WETLANDS IN DRYLANDS:
THE AGROECOLOGY OF SAVANNA SYSTEMS IN AFRICA

PART 2:
Soil and water processes

by Julie Ingram

IIED
INTERNATIONAL INSTITUTE FOR ENVIRONMENT AND DEVELOPMENT

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This review project was supported by the Swedish Agency for Research Cooperation with Developing countries (SAREC) and was coordinated by IIED, London. The review is a collaborative effort, drawing on the wide experience of researchers based in Europe and Africa.

The review is in three parts and is aimed at providing a broad overview of the role of 'valley bottomland' wetlands in savanna agroecosystems in Africa. The role of spatial heterogeneity and farmers' and pastoralists' responses to patchiness is often ignored by researchers, planners and extensionists. The review aims to map out the key issues and suggests a new way of interpreting savanna agroecosystems with important implications for future directions in agricultural and pastoral development in drylands areas.

Part 1 by Ian Scoones: Overview - ecological, economic and social issues.

The overview provides an introduction to the case studies (part 3) and the detailed assessment of biophysical aspects (part 2). It attempts to highlight key issues that run through all analyses of patch use within dryland agroecosystems. Bottomland agriculture and pastoral systems are investigated with a series of case studies. Questions of environmental degradation, land tenure and appropriate economic analysis are also explored. Part 1 concludes with a discussion of the implications for agricultural and pastoral development.

Part 2 by Julie Ingram: Soil and water processes

The review of soil and water processes examines the literature on soil processes by looking at interactions between topland and bottomland in soil formation and movement. Bottomland wetland areas are placed in a landscape context by reviewing catchment level processes. In situ soil and hydrological factors are also examined. Part 2 concludes with an assessment of the potential impact of land use change on patchy wetland areas.

Part 3: Case studies

Part 3a by Are Kolawole: Economics and management of fadama in Nigeria.

Part 3b by Folkert Hottinga, Henk Peters and Sjoerd Zanen: Potentials of bas-fonds in agropastoral development in Sanmatenga, Burkina Faso.

Part 3c by Mohammed Osman El Samanni: Wadis of North Kordofan - present roles and prospects for development.

Part 3d by Zeremariam Fre: Khor Baraka - a key resource in Eastern Sudan and Eritrea.

Part 3e by Misael Kokwe: The role of dambos in agricultural development in Zambia.

Part 3f by Ian Scoones and Ben Cousins: Key resources for agriculture and grazing: the struggle for control over dambo resources in Zimbabwe.

Contributors

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PART 2: SOIL AND WATER PROCESSES

Julie Ingram

Contents

Glossary of technical terms

aquic moisture regime: implies a reducing regime that is virtually free of dissolved oxygen because the soil is saturated by water.

baseflow: flow derived form throughflow and from the water table which flow laterally into stream channels .

Basement Complex: basement complex shields are areas of Precambrian rocks which have remained rigid and associated with acidic crystalline rocks.

catena: a sequence of soils derived from similar parent material and occurring under similar climatic conditions, but having different characteristics due to variation in drainage and relief.

cation exchange capacity: The sum total of exchangeable cations that a soil can adsorb. Expressed as milliequivalents per 100grams of soil or clay.

clayveld: a term used to distinguish soils with relatively high clay content.

colluvium: A deposit of rock fragments and soil material accumulated at the base of steep slopes as a result of gravitational action.

evapotranspiration: The combined loss of water from a given area and during a specified period of time by evaporation from the soil surface and by transpiration from plants. When the moisture supply is unlimited the term potential evapotranspiration is used.

ferricrete: an indurated horizon cemented by iron oxides, often with other sesquioxides (Mn, Al, Ti).

ferrolysis: cyclic process involving reduction of Fe oxides during microbial decomposition of organic matter after water saturation, followed by oxidation of the exchangeable ferrous ions produced.

ferruginous: denoting rocks or mineral containing iron, often resulting in a red colour.

Fersiallitic soils: a group of soils whose clay minerals consist predominantly of 1:1 lattice type and the clay fraction also contains free sesquioxides (Zimbabwe Classification)

gley soil: soil developed under conditions of poor drainage resulting in reduction of iron and other elements and in grey colours and mottles.

groundwater: water that fills all the unblocked pores of underlying material below the water table, which is the upper limit of saturation.

hydraulic conductivity: an expression of the readiness with which a liquid; such as water, flows through a soil in response to a given potential.

hydromorphic soils: a suborder of soils all formed under conditions of poor drainage in wetlands.

infiltration rate: the rate at which water enters the soil under specified conditions.

inselberg: a steep rounded outcrop, hill or mountain usually of granite or gneiss which stands out above a pediment (cf kopje).

interfluve: high ground between different drainage networks (cf watershed and topland).

intergrade: a soil that possesses moderately well developed distinguishing characteristics of two or more soil groups.

laterite: an ill defined term used as a general term for any horizon or formation consisting predominantly of hydrated iron and aluminium oxides. Formed by weathering under tropical conditions especially on iron-rich rocks. In this sense includes plinthite and ironstone.

leaching: the removal of material in solution from the soil.

miombo: term used to describe Brachystegia-Isoberlinia-Julbinardia dominated woodland extensive on plateau regions of southern Africa.

montmorillonite: an aluminosilicate clay mineral with a 2:1 expanding crystal lattice.

mottling: patches of different colour or shades of colour interspersed with the dominant matrix colour.

munga: woodland dominated by Acacia-Combretum association characteristic of basic rocks in southern Africa.

parent material: the unconsolidated and more or less chemically weathered mineral or organic matter from which soil is developed.

pediment: an erosional plain of bedrock developed between mountain and basin areas in arid zones, may be covered by alluvial or colluvial deposits.

redox: reduction-oxidation.

regolith: the unconsolidated mantle of weathered rock and soil material on the earth's surface; loose earth materials above solid rock.

sandveld : a general term used in southern Africa for sandy soils developed on granitic rocks with characteristics of soils developed on old weathered surfaces subject to long periods of leaching.

sodic soil: a soil that contains sufficient sodium to interfere with the growth of most crop plants and in which the ESP is or more aeolian: resulting from wind action.

throughflow: water which flows laterally in the soil layers.

Vertisol: soils high in swelling clays which crack widely upon drying (USDA Soil Taxonomy, FAO Legend)

wadi: seasonal watercourse usually dry

1 INTRODUCTION

It is the purpose of this review to discuss the soil-water relationships of wetlands. Particular consideration is given to the environmental processes active in the catchment which influence the form and function of wetlands, and therefore their potential for, as well as their response to, agricultural or livestock usage.

In this review the general term "wetland" is used to cover the range of inland valley landforms discussed in Part 1. These generally occur at the headwater end of drainage systems in level to gently undulating areas which are remnant of ancient planation surfaces (Dalal-Clayton 1988). In broad terms they constitute elementary drainage systems as distinct from proper fluviatile valleys in more downstream situations which have different morphology, and hydrological and depositional dynamics (Raunet 1985). They can be distinguished from other wetlands with similar features such as floodplains, alluvial plains and pans which exhibit different morphology and channel development; and from marshes and swamps that are permanently waterlogged.

Because of the diversity of inland valley types it is difficulty to describe a typical wetland form or refine a precise definition. One needs therefore to consider them in terms of the processes (past and contemporary) they respond to. The emphasis of this discussion will thus be on reviewing what is known about the soil and hydrological processes active in wetland catchments, rather than concentrating on definitions and descriptions. By looking at catchment dynamics as opposed to status it is also easier to predict the impact of change on wetlands either due to environmental instability or human activities.

2 WETLANDS IN THE LANDSCAPE

2.1 Environmental factors controlling wetland existence and distribution

Most inland valley wetland types in Africa are associated with stable planation surfaces consisting of undulating plains with dominantly convex slopes. They tend to be restricted to areas of low gradient (Thomas and Goudie 1985; Acres et al 1985; Mackel 1985b). In southern Africa they are mainly a feature of the Central African Plateau, as in Zimbabwe where the low relief and gentle river gradient of the central watershed regions favour the formation of dambos (Whitlow 1985). Figure 1 is a block diagram showing the features of a typical dambo landscape in northern Zambia. In central northern Nigeria the most favourable conditions for fadama development are where conditions of stability have existed over a long period as occur in the zone south of the Kaduna/Kano divide (Turner 1985).

Figure 1: Block diagram of a typical dambo landscape in northern Zambia (source: Acres et al, 1985).

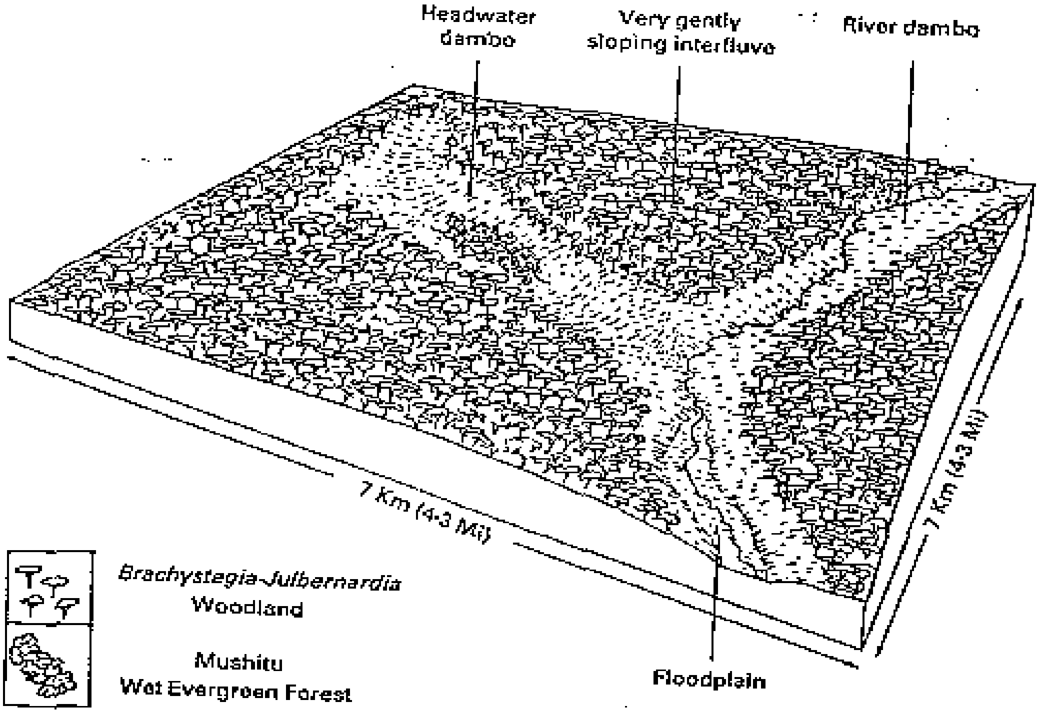


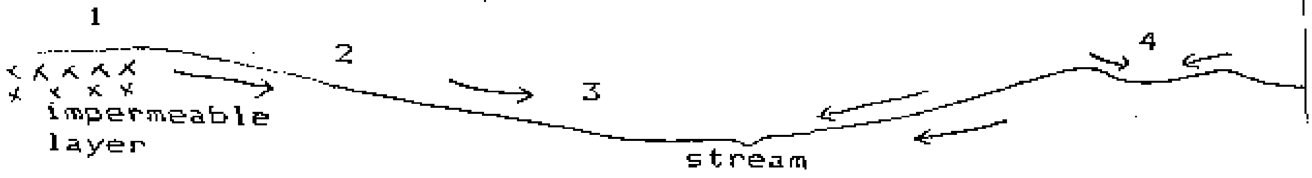
Figure 2: Diagram to show how hydromorphic soils can develop in the landscape in response to different sources of water (source: Moorman et al, 1976).

1 Hydromorphic, impeded rainwater

2 Hydromorphic, interflow water and runoff

3 Hydromorphic to swamp, runoff, stream water, high groundwater

4 Hydromorphic, runoff water



The extent of landscape covered by dambos tends to be related to geomorphic units and degree of plateau dissection. In plateau regions in Zambia dambos have been described as accounting for 5-15% (Mackel 1974) and 10% (Dalal-Clayton 1980) of the landscape compared to figures of 30% for the granitic highveld of Zimbabwe (Rattray et al 1953). Average slope values in the region of dambo occurrence in southern Africa are between 0.5-2.5 degrees (Butzer 1976). As relative relief increases dambos are generally uncommon or more localised; consequently they are not so much a feature of transition zones between planation surfaces (Acres et al 1985).

Certain environmental conditions are considered as prerequisites to wetland maintenance and function. With respect to hydrology, seasonal waterlogging is fundamental to wetland maintenance. This is primarily due to climatic regime but differences result due to geology, geomorphology, soils, vegetation and texture (Acres et al 1985; Whitlow 1980). Bullock (1988) concludes that the hydrological factors that promote development and maintenance of wetlands are the concentration of precipitation both seasonally and within storm events, promotion of lateral movement of water towards the valley bottom and impedance of channel drainage.

In Turner's (1985) opinion the existence of fadamas depends on retention of moisture in the soils which is determined by two major influences: the availability of moisture and the moisture retaining capacity of the soils. She found three factors which have most influence on distribution of total and perennial fadama in central northern Nigeria: climate/vegetation factor (the length of the rainy season being the most important); depth of regolith/rate of erosion; and longitudinal gradient of the valley or depression.

2.2 Wetland position in the landscape

Although wetlands reviewed here are generally headwater or valley bottom features found on lower slopes, they can occur anywhere in the catchment where conditions allow either surface water to collect or groundwater to approach the surface. Taking a broad definition, wetlands are not confined to low lying landforms, they may occur on higher parts of the landscape like river terraces, footslopes and even tops of hills, or where the land surface is level or depressional and soils are heavy textured and impervious (Van Diepen 1985; Kyuma 1985b). Figure 2 shows schematically how wetland sites can develop at different points in the landscape in response to different sources of water.

Whitlow (1980) points out that, depending on rock type and disposition, waterlogging may occur anywhere between the interfluve and valley bottom site with bedrock, clay horizons and ferricrete all capable of modifying the situation of vlei conditions on a slope. In Central Province, Malawi, Meadows (1985) observed dambo development where the wet season rise in water level intersects or lies close to the surface and therefore identified dambos in three situations: the watershed sites where watersheds are smooth with little gradient so water collects in the wet season; valley sites, where dambos develop on sides of gently convex interfluves or along axial drainage lines; and inselberg sites, where the runoff from inselbergs collects at the foot. Whitlow (1985) describes "perched" dambos as developing where a raised water table occurs caused by the presence of impermeable subsoils in the lower members of the soil catena.

A range of different wetland forms which have developed at various positions in the landscape with varying geomorphological and hydrological features have been identified and described. In southern Africa two main dambo forms are distinguished: "headwater dambos", which are channelless and broad, found in the headwater zones of valleys (these correspond to "headwater fadamas" as defined by Turner (1985)); and "river dambos" which are the downward extensions of headwater dambos on either side of the river (Garlick 1961;). Figure 1 shows the position of these two forms. In Zimbabwe DRU (1987) describe the latter as "stream dambos" which are adjacent to second and third order channels while Turner (1985) identifies the larger "streamside fadamas" in Nigeria which occur from the beginning of the stream channel to the point where the floodplain develops. In West Africa Andriesse (1985) and Savvides (1981) distinguish "streamflow valleys" formed on upper parts of the catchment and the "river overflow valleys" along smaller rivers.

Descriptions of other less common dambo sites are also available. Acres et al (1985) describe "slope dambos", which extend headward or laterally up valley sides and have steeper slopes than headwater dambos; and "hanging dambos" ("scarp dambos") which are perched above the escarpment on plateau margins. "Residual dambos" were observed by DRU (1987) in Zimbabwe, these are narrow and linear along first order stream sides. "Flush" and "sand dune" dambo types are identified in Luapula Province, Zambia in addition to "upland", "valley", and "hanging" types (Dougnac 1987), while Turner (1985) discusses "floodplain fadamas" which consist largely of alluvial deposits and features.

In Western Zambia, "linear dambos" which occupy depressions between parallel dunes in the residual dune fields of the Kalahari sands; and long valley dambos mantled by deep muck deposits are found (Brammer and Clayton 1973; Dalal-Clayton 1985, 1988). Linear peat filled dambos are also described by Whitlow (1985) on Kalahari sands in Zimbabwe. Also in Western Zambia seepage strips (known locally as <u>litunga</u>, see Part 3e), which comprise peat overlying sand, occur along the scarp at the margin of the Barotse (Zambesi) floodplain (Verboom and Brunt 1970; Brammer and Clayton 1973). Other wetlands, known locally as <u>dilungu</u>, peculiar to the border areas between Zambia and Zaire, are unlike any other dambo described. They can occur on (flat) interfluves or extend between interfluve upper slopes and drainage lines and have been described as "watershed" dambos (Trapnell 1937, Dalal-Clayton et al 1985).

Often a sequence in dambo development can be identified. In Zimbabwe DRU (1987) describe a sequence of dambo types through headwater, stream and residual which can be seen moving down the valley from the watershed. In the catchments of the Northern Plateau of Nigeria, Turner (1985) also describes a continuous succession from floodplain fadama, through streamside with decreasing amounts of alluvial material, to headwater fadama in which all material is of colluvial or aeolian origin. Similarly Dalal-Clayton (1985, 1988) describes sequences of headwater dambos and river dambos which are related to geomorphic units of increasing plateau dissection.

There are fewer references to wetland position in the agroecological landscape. In the central watershed areas of Zimbabwe dambos are associated with dry land fields or rough grazing land upslope, Figure 4 is a cross section showing the agricultural and vegetational zones commonly found in dambo catchments. Clearly wetlands are just one component of the agricultural landscape, they are not used in isolation, but as part of the overall production system (see Part 1).

2.3 The soil landscape

Where there is a fairly regularly recurring pattern of landscape morphology in an area of fairly uniform parent material, there is generally a regularly occurring sequence of soils associated with it. This topographic sequence is called a catena (Milne 1935) and wetland soils are generally considered to represent the bottom member of tropical catenary sequences (Watson, 1964; Young, 1976, see Figure 3).

In southern and eastern Africa two broad types of catenary sequences can be distinguished: those associated with acidic rocks, sand veld soil types and miombo woodland; and those derived from more basic rocks, dominated by clay soils and characterised by munga woodland.

The former is the catena most often recorded in the classic descriptions of Milne (1947); Webster (1965); and Brown and Young (1962). This savanna catena, which is developed on gently undulating plateaux under a savanna climate on felsic (acidic) -intermediate rocks, is characterised by reddish clay profiles on the crest section becoming yellower on the slope section followed by a lens of bleached or mottled sandy material occurring at the valley floor margin giving way to black clay at the valley centre (Young 1976). Dalal-Clayton (1987) and Priestley and Greening (1956) describe similar sequences for plateau soils in Eastern Zambia, where it was observed that the transition between the soil units can be gradual or fairly abrupt depending on the slope. Figure 3 is a schematic diagram showing sandveld catenary soils and their associated landscape units in Eastern Zambia.

Figure 3: Schematic diagram showing a sand veld catena and associated landscape units in Eastern Province, Zambia. Source: Dalal-Clayton, 1987; Priestley and Greening, 1956).

