sampling metal cores were put in a specially made sample carrier. All the samples were then taken to the laboratory at Mount Makulu Central Research Station in Zambia for both hydro-physical and chemical analyses.

Prior to laboratory chemical analysis, the soil samples were air dried at room temperature, ground by a mortar and pestle and passed through a 2 mm sieve. Both the top and sub-soil were analysed for pH, organic carbon, phosphorus, potassium, calcium, magnesium, sodium and electrical conductivity (EC).

Exchangeable bases (Ca^{++}, Mg^{++},K^{+} and Na^{+}) were extracted by leaching the samples with a 1N solution of ammonium acetate buffered at pH 7.0. Ca^{++} and Mg^{++} were measured by atomic absorption spectrphotometry and K^{+} and Na^{+} by flame photometry.

Organic carbon was measured by the Walkley-Black method. Available phosphorus was determined by the Bray's No.1 method (Knudsen, 1980).

Soil pH was determined in 0.01M $CaCl_2$ using a soil to salt solution ratio of 1:2 on volume basis. EC was determined in a saturation extract (Qien and Krogstad, 1983).

Effective Cation Exchange Capacities (ECEC's) were determined by summing up of extracted K^{+}, Na^{+}, Ca^{++} and Mg^{++} found in extraction with ammonium acetate and exchangeable acidity from a soil extracted with 1N KCl. Exchangeable acidity was determined by titrating the extract with 0.05 N NaOH back to neutral (McLean, 1965).

The determination of the bulk density is described in section 2.5.3 of Chapter 2 as described in Qien and Krogtad (1983).

3.1.2.2 Results and Discussion

Tables 1 and 2 present soil analysis data for Fikolwa and Mudobo Dambos. Soil chemical information presented in Tables 1 and 2 is revealing in terms of environmental conditions in the two Dambos. Fikolwa Dambo presents itself with higher organic matter content (2.82%) than Mudobo (1.46%). However, both Dambos confirm the decreasing organic matter with increasing soil depth up to 100 cm. Loyland and Stuhaug(1987) observed that soil physical properties of most Dambos are strongly related to organic matter content which in the top soil varies from 1.5% to 33%. In the sub-soil, they found that organic matter content varies from 0.5% to 26%. This observation agrees with results of this study in which decreasing

organic matter from the top soil layer to the subsurface layers is observed as a trend.

A perculiar high subsurface organic matter content is observed in the 20-40 cm layer at Fikolwa Dambo due to heavy root penetration of the vegetation in the light sandy clay loam soil. The over-turning and burying of organic matter during land preparation created conditions for intensive root penetration which are important for this increase of organic matter in this layer.

Inundation of some Dambo zones promotes accumulation of organic matter which remains partially undecomposed for some time until the water has receded or the soil has been drained, when oxidation due to proper aeration takes place. At these times most of the accumulated organic matter decomposes and releases nutrients to the soil to make the soil fertile.

It would appear that in most Dambos organic matter accumulation is important in the upper 20 cm layer of the soil profiles of the central/seepage zones in the two Dambos. Farmers believe that its cyclic utilization and accumulation is a major attribute of soil fertility sustainance.

Table 3 gives some threshold value ratings of organic matter, carbon, nitrogen and phosphorus. Organic matter is an important soil constituent, being the base for biological activity and influencing the agricultural characteristics of the soil: base saturation, CEC or ECEC, phosphorus content, nitrogen cycle and structure. The soil colour has often been used as a hint to the organic matter status of the soil; a dark colour particularly in Dambo topsoils being an indicator of high organic matter content. The quality of organic matter is influenced by both the organic carbon and nitrogen percentages. Nitrogen essentially stimulates microbiological activity. If the soil is acidic and temperatures are too low for mineralization to occur, microbiological activity is restricted and organic matter accumulates without much decomposition taking place. Both top soils (0-20 cm) at Fikolwa and Mudobo show high ECEC levels of 14.00 cmol/kg soil and 29.05 cmol/kg soil respectively, decreasing with low pH values in deeper soil layers. However, Mudobo, despite a lower organic matter content, shows higher ECEC values than Fikolwa.

Table 1: Chemical data of the soil profile from Fikolwa Dambo central zone.

Soil depth (cm)	pH ($CaCl_2$)	Org.C (%)	P-Bray-1 (mg/kg)	K ($cmol_+$/kg)	Ca ($cmol_+$/kg)	Mg ($cmol_+$/kg)	Na ($cmol_+$/kg)	CEC (cmolc/kg)	EC mS/m
0-20	4.7	2.82	23.00	0.80	2.50	2.20	0.98	14.08	2.06
20-40	3.9	0.54	5.00	0.15	0.60	0.60	0.19	5.10	0.54
40-60	4.0	0.29	12.00	0.09	0.40	0.30	0.11	1.85	0.16
60-80	3.7	0.18	2.00	0.10	0.40	0.30	0.14	1.50	0.25
80-100	3.8	0.25	2.00	0.10	0.50	0.40	0.16	2.10	1.72

Table 2: Chemical data of the soil profile from Mudobo Dambo central zone.