Soil Units (Priestley and Greening 1956)
A. Sandy clay loam
B. Marginal sands
C. Sandy dambo fringe
D. Heavy dambo soils
E. Parent material
— Laterite

Landscape Units (Dalal-Clayton 1987)
1. Interfluve ridge
2. Footslope
3. Interfluve upper-middle slopes
4. Interfluve lower slopes
5. Dambo margin
6. Dambo

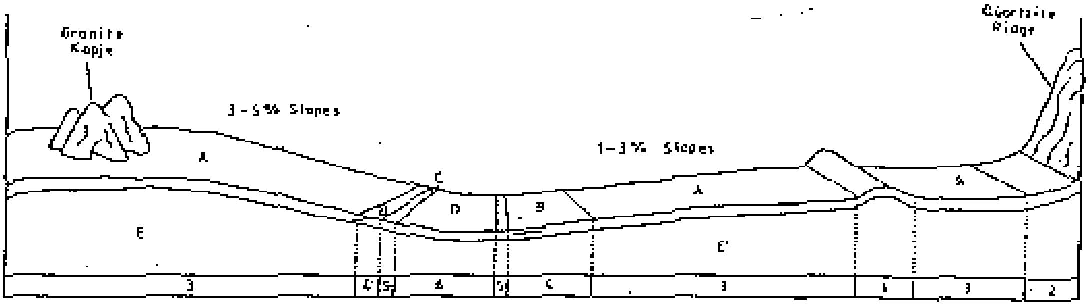
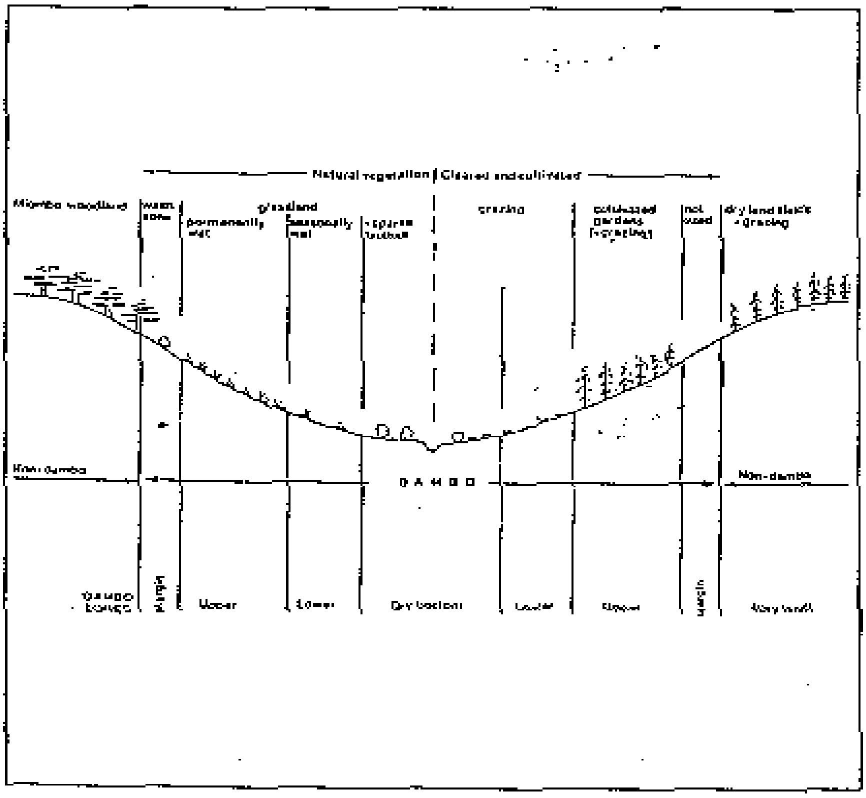


Figure 4: Schematic cross-section showing typical agroecological zones in a dambo catchment in the Zimbabwe high veld (Source: DRU, 1987).



A less obvious sequence is observed in areas of basic rocks, which Dalal-Clayton (1987) terms clay veld areas. In areas of gneiss or intermediate granulite, Mollisols and Alfisols are found on upper and middle slopes with very fertile soils on lower slopes where dark topsoil material washed down by sheet erosion has accumulated. Dambo soils in these areas are characterised by deep heavy montmorillonitic cracking clays (Vertisols).

A catenary sequence on gneissic rocks in the lower rainfall regions of Zimbabwe, where perched dambos have developed, is described by Whitlow (1985). Here the soils become increasingly sodic down the slope as there is insufficient subsurface seepage to completely remove sodium salts eluviated from upper slope soils. As a result, clay disperses and an impermeable subsoil forms on the mid-slope sites. The lower slopes and valley bottoms are characterised by greyish brown mottled sodic soils.

A number of descriptions of catenary sequences in Africa are available; for example, on granite in Zimbabwe (DRU 1987; Savory 1965; Whitlow 1985; Watson 1964; Thompson 1975; Thompson and Purves 1981), for plateau soils in Zambia (Dalal-Clayton, 1987; Priestley and Greening 1956); on granite in Tanzania (Milne 1935, 1947); in the Lilongwe area of Malawi (Billing 1978); on granitic gneiss in Nigeria (Nye 1955); in central northern Nigeria (Turner 1977); on Basement Complex rocks in south-eastern Nigeria (Juo and Moormann 1980); and in the Oshun River area of Nigeria (Okali et al 1979a; Okali et al 1979b).

In summary, wetlands are found in a range of forms and positions in the landscape. They do, however, most commonly occur in "receiving sites" in terms of soil, hydrological and slope processes. Their soils generally represent lower catenary members, whilst in terms of hydrological processes, occurring as they do in lower slope positions as well as drainage headwater areas, they are well placed both to respond to upslope water inputs, and to influence patterns of downstream flow.

2.4 Natural disturbance

Form and function of the wetland will change in response to changes or fluctuations in climate, vegetation, topography and landscape and as such they must be regarded as dynamic features. Indeed Meadows (1985) observed that dambos are sensitive indicators of environmental change, while Thomas and Goudie (1985) propose that a characteristic common to all dambos is that their formation is probably associated with the effects of environmental change. Natural disturbances are an important explanatory factor in understanding wetlands. Natural processes of disturbance must be considered alongside human induced change when examining wetland degradation and sustainable land use (see Section 7).

Wetland form change and destruction

Change in wetland form can be attributed to natural evolution. (Ackermann, 1936; DRU, 1987). Dalal-Clayton (1987) discusses sequences of dambo types in Eastern Zambia and relates their genesis to geomorphic processes over time. Turner (1977) proposes that variations in the physical characteristics of fadamas are a result of differences in the stage of evolution within a cycle of fadama. In this cycle, under conditions of stability, accumulation of fine grained soil particles, mineral nutrients and organic matter in depressions leads to gradual deepening and widening of the fadamas by processes of deep weathering and surface wash.

Turner (1977) observes that the existence of fadamas depends on the maintenance of a delicate balance between erosional valley-forming processes and depositional valley-filling processes. Disturbance of this balance can easily lead to their destruction. Similarly Smith (1985) considered features of the plateau/dambo landscape in Zambia as the result of "fragile equilibria", which are both disturbed and restored by local erosion and deposition without external interference.

Wetlands can be destroyed in two ways: the lowering of the water table may lead to gradual drying out, or an increased rate of erosion may lead to either gradual downstream removal of the deposits or rapid destruction by gullying. Conversely a rise in the water table or return to conditions of stability may restore wetlands (Turner 1977). The change of phase from wetland development to wetland destruction originates mainly through a lowering of the base level.

Two sorts of fadama in Nigeria which have changed form are described (Turner 1985). "Gully floor fadamas" are secondary fadamas which occur when active erosion and deposition cease and the gully becomes stabilised and colonised by vegetation. "Fadama terraces" are former mainstream fadamas into which the stream has become incised. If the stream is further incised, there will be a fall in the water table below the terrace until there is no longer waterlogging in the wet season, so the terrace will no longer be a fadama.

Mackel (1985a) attributes recent ecological changes in woodland and grassland mosaic in Zambia to dambo migration. This involves the headward and lateral extension of the dambo through sheetwash of loose fine material from marginal miombo via the wash zone towards the centre. This creates a lowered and flattened margin that can be more easily flooded during rains, resulting in a site more favourable for grass than trees. The long term result of this migration is the extension of grassland at the cost of the woodland.

As well as the lateral and headward extension of dambos, Mackel (1985b) also discusses destruction through incision of the drainage channel at the lower end due to intense downcutting of the base level. This accelerates surface and ground water flow out of the dambo and lowers the ground water level so the dambo dries out with a consequent change in vegetation. Thus aggradational (or cut and fill) and degradational (or denudational) dambo forms are recognised.

According to Smith (1985) both erosion and deposition can act with great speed. Meadows (1985) concurs that sediment can build up and erode very rapidly, and that perhaps all of it can be removed in a single storm event. Indeed a loss of 5-6 cm of topsoil in one (early rainy season) storm in Eastern Zambia was recorded by Dalal-Clayton (1987).

Climatic stability

Changes in the wetland environment can also be attributed to changes in climate. Bond (1963, 1965, 1967), discussing southern Africa, noted that climatic controls govern the balance between aggradational and erosional phases; aggradation occurring in high rainfall areas where dense vegetation traps colluvial sediment in the dambo. He sees 890 mm mean annual rainfall as the threshold for change from aggradation to degradation and attributes dambos in areas where contemporary precipitation is not appropriate to their development as evidence of climatic change. Mackel (1974), however, stresses climatic change to be of minor importance in changing the situation from one of formation to one of dissection, although scarp dambos are considered to be more sensitive to climatic change, because of steeper slopes and a greater difference in height between the dambo and the base level of the downcutting river (Mackel 1985b).

Drying out of wetlands

Desiccation of wetlands can result from changes in the hydrological system induced by climatic changes. Rattray et al (1953), from a review of meterological data from Zimbabwe, concluded that rainfall over most of the country was below normal in the decade ending with the 1950-1951 season. The Meterological Department stated that drying out of dambos during this period was largely due to deficient rainfall with more marked effects in areas which had not received their average amount.

Secular changes in climate resulting in declines in rainfall or changes in frequency may also have an impact on wetland sites. Reduced rainfall levels, particularly the reduced incidence of heavy rainfall events, in Sudan have been shown to have a significant impact on shallow groundwater recharge, resulting in declines in local water tables (Walsh et al, 1988: 193). This is apparently not offset by increased run-off (due to lower topland infiltration capacity, as a result of deforestation, heavy grazing and drought related reductions in vegetation cover). The result has been reduced wadi and overland flows, reduction in shallow aquifer and perched water table levels in wadi beds and adjacent to inselbergs and the drying out of shallow wells, surface pools and hafirs (Walsh et al, 1988: 181).

The source of inputs can also be important with regard to desiccation. Smith (1985) considers that those dambos which receive less dry season seepage, but large amounts of surface flow, are more likely to dry up during a dry episode, as seepage is unable to remove material in solution.

Conclusion

The scale and time span of these natural disturbances and the wetland response to them obviously varies. However, it is clear that they can have a considerable impact on wetland stability and form, often over relatively short periods and as such might account for change in form of wetlands often blamed on human induced land use change.

3 WETLAND SOILS

3.1 Definition and classification

Many definitions of wetland soils (Moorman & Van de Wetering 1985, Van Diepen 1985). A major distinction should be drawn between seasonally dry wetland soils as opposed to perennially wet ones. Brinkman and Blokhuis (1985) describe the former as mineral soils, while the latter have deep peat at their centre. Criteria used for this distinction, however, vary as do the wetland characteristics which they relate to. For example, Turner (1985) distinguishes perennial fadamas which retain moisture within the maximum rooting depth of crops (approximately 3 m) throughout the dry season, and seasonal fadamas, where the water table falls below this level before the end of the dry season.

The classification of wetland soils has been considered at great length (IRRI, 1985; Juo and Lowe, 1985; USDA, 1975; Moorman and Van de Wetering, 1985; Wilding and Rehage, 1985). The type and duration of saturation (or the moisture regime) that the soil is subject to and the resulting hydromorphic features generally form the basis of wetland soil classifications. According to Van Diepen (1985), the best counterparts of wetland soils in the FAO-Unesco Legend (FAO, 1974) are "soils showing hydromorphic properties within 50 cm of the surface", which applies to Gleysols, Histosols and the gleyic groups of other units.

3.2 Soil formation

There are conflicting views on the origin of dambo soil materials, although two main opposing theories for the development of wetland mineral soil emerge; namely that soils either develop from colluvial and/or alluvial infill or they develop from in situ weathering of parent material.

Whitlow (1985) discusses these with respect to dambos in Zimbabwe where Savory (1965) considers colluvial infilling as the most important process. Purves (1976), however, argues against colluviation on the basis that soils downslope become progressively less weathered and that clay contents decrease up to the dambo margin; this suggests that lower slope soils are younger than deeply weathered and leached upslope soils thus indicating in situ weathering and soil development. Acres et al (1985) observe that it is the preferential wash of fine material toward the dambo bottom and of sandy material down the adjacent interfluve slope that determine dambo parent material. It is most likely, however, that wetland soils have developed from a combination of processes, the intensity and extent of which are determined by individual site characteristics. Whitlow (1985) concludes that dambo soil origins are complex and that the variation in soil characteristics across and down slope is indicative of a combination of eluviation, in situ weathering, and colluviation interrupted by phases of active removal of materials. Catena studies in Eastern Zambia support this view (Dalal-Clayton 1987).

Parent material in wetland depressions is rarely undisturbed, it usually comprises of colluvium and sheetwash deposition from upslope or alluvium from flooding (Thomas and Goudie, 1985). In West Africa Hekstra and Andriesse (1983) observe that former planation surfaces are only found on catena summits and crests. On lower slopes colluvial deposits and material from upslope form soil parent material while in valley bottoms alluvium originating from areas upstream is the parent material.

Meadows (1985) considers that there are a variety of sediment sources and that these, together with the geomorphic processes responsible for dambo infill, can account for the complex stratigraphy he observed at Lifupu Dambo, Malawi. He considers that the textural variation in the dambo transects may be due to in situ geological facies variation as well as characteristics of colluvial material.

In Sierra Leone, boli topsoil and subsoil textures are variable and strongly influenced by lithology suggesting that in situ weathering at the base of swamps is an important evolutionary mechanism, as well as sheetwash from adjacent uplands and fringing swamp terraces (Millington et al 1985).

Clearly there is no single model that explains wetland soil formation as each wetland is an individual case and is subject to a combination of soil forming factors which are site-specific.

3.3 Soil types

Parent material

Parent material has an important influence on soil texture and soil reaction. Acres et al (1985) recognise six broad categories of dambo soils, using texture as the main distinction: peat, sandy clays, sandy, black cracking clays, grey clays and termite soils. Although Acres et al (1985) observe that sandy clay dambo soil textures are most widely reported, their review of dambo soil properties in East and southern Africa shows a textural range from clay to sand. Andriesse (1985) similarly observes that inland valley soil textures in West Africa range from sand to clay, depending on the nature of the parent material, while Brinkman and Blokhuis (1985) report the same range for wetland soils in general. In Sierra Leone, boli soil textures are variable, particularly when adjacent uplands have erodible soils, which have generally coarser textured topsoils due to greater sediment inputs by sheetwash (Millington et al 1985). Zonation downslope and horizon development in the soil profile means that wetlands rarely have uniform texture throughout. In Zimbabwe, Thompson (1969) distinguishes two dambo soil types as a function of parent material: the non-calcic hydromorphic derived from kaolinitic clays; and the calcic hydromorphic dark montmorillinitic clays, alternatively referred to as sand vlei and clay vlei type respectively (Elwell, 1983). This latter distinction accords with the descriptions of two broad dambo soil types on sandveld and clayveld in Zambia (Dalal-Clayton 1987, 1988).

In southern Africa dambos are generally classified on the basis of their pH (Perera 1982). "Sour" dambos are common in wetter areas and on weathered granite and Basement Complex rocks, their soils are mostly weakly acid (pH 4-4.5), for example, at Grasslands in Zimbabwe granite vlei soils have pH in the range 5.2 - 5.9. "Sweet" dambos occur on calcareous rocks and their soils are neutral to strongly acid (pH 7-8) and characteristically dominated by black cracking clays. Wetland soils developed from calcareous sediments or parent material rich in weatherable minerals contain higher salt contents and are more strongly base recharged than adjacent better drained upland (Wilding and Rehage, 1985). A transitional "intermediate" dambo is also recognised with pH levels between 5.5 and 7.

3.4 Wetland zonation

Different zones according to position on the slope can generally be distinguished in wetlands (see Part 1). Three main zones are identified in dambos: "margin", "main dambo" and "sponge" (or eye), although the spatial patterns are often complex and the boundaries poorly defined.

Mackel (1985a) found in Zambia that despite their different shapes there exists a uniform zonation of dambos depending on vegetation, soil type, moisture content and morphodynamics. He distinguishes three zones: the "seepage belt" is found at the lowest part, which is almost flat and most liable to flooding; upslope of this the "lower washbelt" (the largest part of the dambo) is a transitional zone of mixing of the coarse material brought down from upland with fine material in the dambo; and the "upper washbelt" extends up to the edge of the surrounding woodland, and can continue into the woodland. Perera (1982) describes the same zonation in dambos in Zambia, while Acres et al (1985) also recognise this zonation but

Figure 5: Cross-section of a dambo showing zonation and suggested terminology (Sources: Acres et al, 1985; Mackel, 1974; Bullock, 1988).

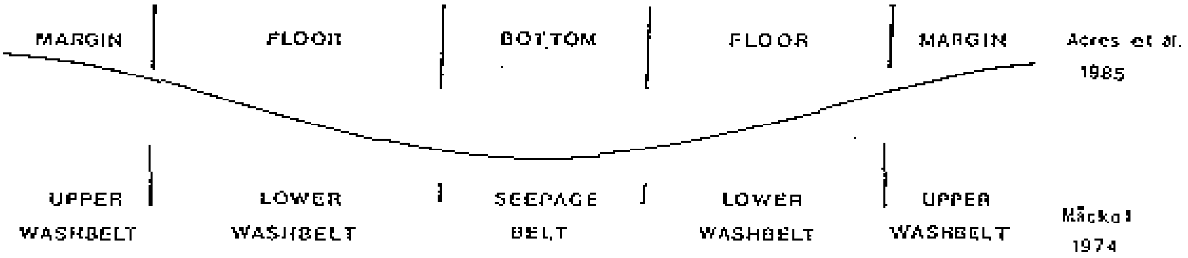
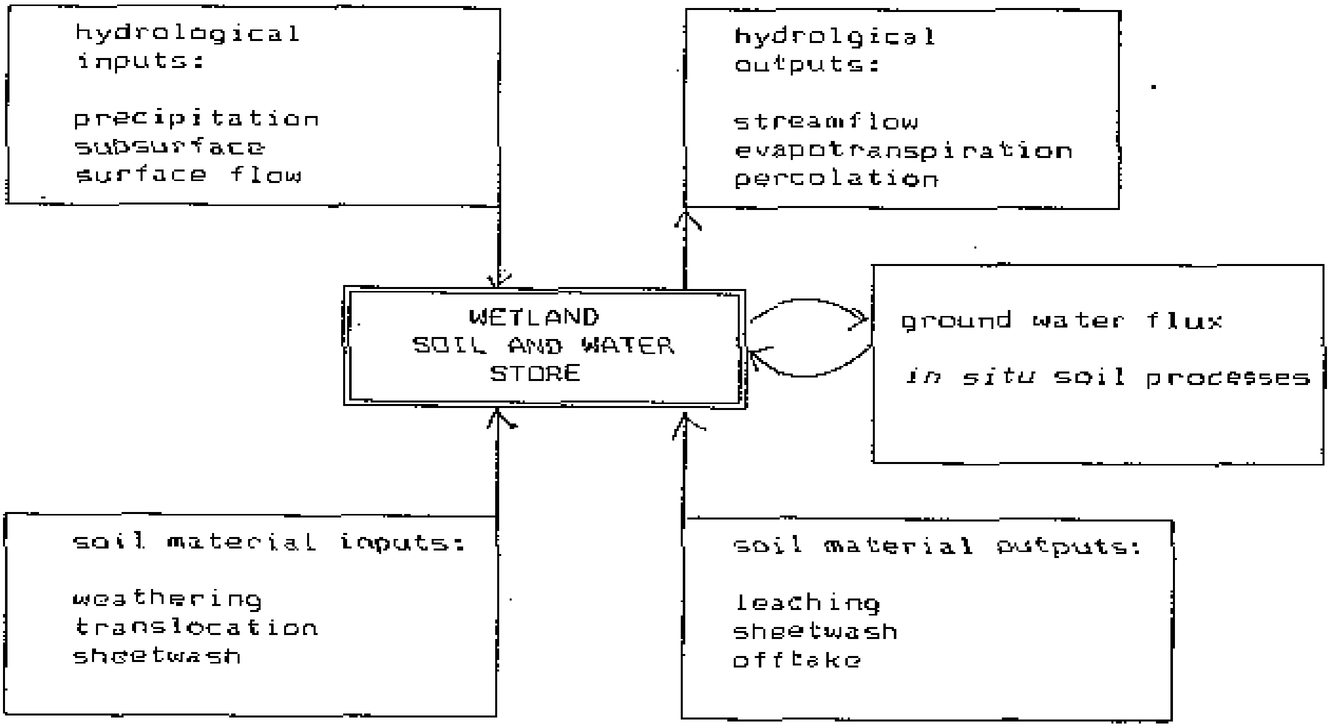


Figure 6: Simple model showing interaction between the wetland store and the processes that control inputs, outputs and internal cycling.



propose a new terminology. Figure 5 shows schematically the position of these zones and the terms used to describe them.

The occurrence and extent of these zones will obviously vary. Acres et al (1985) describe dambos in Tabora, Tanzania where the lower washbelt occupies most of the dambos with the seepage belt varying in extent; the upper washbelt is usually in a narrow fringe merging into woodland.

DRU (1987) recognise two similar upper zones in their study area in Zimbabwe, the "upper dambo zone", a band of seepage below the margin; and the "lower dambo zone" where some ground is saturated during the wet season but dries out by the end of dry season. They describe, however, the lowest part of damboas the "dry bottom zone", as this may be dry throughout the year in broad headwater dambos, in contrast to other parts of Africa where the central part or eye is permanently waterlogged. Figure 4 is a schematic dambo cross section showing these zones.

Zones do not necessarily always occur, they may be absent, as in calcic hydromorphic dambos which are more uniform and dominated by the properties of montmorillinitic clay. Usually, however, there are distinguishable soil differences. The zones themselves may not be homogenous while the boundary between zones is also not well defined, with no clear slope break except where laterite is found (Acres et al, 1985). Whitlow (1985) observes that plant communities, although often used in zoning, are not always reliable indicators unless there is a well defined slope where soil drainage is pronounced. Malaisse (1972), however, talks of an abrupt contact between dry miombo on interfluves and herbaceous vegetation on dambos. Although not always apparent by surface expression, boundaries may be abrupt within the subsurface part of the catena (Dalal-Clayton 1987). The zone boundaries, as a function of water inputs, can also be seasonally shifting.

The differentiation of soils described for a catena from interfluve to valley bottom is often repeated in the wetland itself. Acres et al (1985) describe a common soil sequence in cross section in non-calcic hydromorphic soils consisting of a narrow fringe of sandy soils at the dambo margin, a strip of grey clay soils at the dambo bottom, with a broad zone of sandy clay between. The increase in clay content towards the centre is attributed to preferential wash of fines towards the dambo bottom. This sequence accords with a catena described in eastern Zambia by Dalal-Clayton (1987) although the sandy soils were observed to be more extensive than a narrow fringe at the dambo margin and duplex profiles with loamy sand abruptly over sandy clay were observed at the dambo margins. Figure 3, a schematic diagram of a sand veld catena, shows this zonation. Meadows (1985) similarly observed that particle size declines from the margin of the Lifupa Dambo, Malawi with sandy soils of the wash belt giving rise to clays in the seepage belt. Zonal distribution of organic matter also occurs with peaty horizons increasing from wetland margins to lower grassland (Whitlow 1985; Savory 1965).

4 UPSLOPE INFLUENCES ON WETLANDS

Wetlands can be viewed as interruptions to water flow between the upland or interfluves slopes and the stream channels below. Their form, function and maintenance therefore is influenced both by the soil and hydrological processes on the upland slopes as well as processes within the wetland itself. Patterns of downstream flow emanating from wetlands operate in response to these. All components of the system therefore need study with respect to how changes in their status can influence the wetland environment. This section considers the role of the soil and hydrological processes active in the catchment upslope of wetlands.

4.1 Hydrological processes

Wetland form and function depend on the presence and movement of water. Figure 7 shows the role of the wetland as a store or transfer site in the hydrological cycle of the catchment as a whole and illustrates the importance of upslope hydrological processes to wetland dynamics. The main sources of hydrological inputs into and losses from the wetland are considered here.

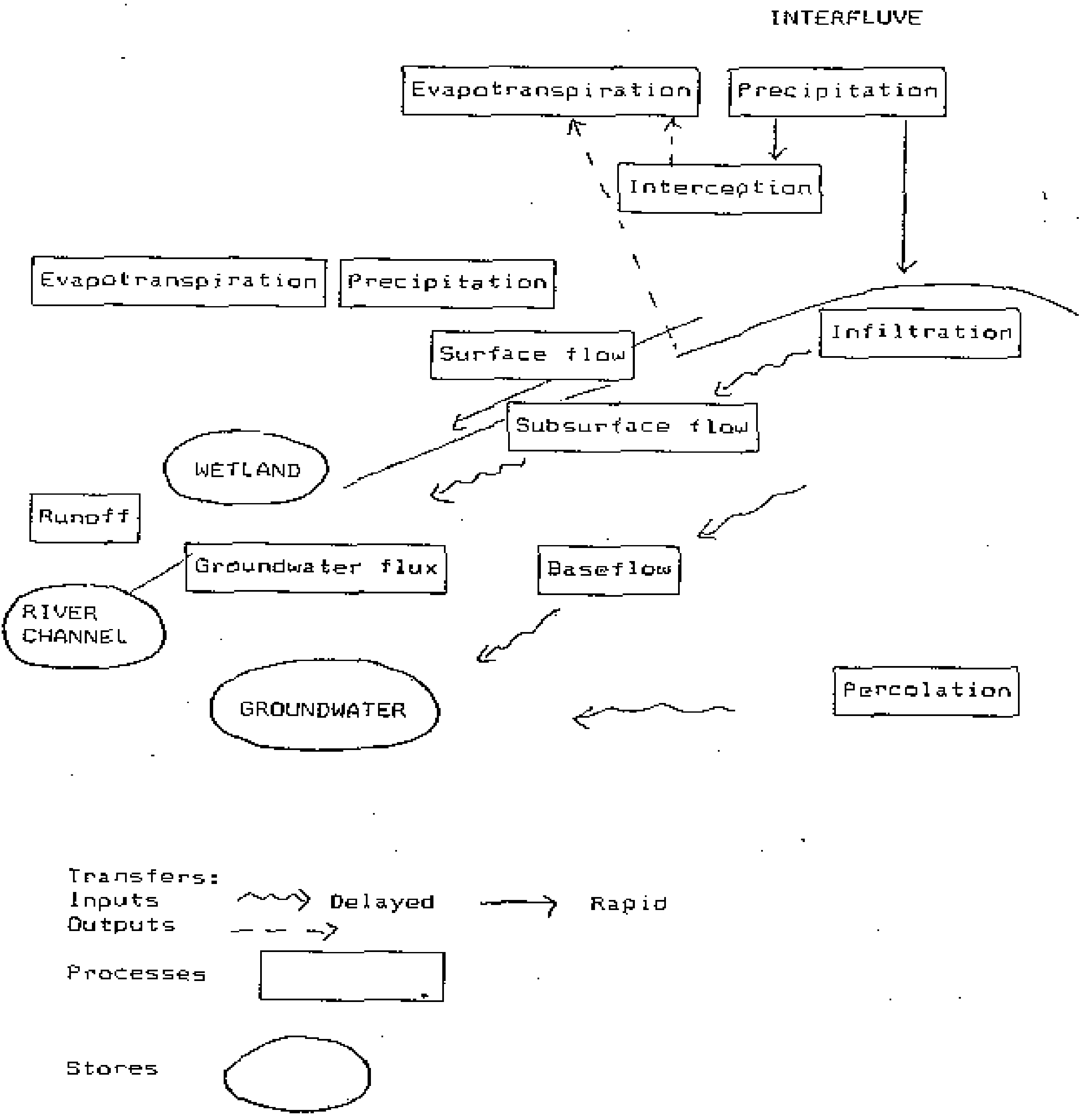
Sources of inputs

Different wetland forms will receive water from different sources, depending on their position in the landscape. Streamflow valleys in the uppermost parts of the river catchments, for example, receive water from rainfall, runoff and seepage, while the main water source to downstream river overflow valleys is overflow from the river (Andriesse, 1985). Moorman and Van Breemen (1978) distinguish two main types of wetland on the basis of hydrological conditions: those which mainly receive water by ground water as well as precipitation; and wetlands which mainly receive water by surface runoff, streams etc. This distinction, however, belies the dynamic aspect of different inputs.

Three main sources of water inputs to the wetland system are recognised: precipitation, surface flow and subsurface flow. It is generally believed that subsurface flow from interfluves contribute most to dambo groundwater (Acres et al 1985; Rattray et al, 1953; Robertson 1964). The contribution from subsurface flow is evident as a seepage zone at the lower slopes and at the dambo margin, with the amount depending on the size of the catchment and interfluve width (Acres et al 1985). In Sierra Leone the main water inputs to bolis are considered to be surface runoff, throughflow from adjacent uplands and ground water seepage (Stobbs 1963; Millington et al 1985). These observations, however, are rarely backed up with quantitative data.

Results from major water balance studies in catchments in Luano, Zambia concluded that the main part of dambo water

Figure 7: The hydrological processes operating in catchments and the inputs and outputs that influence wetland dynamics (after Begg, 1986).



storage is derived directly from precipitation onto the dambo with the contribution from the interfluves only occurring during the dry season (Balek and Perry 1973). Whitlow (1985) offers some support to this view. DRU (1987) working at Chizengeni dambo in Zimbabwe found that the contribution from interfluve sources was a third the precipitation which fell on the non-dambo portion, and that direct precipitation on to the dambo constituted 57% of total runoff from the catchment. This will clearly be a function of the extent of the dambo within the catchment.

Surface versus Subsurface flow

The partition of precipitation input to the interfluve into surface and subsurface flow will depend both on the intensity of the rainfall and the infiltration capacity of the soil surface; the latter being a function of soil characteristics, vegetation cover and slope. The influence of the soil-vegetation complex on runoff generation and the impact of vegetation change has been the subject of a few major hydrological studies in Africa which are reviewed by Whitlow (1983) and Turner (1977) and considered later in Section 7.

The nature of the upper slope members of the catena is important in determining the extent of subsurface flow. Savvides (1981), discussing fadamas in the Bida area of Nigeria, observes that sandstone formations, with a high rate of water absorption in the interfluves, are necessary for rain to percolate and seep out at valley edges. In sand veld areas of southern Africa, where many middle and lower slope catena members are characteristically duplex profiles (with sand abruptly overlying sandy clay), water can rapidly penetrate the upper sandy horizons but cannot drain through the underlying heavier material and so drains laterally into the dambo (Dalal-Clayton 1987, 1988).

Surface runoff is increased with an increase of slope angle of the soil surface. Gently sloping terrain encourages infiltration but enables free lateral subsurface flow. The gentle terrain of much of the granitic sand veld in Zimbabwe induces infiltration rather than runoff, while the high infiltration capacity and low retention of the interfluve soils encourages absorption and throughflow (Whitlow 1983). Using reported figures of rainfall intensity and infiltration capacity for sand veld soils in Zimbabwe, Bullock (1988) concludes that as infiltration rate is rarely exceeded by rainfall intensity under miombo woodland, due to the sandy nature of the soil, the greatest contribution from interfluves is by subsurface flow. He recognises, however, that surface runoff is occasionally generated by intense storms, as is evidenced by the occurrence of sheetwash. The source of precipitation input, as well as the nature of interfluve flow, varies seasonally. Bullock (1988) suggests that in Zimbabwe, throughflow is only important as an input to dambos in the dry season, while direct precipitation accounts for most of wet season input.

The amount, variability and seasonality of inputs will influence the availability of water in wetlands and therefore have important implications for their agricultural potential. This point is considered further in Section 5.

Sources of losses

The proportion of precipitation input to interfluves which reaches the wetland will be determined by the extent of losses due to interfluve evapotranspiration and percolation into the regolith.

Evapotranspiration

Evapotranspiration is one of most decisive factors in the water balance equation, indeed data for the Chizengeni catchment in Zimbabwe shows that evapotranspiration is the greatest single component in the water budget after rainfall (DRU 1987). Losses by evapotranspiration are a function of surface cover, climatic variables and soil moisture deficit. They will therefore be subject to seasonal, annual and regional variations.

Evapotranspiration losses from the interfluves

The extent and seasonal variation of evapotranspiration rates from the interfluve in relation to precipitation will determine the volume and timing of subsurface flow from the interfluve. The rates, and the factors that control them, therefore have an important influence on water inputs into, and the hydrological dynamics of, the wetland.

Although reported measurements of catchment evapotranspiration losses vary, they do demonstrate that evapotranspiration can constitute a major loss from the system. Hough (1986, citing Alexandre 1978), observes that evapotranspiration can account for up to 90% of the total precipitation at moist miombo sites. Drew (1971), measuring evapotranspiration directly from tree branches, recorded 35 mm/day from Brachystegia species (in miombo), while Balek and Perry (1973) report that in Zambia all stored water from flatter wooded interfluves can be taken up by evapotranspiration with values in the order of 1300-1450mm/yr recorded, and that potential evapotranspiration can in fact be exceeded.

Rattray et al (1953) noted the seasonal influences on evapotranspiration; commenting that vleis are wetter at the start of the cold season because there is less activity by interfluve trees at this time. In the Chizengeni catchment, Zimbabwe it was found that although the dry season rate (evapotranspiration mean) for the dryland area (grazed or cultivated) is low (0.44 mm/day), the large area means that the overall volume is high, accounting for > 40% of the total evapotranspiration from the catchment (DRU 1987). High evapotranspiration values for upland grazing were also observed which indicate that losses from the upland portion of the dambo catchment are likely to continue through much of the dry season.

Evapotranspiration losses from wetlands

It is assumed that wetland vegetation transpires at potential or maximum for much of the year because of the availability of water, and continues to evapotranspire during the dry season due to the high water table (Whitlow, 1985; Hough, 1986). It is suggested that more water is lost from a wetland than from an equivalent area of open water because the water is spread out laterally over a wide area. However, it is also argued that wetland plants shield the water surface from exposure to sun and wind and so less water is lost than from an open surface (Begg 1986).

Estimates of dry season evapotranspiration at Chizengeni catchment, Zimbabwe show that the dambo is the main surface for evapotranspiration in the dry season (evapotranspiration mean 1.22mm/day) with the "upper dambo zone" being most significant (DRU 1987). In contrast Balek and Perry (1973) put annual evapotranspiration losses from dambo grasses at a third those from Brachystegia woodland on the interfluves; the most significant part of evapotranspiration occurring during the rainy season. A review of their data shows that evapotranspiration rates from dambos are consistently lower than from the woodland zones for the whole year, and (in contrast with woodland values) were never found to exceed potential evapotranspiration. Bullock's (1988) analysis of river flow data in Zimbabwe, however, do not support the different evapotranspiration rates presented by Balek and Perry (1973) for different vegetation communities.

Different sources of maximum evapotranspiration within the dambo have been identified. Bullock (1988) suggests that rapid depletion of water by evapotranspiration occurs from the upper soil horizons of the dambos in Zimbabwe such that dry season water tables are confined to the gleyed zone which is inaccessible to roots and represents the main storage component of the dambo. Dalal-Clayton (1988) states that this is particularly the case in sandy over sandy clay/clay duplex soils in sand veld areas in Zambia. Bullock (1988) also suggests that the persistence of high water tables caused by the impedence of subsurface flow from upslope at the dambo margin is the primary source of dry season evapotranspiration loss, while deeper throughflow passing beneath the dambo is protected from the evapotranspiration processes and so can contribute to streamflow. Similarly the highest dry season evapotranspiration rates were observed at the "upper dambo zone" at Chizengeni, where water from upslope is pushed to the surface by impermeable rock and plant growth is most vigorous (DRU 1987). If the wetland margins evapotranspire at higher rates, more wetlands in the catchment should result in more evapotranspiration due to an extensive dambo perimeter.

The extent and seasonality of loss by evapotranspiration from wetlands has important implications for the volume and timing of streamflow as considered in Section 6. The impact of wetland land use on evapotranspiration rates and therefore water resources is also an important consideration and discussed in Section 7.

4.2 Catenary processes

Lateral subsurface or surface water flow from the interfluve and valley sides determines the soil material inputs to and outputs from wetland patches. Processes in the soil catena are dependent on the presence and movement of water and therefore inseparable from hydrological processes.

Variations in soils within a catena are usually attributable to differences in internal drainage (subsurface flow) and lateral movement of dissolved and suspended material. On the other hand, surface runoff is responsible for movement of soil particles downslope as sheetwash; while mass movement and soil creep also contribute to slope erosion. Raunet (1982) considers that these mechanisms are operative in influencing "tropical valley bottom" characteristics, with superficial runoff generating mechanical erosion; and percolating water being responsible for solutional removals and transformation products. Thompson (1975) observed that both sheetwash and throughflow are responsible for moving nutrients and clay into dambos in Zimbabwe.

Differences in moisture regimes between member soils, as well as the effects of lateral movement through them, is important in the differentiation of soils in a catena; both factors being accentuated by marked seasonal rainfall. According to Thompson and Purves (1981) the effects of this seasonal pattern is that rain is concentrated into a limited period so the amount of water absorbed is more than can percolate to depth and therefore flow is enhanced. Surface runoff will also accumulate to a greater extent on lower slopes than if rain was evenly distributed throughout the year. In Zimbabwe these phenomena have two main effects: the marked translocation from upland to lowland of clays and soluble weathering products; and the reduction and removal of iron as a result of anaerobic conditions induced by waterlogging in the lower soils.

The rise and fall of groundwater and the generation of anaerobic conditions is also an important element of catenary processes. Lower catenary processes are not only dependent on lateral subsurface flow into wetlands, but also the degree of fluctuation in the wetland itself. The latter is a function of seasonal rainfall regime, regolith character and bedrock disposition of both the wetland depression and the adjacent upper slopes (Whitlow 1988).

Throughflow

Clay translocation

Clay translocation is the removal of dispersed clay particles from the upper soil horizons by water moving vertically and laterally within the soil. This requires both active throughflow and for clays to be in a dispersed state. Slaking or dispersion of clay particles in percolating water can occur when soil is first wetted after a dry period. In Zimbabwe, in Fersiallitic soils over granite, Thompson and Purves (1981) state that the clay fraction is rendered mobile and translocated laterally downslope as a result of "deferration" (the reduction, mobilisation and removal of iron laterally under anaerobic conditions). Lateral and vertical translocation of clay are coincident; the former results in the textural transition of soils from coarse to finer material often described down a slope in siliceous soils, while the latter results in heavier textures lower in the profile. In Zimbabwe clay translocation downslope is the main feature in soils from siliceous material (Thompsom and Purves 1981) while, in central northern Nigeria, Turner (1977, 1985) describes fadama soils (bottom members of the catena) as tending to have a higher clay content than the ferruginous tropical interfluve soils they are derived from. This textural differentiation is often repeated within the wetland itself with clay content increasing towards the centre.

Patterns of increasing clay content downslope, however, do not always occur and Young (1976) states that it has not yet been proven that lateral translocation of clay particles occurs in appreciable amounts. Variation in texture downslope was observed by Savory (1965) in a catena on granitic rock at Grasslands, Zimbabwe; while Thompson (1975) describes a catena on granite in Zimbabwe from kopje down to vlei. The heaviest textured soils occur near the base of the kopje and the clay content of lower slope soils are less than would be expected with translocation. In Eastern Zambia Dalal-Clayton (1987) observed soils becoming increasingly more sandy downslope in catenary sequences on sandveld resulting in a deep sand lens on the lower interfluve slopes and dambo margins with the fine material carried into the dambo centres. Similarly coarser grained soils are described by DRU (1987) in lower segments of a catena on granitic rock at Chizengeni in Zimbabwe.

Translocation of soluble weathering products

Percolating water will remove the soluble products of weathering from soil profiles on interfluves and upper slopes. Water moving laterally will carry these to profiles on the mid and lower slopes, where wetlands occur. All substances involved in vertical, leaching including silica, iron, salts and exchangeable bases, are also carried laterally. Profiles lower down the slope will be illuvial and usually have a higher pH because they receive salts and bases from upslope. Christianson (1981) explains the dark colour of the clayey mbuga soils occurring in Ugogo, Tanzania as due to calcium which is brought downslope. The ash produced following the burning of vegetation is another source of bases, which can be dissolved and carried downslope by throughflow.