Soil depth (cm)	pH $CaCl_2$	Org.C %	P-Bray-1 (mg/kg)	K ($cmol_+$/kg)	Ca ($cmol_+$/kg)	Mg ($cmol_+$/kg)	Na ($cmol_+$/kg)	CEC (cmolc/kg)	EC mS/m
0-20	5.7	1.46	36.00	0.65	4.70	2.30	0.81	29.05	4.00
20-40	4.4	0.41	6.00	0.40	0.90	0.60	0.51	4.71	1.00
40-60	4.0	0.23	4.00	0.15	0.60	0.40	0.20	1.95	0.38
60-80	4.1	0.16	3.00	0.10	0.50	0.30	0.14	2.40	0.27
80-100	4.1	0.11	5.00	0.08	0.50	0.20	0.12	1.76	0.25

Table 3: Ratings of organic matter, carbon, nitrogen and phosphorus levels in soils.

Ratings	Total O.M (%)	Total Carbon (%)	Total Nitrogen (%)	C/N	Available- P Bray-1 (mg/kg)
Very high	>6.0	>3.50	>0.30	>25	-
High	4.3 - 6.0	2.51 - 3.50	0.226 - 0.300	16-25	>40
Medium	2.1 - 4.2	1.26 - 2.50	0.126 - 0.226	11-15	10 - 40
Low	1.0 - 2.0	0.60 - 1.25	0.095 - 0.125	8-10	<10
Very low	<1.0	<0.60	<0.095	<8	-

Sources: Ilaco(1981) and Young (1976)

Because of higher wetness throughout the Dambo at Fikolwa than Mudobo, the topsoil at Fikolwa has a lower **electrical conductivity** of 2.06 mS/m than the 4.00 mS/m for the top soil at Mudobo (Tables 1 and 2). At the 20-40 and 40-60 cm depths the values at Fikolwa indicate (as could be expected) more leaching than at Mudobo. At 60-80 cm depth the values for the two Dambos were equal. At 80-100 cm depth the value for Fikolwa was mucher higher than that at Mudobo, indicating some accumulation of salts leached from the upper layers to this layer at Fikolwa. It must be remembered, however, that all these values are very low and that the differences are of no practical significance.

The topsoil **pH** levels of 4.7 and 5.7 at Fikolwa and Mudobo respectively, are also a manifestation of a higher degree of leaching of bases from the wetter Fikolwa Dambo (Tables 1 and 2). The presence of higher organic matter in the central zone of Fikolwa probably also contributes to the lowering of the pH, due to the release of acids during decomposition. The difference in topsoil pH levels between the Dambos is big and important. A pH of 5.7 is favourable, but 4.7 is too acid and plant nutritional problems may develop. There is however no significant difference in subsoil pH between the two Dambos. The trend at both sites is that of a sharp decrease in pH below the top 20 cm layer to very low values. Below 20 cm the pH values remain constant to 100 cm depth. The usual burning of vegetation during land clearing could be a contributing factor to higher topsoil pH levels because ash with higher base content may have a liming effect. There may also be a higher buffering effect to pH change due to the higher organic matter level.

According to Moorman and Van Breemen (1978a) soils with high organic matter contents are commonly deficient in phosphorus, potassium, copper and molybdenum.

According to Brady (1974), both phosphorus and potassium contents of peat are low with potassium being exceedingly so in compariosn with mineral soils. Maximum phosphorus availability normally occurs at pH 5.5-7.0 and decreases below pH 5.5 and above pH 7.0. According to the ratings in Table 3 available phosphorus levels in the topsoil (0-20 cm) layer were medium (23 mg/kg) and high (36 mg/kg) for Fikolwa and Mudobo Dambos respectively (Tables 1 and 2). Although the authors quoted regard 23 mg/kg as medium, it is actually adequate for optimum production of crops. Subsoil P levels are low in both Dambos, which is normal for subsoils, except for the 40-60 cm layer at Fikolwa with a P content is quite higher than normally found in subsoils.

Generally, phosphorus levels are usually low in Dambo soils under natural conditions. When phosphorus is deficient, addition of organic matter or manure will increase the availability of soil phosphorus. At Fikolwa the moderately high level of phosphorus in the top soil can be attributed to accumulation of moderate applications of kraal manure. At Mudobo addition of kraal manure to Dambo garden soils is probably the source of the relatively high topsoil phosphorus level. The latter is promoted by the presence of a cheap source of manure from the high population of cattle in the area. Kraal manure is a very good alternative source to inorganic fertilizers whose prices are unaffordable for smallholder farmers. Soil sub-mergence increases the availability of phosphorus (Mitsui, 1960 in: Tadano and Yoshida 1978) and where wetland crops like rice are grown in lowland valley Dambos, e.g in the Western province floodplains and in Eastern and Luapula provinces, phosphate application becomes less important.

Calcium, magnesium, and potassium tend to be very high in strongly alkaline soils and will show low levels when acidic conditions prevail. Ratings of exchangeable bases that can be applied to indicate the base status of the two Dambo soils are given in Table 4.

Table 4: Ratings of exchangeable bases (in $cmol_+/kg$)

Ratings	Ca^{++}	Mg^{++}	K^+	Na^+
Very high	>20	>8	>1.2	>2.0
High	10-20	3-8	0.6-1.2	0.7-2.0
Medium	5-10	1.5-3.0	0.3-0.6	0.3-0.7
Low	2-5	0.5-1.5	0.1-0.3	0.1-0.3
Very low	<2	<0.5	<0.1	<0.1

Source: Ilaco (1981).