The nature and amount of soluble products transported downslope, however, will depend on the interfluve parent material and the intensity of its weathering and vertical leaching. Upslope soils which are old, highly weathered and leached, as described by Millington et al (1985) in Sierra

Leone, for example, are unlikely to release bases for passage downslope.

Iron and manganese compounds can be reduced and mobilised under anaerobic conditions induced by waterlogging occurring anywhere in the catena. These are transported downslope in the soil solution and may be oxidised at the seepage zone at the wetland margin, the more iron-rich the parent material, the more extensive the deposit. For instance, groundwater laterite horizons in wetland soils are evidence of seepage from upslope. In some wetlands in Zimbabwe stones and pebbles are occluded during ferricrete development creating a conglomerate (Thompson and Purves 1981). Dalal-Clayton (1988) observes that ferricrete outcrops are common along dambo margin seepage zones throughout the sand veld areas of Zambia. Meadows (1985) similarly observed nodular laterite gravel to be common below the "wash belt" at Lifupa Dambo, Malawi. Ferricrete nodules can also occur at depth in waterlogged and well drained sites and laterite commonly underlies dambos (Savory, 1965; Acres et al 1985; Magai 1985). Many boli and inland valley swamps in Sierra Leone are characterised by iron rich scum on the water in channels adjacent to slopes, indicating a high iron concentration in subsurface seepage water from adjacent upland Ferralsols (Stobbs 1963).

The downslope movement of dissolved material in throughflow also has implications for applications of fertiliser upslope. Rainfall immediately following application may result in vertical and/or lateral leaching into the wetlands of more soluble fertilisers.

Surface flow

Surface flow is associated with the movement of suspended material in wash and rill processes resulting in the deposition of sediments downslope. There is usually preferential wash of fine material from the interfluve to valley bottoms resulting in a textural transition downslope. The nature and amount of sediment movement depends on upslope soil properties, rainfall characteristics, steepness of slope, distance from the slope crest and land use.

Stocking (1986) has demonstrated that considerable amounts of nutrients and soil organic matter can be removed in sheetwash, estimating that the potential annual nutrient loss in sheet erosion on sandy soils in Zimbabwe to be in the order of 0.97 kg/ha nitrogen, 0.155 kg/ha phosphorus and 10.7 kg/ha organic carbon per t/ha/year soil loss. Considering that estimates of soil loss from these soils under traditional agriculture are in the range 30-50t/ha/year (Elwell 1984), this represents a sizeable loss of soil nutrients. These losses from upslope, however, represent potential gains to lower slopes and wetlands.

Catenas

Although the parent material will be an important factor determining soil differentiation down the slope, certain trends in soil characteristics arising as a net result of the processes discussed above can generally be expected. These are, moving down the slope: increased soil depth; an increase in clay content; an increase in organic matter content and depth of the surface organic matter horizon; reduced acidity; and an increased expression of hydromorphism.

4.3 Wetland soil fertility

Wetland depressions will be receiving sites, or stores, for the suspended and dissolved material transported in surface and subsurface lateral flow from upslope. The extent of their accumulation in the wetland depends on the amount and duration of water passing through (this being a function of water source and flow patterns); the physical environment and how it affects resistance to flow (surface and subsurface); the solubility of the material; and the soil chemical environment (e.g. whether it is favourable to retention of nutrients).

Wetland soils commonly serve as repositories for salts and soluble products of weathering transported from adjacent uplands by overland flow, throughflow or ground water recharge. Consequently they usually have a higher pH than upland soils (Wilding and Rehage, 1985; DRU 1987; Turner, 1977, 1985).

Receipt of suspended and dissolved material from upslope has implications for wetland soil productivity. It is generally believed that the accumulation of soil fines and their constituent nutrients, organic matter and bases in wetland soils increases their physical and chemical fertility compared to adjacent slopes. In Zimbabwe, Thompson (1969) states that "vlei soils are always inherently more fertile than surrounding topland soils", while Rattray et al (1953) observe that dambo soils are normally rich in organic matter and usually have more 'body' and fertility than those of the surrounding upland. In central northern Nigeria Turner (1977, 1985) describes fadama soils as generally finer grained than the upland soils and richer in mineral nutrients and organic matter. Dalal-Clayton (1987) describes how deep fertile soils have developed on lower slopes in clay veld areas of Eastern Zambia. These additions of organic matter to wetland soils can enhance both physical and chemical fertility.

DRU (1987) found that soils of the "upper dambo zone" at Chizengeni dambo in the granitic areas of Zimbabwe had higher CEC (cation exchange capacity) values (6.2 vs 1.9 meq/100 g clay), base saturation (60% vs 25%), available phosphorus (11 vs 6 ppm), more fines and a more favourable pH (6 vs 5.5) compared to the dry topland soils. Turner (1977) similarly reports higher mean CEC values for fadama soils compared to upland soils (14 meq/100g vs 8 meq/100g soil), although base saturation levels were similar for both soils (43% vs 42%).

In Zambia the dambo seepage zone is sometimes flushed by nutrient rich spring water which increases pH and improves phosphorus, potassium and nitrogen status, although the basis for this is not clear (Dougnac 1987). Perera (1982) in a study of soils of the Katanga series (developed on limestone parent material) in the Lusaka Province, Zambia found that the dambo gleys compare favourably with corresponding upper catena soils in respect of nearly all soil chemical properties analysed. He suggests that these properties, while partly the result of heavy texture and slower organic matter decomposition, originate also from transfer in solution of ions from higher parts of the catena.

Wetland soils therefore often represent fertile patches in the landscape with high potential for agricultural production. Their use, however, is often restricted by difficult physical properties resulting from heavy textures and waterlogging. In Tanzania Milne (1947) describes how alluvial soils which have developed in response to cycles of wet season waterlogging and dry season aridity, lose their former fertility and acquire the 'unpleasant' physical properties of 'true mbuga soils'.

Although wetland sites benefit from inputs of soil material they are also subject to the effects of leaching and erosion which remove these same materials from the system. Figure 6 is a simple model showing the interaction between the wetland store or transfer site and the processes that control inputs and outputs. Other sources of losses from the system include nutrients lost by grazing, burning and harvesting (collectively described as offtake).

The balance between inputs and outputs is clearly important to wetland form. Smith (1966) notes that both the shape and spacing of dambos are the result of balances between the supply of rainfall to the seepage zone of the soil and depletion of the seepage zone by springs along laterite outcrops and free faces at dambo edges. If a dambo does not have a sufficient dry season flow to remove all that comes into solution it becomes clogged, and in time reverts to a condition like an undissected plateau soil.

Internal pathways of nutrient transfer also exist in wetlands and in this respect some of the models developed to explain nutrient relationships in African swamps might be applicable (Denny 1985). It is possible, like rooted swamps, that wetland vegetation can act as a nutrient pump, or like some swamps have the ability to deplete or enrich elements in the water flowing through them (Begg 1986).

Accumulation of some materials can lead to problem wetland soils. In Zimbabwe the proportion of sodium ions to calcium + magnesium ions and the degree and duration of water movement determine whether bases accumulate downslope or are removed. In lower rainfall areas (500-650 mm) Fersiallitic soils on uplands are usually associated with areas of sodic soils in lower catena positions, because of insufficient rain and amount/duration of lateral flow to remove sodium rich bases and clay brought down from upslope. In higher rainfall areas increased movement of water within the wetland soils removes bases, notably sodium, thereby reducing the tendency for sodic soil formation (Thompson and Purves 1981).

In some circumstances evaporation of salts in wetlands may lead to accumulation of harmful concentrations at the soil surface or in the root zone and salinity problems may develop in the dry season. This potential hazard is recognised in valley bottoms in the northern parts of tropical subsaharan Africa (Hekstra and Andriesse 1983). The presence of ferrous ions in seepage water entering wetlands has also been noted to induce iron toxicity in rice.

Wetland soil fertility status is also a function of parent material, soil age and moisture status. In Sierra Leone, Millington et al (1985) found that the agricultural potential of bolis and inland valley swamps is limited by their fertility levels; boli soils being particularly deficient in phosphorus. They explain this as being due to their derivation from old and leached parent material.

Okusami (1985) found that soil fertility was the key constraint to sustaining rice yields in hydromorphic soils of West Africa, with soils of inland valleys derived from intensely weathered soils of adjacent uplands being less fertile than the younger alluvial plain soils. He found CEC and organic matter levels to be low, potassium to be deficient and topsoils to be acid. Similarly Andriesse (1985) recognises the main constraint to rice cultivation in the wetlands of the WURP study area in West Africa to be the coarse soil that prevails in the sedimentary formations and granitic rocks.

The fertility of wetland soils is not always enhanced by inputs from upslope. Whilst some wetland soils are clearly more chemically fertile, others merely reflect the impoverished conditions of the soils upslope. Difficult physical conditions and toxic accumulations can also act as soil constraints to wetland use.

5 IN SITU PROCESSES

5.1 In situ hydrological processes

Groundwater fluctuations

Water table fluctuation in wetlands is important in terms of the patterns of flux, duration of waterlogging, seasonality, persistence in dry season, volumes involved, and time of initial rise and depletion. These not only control soil processes but also the potential for agricultural development.

Initial rise of water table

The proportions of the hydrological input into the wetland from the interfluve or directly from precipitation, and the seasonality of these relative sources will affect the time and rate of the initial rise of water table. For example, response will be more rapid where direct precipitation is the major input to the wetland. In measurements of ground water levels, Balek and Perry (1973) report from Zambia that dambos appear more sensitive to precipitation than non-swampy areas; ground water levels rise rapidly soon after the rainy season starts, then become more or less constant because the dambo is fully saturated and precipitation is lost in runoff. Acres et al (1985) talk of ground water level rise "some time" after the start of the rains, depending on the incidence, intensity and amount of precipitation.

Wet season fluxes have been observed to be a function of soil type, both of the wetland and the adjacent slopes, with a more rapid flux in sandy soils compared to a slower one in clay soils which absorb less runoff. Fluctuations and timing of seasonal water table rises will also depend on the vegetation cover of the topland areas, especially if subsurface flows are important. Farmers in Zimbabwe observe a rise in dambo water table before the onset of the rains. This may be attributable to the decrease in woodland evapotranspiration during this period, with subsurface water flows appearing in the bottomlands.

Turner (1977) working in Nigeria observes that annual fluctuations in groundwater are greatest in the interfluve areas and least in the fadamas. Similarly DRU (1987) report a significantly greater fall in groundwater levels on the upper regions of Chizengeni catchment compared to in the dambo. Great differences between groundwater conditions in different wetlands have also been reported; measurements of fluctuations in fadama water tables by Ipinmidun (1971 cited by Turner 1977) revealed this. Seasonal fluctuations are particularly affected by upstream dam building and water control (see Part 1).

Duration and persistence

The duration and persistence of wetland water tables is a function of wetland storage capacity, contributions from upslope aquifers as well as input characteristics. Wetland form (depth and slope), underlying geology, soil type and depth, and vegetation all influence the capacity of wetlands to store water.

Savvides (1981) observes that in sandstone areas in Nigeria the duration of swamps (fadamas) depends on the storage capacity of the strata over an impermeable layer and the movement of water through them; both in the interfluve and the wetland. Where the soil surface has a high intake rate and the lower strata a high storage capacity and low movement rates, swamps will develop for longer periods. The slope of the impermeable layer also influences the amount and duration of seepage. Savvides (1981) also expects swamps fed by large watershed areas to last longer. The influence of aquifer storage upslope on wetland duration is considered further in Section 6.

A distinction can be made between dambos with persistently high water tables and those with more fluctuating water tables. This appears to be related to the rainfall regime. In higher rainfall areas dambos are more likely to be saturated with the result that ground water levels remain constant in the wet season; whereas fluctuating water tables are associated with drier areas where saturation does not occur. Greater annual variability can be expected where saturation varies with precipitation distribution. If saturation is achieved in the wet season, persistence for several weeks after rain, with water table levels at the surface, can be expected. The persistence of high water tables into the dry season for one month to several weeks has been observed (Muneka and Mwassile, 1986; Cormack 1972).

Depletion

Researchers present variable data on the rate of depletion of dambo ground water, reporting a gradual fall (Kanthack 1945, cited by Bullock 1988); an initial rapid fall followed by constant fall (Balek and Perry 1973); or a fairly rapid but steady fall followed by a slower steady fall (Turner 1977). Although, most dambo type wetlands have an outlet, in some isolated dambos or pans with no outlet, water escapes through seepage or evaporation (Veldkamp 1986).

Balek and Perry (1973) explain that a limited storage capacity of dambo aquifers results in dambo depletion times being constant and attribute intermittency of dambo outflow to duration of rainy season rather than amount of rain. Thus a shorter dry season may result in perennial outflow from the dambo.

Other factors, such as slope and lithology, are important in determining the duration of dry season baseflow. Discharge measurements taken from streams draining swamps in Sierra Leone show significantly different depletion rates between lithologies. This lithological control over dry season depletion suggests that the major variation in water losses is due to groundwater seepage (Millington et al 1985). Discussing conditions in the Bida area of Nigeria, Savvides (1981) observes that the relationship between timing of streamflow in swamps and rainfall is not absolute because of geological and seasonal complications.

Internal drainage

Surface drainage is generally poorly defined in wetlands, but discontinuous channels can occur. In his case study at Grasslands, Zimbabwe, Whitlow (1980) describes how jointing in granitic rocks creates a pattern of basins and rises leading to an irregular drainage pattern. Irregularity in topography can also result in throughflow being concentrated into subsurface channels or pipes, with drainage via such a system being more rapid than lateral seepage. Mackel (1985b) observed such a continuous underground flow in the lower layers of dambos in Zambia where surface water percolated down cracks or into holes at the edge of termite mounds. Such piping is very important for subsurface drainage in sodic soils.

The nature of the drainage may also change through the season, depending on the properties of the wetland soils. For example, in Vertisols, where wide cracks develop during the dry season, drainage is rapid down the cracks at the onset of the rains but becomes slow when the soil swells and the cracks close. Whitlow (1980) notes that organic matter deposition also affects wetland drainage with throughflow seeming to occur along the interface between the organic horizons and the underlying sand.

5.2 Availability of water for agriculture

The greatest asset of wetlands in terms of agriculture is their ability to act as stores of water within the catchment, Figures 6 and 7 illustrate this role.

In areas where rainfall is a constraint, the value of wetlands agriculturally is mainly due to the fact that they remain wet far into, and sometimes throughout, the dry season. The problem in evaluation of the potential of these soils, however, is the dynamic nature of this important characteristic, since water tables fluctuate over several metres during one year and in differing patterns between years. It depends on the entire watershed, as well as the topographic situation of the wetland, as to whether it will receive sufficient water during the dry season to produce a crop (Veldkamp 1986).

The soil moisture regime is important to wetland agricultural potential, particularly with respect to the initial rise of the water table, in terms of planting time; its depth, in terms of suitable crops; duration of availability, and in terms of the length of the growing season. These characteristics are subject to the variability and seasonality of the relative sources of water input as considered above. There are cases where dambos may be wet during some dry seasons but are completely dry in other dry seasons. Veldkamp (1986) describes this as a common occurrence in shallow dambos where underlying laterite causes stagnation of water in wet periods. In long dry periods where there is no water supply the water evaporates until the dambo is dry. The importance to agriculture of this variable status of wetlands is clear.

Rainfall variability also results in dynamic boundaries between zones in the wetland, as well as between wetland and dryland (Brinkman and Blokhuis, 1985). It can also lead to fluctuation between perennial and seasonal wetland forms (depending on the criteria employed). The greatest variability in wetland water availability exists in the more marginal rainfall areas. Clearly the key to successful exploitation of wetlands is flexibility of cropping systems (see Part 1; Part 3).

One of the main physical constraints to wetland cultivation in wetter areas is liability to flooding and the only crop that thrives when its roots are submerged is swamp rice. Moormann et al (1976) consider the hydromorphic lands of Nigeria to have great potential for increasing rice production because the growing season is prolonged by additional soil water, however, this potential is restricted by other limiting soil properties (IITA 1987/88).

However wetland rice farming should not be viewed in isolation. In Sierra Leone farmers invest in wetland cultivation only in combination with dryland rice farming. Men and women may concentrate to different extents on cultivating rice on different parts of the catena (Richards, 1986; Leach, 1990). An exclusive concentration on wetland development may result in inappropriate development strategies.

Rice has specific hydrologic requirements. To achieve paddy conditions, the rainfall in the valleys and throughflow from upland must first replenish groundwater to the surface. Gunneweg et al (1985) found that during dry years in Bida, Nigeria the contribution from groundwater was nil and rainfall was insufficient to maintain a layer of water on fields, while during wet years the groundwater flow is considerable and farmers tap the seepage zone for rice cultivation. In Sierra Leone data suggests that 90% of wetlands in the plateau will be dry at the surface by late April and therefore potential for continuous rice cultivation exists only for about 10% of wetlands developed on the Basement Complex which maintain standing water (Millington et al 1985). In the Tabora region of Tanzania characteristics of mbuga have been found to compensate for inadequate and unreliable rainfall and consequently proved suitable for rice. This suitability, however, varies among the different zones, while site conditions vary from year to year (Silva 1987).

Different wetland zones have potential for different uses (see also Part 1). In the wet dambo zone the water table is sufficiently close to the surface to permit grass and crops to grow, normally <2 m throughout the year and <0.5 m during the wet season (DRU, 1987). In Zimbabwe soil moisture is still available in the "upper dambo zone" in the dry season for plant growth when the rest of the area is dry, and it is here that the cultivated gardens are found. Similarly the "upper grassland seepage zones" of plateau dambos in Zambia were found to be the most promising areas for dry season cultivation (Dougnac 1987). In Nigeria vegetables are chosen according to their rooting depth to correspond to differing ground water levels in different parts of the wetland, while in Zambia peasant farmers recognise the potential of the "upper wash zone" and "seepage zones" of dambos for rice and wheat during summer and winter months respectively (Perera 1982). Dambo seepage zones are also important for vegetable production in the early dry season in southern Africa, the crops using residual moisture. Perera (1982) suggests that in Zambia the methods used by farmers for selecting suitable sites for cultivation, using traditional norms for estimating wetness of the different zones, are useful indicators of site productivity.

5.3 In situ soil processes

In situ soil processes, as distinct from catenary processes, are restricted to the wetland depression itself and are primarily a function of the wetland moisture regime.

The morphological properties of wetland soils are well known (Blume and Schlichting, 1985; Stoops and Eswaran, 1985; Kyuma 1985b) but the pedological processes are rarely considered or understood according to Wilding and Rehage (1985). Although hydromorphic properties are common to wetland soil, Stoops and Eswaran (1985) note that different morphological expressions of soil "wetness" may be expected according to the dominant pedogenic processes active in the area and the degree of evolution of the soil material. Reduction and gleying constitute only one of the properties diagnostic of wetland soils with many of the pedogenic processes the same as in soils in non-aquic regimes (Wilding and Rehage 1985).

Redox transformations

Chemical processes in aquic moisture regimes are dominated by reduction or alternating cycles of oxidation and reduction. Iron and manganese transformations, and phosphate and trace element mobilisation are characteristics of seasonally or permanently saturated soils (Wilding and Rehage, 1985). Alternating oxidising-reducing conditions result in the release of iron and manganese from primary minerals, and their segregation into mottles and concretions. These are a common feature in wetland soils. The degree of mottling depends on the iron content of the soil and the duration of dry conditions. Petroferric material deposition can be associated with present or relic redox conditions. Prolonged saturation and the coincident reduction and mobilisation of iron and manganese compounds results in gleying which is characterised by pale blue/grey soil horizons. A major distinction is made between "ground water" and "surface water" gleys. In some soils, wetness does not lead to reducing conditions as the groundwater may contain considerable amounts of dissolved oxygen, such as in areas with moderate relief and lateral water flow.

Submergence tends to increase pH of acid soils and depress pH of alkali soils (Wilding and Rehage 1985). Alternating oxidation and reduction of iron can lead to soil acidity because of the effects of ferrolysis (Brinkman, 1970; Dougnac 1987). The development of acidity intensifies with the decreasing periodicity of saturation, while the intensity of ferrolysis and development of acidity is greatest in aeric intergrades to aquic moisture regimes (Wilding and Rehage 1985).

Organic matter accumulation

Surface organic matter accumulation is characteristic of hydromorphic soils that occur in waterlogged bottom slope positions. This accumulation is due to the slow breakdown under anaerobic and acidic conditions, which acts to reduce bacterial activity.

Whitlow (1980) observes that the accumulation of organic matter is related to poorly drained sites and their respective vegetation types. The amount of organic matter accumulation will depend on litter inputs from the vegetation. It is suggested by Turner (1985) that because the growing season in wetlands is much longer than on the surrounding upland, a greater biomass is produced and, under natural conditions, the soils become richer in nutrients and organic matter. The extent and duration of waterlogging also influences the amount and nature of organic matter accumulation with peat soils only found in the wettest sites (Acres et al 1985).

Turner (1977) reports that organic matter concentrations at the surface of fadama soils in Nigeria can be up to three fold those of adjacent interfluve soils. Similarly Dalal-Clayton (1987) describes how organic matter content in interfluve topsoils of sand veld soils rarely exceeds 1% compared to lower catena slopes and dambos sites where it may reach 2-3%. The pattern of organic matter deposition in wetlands, however, can be irregular, influenced by subsurface bedrock and its effect on drainage. In the Grasslands dambo developed over granite in Zimbabwe, areas of peaty soils over 60 cm in depth occur not only within the central parts (or "eyes") of the dambos, but also as islands and irregular mires outside these central sump zones due to restrictions of water seepage by subsurface bedrock (Whitlow 1980).

The degree of dry season oxidation of organic matter which depends on the level of the water table and its seasonal flux also determines the amount of surface organic matter. In the Central Province of Malawi, for example, Meadow (1985) states that surface organic matter content in dambos will never rise over 10% because of the dry season oxidation.

Transport and immobilisation of salts

Wilding and Rehage (1985) observe that the transport and immobilisation of salts in hydromorphic soils are dynamic and functions of water flux. Salts can be concentrated at the surface or at depth depending on the direction of flow, seasonality, and the mechanism of recharge and discharge. In depressional landforms, central areas may be strongly leached while elevated areas have salts and carbonates near the surface due to evaporative capillary pumping. Acres et al (1985) observe that higher evapotranspiration rates from termite mounds often result in the precipitation of salts and even calcium carbonate in dambos. However, while salts, particularly concretions of carbonate, are a usual feature in alkaline cracking clay dambos, salt concretions are seldom found in sand veld dambos (Dalal-Clayton 1988). In scarp dambos in Zambia Mackel (1985b) notes that the variable groundwater circulation and vertical and horizontal distance from the seepage belt influences the leaching, impeded transportation and illuviation of carbonates. Wilding and Rehage (1985) consider that the intensity of salt leaching increases with decreasing periodicity of saturation. Under some conditions, dambos can be cleared by solutional weathering (Smith 1966).

Clay translocation

Textural differentiation between surface and subsurface horizons commonly observed in wetland soils is usually attributed to clay translocation. Thompson (1975) describes soils of dambos and adjacent marginal areas over granite as sands in the surface horizons with a pronounced change in the lower profile to sandy clay loam and sandy clay. He notes that where the water table rises to the same level consistently, the textural change is abrupt, but less well defined where the seasonal rise is irregular. Roberts (1988) also gives details of an acid sandy clay dambo soil in Tanzania showing typical coarsening upwards, while Turner (1977) describes an increase in clay content with depth in fadama soils in Nigeria. Such textural differentiation, however, is not always a feature of wetland soils, for example, Savory (1965) observed variation in textures within individual dambo profiles over granite in Zimbabwe.

Wilding and Rehage (1985) consider that clay translocation as an explanation for textural differentiation has been overstated and that the effect might be attributed to other soil processes. For instance, Dalal-Clayton (1987,1988) observes that ferrolysis, which destroys clay leaving residual sand in the upper profile, is a widespread mechanism leading to the development of duplex soil profiles in many dambos in southern Africa, where white bleached sand abruptly overlie mottled sandy clay to clay.

Structural development and stability

The effects of desiccation on the structure of A and B horizons in wetland soils are discussed by Wilding and Rehage (1985). In the surface horizons water-stable aggregates are favoured, whereas in subsoil horizons larger less stable structural units of weaker grade occur. The structural development of the A horizon increases with the duration of saturation, while that for the B horizon intensifies with decreasing duration of saturation.

Vertisols are subject to structural instability due to alternate shrinking and swelling of clay in the dry and wet seasons respectively. Movement by flora and fauna is also important to the structural development of wetland soils.

Redistribution of sediments

Internal redistribution of sediments by erosion and deposition can account for textural zonation and variation within wetland soils, as well as irregular micro-relief. Surface wash transports and sorts the veneer of material received from higher sites, often with the preferential wash of fines towards the dambo bottom (Perera 1982; Acres et al 1985). Meadows (1985) recorded limited erosion within Bunda Dambo, Malawi but his results gave some support to Mackel's (1985b) view that the "wash belt" is the zone of sheetwash and maximum erosion around the dambo edge. In Zambia, Smith (1985) describes how, at the beginning of the rains, the sudden fall of large drops on an unprotected surface where the soil is light and sandy means the ground may be covered with a short lived sheet of muddied water which leaves a thin layer of sediment after soaking, if the ground slopes sediment is deposited lower down. Where erosion of laterite outcrops creates a scarp feature, the free face is often deeply eroded but below the laterite the flood decelerates and drops its load producing a marginal deposit of transported sand (Smith 1966).

Other factors may be important in the supply and resorting of sediments in dambos, such as termites. An important source of sediment is earth freshly brought to the surface by ants and termites; these unconsolidated heaps are particularly susceptible to splash and sheetwash. Discontinuous surface drainage and subsurface piping also act to distribute sediments (Meadows 1985; Mackel, 1985b). Sodic dambo soils have been observed to be particularly prone to such subsurface erosion (Stocking 1979).

Conclusion

The periodicity of saturation is the most important determinant of wetland soil processes. The factors that influence water table flux and therefore soil saturation have been discussed above. The seasonal nature of the hydrological inputs will enforce seasonality in the soil processes, for example zoogenic activities; oxidation of organic matter, iron and manganese; and salt evaporation will all be predominantly dry season processes, while reduction of Fe and Mn; organic matter accumulation; leaching of salts; and redistribution of sediments by water are associated with the wet season.

Wetland soils develop in response to the suite of in situ processes as well as the catenary processes described earlier. Their properties therefore reflect a complex and dynamic system. The effects of changes in wetland soil moisture regime induced by natural or man made disturbances are therefore difficult to predict (see Section 7).

5.4 Wetland soil properties

Wetland soils share a range of properties common to hydromorphic soils which these relate to both catenary and in situ processes. These relationships are summarised in Table 1, while the common properties are listed in Box 1. Wetland soils may not necessarily have all these properties, their occurrence and extent will depend on local soil factors.

Soil heterogenity

A factor that complicates any description of wetland soil properties is their heterogeneity, a feature, often associated with soils formed from colluvial/ alluvial deposits. Turner (1986) comments that dambo soils are very variable, often changing rapidly over short distances both vertically and horizontally, while Andriesse (1985) found wide variation both between and within inland valley soils because of morphogenesis, location, hydrologic regimes, lithologic origins and climatic conditions.

Heterogeneity in soil characteristics can have important implications for wetland cultivation. For example, the variation in rice yields in inland valley swamps and bolis in Sierra Leone is attributed to complex patterns of fertility (Millington et al 1985). Kyuma (1985b) similarly demonstrates a wide variability in fertility indicators of wetland soils in the tropics. Turner (1977) attributes variable soil fertility within fadamas to heterogeneity of soils and to uneven nutrient losses through leaching, erosion, crop removal and vegetation differences. Internal variability of texture and drainage also complicate management decisions and restrict the choice of crops which are suitable. Further observations of the heterogeneous nature of wetland soils on micro-relief have been made (Dalal-Clayton 1987; Whitlow 1980; Christiansson 1981).

Although if it is possible to characterise the soils of wetlands in general terms (e.g. Box 1), individual wetland sites will all have their own specific collection of soil potentials and constraints. It is this complexity which must be responded to by farmers' strategies (see Part 1).

Figure 8: Properties common to wetland soils and their relationship to catenary and in situ processes.

HYDROLOGICAL PROCESSES	CATENARY PROCESSES	*IN SITU* WETLAND PROCESSES	RESULTING SOIL PROPERTIES
throughflow	Fe translocation	oxidation	iron nodules ferricrete etc
	clay translocation	clay accumulation	high clay content
	base translocation (from weathering, fertilisers, ash)	immobilisation	high pH high base status high fertility
		sodium accumulation	high ESP
(seasonal) waterlogging		redox transformations	Fe & Mn mottles, petroferric material
		ferrolysis	low pH
		reduction & mobilisation of Fe & Mn	gleyed horizons
		clay translocation (eluviation of organic matter & sesquioxides)	textural differentiation down profile Albic horizon
		organic matter accumulation	high surface organic matter, CEC, WHC
		pedoturbation	
		structural development	stable surface aggregates less stable subsoil aggregates
		leaching	low pH
evaporation		salt precipitation	high salt content
surface flow	sheetwash	sediment deposition (+ SOM + nutrients)	increased fertility textural heterogeneity
		sediment redistribution	
		sediment removal)	reduced topsoil
surface flow		gullying	exposed subsoil horizons

WHC = water holding capacity, SOM = soil organic matter, CEC = cation exchange capacity, ESP = exchangeable sodium %

Box 1: Wetland soil properties - implications for agricultural and grazing use

Poor drainage: A common property of dambo soils is their poor drainage, indicated by the presence of a gley horizon within 100 cm of the surface. Seasonal waterlogging results in mottling and gleying. Poor or variable drainage in wetlands restricts the choice of crops, although some cultivation techniques, such as ridging and mounding enable more crops to be grown in these areas.

High clay content: Clays increase down the slope as well as down the profile due to translocation and ferrolysis. Abrupt textural boundaries of sandy soils over heavier clayey soils in wetland profiles can act to hinder root penetration and may lead to ponding of water in the upper horizons. The impermeability of the clayey subsoil may be accentuated by compaction caused by mechanised agriculture and grazing.

Surface organic matter accumulation: Accumulation of some organic matter due to waterlogging benefits the soil by improving water holding capacity, CEC and structural stability. However, excessive amounts of undecomposed organic material under wet conditions do not produce an environment favourable for crop growth.

Ferricrete deposits: Subsoil ferricrete deposits, due to waterlogging and translocation, can become impermeable barriers to root penetration and water drainage thereby constraining crop growth. Where iron deposits have irreversibly hardened and cemented upon exposure to air they render the soil unusable.

High pH levels: Soil alkalinity may increase due to receipt of translocated bases downslope; evaporation; or from redox conditions in alkali soils. In contrast to relatively acidic interfluve soils, plant nutrient availability (and therefore soil productivity) will be greater in wetlands soils if pH levels approach the pH 6-7 range. In some circumstances evaporation of salts in wetlands may lead to accumulation of harmful concentrations at the soil surface (eg. salinisation).

Low pH levels: Soil acidity may increase due to redox in acid soils, ferrolysis and leaching. In situ soil processes can result in the leaching of salts and development of acidity. Excessive wetness for long periods results in dilution and washing out of plant food. Surface water gley soils tend to be chemically poor, as years of leaching under reduced conditions in the wet season, alternating with oxidation in the dry season, have reduced the clay content, CEC and base saturation in the surface and near-surface horizons.

6 THE INFLUENCE OF WETLANDS ON STREAMFLOW RESPONSE

Wetlands are well placed within drainage systems to influence streamflow. They can be considered as areas where water from the upland catchment is interrupted in its passage to the stream channel, hence the concept of storage, transfer or buffer area has developed (Figure 7).

The following discussion is based largely on research carried out in dambo catchments in southern Africa. A number of opinions exist on the ability of wetlands to store water and to influence streamflow regimes. Two main views are held:

- that dry season flow is maintained and flood peaks suppressed by wetlands due to their high storage potential;
- that wetlands do not maintain flow and may even reduce yield because groundwater storage is depleted more by evapotranspiration than by baseflow.

Bullock (1988) has prepared a comprehensive review of results of empirical studies on the effect of dambos on catchment yield, baseflow regimes and storm flow generation. Some of his points are repeated here.

6.1 The effect of evapotranspiration on catchment yield

The volume of water available in the wetland to contribute to streamflow is determined in part by the extent of evapotranspiration from the catchment. Given that some workers (Balek and Perry 1973; DRU 1987) have observed that the dambos and woodland communities evapotranspire at different rates, some argue that it is the relative extent of these two communities in the catchment which will determine catchment yield.

Researchers looking at variation in annual yield from basins containing different proportions of dambos have come to different conclusions, although there is rather more emphasis on a role which reduces both total yield and baseflow (British Geological Society 1989).

Balek and Perry (1973) found that although evapotranspiration from miombo woodland was three times that from dambos, the annual volume of runoff from the four catchments they studied in the Luano basins, Zambia was independent of the extent of dambos. They attributed variability of annual runoff to fluctuating evapotranspiration from the woodland community alone, with evapotranspiration from the dambo being constant because of annual saturation.

In Zimbabwe, Bullock (1988) found similarity between dambo and woodland evapotranspiration losses, and concluded that catchment yields are independent of dambo density, although he does note that within areas of more deeply weathered regolith, where greater recharge occurs, the effects of dambos in promoting dry season evapotranspiration losses can be identified. Consequently he does not support the hypothesis that dambos reduce annual yield through dry season evapotranspiration.

Others, however, report that dambos reduce catchment yields by increasing evapotranspiration losses and observations of low flow are used to support views of reduced yield with increasing dambo density (Hill and Kidd 1980; Drayton 1986 cited by Bullock 1988). The ambiguity in research findings is likely to relate to variations in dambo type dependent on the state of geomorphological development (British Geological Society 1989).

6.2 Dry season flow

It is commonly believed that dambos increase the duration and magnitude of dry season flow by acting as a sponge which gradually releases water from dambo storage. This sponge model is popular but considered too simplistic by some researchers, particularly now that results are available from empirical studies showing that depletion of ground water storage due to evapotranspiration losses can exceed those due to dry season flow. Begg (1986) considers that wetlands have a dual role, since they both sustain, (through storage) and deplete (through evapotranspiration) water yields (Figure 9). Water storage is a function commonly attributed to wetlands although storage capacity depends on the size of the basin, the level of the water table, the nature of the soil and the depth to which it is permeable, while release is determined geologically or topographically (ibid).

Arguments can be presented both to support and to dispute the hypothesis that wetlands sustain and regulate flow; although there would appear to be more evidence available which disputes the hypothesis.

Evidence suggesting that wetlands sustain streamflow

Comparing winter flow data from Lunsemfwa and Mulungushi catchments in Zambia, Kanthack (1945, cited by Bullock 1988) argues that dambos maintain dry season flow, with greater ground storage of the Lunsemfwa catchment ascribed to more extensive dambos. Schulze (1979, cited by Begg 1986) showed that flow from a wetland buffered catchment in South Africa was higher and less variable than from a neighbouring unbuffered catchment and that streamflow was prolonged. Gill (1974, cited by Turner 1977) explains the smoother hydrograph of the lower Sokoto-Rima basin in Nigeria compared to the variable discharge characteristics of the upper basin to gradual release of water stored in fadamas.

Evidence suggesting that wetlands do not sustain streamflow

The major explanation for observations that dambos do not maintain dry season flow is that depletion of groundwater reserves occurs through winter evapotranspiration processes in the catchment, so reducing water available for dry season

Figure 9: The dualistic role of wetlands in the hydrological response of the catchment (Source: Begg, 1986).

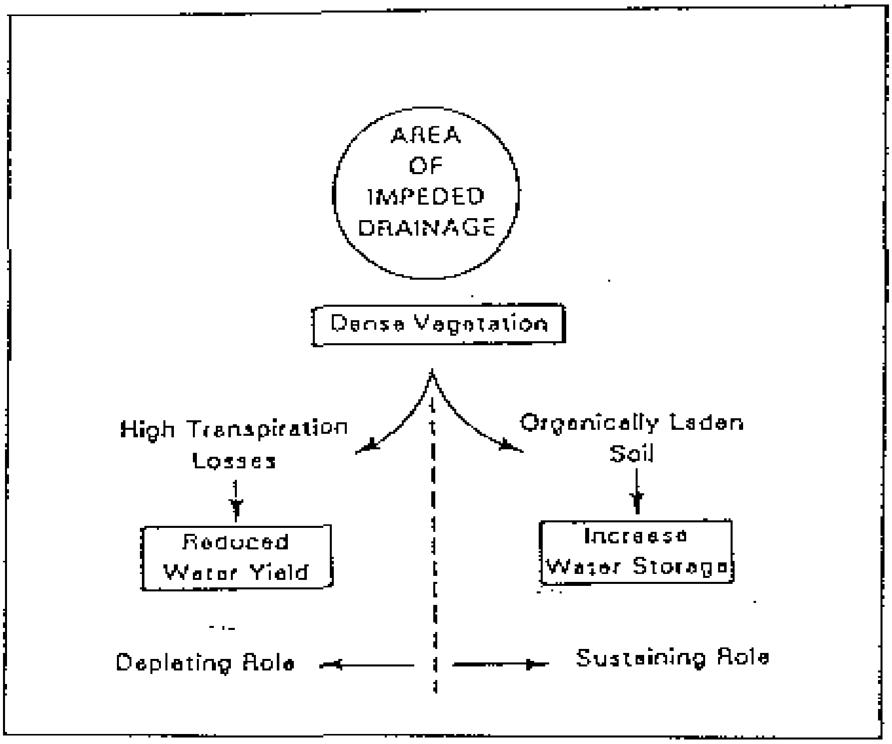
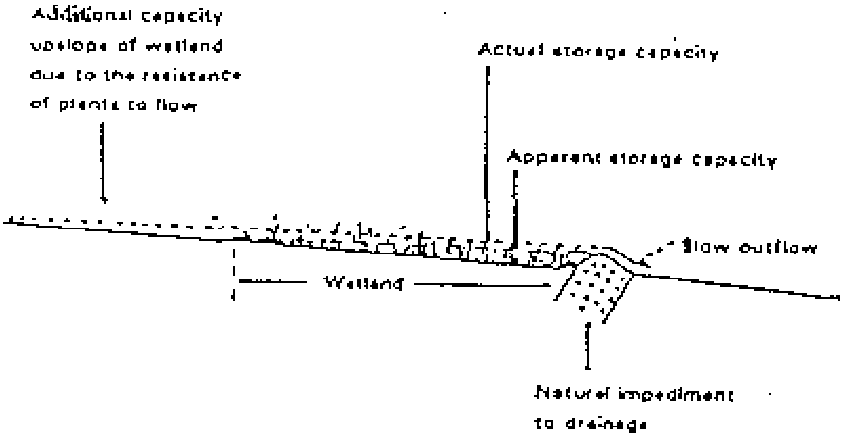


Figure 10: An explanatory diagram of the upslope capacity of a wetland to store additional water and attenuate floods, even when the normal storage basin is apparently full (Source: Begg, 1986).



flow. A dry season water balance was calculated by DRU (1987) for the Chizengeni catchment, Zimbabwe indicating that the volume of dry season streamflow is very small (14.2×10^3 m^3) compared to evapotranspiration losses (310×10^3 m^3).

The relative significance of evapotranspiration rates from the dambos and woodland communities has been considered. Balek and Perry (1973) found that in the higher, flatter parts of the catchment, all the water storage can be taken up by evapotranspiration so that outside the dambo area only the transitive zone contributes towards baseflow.

In Malawi, Drayton et al (1980, cited by Bullock 1988) found no significant difference in late dry season flow of basins with and without dambos. This was attributed to low water movement rates of the dambo providing a source of water for vegetation during the dry season without releasing water to the river. Low water movement rates and limited storage capacity of dambos were cited by Muneka and Mwassile (1986) as an explanation for low dry season flow.