The soils at Fikolwa would generally be expected to exhibit lower levels of bases and base saturation than Mudobo Dambo, because of the higher degree of leaching at Fikolwa. This is indeed the case in the top and middle layers (Tables 1 and 2). In the deepest layer (80-100 cm) the situation is reversed, as was also the case with EC, again indicating accumulation of soluble salts and bases in this layer at Fikolwa due to some restriction to leaching beyond this layer.

Similar to the situation with phosphorus, there is a sharp drop in exchangeable base content between the topsoil and the subsoils at both Dambos. This is true not only for the total base content, but for each of the individual bases also. The only exception is the small drop in potassium content between the 0-20 and 20-40 cm layers at Mudobo Dambo.

The results in Tables 1 and 2 show high **potassium** levels in the topsoil for both Fikolwa and Mudobo Dambos, but also medium levels show in the sub-soil (20-40 cm) for the latter. One source of high topsoil K^+ is burning of grass and accumulated organic matter, particularly at Fikolwa. Burning of vegetation in Dambos is not uncommon, particularly when land preparation takes place, and it is a source of potassium. Burning also increases the available bases from the resulting ashes and thus high levels of EC would manifest. At both Dambos the subsoil potassium levels are low to very low (except in the 20-40 cm layer at Mudobo).

Sodium levels are high in the topsoil and low in the subsoil at both Dambos, except in the 20-40 cm layer at Mudobo where it is medium. It is a common feature that groundwater that seeps laterally through the soils of adjacent uplands to a Dambo may be a source of sodium, and various plant nutrients that accumulate in the soil of the Dambo. The high sodium levels, and especially the high ratio of sodium to cations like calcium and magnesium, are matters for concern since it may cause dispersion of the soil and poor physical conditions.

3.1.3 Soil Physical Properties

3.1.3.1 Sampling and Analytical Procedures

Undisturbed 100 cm^3 sample cores were taken for the determination of soil moisture retension capacities at different tensions, using pressure-membrane extraction apparatus operated at 0 kPa, -10 kPa, -33 kPa, -100 kPa, -200 kPa and -1500 kPa (Richards, 1948).

Soil textural classes were determined by using the International pipette method as described in Section 2.5.1. Bulk density was determined by the method described in Section 2.5.2.

3.1.3.2 Results and Discussion

The two Dambos notably have sandy soils, exhibiting a Sandy Loam (SL) textural class throughout the profiles (Table 5). This physical characteristic is of interest particularly because of the good drainage occurring in the upper grassland and seepage zones. With such good drainage, infiltration of rain water is enhanced in the upper fringes of the Dambo and is responsible for sub-surface flow and recharge to the main Dambo area.

Table 6 shows hydro-physical soil data as determined for soil samples from the Dambos at Fikolwa and Mudobo. **Water holding capacities** of 170 mm/m and 226 mm/m at Fikolwa and Mudobo respectively were found. These are calculated values obtained as a difference between Field Capacity (FC) and Wilting point (WP) measured at –10kPa and –1500kPa respectively (Hansen ***et al.***, 1980).

Hansen *et al.* (1980) described FC to be associated with a soil water tension of about –10kPa for sandy soils and –33kPa for clayey soils. The two Dambos manifest themselves as sandy soils. Soil water holding capacities of soils vary with soil texture, organic material and many other factors.

The Plant Extractable Soil Water (PESW), is the soil water between FC and WP. PESW is the same as the term Available Soil Water (ASW) and is often used for irrigation system design and operation (Ritchie, 1985).

Table 5: Particle size distribution and textural classification of Fikolwa and Mudobo Dambo soils.

Fikolwa									
Soil depth (cm)	**Clay (%)**	**Silt (%)**	**Total Sand (%)**	**Very fine sand (%)**	**Fine sand (%)**	**Medium sand (%)**	**Coarse sand (%)**	**Very coarse sand (%)**	**Textural class**
0-20	**17**	**7**	**76**	**5**	**17**	**30**	**19**	**5**	**L**
20-40	**18**	**21**	**61**	**8**	**20**	**21**	**10**	**3**	**SL**
40-60	**11**	**22**	**68**	**7**	**21**	**22**	**12**	**5**	**LS**
60-80	**11**	**20**	**69**	**5**	**16**	**27**	**16**	**5**	**SL**
80-100	**4**	**10**	**86**	**3**	**13**	**32**	**26**	**12**	**SL**
Mudobo									
0-20	**18**	**47**	**36**	**14**	**15**	**4**	**2**	**1**	**SL**
20-40	**16**	**19**	**64**	**13**	**30**	**12**	**5**	**4**	**SL**
40-60	**4**	**18**	**78**	**13**	**34**	**18**	**7**	**6**	**SL**
0-80	**15**	**15**	**70**	**13**	**28**	**13**	**7**	**8**	**SL**
80-100	**8**	**18**	**73**	**10**	**21**	**15**	**11**	**16**	**LS**

In both Dambos the soils have very high soil moisture holding capabilities. Mudobo has a higher Available Soil Water Capacity than Fikolwa Dambo. This is due to the higher percentage of silt and clay particles. Even the fine sand fractions are higher in Mudobo than in Fikolwa, which manifest a higher percentage of coarse sand. Fikolwa, whilst exhibiting higher soil moisture contents at field capacity, has a so much higher soil moisture retention at wilting point that the difference between FC and WP is smaller at Fikolwa than at Mudobo.