Bullock (1988) suggests that dry season baseflow from three small dambo systems he studied in Zimbabwe may be explained by rapid depletion of water from the upper horizons of the dambo by evapotranspiration, such that dry season water tables are confined to the gleyed zone which is inaccessible to roots and represents the main storage component of the dambo.

According to the hydrological model developed by DRU (1987) of the Chizengeni dambo, Zimbabwe, during the early dry season water passes from the replenished aquifer above the dambo into the upper dambo where plant growth is vigorous and evapotranspiration high. From here, some water passes into the lower dambo with further evapotranspiration losses, while some reaches the dry dambo bottom, the rest going out into the stream as catchment baseflow. As the dry season proceeds there will be reduced replenishment of lower dambo storage because of reduced hydraulic conductivity as the upper aquifer is depleted. This means that less water leaves the aquifer and evapotranspiration losses from the upper dambo continue. The lower dambo and the dry dambo bottom begin to dry out, and water reaching the stream as baseflow is depleted. Towards the end of the dry season, flow from the upper aquifer is only sufficient to provide for evapotranspiration from the upper dambo and there is no surplus for the lower dambo.

Contributions from upslope aquifers to wetlands

Maintenance of dry season flow can be controlled from sources other than wetlands. DRU (1987) contend that the principle aquifer storage during the dry season lies beneath the upper dryland area of the catchment; the dambo having only limited aquifer storage which is depleted early. Bullock (1988) suggests that where storage capacity is shallow, and winter potential evapotranspiration rates are high, dry season flow cannot be maintained by dambos alone and it is likely that subsurface contributions from the regolith can continue to replete the dambo's storage throughout the dry season, can contribute to the evaporation losses at the dambo margin or can contribute to streamflow by passing beneath the dambo.

Savvides (1981) similarly attributes control of swamp duration to the upslope arrangement, slope and depth of strata while Begg (1986) observes that upslope storage is due to the resistance of wetland plants (Figure 10).

Clearly the role of wetlands in sustaining dry season flow is not as simple as previously imagined; contributions from other aquifer sources need to be considered as do the effects of evapotranspiration throughout the catchment. The impact of land use change in different parts of the catchment are therefore likely to be complex (see Section 7).

6.3 Storm flow

Balek and Perry (1973) state that under the moist conditions of a high rainfall area of Zambia, maximum ground water storage capacity is not sufficient to store all the rainfall during the rainy season. The dambo therefore becomes the main source of surface runoff. They found that surface runoff occurred from a high percentage of the dambo area, and that surface runoff formed the largest part of the total runoff in all catchments containing a dambo. This they attribute to overstorage of the dambo aquifer. Robertson (1964), monitoring dambo drainage in Zimbabwe, similarly found a large proportion of storm surface runoff was derived from undrained saturated dambo areas. Bullock (1988), however, found that dambos were insignificant in storm flow generation at the regional level in Zimbabwe.

Other workers argue that dambos act to attenuate floods due to their storage characteristics (Schulze, 1979; Archer, 1980; Drayton et al, 1980). Flood suppression has been attributed to a greater capacity for overbank storage in the dambo catchment, while the reported delay and attenuation of storm runoff and flood peaks has been attributed to the soil moisture deficit of the dambo in the early wet season, with surface runoff commencing only when the dambo is saturated (Bullock 1988; Kanthack, 1945; Balek and Perry, 1973).

Resistance of dambo grasses is also considered important in delaying the start and increasing the duration of run-off (Muneka and Mwassile, 1986; Balek and Perry 1973; Begg 1986; Figure 10).

Bullock (1988) suggests that the differing observations of the effects of dambos on storm flow may be due to the fact that in higher rainfall areas, like Luano catchment, Zambia (1270 mm mean annual rainfall), dambos are saturated each year, and therefore conducive to runoff generation. Such conditions are constant year by year so annual volumes of surface runoff are directly proportional to annual rainfall inputs (Balek and Perry 1973). In low rainfall areas, however, where dambos have been interpreted as flood suppressors, it takes longer for a dambo to become saturated before runoff occurs and variations in rainfall will bring about variations in storm flow response. This would apply both on sandy dambos, because of infiltration rates, and on montmorillinitic dambos, because of storage within cracks.

6.4 Other Catchment Components

Dambos are not the only catchment components which influence streamflow response. Although relationships between dambo density and streamflow have been identified, it is pointed out that dambo density may be considered a direct expression of relative relief within a basin, and that this may directly influence baseflow regimes, rather than the dambo itself, as indexed by the mean annual flood (Bullock 1988). Bullock (1988) also found that dambos are not distinct from other hillslope components in their storm flow generation.

6.5 Conclusion

From his review, Bullock (1988) concludes that although dambos are recognised as important in influencing streamflow patterns, the nature of the influence is complex. Variations in rainfall inputs, soil moisture deficit and local variations in dambo characteristics mean that there is no single characteristic response. It is difficult therefore to predict the hydrological impact of agricultural development in the catchment, although with some limited understanding of which catchment features (dambo and woodland) influence water storage and evapotranspiration losses, it should be possible to develop some general model of impact (see Section 7).

7 THE IMPACT OF LAND USE CHANGE ON WETLANDS

7.1 Introduction

Wetlands are components of a dynamic landscape, their function and characteristics controlled by upslope and in situ soil and hydrological processes. Disturbances both upslope and within the wetland patch itself can affect these processes and result in fundamental changes to the wetland system which may even threaten their existence.

Wetlands may be degraded in two ways; either through lowering of the water table which leads to drying out, or through an increased rate of erosion leading to destruction through gullying or removal of deposits downstream.

In Zimbabwe the causes of desiccation and channel incision within dambos are yet to be established, as it is difficult to judge whether climatic changes or humans' activities have a greater impact (Whitlow 1985; Rattray et al 1953). Stocking (1978, 1981) suggests that natural factors may be as, or more, important than human factors in the initiation of erosion in the Communal Lands. In Zambia, Mackel (1985a) attributes the instability of the zonation of dambo vegetation at the boundary between miombo and grassland to ecological influences, as well as the impact of man. Walsh et al (1988) observe that the hydrological consequences of rainfall decline in the semi-arid areas of Sudan vary because of a variety of human responses and associated hydrological and agricultural impact.

As there is no such thing as a typical wetland it is difficult to identify a typical wetland response to changing land use patterns. Each catchment is subject to a variety of environmental conditions and each has experienced a different land use history.

7.2 Effects of land use change on hydrological status of wetland

Land use changes can have an important effect on the hydrological processes of evapotranspiration, infiltration and on wetland storage capacity, all of which are important to the wetland's potential as an agricultural resource, as well as its ability to contribute to streamflow.

Infiltration

The importance of infiltration to hydrological and catenary processes is clear. Infiltration is affected by plant cover, soil and rainfall characteristics. Vegetation can enhance infiltration by reducing the impact of raindrops on the surface through interception; by promotion of good surface soil structure through organic inputs; by the accumulation of litter at the surface which protects the soil surface and slows down overland flow; and by deep rooting which aids percolation. Soil texture, soil moisture status, organic matter, structure and clay types are the important soil properties influencing the infiltration capacity of the soil.

Human activities can have a considerable impact on the nature of the plant cover through clearing or modifying the natural vegetation, and on the properties of the soil by introducing cultivation and grazing. Although not always deleterious, these practices can result in reduced infiltration, the consequences of which are twofold:

Firstly, reduced infiltration will result in more surface runoff and a greater and more rapid loss of water from the catchment. The time lapse between the start of storms and initiation of surface runoff will be reduced so inputs to the wetland from upslope and resulting streamflow response will be more rapid with flooding often occurring downstream. With increased runoff, throughflow is proportionately less and the recharge of ground water storage falls with the result that baseflow yields also fall and desiccation can result. Whitlow (1983) observes that land use activities that reduce infiltration induce a greater degree of aridity, which once started is reinforced in a cycle of less soil moisture-less plant growth-less plant cover-more surface crusting and erosion-more runoff-less soil moisture.

A fundamental danger to wetlands is therefore that of drying up, a risk accentuated by overuse of water supply for watering stock or for irrigation which can further lower the water table (Rattray et al 1953; Turner 1986).

Secondly, increased runoff increases the risk of soil loss through surface wash and rill erosion processes. Erosion can result in change in wetland form due to deposition of sediment derived from upslope or removal from, and redistribution of sediments within, the wetland itself.

Evapotranspiration

Considering the water balance in simple terms, any changes in land use that reduce evapotranspiration will result in more water being available for ground water storage, conversely those that increase evapotranspiration will have the opposite effect.

The type, extent and seasonality of vegetation affects evapotranspiration and it is generally expected that rates from cropped and grazed land are less than from wooded land. Land use changes, in that they involve modification of vegetation, will therefore have an impact on the hydrological status of the catchment. The relative evapotranspiration rates for different land use types and the proportion of this land use in the catchment is the key to the extent of this impact.

Some zones in the interfluve and the wetland have been noted to evapotranspire more rapidly, for example, the upper dambo zone (DRU 1987) and dambo margins (Bullock 1988). Balek and Perry (1973) recorded the highest evapotranspiration rates at the flat interfluve crests in miombo woodland in Luano, Zambia. Land use changes at these points will consequently have the greatest impact on the hydrological system.

Storage capacity

The reduction or removal of wetland vegetation with grazing and cultivation can affect wetland storage capacity. Hindson (1961) commented that observations of dambos losing their sponge effect when grass is removed suggest that dambo vegetation is an important factor in the maintenance of dry season flow, as well as flood suppression. Both soil properties and wetland slope and depth can be modified if large amounts of sediment are deposited or removed due to erosion upslope or in the wetland. Deposition of sediments can result in making the wetland shallower thereby reducing its storage capacity and may eventually result in the wetland being completely clogged up. In Zimbabwe the threat to dambos of siltation may be inferred from the extent of siltation recorded in dams and weirs, which can be in excess of 50% (Elwell 1983b). Changes in soil organic matter status and distribution in the profile upon cultivation or burning can also affect storage potential. In Western Zambia, Brammer and Clayton (1973) attributed loss of water storage capacity to peat shrinkage resulting from dambo drainage. Exposure or disruption of deeper soil horizons in wetlands, which are protected from evapotranspiration and act as the main dry season storage component (Section 3), may also occur through cultivation and affect dry season flow.

In summary, change in the hydrological status of the catchment brought about by land use activities may result in increased erosion and desiccation in wetlands, as well as in the catchment as a whole. The economic impact of such changes must now be considered.

7.3 Land use practices and their consequences

Woodland

Upslope woodland

Woodland is generally the natural vegetation of the interfluve areas in savanna and wetter areas of Africa, which, although rarely undisturbed, does provide a permanent surface cover unless it is in a very degraded condition. Plantation is an alternative forest cover which can also offer good cover except during the initial clearance stage.

The hydrological function of forests is well studied, particularly their role in promoting infiltration, thereby sustaining perennial flow, reducing frequency and magnitude of floods, and reducing erosion. Deforestation causes dramatic shifts in various components of the hydrological cycle. Lal (1983) found deforestation in the humid tropics caused an increase in direct runoff and baseflow which was associated with a corresponding decrease in soil water storage, evapotranspiration and surface water detention. A number of examples of the effects of forest cover removal on catchment yield can be cited. For example, in Zimbabwe the annual yield from the Upper Save basin was 50% greater in 1978 than 1955 and was attributed to a reduction in the extent of natural woodland in the upper basin (Du Toit 1985). In the Luano basins, Zambia removal of 95% of natural tree cover and settlement by subsistence farmers resulted in an increase in total annual flow of more than 50% (Muneka and Mwassile 1986). The effects of deforestation and change in land use on the hydrological balance have been reviewed by Perera (1973); Hibbert (1967) and Lal and Russell (1981).

The consequences of upslope forest clearance for wetlands will be an increased movement of water through the system. This may initiate gullying through a larger surface runoff component. Thus erosion can occur in wetlands purely as a result of changes in land use activities in the toplands. In Sierra Leone clearance of upland vegetation for cultivation resulted in erosion and downstream flooding leading to wetland areas being abandoned (Jalloh and Anderson 1985). Turner (1977) warns that increased flooding from uplands in central northern Nigeria due to vegetation clearance leads to destructive flooding of fadamas and deposition of large quantities of sediment which might bury crops.

The benefit of forests in the promotion of infiltration and maintenance of flows is balanced by reduction in the actual volume of discharge due to evapotranspiration. Forest clearance and alternative land use usually results in reduced evapotranspiration loss, leaving more water available for interflow. Without the effects of increased surface flow due to clearance, this would result in more contributions to the wetland system through seepage and an associated rise in dry season flow. In Senegal an increase in ground water level in wetlands following forest clearance was calculated to be more or less equal to the cumulative transpiration of the forest vegetation during the dry season of 4-5 months (Charreau and Fauck 1970, cited by Veldkamp 1986). In Nigeria rises in water table levels in the period 1940-1960 were thought to be the result of reduced transpiration losses through vegetation clearance (Jones 1960, cited by Turner 1977). Turner (1977) however, points out that increased groundwater recharge following vegetation clearance may only apply to more arid areas. If efficient water users, such as Eucalyptus species or irrigated crops, replace the natural forest on the topland slopes, evapotranspiration losses would increase and reductions in discharge would result.

Hough (1986) proposes that manipulation of vegetation structure and species composition of miombo woodland in southern Africa can modify evapotranspiration losses and offer most potential for increased dry season baseflow. DRU (1987) consider that removal or addition of topland trees may have a more important influence through evapotranspiration losses than cultivation on the dambo itself. They suggest that removal of miombo woodland for cultivation or grazing in the Communal Lands of Zimbabwe resulted in reduced evapotranspiration and may have contributed to reactivation of dambo systems marginal areas for their distribution.

Wetland forestry

The effect of tree planting at wetland margins is generally considered to cause drying out. This, however, is a controversial issue. Clearly the species, density of planting and wetland stability are all important factors. For instance, Eucalyptus planted adjacent to wetland areas have resulted in desiccation in some areas. Rattray et al (1953) conclude that in southern Africa, trees in wetlands only constitute a danger to water supplies in marginal rainfall areas.

Cultivation

Whitlow (1983; 1989) considers that the hydrological impact of cropping in the catchment is greater than that of forests since sparse plant cover and poor conservation can result in reduced infiltration, rapid runoff and irregular streamflows. The effect, however, is variable depending on the nature of the site and the precautions taken to prevent excessive runoff and soil erosion.

The crop type and the seasonal patterns of cultivation are important with respect to extent and timing of cover, which influence the infiltration rate. Where crop canopy is sparse there is less interception and rainsplash occurs on the soil surface. Crop type, stage of growth and density of planting all affect the extent of cover. Timing of cover is also important as late planting means soil is exposed to most intensive storms at the beginning of the rainy season. The crop type, its density, yield and management also determine how much plant litter is added to the soil to increase organic matter content (and so improve water storage capacity) and to protect the surface.

Disturbance of soil by cultivation practices affects infiltration capacity and soil moisture retention and therefore the rate of runoff and erosion, the effects varying with the type of cultivation (Kowal 1969; Whitlow 1983; Staples 1939). Hoeing can help break up the surface and increase infiltration capacity and, where deep ploughing mixes heavier texture from below with lighter texture above, this increases the moisture retention. Compaction, resulting from mechanised cultivation, however, can degrade soil structure and reduce infiltration. For example plough pans readily develop in some sandveld soils under mechanised agriculture, resulting in increased runoff and erosion. Mechanised agriculture may also exacerbate the impermeability of the abrupt textural boundary in some duplex soils.

Upslope cultivation

Cultivation of surrounding upland may have a greater effect on moisture conditions of wetlands than cultivation of the wetland itself (Rattray et al 1953). In that upslope cultivation usually replaces natural vegetation, the effects are inseparable from the consequences of woodland clearance; the overall effect generally being reduced infiltration and increased runoff and erosion. Studies which compare infiltration rates, runoff and sediment losses under different land use and cultivation methods demonstrate this (Staples 1939; Dalal-Clayton 1980). Again the extent of loss depends on the protection afforded to the land. Erosion of a similar intensity as on overgrazed plots was recorded on unprotected cultivated fields on the upper and lower pediment slopes in Ugogo, Tanzania (Christiansson 1981).

The hydrological consequences of reduced infiltration have been considered above. Begg (1986) reports how intensive farming and grazing of the Blaaukrantz River catchment, including wetlands, in South Africa resulted in severe erosion, as well as the flow of the river ceasing to be perennial. In Eastern Zambia it is suggested that sheet erosion, accentuated by poor farming practice, is responsible for the occurrence of soils with a deep organic rich topsoil below cultivated fields (Dalal-Clayton 1987). Mackel (1985b) observes that in some areas miombo woodland is cleared close to the dambo for cultivation, leaving the surface unprotected, with the result that erosion is accelerated and the gradual lowering of the surface occurs exposing the area to frequent waterlogging or even flooding in the rainy season.

Removal of soil from topland areas through sheet erosion may have a range of effects on bottomland areas. Changes in soil structure (e.g. removal of organic matter/upper horizons) will have an impact on catchment hydrology: increasing run-off and reducing infiltration. This may act to increase surface flows to bottomland areas, but alter their seasonality and concentrate their impact on particular run-off events. Such changes in soil properties may thus act to impair the regulatory effect of the catchment area on system hydrology. Soil loss from the catchment area may also result in increased deposition in the bottomland area. Depending on the type of soil removed, this may act to increase or decrease the soil fertility of the bottomland areas.

Concentrated flows of water channelled by gullies formed on the topland areas are most likely to have detrimental effects on bottomland areas, creating incised gullies within the valley bottomland. Concentration of run-off into valley bottomlands is an increasing phenomenon in Burkina Faso (Reij et al, 1988: 57). Run-off no longer spreads across the valley bottom floor, but concentrates along central drainage channels. The result has been gully formation which may incise backwards up to 40-50 metres per year. The construction of semi-permeable rock dams within gullies has started in many areas to reduce the impact of this degradation (see Part 1; Part 3b).

The construction of upstream dams and irrigation schemes on the downstream productivity of bottomland areas has been a major issue in northern Nigeria (Adams, 1988; Adams and Hollis, 1989). Reductions in flooded area and lowering of water tables in floodplain agriculture have resulted in reductions of yields (see Part 1; Part 3a).

Wetland cultivation and soil erosion

Under natural vegetation, erosion rates from wetlands are generally not high. In dambos, for instance, gradients are gentle and continuous channels are absent, outflow is therefore slow and prolonged. Consequently erosion is negligible with some fine particles transported down the valley, while coarser materials are deposited (Acres et al 1985). Meadows (1985) recorded small erosion losses (0.01-0.36 t/ha/yr) from the three zones of Bunda Dambo in Malawi with maximum loss from the upper wash zone. Kyuma (1985b), discussing wetlands of the tropics in general, considers that wetland soils are immune to erosion hazard thereby making fertility preservation easier.

In their natural state, wetlands are well protected by vegetation from the effects of sheet and gully erosion, with dense plant cover intercepting overland flow and diminishing its erosive power (Roberts and Lambert 1990; Begg 1986). Mackel (1985b) observes, however, that grass cover in dambos and woodland seems to favour sheetwash, whilst cultivation and cattle trampling leads to linear erosion which results in the formation of discontinuous gullies or stream channels.

Cropping systems generally offer less permanent cover than the natural wetland vegetation, thereby exposing the soil to an increased risk of erosion. Surface exposure, however, is a function of the system of cropping and the level of use. For example, dry season cultivation, where it increases ground cover above that of heavily grazed wetlands, will reduce surface runoff.

Good cultivation husbandry with ploughing across slope and many physical barriers which act to increase surface roughness (compared to grazing) can all reduce erosion hazard. In Zimbabwe, DRU (1987) note that garden cultivation reduces surface runoff compared to heavy grazing. In Zambia, Acres et al (1985) also report that dry season garden fences in dambos act as effective barriers to erosion. Similarly rice cultivation techniques enhance the advantage of wetland immunity to erosion, with bunds constructed for paddy rice designed to intercept runoff.