Fikolwa Dambo is a wet Dambo whereas Mudobo is a dry Dambo. This is supported by the soil field moisture contents at the time of sampling at the peak dry season in August just before the onset of the rains. Field soil moisture contents at Fikolwa matched those at wilting point in the 0-20 cm and 20-40 cm layers and were higher than its wilting point in the 40-60 cm, 60-80 cm and 80-100 cm layers whereas those of Mudobo were lower than its wilting point, except in the bottom layer (80-100 cm) and some sign of available water in the 40-60 cm layer (Table 6). At Fikolwa there is evidence of a perched water table at 40-60 cm where the soil moisture content of 0.64 cm^3/cm^3 was higher than at 0 kPa soil water tension. This was just above a compacted soil horizon where there was a sharp increase in bulk density from 1 500 kg/m^3 to 1 940 kg/m^3. The fact that at Mudobo field soil moisture contents fell well below the soil moisture content at wilting point indicates the need and importance of irrigation in this Dambo for crops have to survive, particularly because a noticeable root restricting bulk density starts at 40 cm depth, giving an effective rooting depth of only 40 cm.

Table 6: Hydro-physical soil properties of Fikolwa and Mudobo Dambos.

Depth (cm)	Bulk density (kg/m^3)	Field Soil Moisture Content cm^3/cm^3	0 kPa SMC (cm^3/cm^3)	-10 kPa SMC (cm^3/cm^3)	-33 kPa SMC (cm^3/cm^3)	-100 kPa SMC (cm^3/cm^3)	-200 kPa SMC (cm^3/cm^3)	-1 500 kPa SMC (cm^3/cm^3)	Soil Textural class
Fikolwa Dambo									
0-20	1 260	0.24	0.56	0.38	0.35	0.32	0.30	0.24	**L**
20-40	1 580	0.14	0.54	0.38	0.32	0.27	0.23	0.17	**SL**
40-60	1 520	**0.64***	**0.61***	0.39	0.21	0.13	0.08	0.18	**LS**
60-80	1 940	0.23	0.47	0.33	0.30	0.24	0.22	0.20	**SL**
80-100	1 840	0.30	0.44	0.36	0.33	0.26	0.24	0.20	**SL**
Mudobo Dambo									
0-20	1 240	0.15	0.59	0.36	0.30	0.26	0.24	0.20	**SL**
20-40	1 620	0.09	0.44	0.30	0.25	0.21	0.18	0.10	**SL**
40-60	1 790	0.13	0.64	0.41	0.29	0.19	0.15	0.08	**SL**
60-80	1 840	0.09	0.55	0.34	0.23	0.14	0.12	0.07	**SL**
80-100	1 940	0.21	0.48	0.27	0.22	0.17	0.15	0.10	**LS**

SMC = Soil Moisture Content

Fikolwa: Available Soil Water Holding Capacity = 170 mm/m

Mudobo : Available Soil Water Holding Capacity = 226 mm/m

*** High values due to a perched water table.**

Bulk densities in both lower profiles are extremely high (Table 6). Bulk densities from about 1 800 kg/m^3 are considered to totally prevent root growth (Ritchie, 1985). Such values are reached at 60cm in Fikolwa Dambo and 40 cm in Mudobo Dambo. This means that Fikolwa Dambo has only 60 cm effective rooting depth and Mudobo only 40 cm, especially the latter being very shallow for irrigated cropping. The perched water table in the 40-60 cm layer at Fikolwa means that at this Dambo roots will also be restricted to a depth of only 40 cm.

For both Dambos, a high organic matter content in the upper layer (0-20 cm) gives lower bulk densities and higher soil moisture contents under field conditions and at wilting points. It is noteworthy that, because of its influence on bulk density and the water content at wilting point, organic matter actually lower the plant available water content of the soil. This is clear from the data for the difference between field capacity and wilting point for the 0-20 cm layers.

3.1.3.2.1 Dambo Environmental Conditions Governing Water Movement

During the rain season Dambo soils tend to flood, particularly in the central zone. During an excessively flooding regime, most soils would get saturated with water. Water movement in the soil under saturation is much faster than unsaturated soil water movement because the unsaturated conductivity is much slower. Water movement from a water table to the root zone of plants is unsaturated flow. This phenomenon occurs inspite of the fact that a zone of near saturation, called the "capillary fringe", always exists above the water table. Upward movement of water is restricted by unsaturated hydraulic conductivity, which is usually much less than saturated hydraulic conductivity. Some models assume that the hydraulic conductivity is zero below the Field Capacity (Ritchie, 1985). This leads to the conclusion that water for

evapotranspiration comes from rainfall, irrigation or root movement into a moist soil zone. Unsaturated flow of soil water will take place inside and to the root zone when portions of the soil become dry. Water also can be supplied to the roots from shallow water tables.

3.1.4 Ground Water (Well Water) Quality for Irrigation

3.1.4.1 Sampling and Analytical Procedures

Water samples were collected from six hand dug wells used as sources of irrigation water in different Dambos. Clean water sample bottles were used to collect the water by filling them up and covering them with a lid supplied with a seal to ensure the bottles are not unduly opened. The bottles were then taken to the laboratory at Mt. Makulu Central Research Station for analysis of pH, P, K, Ca, Mg, Na and electrical conductivity. Sodium Adsorption Ratio was calculated by using the Gapon Equation (Kelly, 1948) as follows:

SAR = $\mathbf{Na^{+}/((Ca^{++} + Mg^{++})/2)^{1/2}}$ ……………...(1)

3.1.4.2 Results and Discussion

Chemical data for water samples from six wells used as sources for irrigation water in Dambos are presented in Table 7.

Table 7: Water analyses for seven wells in Siachitema, Fikolwa, Mudobo and Kanchele Dambos.

Well Location	pH ($CaCl_2$)	P (mg/kg)	K ($cmol_+$/kg)	Ca ($cmol_+$/kg)	Mg ($cmol_+$/kg)	Na ($cmol_+$/kg)	EC (mS/m)	SAR
Mudobo	6.4	7	18.90	0.80	2.10	14.50	2.10	12.04
Siachitema	6.1	2	5.00	1.20	0.70	5.50	0.57	5.80
Kanchele-well 1	6.1	2	11.40	1.00	0.90	10.30	0.83	10.60
Kanchele-well 2	6.2	3	8.10	0.80	0.80	7.50	0.85	8.38
Kanchele-well 3	8.7	2	5.90	7.20	0.30	8.40	1.65	4.34
Fikolwa	6.3	2	5.00	trace	trace	6.50	530	>15

From the results in Table 7 it is evident that the well water from Mudobo Dambo, which has granitic rocks as parent material, shows a lower **EC** level (2.10 mS/m) than Fikolwa (530 mS/m) with mica schist as parent material. Water with an electrical conductivity of more than 200 mS/m is usually considered unfit for land application due to high salinity. The water well at Fikolwa would therefore be considered to have a salinity problem.

Sodium Adsorption Ratio (SAR) is considered to be a better indication of potential sodicity problems that could develop during irrigation than the sodium content of the water as such. Water with a SAR higher than 5 is considered to be unfit for irrigation. SAR values of the water sources at all locations except Kanchele-well 3 are higher than 5, indicating that sodicity problems may develop in soils if provision is not made for adequate drainage to leach out the sodium.

The high SAR values are not caused by high sodium levels, but by very low calcium and magnesium levels. SAR values of water from the wells in Fikolwa and Mudobo Dambos are the highest of the wells tested. In the previous section it was indicated that there are

signs that relatively high ESP levels are developing in the soils of these Dambos. This situation calls for the development and implementation of innovative management strategies. On the one hand, ditch drains can be used effectively to provide leaching during the rain/flood season. On the other hand, this may cause dessication of the Dambos. One could look at opening ditch drains during the first part of the rain/flood season and then closing off their outlets to the river to collect water in the Dambo water table for the following dry season. Addition of gypsum could also be used to lower the effect of high SAR and to replace the sodium from the soil's exchange complex before leaching.

High exchangeable sodium is manifested by a dispersed (deflocculated) clay system which greatly reduces both air and water entry into the soil. A deflocculated soil without structure can easily be compacted and would form hard pans in the soil profile. In the previous section it was shown that Dambo subsoils have very high bulk densities. However, sandy soils, as are found at Fikolwa and Mudobo, are correspondingly less affected by increasing sodium on the exchange complex because of their low clay content.

From the results salinity does not seem to be a problem, except in the borehole at Fikolwa. Sodicity (high SAR) seems to be the danger.

3.1.5 Suggested Key Modifiers for Dambo Classification

Modifiers presented in Table 8 are essentially a development of inventories of Dambo attributes. To avoid professional bias in the classification, these attributes, as far as possible, are based on numerical expressions. As these modifiers are effectively wetland attributes they have been defined to avoid subjective interpretation. The approach is by no means "full-house" but could be revised in view of new advances. It is based on the U.S.

Department of the Interior system for classification of wetlands in which a basic description is extended through the use of so-called modifiers (Cowardin ***et al***,1979).

The features that all Dambos share is that they exist in headwater catchments and their soils are periodically saturated, usually as a consequence of impeded drainage arising from heavy textured subsoils and the low slope angles which reduce throughflow efficiency. Since there is little to be gained by protracted analysis of the exact definition of a Dambo, and there are numerous variants on the theme, a simple definition, which is both comprehensive and inclusive of the salient features without being too restrictive, is suggeted.

The modifiers presented in Table 8 should be viewed as a first attempt to introduce more scientifically rigorous definitions to Dambo **"types"** although it is possible that the modifers may need to be revised in the light of future findings (M^c^Cartney and Daka, 1998).