Some soils are more erodible than others, for example, sodic soils, sometimes found in lower dambo sites in Zimbabwe and Zambia, are very dispersive and particularly vulnerable to erosion. Clearly these soils should be treated sensitively. DRU (1987), however, found that garden cultivation appears to conserve rather than threaten this type of soil against gully erosion at Chizengeni dambo (where ESP values are in the dispersive range).

Sediment yields from six plots on cultivated dambo soils at Chizengeni, Zimbabwe did not exceed 1t/ha/yr, indicating that sheet erosion is not a significant problem. The highest rate was recorded on a maize field plot and the lowest from a plot with high slopes, but a good cover of short grass (DRU 1987). According to DRU (1987) the main areas subject to sheet wash are the dambo margins, soil removal here being a function of slope length and agricultural practices upslope; the greater the length of uninterrupted slope on the interfluve slopes, the greater the volume and velocity of water running off and therefore the greater the potential for erosion in the dambo.

Wetlands are also at risk of destruction through gullying (Agnew, 1973). Turner (1977) reports that many former fadamas have been destroyed by gullying in the Kano basin, and that those with incised streams are particularly susceptible to gully initiation, while cultivation may lead to re-incision of formerly stabilised gullies. Gullying is also considered to be the major erosion problem for Zimbabwe dambos. DRU (1987), however, found that soil loss through gully erosion could not be correlated with levels of cultivation. In fact their data suggests that serious gully erosion is often associated with factors other than cultivation, such as soil type and grazing. Whitlow (1989) similarly found no spatial correlation between gullying and cultivation or settlement density in Zimbabwe, but found an association with grazing, with the initiation and growth of gullies corresponding with livestock increases, as well as rainfall variations. Dalal-Clayton (1988) also observes that poor road and mitre drain maintenance are major causes of gully development in the plateau areas of Zambia.

Work in Zimbabwe suggests that there is no evidence that traditional dambo cultivation poses a greater erosion hazard than other land use practices (e.g. DRU 1987; Lambert et al 1990). Clearly soil erosion is related to land use patterns on the catchment as a whole and not just activities on the wetland itself.

Wetland cultivation and water resources

The extent of dry season evapotranspiration from the wetland will affect the amount of water available for dry season flow. In considering the impact of wetland cultivation on water resources it is necessary therefore to compare evapotranspiration rates from different crops (and their management systems) with those from natural wetland vegetation. Begg (1986) suggests that maize evapotranspires at a lower rate than normal wetland plants and so might be considered as a means of conserving groundwater. Rattray et al (1953) observe that winter crops increase evapotranspiration losses in dambos in Zimbabwe and that ploughing exposes the damp soil surface to high evaporation rates of the dry season.

DRU (1987) consider that cultivation on dambos without irrigation is unlikely to significantly alter the evaporative water use compared to intensive grazing. The effect of cultivation on the dambo with irrigation is discussed with reference to the model developed for the Chizengeni dambo, Zimbabwe. During the dry season the water stored in the aquifer above the dambo is separated from the stream and lower dambo by a relatively impermeable barrier. The lower areas of the dambo which might contribute to streamflow consequently dry out early in the dry season. Cultivation in these lower areas could result in early cessation of streamflow (cultivation in these areas, however, was not observed in any of their study sites). Even when streamflow ceases, water is still available in the upper areas of the dambo and increased usage here should not affect late dry season flow, but instead will affect the aquifer above the dambo. This depletion of the non-dambo aquifer upslope will reduce slightly the contribution of subsurface flow which recharges the dambo storage. Irrigation in the upper dambo therefore, may lead to a small decrease in early wet season baseflow.

The effects on upslope aquifer storage and recharge, and streamflow of bringing a heavily grazed dambo under irrigated cultivation were considered for Chizengeni dambo, Zimbabwe. Estimating an increase of crop coefficient for a range of vegetables to be 30% over dambo grazing, analysis shows that if 10ha are intensively cultivated and irrigated then the water table in the non-dambo zone would fall an additional 50mm, 2.9% of average fall (1.72m). If, however, evapotranspiration were increased by 60%, due to drought or different crops, and the whole of the upper dambo zone (34ha) was irrigated, then it is predicted that the water table in the aquifer would fall an additional 20%.

Given this analysis and discussion, Lambert et al (1990) consider that only when extensive cultivation of dambos takes place with mechanised pumping from wells is there likely to be a serious depletion in ground water resources. They recommend continuing with micro-scale irrigation which can be environmentally sustainable and suggest a three fold increase in present levels of cultivation with environmental safeguards. The economic justification for this strategy of sustainable, use as an alternative to complete preservation, has been discussed in Part 1.

Drainage and wetland moisture regime

Wetland cultivation sometimes requires drainage for proper root development and aeration. The principle danger of such drainage is the risk of development of a gully down the centre, with the result that the water table is lowered and the wetland dries out.

Turner (1986) reports a rapid fall in the water table early in the dry season following wetland drainage and scouring of drains which become gully heads. Similarly in Zimbabwe, prior to 1950, gullying caused by concentrated runoff from deep ditching practised by commercial farmers resulted in water tables being lowered and dambos drying out (Whitlow 1990). The effect of drainage can differ with different soil types. Acres et al (1985) note that if a deep drain is dug or if a gully forms on sandy soils, the effect would be to drain the dambo over a wide area and reduce storage drastically, whereas drains and gullies on clay soil have a less direct effect, as water movement is slower. Storage capacity can also be reduced when the wetland dries out through destruction of vegetation cover, and oxidation of humus and peat shrinkage, the latter is described by Brammer and Clayton (1973).

In discussing vleis in Zimbabwe, Rattray et al (1953) notes that the wetland moisture regime should not be altered too much by drainage. They conclude that drainage need not be deleterious and, where it is carefully controlled and permits efficient use of the wetland on a sustained basis, then it is acceptable. Turner (1977) warns of the danger of increasing soil salinity if large scale irrigation schemes are introduced in wetlands without drainage.

Hough (1986) concludes that the overall effect of draining dambos on dry season baseflow is unclear since, although drainage and channel development of the dambo will lower the water table and allow vegetation establishment, it will also reduce dry season evapotranspiration.

Cultivation and wetland soil properties

Wetland degradation is not restricted to erosion and desiccation; less tangible changes in soil physical and chemical properties can result when wetlands are cultivated.

For example, Dougnac (1987) notes that garden cultivation can result in changes in chemical and physical properties of dambo soils.

Most cultivation practices will result in a change from a seasonally anaerobic to a largely aerobic regime (Roberts 1988). A change in the moisture regime brought about by drainage, cultivation or irrigation will affect the suite of in situ processes associated with seasonal waterlogging which were discussed in Section 5. For instance, a decline of organic matter content can result from oxidation following a change to an aerobic regime with cultivation and drainage. A decline in organic matter content brings deterioration of soil structure, fertility and water holding capacity, as well as predisposing the soil to the risk of erosion.

DRU (1987) considered the effects of cultivation on soil organic matter in dambos in Zimbabwe, comparing cultivation plots with adjacent grazed areas. They found that mean organic matter levels were consistently lower for cultivated than uncultivated plots (4.1% versus 3.5%) but that the level of organic matter of cultivated dambo soil rarely falls below 2.5%. This suggests that, having declined with initial cultivation, organic matter levels appear to subsequently stabilise at >2%; a level capable of maintaining soil as a fertile resource.

Two examples of contrasting response of wetlands to cultivation are given for Zimbabwe. In the case of the Charter vleis, drying out was attributed to continuous wheat cultivation resulting in the breakdown of organic matter; ploughing across waterways with consequent gully formation; drainage of the dambos; and a series of dry years. In contrast, the granite dambo areas of the Hillside Experiment Station sustained fertility after 20 years of cultivation. This was attributed to maintenance of organic matter levels with regular green manuring, manuring and fertiliser applications which produced a highly productive piece of land (Rattray et al 1953). These examples demonstrate the value of maintaining organic matter levels in wetland cultivation.

Chemical changes upon oxidation also affect soil reaction and consequently nutrient availability. Dougnac (1987) describes how once drainage is established ferrous ions will be oxidised to ferreic and the pH of the soil falls. Sulphur oxidation, which can occur when wetland soils are drained, is also an acidifying process. Irreversible hardening of iron deposits can also occur upon exposure to air. Agnew (1973) describes how in Mkwinda dambo, Malawi, a fall in dry season ground water level brought about by incision of the channel through gullying has resulted in oxidation of the subsoil and hardening of the iron oxide layer above it at the dambo margins into a laterite carapace.

Grazing

The main problem associated with excessive grazing in the catchment is degradation of the vegetation which affects wetland hydrology and encourages soil erosion. Removal of grass that covers and protects the soil and compaction of the surface by trampling, which reduces permeability and increases the amount of runoff all contribute to make heavy livestock use one of the major causes of soil erosion. Locally the effects of livestock trampling and compaction can be serious with greater hazard where runoff is concentrated along tracks and around dips and water holes.

Reduced cover, in that it leads to less infiltration and more surface runoff, results in a peaked stream regime. In East Africa loss of surface grass caused by heavy grazing led to reduced infiltration and caused storm flow accounting for up to 40% of all precipitation (Perera 1973).

Grazing not only results in a reduced grass sward, but also a change in species composition. Whitlow (1983) notes that bush encroachment is associated with grazing where depletion of grasses promotes the spread of woody species. This has serious hydrological effects.

The effects, however, are not always deleterious. Controlled, continuous grazing is known to maintain vegetative growth of grass and encourage a low growing, productive sward (Acres et al 1985; Roberts 1988; see Part 1).

Periodic burning of grazing lands is a common practice; the effects depending on the time of burning. Late dry season burning is more intense and therefore more destructive, leading to greater loss of soil organic matter (thereby reducing water holding capacity and moisture content of the soil, as well as fertility); exposure of the ground to early wet season storms resulting in surface capping; loss of ash in increased runoff; and inevitably a reduction in plant cover. Buring of wetland vegetation not only reduces their storage capacity but also exposes the soil to the desiccating effects of sun and wind thereby increasing evaporation losses from the moist soil surface. Other deleterious effects of buring are observed, in Zimbabwe Whitlow (1985) describes how buring of peat filled dambos on Kalahari sands lead to drying out and associated oxidation of sulphides derived from underlying bedrock to form free sulphuric acid resulting in extremely acid soils (pH range 2.4-3.5).

The nutrient budget of the dambo is also affected by burning which can lead to a gradual decline in the productivity of the system through erosion and leaching of the ash and loss of nitrogen by volatisation (Whitlow 1985). However, occasional burning to improve grass quality in 'sour' dambos is recommended by Ferreira (1977).

Wetland grazing

Dry season grazing of cattle and other livestock is one of the most common usages of wetlands since moisture is available to support vigourous grass growth when other grazing is limited (see Part 1). Widespread deterioration of dambos in Zimbabwe, in the form of serious gullying, is associated primarily with heavy grazing which now occurs more or less throughout the year on dambos, as access to dryland grazing decreases (Whitlow 1989, 1990; DRU 1987). The problems of overgrazing in dambos is widespread in Zambia, Malawi and Zimbabwe and parts of Tanzania where pressure on land is equally high (Acres et al 1985). This problem has been exacerbated because declining productivity elsewhere in the catchment has resulted in an extension of dambo gardens (Whitlow 1985; Agnew 1973). A result of this is that livestock are restricted to grazing the wetter zones of the dambo which are more prone to erosion, gullying and puddling. This effect, together with recent droughts, has resulted in some dambos drying out (Whitlow 1985).

The erosion hazard in wetlands is made worse when cattle congregate around water holes. Severe localised gullying results, leading to lower water tables and eventual drying out of wetlands. Wet season grazing and grazing in the wetter parts can also lead to degradation of wetland soil structure by puddling, with corresponding lowering of infiltration capacity.

Grazed wetlands are not only subject to runoff generated in the wetland itself, but also to runoff from the upper catchment, particularly when they have lost their protective vegetative cover. Priestley and Greening (1956: 31) comment on the problems of livestock impact on Zambian dambos:

> "Excessive and uncontrolled run-off from the slopes above... is made even more dangerouse when the dambos have been overgrazed and badly poached by cattle... Many dambos are being severely poached towards the end of the rains when the land is soft. These scars do not heal but are made worse in the dry season when cattle congregate in search of water, with the result that erosion gets a foothold at the onset of the following wet season.."

Theisen (1976: 2) notes:

> "Erosion usually begins where cattle "mill around" the verges of vlei wells and watering points; or in sponge land where grazing remains green in winter; or in cattle tracts which intersect the vlei. This erosion is usually of the deep gully type which affects the drainage and desiccates the land."

Grazing may not always result in degradation. Although the scarp dambos in the southern part of the Lusaka Plateau are heavily used for grazing, no severe damage in the form of gully erosion was found and the water supply from the springs remained unaffected (Mackel 1985b). Grazing can have favourable impacts, such as the supply of dung or the hardening of ground and the consequent improvement in grass quality.

The hydrological impact of wetland grazing on downstream flow will depend to some extent on the evapotranspiration of the grazed sward compared to the natural wetland vegetation. The original vegetation of dense long grass is replaced by short grass and is poorly covered in the dry season. A reduced cover resulting from grazing would be expected to evapotranspire less, making more water available for streamflow. A strong inverse relationship between grass biomass and streamflow has been shown; this increases dry season base flows (Hibbert 1969, cited by Hough 1986).

Box 2 summarises the various potential impacts of land use change on soil and water processes.

Box 2: Impacts of land use change

The effects of upslope land use change on wetland patches and streamflow characteristics:

- * Changes in upland infiltration rates and the partitioning of flow between surface and subsurface may affect hydrological and sediment inputs to the wetland and may lead to erosion and desiccation of the wetland.
- * Changes in topland evapotranspiration alters the amount of water available for upslope and wetland aquifer storage, and consequently dry season flow.
- * Changes in status of upslope aquifers due to depletion by abstraction or increase due to irrigation will have downstream effects.
- * Change in wetland storage capacity may be due to accumulation of sediments or effects of runoff from upslope.

The effects of wetland land use change on wetland patches and streamflow characteristic:

- * Changes in bottomland evapotranspiration alters the amount of water available for wetland storage, and consequently dry season flow.
- * Changes in wetland storage capacity occur through cultivation, grazing, burning, and erosion or deposition. This affects ability to sustain flows, suppress floods or generate runoff.
- * Reduced infiltration through removal of plant cover and compaction increases the risk of erosion and sediment loss downstream, and lowers the water table.
- * Changes in wetland soil moisture regimes may disturb wetland in situ soil processes with consequences for soil properties and water quality.
- * Increased runoff and overuse of water supply through irrigation or watering stock can lead to lowering of the wetland water table.

Conservation of wetland under agriculture/grazing

With careful management, many of the deleterious effects of land use change on wetlands are avoidable. Rattray et al (1953) consider that, if precautions are taken, sustainable farming practice is possible. According to Acres et al (1985) conservation of dambos depends on: maintaining and improving dambo capacity for long term water retention; maintaining soil fertility for crop cultivation and preserving good quality forage for grazing.

To be effective, conservation measures should not be confined to the wetland alone, but should encompass the whole catchment; the priorities for management being to maximise infiltration and soil moisture storage and minimise evapotranspiration and surface runoff whilst avoiding erosion, compaction, fire and exposure of soil organic matter.

Some cultivation techniques conserve rather than degrade soil (Roberts 1988; Hindson 1977, see Part 1). Contour ridges are a means of controlling excess surface flow and thus protection from erosion. Perera (1982) observes that bunding constructed at the top of the field in the dambo seepage and upper wash zones offers good control of water resources. Soil and water conservation can be improved by aligning ridges and drains close to the contour so that they do not scour in the rain and can be blocked in to conserve moisture (Acres et al 1985). Properly constructed, well grassed waterways and shorter lengths of contour ridging in cultivated wetlands were recommended in Zimbabwe to protect land from erosion (Elwell and Davey 1972).

Care is needed in the implementation of some conservation measures, however, as sometimes even greater damage can be done by their incautious use. For example, poorly constructed contour ridges might break, unleashing a large and destructive flow of water. The importance of planning dambo conservation and utilisation within the context of the drainage basin as a whole is also clear. In Malawi construction of a dam to halt headward erosion of the Mkwinda dambo has had considerable effects on the hydrology both upstream and downstream of the barrier, as well as accelerating gully erosion in the dambo itself (Agnew 1973).

Although some wetland soils are naturally fertile, conservation of resources and inputs are necessary if agricultural production is to be sustained. Fertile wetland soils can provide high yields initially with minimal or no inputs and as such have been exploited by farmers (Whitlow 1990; Perera 1982). Without inputs or recycling of nutrients, however, such sites may have to be abandoned within a few years.

Suggested improvements to wetlands include mowing of grasses instead of burning, seeding with improved grasses and legumes and use of rotations and organic fertilisers. Rattray et al (1953) believe that proper control of the water table to maintain satisfactory soil moisture is the crux of improving dambo pastures, and recommend control of the water regime of dambos by drainage, but only with a view to more sustained usage.

The advantages of conservation practices and good husbandry are clear and are often reflected in yields; a direct relationship between crop yields and the hydrological status of a catchment has been observed (Whitlow 1983).

Some workers recognise indigenous cultivation techniques of peasants as more suitable to wetland soils than mechanical monocropping (DRU 1987; Turner 1986). Perera (1982) proposes that wetland cultivation should be restricted to peasant farmers because hoe or ox ploughing are more suitable for the soils than tractors, and because traditional methods can be more flexible and responsive to the different potential of the wetland zones. In southern Africa garden cultivators employ a number of traditional management techniques to improve soil fertility such as ridging or mounding for drainage; and burning and humus/dung additions to promote fertility.

The question of whether wetland degradation is irreversible also needs addressing. Under circumstance of natural disturbance Turner (1977) proposes that fadamas can be restored with a rise in the water table or a return to conditions of stability. Reports of man's rehabilitation attempts, however, are mixed. Despite intense efforts to rehabilitate the Blauukrantz River catchment area in South Africa with substantial success, the flow of the river, which ceased with cultivation in the catchment, never recovered (Begg 1986). In Zimbabwe, however, dams introduced upstream of degraded wetlands to store runoff and increase infiltration together with fencing of sponges proved successful in rehabilitating degraded dambos resulting in the restoration of streamflow emanating from localised wetlands (Whitlow 1990). In contrast dam construction at the Mkwinda dambo, Malawi to stop headward recession through gullying led to overflow and severe lateral gullying which threatens the whole dambo (Agnew 1973).

Mackel (1985b) suggests that gullies created by linear erosion initiated by vegetation removal in dambos can be refilled by sheet wash when people stop cultivating and the protective vegetation cover regenerates. Turner (1977), however, suggests that regeneration of vegetation may be difficult particularly where flooding occurs (Turner 1977).

In summary, it is clear that wetland degradation can result from disturbances to catchment soil and hydrological processes brought about by land use change, both on the topland and in the wetlands themselves. The principle forms of wetland degradation are erosion and desiccation; although more insidious changes in soil properties occur in response to changes in wetland soil moisture regime. Movements of soil and water within the landscape are altered by degradation processes; these may increase the patchiness of the environment and require adaptive responses by farmers to such changes.

Recent research suggests that, in some areas, wetlands are not as fragile as previously thought (DRU 1987). Land use change therefore need not always have deleterious consequences, and with appropriate management, wetland patches represent important agricultural and grazing resources.

8 CONCLUSION

Wetlands in Africa are diverse ecosystems that defy standardised description, definition and classification. This is because they have developed and function in response to a range of environmental factors, which can change in time and space. They are best considered therefore as complex and dynamic systems.

This review has concentrated on the understanding of soil and water processes. This has set the wetland patch within the wider landscape. Wetlands are strongly influenced by upslope catenary and hydrological processes, as well as capable of exerting some regulation on downstream flow. Interactions at the catchment level are complex and incompletely understood. 'Degradation' processes in one part of the landscape may detrimentally or positively affect production in another part, depending on a whole range of interacting factors. A case by case assessment is needed. It is by no means clear that what may be seen as topland 'degradation' (land clearance, deforestation, soil erosion, increased run-off, etc) will necessarily have a negative impact on bottomland production. In some cases changes on the topland may act to increase bottomland productivity. Degradation processes thus often tend to increase the 'patchiness' of the landscape by, for instance, moving soil downslope to particular receiving sites. Farmer responses to such change will therefore require an increased adaptation to patchiness. This may require a greater concentration of production activities in bottomland patches (see Part 1).