Table 8: Key Modifiers for classification of Dambo types

	Modifiers	Description
Location	Source Valley	Dambo contains the source of a stream may or may not have a well defined channel in the valley bottom. Water input to the Dambo is predominantly rainfall and inflow from the surrounding interfluve. Dambo lies either side of a well defined stream channel at least 2 km from the start of a well defined stream channel. A component of the water into the Dambo during the wet season may rise from the overtopping of stream banks.
Period of saturationPeriod of saturationPeriod of saturation	Wet Dry	In most years of average or above average rainfall, the soil profile at seepage zone remains saturated to within 10cm of ground surface for greater than half the dry seaosn. In most years of average or above average rainfall, the water content of soils at the seepage zone at depths greater than 10cm below the ground surface decreases below saturation before half the dry season is over.
Soil chemistry	Sweet Intermediate Sour	pH of surface soils at the centre of the Dambo (i.e. valley bottom) is greater than 7.0 in August+. pH of surface soils at the centre of the Dambo (i.e valley bottom) is 5.6 - 6.9 in August. pH of surface soils at the centre of the Dambo (i.e valley bottom) is less than 5.5 in August.
Slope	Low Medium Steep	Average slopes from the valley bottom to the seepage zone are less than 0.5%. Average slopes from the valley bottom to the seepage zone are greater than 0.5% but less than 4%. Average slopes from the valley bottom to the seepage zone are greater than 4%.
Use	Cultivated Grazed Non-utilized	More than 10% of the Dambo is used for garden (dimba) cultivation. Dambo is used for grazing and/or stock watering. Dambo is not utilized for grazing and cultivation is less than 10%.

3.1.6 Examples of Dambo Classification:Classification of Fikolwa and Mudobo Dambos

The following attributes apply to the two Dambos as presented in Table 9. Quantitative and qualitative information on Dambo morphology, hydrology, soil chemistry and utilization data, as obtained from the field results presented in the previous sections, was used. Based on these, the following attributes are characterized for the two Dambos:

Table 9: Attributes of Dambos at Fikolwa and Mudobo.

Dambo	**Location**	**Stream flow**	**Wet/Dry**	**pH**	**Slope**	**Dambo use**
Fikolwa	Source	yes	Wet	4.7	0.0 - 0.5%	Non-utilized
Mudobo	Source	No	Dry	5.7	0.5 - 1.0%	Cultivated/grazed

From the foregoing the two Dambos are classified as follows:

A. **"Fikolwa is a wet non-utilized sour source Dambo"**

Note that non-utilized does not preclude the use of the Dambo but indicates limited use up to 10% of the Dambo area because of inherent limitations such as wetness and acidity. In this study it was found that only up to 5% of Fikolwa had actually been utilized.

B. **"Mudobo is a dry medium grazed and cultivated intermediate source Dambo."**

Mudobo Dambo is essentially an upland Dambo which farmers use for dry season cattle grazing. When water tables recede appreciably, farmers use hand dug wells to access water for irrigation of vegetables.

3.2 Long-term Land Use Changes In Dambos and Their Catchments

Land use in Dambos pertains to the cultivation practices, cattle grazing activities, clearing of land in the catchment for agricultural development and settlement of people. Many reasons abound for the changes in Dambos and their catchments. This section gives an analysis of human activity and climatic factors as they have affected Fikolwa and Mudobo Dambos.

3.2.1 Research Procedures

Information from some farmers who have been in the areas since late 1960's, coupled with that obtained from field surveys and aerial photo interpretation, was revealing. Aerial photos with time intervals of ten to sixteen years were chosen in order to observe long-term changes in land utilization and any environmental effects utilization had.

By pairing the aerial photos for each time interval of ten years, i.e 1970, 1980 and 1991, for Mudobo Dambo and a time interval of sixteen/ten years i.e 1967, 1983 and 1993, for Fikolwa, stereoscopic analyses were made and air photo moisaic maps at a scale of 1: 250,000, depicting land use (upland fields, Dambo gardens) rivers, buildings, forests and grasslands, wet Dambo and roads. Using square grids within the mosaic maps with the help of a 1: 250,000 topographic map, the above attributes were characterized in terms of their extent within a given Dambo. The changes for each time interval were noted and these were combined with actual groundtruth information from interviews of key informants and transect walks across each Dambo.

3.2.2 Results and Discussion

3.2.2.1 Land Use Patterns at Mudobo and Fikolwa Dambos

Table 10 highlights some data regarding land use patterns in catchment and associated upland areas in Mudobo and Fikolwa Dambos and their changes over time.

Table 10: Land Characteristics in Dambos and their Catchments

Year	Catchment Area (Ha)	Wet Dambo Area (Ha)	Dambo Gardens (Ha)	Upland Fields (Ha)	Built Area and roads (Ha)	Forest/ grassland (Ha)
Mudobo Dambo						
1970	1 000	250	125	100	25	500
1980	1 000	225	25	175	125	400
1991	1 000	225	200	75	175	325
Fikolwa Dambo						
1967	1 200	125	0	6.25	318.75	750*
1983	1 200	100	275	50	450	325*
1993	1 200	75	300	150	450	225*

*** Covered by bush and grassland**

3.2.2.2 Vegetation Changes

It is evident from the results in Table 10 that there are signs of forest vegetation declining with time in both the study areas of Fikolwa and Mudobo Dambos. At **Fikolwa** Dambo land area under bush and grassland was 750 ha in 1967 but reduced to 325 and 225 ha in 1983 and 1993 respectively. This represents an annual rate of decrease of 3.3%. It can therefore be estimated that by the year 2023 all the trees in the catchment of Fikolwa Dambo will be cleared if their cutting goes on unabated.

At **Mudobo** Dambo there were 500 ha of land under forests in 1970 and 400 ha and 325 ha in 1980 and 1991 respectively. This shows that forest vegetation has been depleted at an annual rate of about 2%. At this rate, the catchment forest would be depleted by the year 2041.

The reasons for the deforestation and grassland clearing are common in the two study areas. Information from the aerial photos, coupled with map interpretation and interviews from farmers reveal the following:

1. Tobacco cultivation in upper catchment areas of both Dambos promotes the cutting of trees for fuel wood used in curing tobacco.
2. At various times, trees have been cleared for opening up new fields for cultivation of other crops like maize, sunflower, groundnuts etc. according to the well-known "slash and burn" technique.
3. Uncontrolled bush fires are responsible for the depletion of grassland bushes and some forest species. Fires are set up in order to hunt small animals and also to clear the bush for cultivation.
4. Cutting of trees for making charcoal is common in both areas.
5. Cutting of trees for timber and fuel wood for domestic purposes.
6. Trees are cut to make beehives from their bark in order to collect honey from them.

The 3% rate of deforestation at Fikolwa Dambo is largely due to the greater ease of clearing grassland bushes as compared to cutting of large forest trees at Mudobo Dambo.

The vegetation in the Dambo at Fikolwa is largely covered by hyparhennia grass inter-spaced with 'Ifinsa" trees - water indicators and surrounded by miombo woodland. At Mudobo Dambo, the surrounding vegetation in the catchment is that of mopane woodland. Mopane trees are often used for making beehives, making fibre for construction purposes and making charcoal.

3.2.2.3 Dambo Gardens And Upland Cultivation

Table 10 gives an indication that there were virtually no Dambo gardens at **Fikolwa** in 1967 but sixteen years later in 1983, a sharp increase to 275 ha of Dambo gardens are evident in both the wet and dry Dambo areas. According to farmers' responses to the interviews, the absence of gardens in 1967 at Fikolwa was partly due to heavy flooding and frost occurrence in the winter months of July and August.

Table 10 further supports these views with values showing the presence of large wet areas (125 ha). Evidence from this study also reveals that major parts of Fikolwa Dambo are acidic in nature and thus utilization is restricted or requires sound management practices for proper soil amelioration. However, 5% of the Dambo, including outlet stream banks which stretch for over 1 km are used for cultivation of vegetables and nurseries for tobacco seedlings. The latter is the reason for a larger area under Dambo gardens (275 ha) in 1983 than the actual wet Dambo area of 100 ha in extent.

Note that the progressive decrease of wet Dambo areas from 125 ha (1967) to 100 ha (1983) and 75 ha (1993) is associated with slight increase in Dambo gardens from no gardens in 1967 to 275 ha (1983) and 300 ha (1993) - an indication of flood recession. Between 1983 and 1993 the further increase in area under Dambo gardens at Fikolwa was very small, only from 275 ha to 300 ha. Thus the rapid increase of 17 ha per year observed in the first sixteen years dropped to an increase of only 2 ha/year over the ten year period of 1983 to 1993. This may signify that almost all households may have accessed Dambo land.

Farmers allude to the fact there were five villages in 1967 as compared to seven and nine in 1983 and 1993 respectively. This conforms to the information in Table 10 wherein the built area and roads coverage remained constant at 450 ha between 1983 and 1993.

It would appear that there is a relationship between reduced rainfall and wet sites in Dambo areas, asone would expect. High rainfall favoured upland cultivation as opposed to cultivation of Dambos. This is logical, since high rainfall will enable successful rainfed cropping in upland areas, while Dambos will be subject to flooding. Conversely, reduced rainfall is associated with with reduced wet sites (little or no flooding) in Dambos and thus favourable conditions for Dambo gardens whereas upland rainfed crops will suffer drought stress during such seasons. This is best illustrated by the sharp increase in area under Dambo gardens and sharp reduction in upland fields at Mudobo Dambo in 1991 when annual rainfall was at the extremely low level of only 550 mm.

The increased use of Dambo gardens can, apart from poor rainfall affecting upland fields, be attributed to the expansion of the village community population due to the advent of schools, hospitals, churches and post offices which have since attracted the settlement of many villages.

The liberalization of the economy to a free market and Government's decision not to be involved in marketing of the staple and other cereals, and removal of Government subsidy on agricultural inputs which supported the growing of upland cash crops, saw reduced cultivation of these crops and forced a shift to staple maize and vegetable growing in gardening as a way of coping with food insecurity. This policy change was well-meant,

but its practical implementation is fraught with many problems, as was also clearly outlined by Kwa-Mensah (1999). These factors coupled with rainfall as a major determinant of cropping in Dambos and upland fields are important, particularly at Mudobo where upland cash crops were grown by many farmers. It is noticeable at Mudobo that the shift from cash crops to staple maize in upland areas also reflects on the adoption of Dambo gardens.

3.2.2.4 Trends in Land Areas Covered by Wet Dambos

Figure 9 indicates that rainfall at Fikolwa Dambo was low the whole period of 1989 to 1991. The 1991 season itself had very low rainfall and saw the entire Southern Africa hit by the worst drought in human memory on the continent of Africa. There appears to be a lag recharge period because 1993 despite being a high rainfall year at Fikolwa, still had reduced wet Dambo areas, showing the effects of the previous dry years which may have lowered the water tables tremendously.

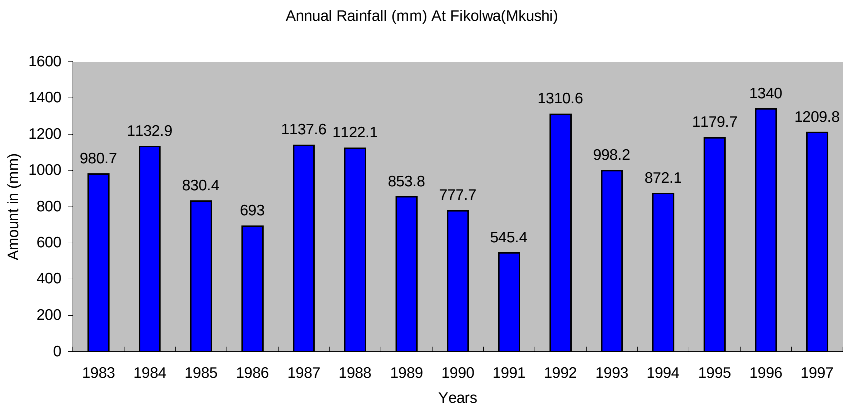

Figure 9: Annual rainfall totals at Fikolwa

Table 10 indicates that in general terms, there has been a slight decrease in the wet areas of both Dambos. Mudobo Dambo shows an average annual decline of about 1% between 1970 and 1980, after which there was no further decline.

At Fikolwa Dambo the average annual decrease in wet Dambo area from 1967 to 1983 was about 1.5%, after which it decreased by about 2.5% per annum between 1983 and 1993. The latter decreases are alarming and could possibly be attributed to the much bigger degree of deforestation at Fikolwa than at Mudobo. Deforestation in the catchment area seems to have had negative effects on the recharging of the Dambo, enforcing an overall dessication of the main Dambo.

Farmers at both locations attribute the reduction of Dambo land to drying as a result of poor rainfall over the years. McCartney and Daka (1998) quote Grant (1995) as follows: ***"The cropping potential of the Dambos results from the availability of water to crops, especially during periods of mid-season drought. It does not result from inherent nutrient availability."***

It would appear that the larger areas of Dambo gardens than actual wet Dambo area is supported by the existence of widespread seepage zones and good aquifer recharge with shallow water tables from which hand dug wells would support appreciable sizes of gardens.

3.2.2.5 Erosion

Erosion was not evident in either Fikolwa or Mudobo Dambo. However, the upland areas in the catchment of Mudobo showed evidence of soil being dislodged by cattle foot tramping along small tracks. This soil can be easily carried away by rain and is normally deposited in Dambos or streams. The upland areas of the Mudobo catchment also have some gullies formed in places of poor drainage, with petroplinthite impeding water entry into the soil and confining it in small channels formed by human activity or cattle. Farmers recognize the fact that overgrazing in the Dambo would cause erosion. At Fikolwa, both the upland and Dambo are free from erosion. Upper catchment areas with deep sandy soils promote infiltration of water and sub-surface flow to recharge lowland areas, particularly the Dambo itself. The effects of catchment deforestation on erosion and the benefits gained by planting trees on degraded and eroded catchments will be dependent on the situation and the management methods employed. However, afforestation itself is not a quick panacea since one needs to know the type of tree species to plant. Other remedies would include the following:

1. Erosion control using contour bands re-enforced with vertiver grass on steep slopes.
2. Reduce or stop indiscriminate cutting down of trees in the catchment area by planting fuel wood plantations in the watershed area. The programme can set up agro-forestry nurseries in conjunction with rural communities and NGOs.
3. Advise farmers not to overgraze their land by not overstocking.
4. Protecting catchment and Dambo vegetation from indiscriminate bush fires.
5. Cultivating across the Dambo slopes in order to arrest the problem of siltation of river and dams.

3.3 CONCLUSIONS

1. Rainfall has a major influence on the land-use changes in Dambos and their upland rainfed fields: Firstly drought years cause prolonged dessication of Dambos, with a good rain season showing a lag time of recharge. Secondly, Dambos act as safety-nets during such drought periods because of their moisture storing potential and less upland fields are used. A good rain season with flooding hazards sees less utilization of Dambos than upland fields which are free from flooding.

2. The above classification reveals some of the ground truth information at Fikolwa where vegetables are difficult to grow. This can be due to soil acidity, particularly in the central/seepage zones where the topsoil pH value was 4.7. Vegetable species tolerant to soil acidity should be identified and grown in this Dambo if it has to be fully utilized (see Table 12 in Chapter 4). Other crops will do well in the rain season, when it is expected that soil pH will be high, provided that flooding will not damage them. Planting on ridges may help. Mudobo Dambo on the other hand would support a wider range of vegetables on account of absence of high soil acidity in topsoil.

3. Acidifying nitrogen fertilizers and excessive nitrogen application must be avoided. Limestone Ammonium Nitrate could be the preferable choice.

4. Less tolerant crops to soil acidity are cabbage, rape, broccolli, cauliflower, chinese cabbage, lettuce, Okra and bulb onion. These will flourish within a pH range of 6.0 - 6.8. This range is most likely to occur in the transition and upper grassland zones of most Dambos. Use of a treadle pump to lift water to gardens in these zones is a must.

5. Use of animal manure at Mudobo is a major source of phosphorus.

6. Water sources from the two Dambos are shallow wells which do not dry up easily. At Fikolwa water from the stream is used for river bank gardening at the outlet.

7. Gradual slopes towards the central zones allow for steady deposition of nutrients from the surrounding high ground. This adds to the fertility status of the soil.