REFERENCES

Ackermann E 1936. Dambos in Nordrhodesien. Wissenschaftliche Veroffentlichungen des Deutschen Instituts fur Landerkunde (Leipzig) N.F.4, 147-157.

Acres BD, Blair Rains A, King RB, Lawton RM, Mitchell AJB and Rackham LJ 1985. African dambos: their distribution characteristics and Use. Zeitschrift fur Geomorphologie; Supplementband 52, 63-86.

Adams W 1988. Rural protest, land policy and the planning process in the Bakolori project, Nigeria. Africa, 56, 315-335.

Adams W and Hollis G 1987. Hydrology and sustainable resource development of a Sahelian floodplain wetland. Hadeija-Nguru wetlands conservation project, IUCN.

Agnew S 1973. Dambo drainage and its effects on land use in Malawi. E. Afr. Geogr. Rev. No.11, 43-51.

Alexandre J 1978. In: Tropical Forest Ecosystems, UNESCO/UNEP/FAO UNESCO, Paris.

Andriesse W 1985. Wetlands in subsaharan Africa Area and Distribution. In: The Wetlands and Rice in Subsaharan Africa. Eds. Juo ASR, and Lowe JA. Proceedings of an international conference on wetland utilisation for rice production in subsaharan Africa, 4-8 November 1985, Ibadan, Nigeria. IITA, 12-15.

Balek J and Perry JE 1973. Hydrology of seasonally inundated African headwater swamps. J. of Hydrol., Vol 19, 227-249.

Barnes DL and Frankling MJ. 1970. Runoff and soil loss on a sandveld in Rhodesia. Proceedings of the Grassland Society of South Africa 5, 140-144.

Begg G 1986. The wetlands of Natal (Part 1) - an overview of their extent, role and present status. Natal Town and Regional Planning Report, Vol. 68.

Billing DW 1978. Chitedze Agricultural Research Station, detailed soil survey. Ministry of Agriculture and Natural Resources, Soil Survey Section, Lilongwe, Malawi.

Blume HP and Schlichting E 1985. Morphology of wetland soils. In: Wetland soils: characterisation, classification and utilisation. Proceedings of a workshop held 26 March- 5 April 1984, IRRI, Los Banos, Philippines, 161-176.

Bond G 1963. Pleistocene environments in southern Africa. In: African ecology and human evolution. Ed. Howell FC and Bourliere F, Aldine Press, Chicago, 308-334.

Bond G 1965. Quantitative approaches to rainfall and temperature changes in the Quaternary of Southern Africa. Geol. Soc. Amer. Spec. paper 84, 323-336.

Bond G 1967. River valley morphology, stratigraphy and palaeoclimatology in southern Africa. In: Background to evolution in Africa. Ed. Bishop WW and Clark J., University of Chicago Press, Chicago, 303-311.

Brammer H and Clayton DB 1973. Detailed soil survey of Kataba valley research substation, Western Province, Zambia. Soil Survey Report No. 8. Land Use Services Division. Ministry of Rural Developement, Lusaka.

Brinkman R and Blokhuis WA 1985. Wetland in subsaharan Africa. Classification of the soils. In: The Wetlands and Rice in Subsaharan Africa. Eds. Juo ASR, and Lowe JA. Proceedings of an international conference on wetland utilisation for rice production in subsaharan Africa, 4-8 November 1985, Ibadan, Nigeria. IITA, 31-42.

British Geological Survey and others 1989. The Basement Aquifer Research Project 1984-1989: final report to the Overseas Development Administration. British Geological Survey Technical Report WD/89/15.

Brown P and Young A 1965. The physical environment of central Malawi, with special reference to soils and agriculture. Government Printer, Malawi.

Bullock A 1988. Dambos and discharge in central Zimbabwe. PhD thesis, Department of Geography, University of Southampton, UK.

Butzer KW 1976. Geomorpholgy from the earth. Harper and Row, New York.

Charreau C and Fauck R 1970. Mise au point sur l'utilisation agricole des sols de la region de Sefa (Casamance). Agron. trop. Vol XXV, 2, 151-191.

Christiansson C 1981. Soil erosion and sedimentation in semi-arid Tanzania. Studies of Environmental change and ecological balance. Scandinavian Institute of African Studies Uppsala and Dept. Physical Geography University of Stockholm.

Cormack JM 1972. Efficient utilisation of water through land management. Rhod. Agr.J., Vol 69 (1), 11-16.

Dalal-Clayton DB 1980. Investigations into the nature and distribution of sandveld soils of the Central Province of Zambia with observations on their land use potential. Soil Bulletin No 6 Soil Survey Unit, Dept of Agric. Zambia.

Dalal-Clayton DB, English C., Williams GJ. and Spaargaren O. 1985. A Geomorphic legend for Zambia. Technical guide No.15. Soil Survey Unit Research Branch, Department of Agriculture, Zambia.

Dalal-Clayton DB 1987. Reconnaissance soil survey of the Mtetezi river area, Eastern Province, Zambia, Soil Survey Unit, Research Dept, Dept of Agric. Zambia.

Dalal-Clayton DB 1988. The construction and critical appraisal of reconnaissance soil mapping: A geomorphic and soil taxonomy based approach in Eastern Zambia. D.Phil Thesis. Univ. Sussex.

Denny P (Ed.) 1985. The ecology and management of African wetland vegetation, Geobotany 6, Dr W Junk Publishers, Dordrecht, Netherlands, 344pp.

Dougnac M 1987. The use of residual moisture in wetlands. An alternative for food production during the wet season. In: Improving food crop production on small farms in Africa, FAO, Rome.

Drayton RS 1986. Dambo hydrology - an application of satellite remote sensing to water resource studies in the Third World. Proceedings of a symposium on mapping from modern imagery. International society for photogrammetry and remote sensing commission IV and Remote Sensing Society, Edinburgh, Scotland, 8-12 Sept. 1986, 125-134.

Drayton RS, Kidd CHR, Mandeville AN and Miller JB 1980. A regional analysis of river floods and low flows in Malawi. Institute of Hydrology Report No. 72, Wallingford.

Drew 1971. In: Balek J and Perry JE 1973. Hydrology of seasonally inundated African headwater swamps. J. of Hydrol., Vol 19, 227-249.

DRU 1987. By Bell M, Faulkner R, Hotchkiss P, Lambert R, Roberts N and Windram A. The use of dambos in rural development with special reference to Zimbabwe. Final report of ODA Project No. R/3369.

Du Toit RF 1985. Soil loss, hydrological change and conservation attitudes in the Sabi catchment of Zimbabwe. Environmental Conservation Vol. 12 (2), 157-166.

Elwell HA 1983a. Notes on conservation aspects of vlei use. Institute of Agricultural Engineering, Borrowdale, Zimbabwe. Mimeo, 2pp.

Elwell HA 1983b. The degrading soil and water resources of the Communal Areas. TThe Zimbabwe Science News, Vol 17, Nos 9/10, 145-147.

Elwell HA 1984. Sheet erosion from arable lands in Zimbabwe: prediction and control. In: Challenges in African Hydrology and Water resources (Proceedings of the Harare Symposium July 1984) IAHS Publ. No. 144, 429-437.

Elwell HA and Davey CJN 1972. Vlei cropping and soil and water resources. Rhodesian Agricultural Journal Technical Bulletin 15, 155-168.

Ferreira R 1977. Dambos: their agricultural potential. Part 4 Cattle grazings. Farming in Zambia II, 1-2.

FAO-Unesco 1974. Soil map of the world Vol 1: Legend. Unesco, Paris.

Garlick WG 1961. Section on dambos in : The geology of the Northern Rhodesian Copperbelt. Ed. Mendelshn F, Macdonald and Co. Ltd, London.

Giardino JR and Mackel R 1985. Correlative development of dambos and dwalas: plateau regions of Zambia. Zeitschrift fur Geomorphologie; Supplementband 52, 187-200.

Gill MA 1974. Hydrological characteristics of the Sokoto-Rima basin. Savanna 3/1, 61-76.

Gunneweg H, Evers A and Huizing A 1985. Wetlands in subsaharan Africa. A model to assess proposed procedures for water control: application and results for two small inland valleys. In: The Wetlands and Rice in Subsaharan Africa. Eds. Juo ASR, and Lowe JA. Proceedings of an international conference on wetland utilisation for rice production in subsaharan Africa, 4-8 November 1985, Ibadan, Nigeria. IITA, 87-96.

Hekstra P and Andriesse W 1983. Wetland Utilization Research Project West Africa. Phase I The Inventory, Volume II: The physical aspects. International Institute for Land Reclamation and Improvement and STIKBOKA, Wageningen, Netherlands.

Hibbert AR 1967. Forest treatment effects on water yield. Proceedings of International Symposium for Hydrology. Penn. State Univ. 527-542, Pergamon Press.

Hibbert AR 1969. Water Resources Research 5, 634.

Hill JL and Kidd CHR 1980. Rainfall-runoff relationships for 47 Malawi catchments. Report No. TP7, Water Resources Branch, Malawi.

Hindson JRE 1961. Protection of dambos by means of contour seepage furrows. Minist. Agric. Interim Report, Lusaka 53pp.

Hough J 1986. Management alternatives for increasing dry season base flow in the miombo woodlands of southern Africa. Ambio, Vol 15 (6), 341-346.

IITA 1987/1988. Rice based cropping systems in inland valleys. In: IITA Annual Report and Research Highlights 1987/1988.

Ipinmidun WB 1970. The agricultural development of fadama with particular reference to Bomo fadama. Nigerian Agricultural Journal, 7/2, 152-163.

Jalloh M and Anderson G 1985. Wetlands in subsaharan Africa. Integrated development of watersheds in Sierra Leone. In: The Wetlands and Rice in Subsaharan Africa. Eds. Juo ASR, and Lowe JA. Proceedings of an international conference on wetland utilisation for rice production in subsaharan Africa, 4-8 November 1985, Ibadan, Nigeria. IITA, 275-283.

Jones EW 1960. The rise in the water table in parts of Daura and Katsina Emirates. Records Geological Survey, Nigeria, 4, 1957, 24-28.

Juo ASR and Moormann FR 1980. Characteristics of two toposequences in south-eastern Nigeria and their relation to potential agricultural land use. Nigerian Journal of Soil Science, Vol,1, 47-61.

Juo ASR, and Lowe JA. (Eds.) The Wetlands and Rice in Subsaharan Africa. Proceedings of an international conference on wetland utilisation for rice production in subsaharan Africa, 4-8 November 1985, Ibadan, Nigeria. IITA, 43-58.

Kowal J 1969. Some physical properties of soil at Samaru, Zaria, Nigeria. Nigerian Agricultural Journal 6/1, 18-29.

Kyuma K 1985b. Fundamental characteristics of wetland soils. In: Wetland soils: characterisation, classification and utilisation. Proceedings of a workshop held 26 March- 5 April 1984, IRRI, Los Banos, Philippines, 191-206.

Lal R and Russel EW (Eds.) 1981. Tropical Agriculture Hydrology, Wiley, Chichester.

Lambert RA, Hotchkiss PF, Roberts R, Faulkner RD, Bell M and Windram A. 1990. The use of wetlands (dambos) for micro-scale irrigation in Zimbabwe. Irrigation and Drainage Systems 4, 17-28.

Leach M 1990. Images of propreity: the reciprocal constitution of gender and resource use in the life of a Sierra Leonean forest village. Unpublished PhD, University of London.

Ledger DC 1961. Recent hydrological changes in the Rima Basin, N. Nigeria. Geographical Journal, 127, 477-487.

Mackel RM 1974. Dambos: a study in morphodynamic activity on the plateau regions of Zambia. Catena, 1, 327-365.

Mackel RM 1985a. Dambos and related landforms in Africa - an example for the ecological approach to tropical geomorphology. Zeitschrift fur Geomorphologie; Supplementband 52, 1-23.

Mackel RM 1985b. Dambo environments of the central plateau region of Zambia. Zamb. Geogr. J. 35.

Magai RN 1985. Wetland soils of Zambia. In: Wetland soils: characterisation, classification and utilisation. Proceedings of a workshop held 26 March- 5 April 1984, IRRI, Los Banos, Philippines 489-498.

Malaisse F 1978. In: Tropical Forest Ecosystems, UNESCO/UNEP/FAO UNESCO, Paris.

Meadows ME 1985. Dambos and environmental change in Malawi, Central Africa. Zeitschrift fur Geomorphologie; Supplementband 52, 147-169.

Millington AC, Helmisch F, Rhebergen GJ 1985. Inland valley swamps and bolis in Sierra Leone: hydrological and pedological considerations for agricultural development. Zeitschrift fur Geomorphologie; Supplementband 52, 201-222.

Milne G 1935. Some suggested units of classification and mapping, particularly for East African soils. Soil Res., 4, 183-198.

Milne G 1947. A soil reconnaissance journet through parts of Tanganyika Territory, Dec 1935-february 1936. J Ecology 35, 192-265.

Moormann FR and Veldkamp WJ 1978. Land and Rice in Africa: constraints and potentials. In: Buddenhagen IW, and Persley G (Eds.), Rice in Africa. London, Academic Press, 29-43.

Moormann FR, Perez AT and Veldkamp WJ 1976. The potential of hydromorphic rice cultivation in Nigeria. NAFPP workshop paper. IITA, Ibadan, Nigeria.

Muneka and Mwassile 1986. Some aspects of the hydrology of dambos in Zambia. Proceedings of national workshop on dambos, Nanga, April 1986, Ministry of Agriculture and Water Development (Zambia) and FAO, 111-127.

Nye PH 1955. Some soil forming processes in the humid tropics. J Soil Sci. 6, 51-83.

Silva GL 1987. Potential for improving rice production in Tabora region, Tanzania and implications for village planning. ODNRI Bulletin No. 29.

Okali C, Oben D, Ojo-Atere 1979b. The management and use of hydromorphic toposequences in the Ogun River basin: the case of traditional farmers in the Ofada area of Ogun State. IITA Discussion paper No. 5.80, Agric. Economics.

Okali C, Oben D, Ojo-Atere T and Lawson T 1979a. An evaluation of farmers knowledge and use of hydromorphic toposequences in the western state of Nigeria: findings from selected areas of the Oshun River basin. IITA Discussion paper No. 4/79, Agric. Economics.

Okusami TA 1985. Wetlands in subsaharan Africa. Properties of some hydromorphic soils in West Africa. In: The Wetlands and Rice in Subsaharan Africa. Eds. Juo ASR, and Lowe JA. Proceedings of an international conference on wetland utilisation for rice production in subsaharan Africa, 4-8 November 1985, Ibadan, Nigeria. IITA, 59-65.

Perera NP 1982. The evolution of wetlands (dambos) of Zambia, and their evaluation for agriculture - a model for the management of wetlands in sub-humid eastern and southern Africa. International Journal of Ecology and Environmental Science, Vol 8, 27-38.

Priestley M and Greening WP 1956. Ngoni land utilisation survey 1954-1955, Govt Printers, Lusaka, Zambia.

Purves WD 1976. A detailed investigation into the genesis of granite derived soils. Unpubl. D. Phil thesis, University of Rhodesia.

Rattray JM, Cormack RMM, and Staples RR 1953. The vlei areas of S. Rhodesia and their uses. Rhodesia Agricultural Journal 50, 465-483.

Raunet M 1982. Les bas-fonds en Afrique et a Madagascar. IRAT Service de Pedologie Monograph, 56pp.

Raunet M 1985. Les bas-fonds en Afrique et a Madagascar. Zeitschrift fur Geomorphologie; Supplementband 52, 25-62.

Reij C, Mulder P and Begemann L 1988. Water harvesting for plant production. World Bank Technical Paper, 91. World Bank, Washington.

Richards P 1986. Coping with hunger: hazard and experiment in an African rice farming system. Allen and Unwin, London.

Roberts N 1988. Dambos in development: management of a fragile ecological resource. Journal of Biogeography 15, 141-148.

Roberts N and Lambert R 1990. Degradation of dambo soils and peasant agriculture in Zimbabwe. In: Soil Erosion on Agricultural Land. Ed. Boardman J, Foster IDL and Dearing JA. John Wiley and Sons Ltd.

Robertson LAN, 1964. Research into the use of wet and marginally wet land. Federal Department of Conservation and Extension, Salisbury.

Savory RM 1965. The relationship of soil development to water table levels in a granite vlei at Marandellas, Southern Rhodesia. Unpublished Msc. Agriculture thesis, University of London.

Savvides L 1981. Guidelines to improving valley swamps (fadamas). A procedure and approach followed in the Bida Agricultural Development Project, Bida, Nigeria, BADP. 64pp.

Schulze RE 1979. Hydrology and water resources of the Drakensberg. Natal Town and Regional Planning Reports, Vol 42, 122-123.

Smith AG 1966. Local influences on the development of dambos in Zambia. Rec. Geol. Survey of Zambia, Vol 10, 30-34.

Smith AG 1985. Dambos, pediments and fragile equilibria on the Zambian plateau. Zeitschrift fur Geomorphologie; Supplementband 52, 171-186.

Staples RR 1939. Runoff and soil erosion tests in semi-arid Tanganyika. Third report Ann. Rep. Dept. Vet. Sci. Anim. Husb. for 1938. Vol II, 109-119.

Stobbs AR 1963. The soils and geography of the Boliland region of Sierra Leone. Thanet Press, Margate.

Stocking MA 1978. Relationship of agricultural history and settlement to severe erosion in Rhodesia - Zambezia 6, 2, 129-145.

Stocking MA 1979. Catena of sodium rich soil in Rhodesia. J. Soil Sci. 30, 139-146.

Stocking MA 1981. Causes and prediction of the advance of gullies. Proc. S.E. Asia Reg. Symp. on Problems of soil erosion and sedimentation, Bangkok, 37-47.

Stocking MA 1986. The cost of soil erosion in Zimbabwe in terms of the loss of three major nutrients. Consultants Working Paper 3, Soil Conservation Programme, AGLS FAO, Rome 164pp.

Stoops G and Eswaran H 1985. Morphological characteristics of wetland soils In: Wetland soils: characterisation, classification and utilisation. Proceedings of a workshop held 26 March- 5 April 1984, IRRI, Los Banos, Philippines, 177-190.

Theisen RJ 1976. Development in rural communities. Zambezia 4, 93-98.

Thomas MR and Goudie AS, 1985. Dambos: small channelless valleys in the tropics. Zeitschrift fur Geomorphologie; Supplementband 52.

Thompson JG 1969. The classification and cultivation of wet land and vleis. Unpubl. paper, Ministry of Agriculture, Harare.

Thompson JG 1975. Granite soils in Southern Rhodesia. Rhodesian Agricultural Journal, Vol 54 (2), 121-128.

Thompson JG and Purves WD 1978. A guide to the soils of Rhodesia. Rhodesia Agricultural Journal Technical Handbook 3.

Trapnell C 1937. The soils, vegetation and agricultural systems of NE Rhodesia. Report of the ecological survey (1953), Lusaka.

Turner B 1977. The fadama lands of central northern Nigeria: their classification, spatial variation, present and potential use. PhD thesis, University of London.

Turner B 1985. The classification and distribution of fadamas in central northern Nigeria. Zeitschrift fur Geomorphologie; Supplementband 52, 87-113.

Turner B 1986. The importance of dambos in african agriculture. Land Use Policy: Vol 3, Number 4. Land Use in Africa. Butterworth Scientific, Guildford UK, 343-347.

Van Diepen CA 1985. Wetland soils of the world, their characterization and distribution in the FAO-Unesco approach. In: Wetland soils: characterisation, classification and utilisation. Proceedings of a workshop held 26 March- 5 April 1984, IRRI, Los Banos, Philippines

Veldkamp WJ 1986. Suitability of wetland for agricultural development. Proceedings National Workshop on Dambos, Nanga, April 1986, Ministry of Agriculture and Water Development (Zambia) and FAO, 34-46

Verboom and Brunt 1970. An ecological survey of Western Province, Zambia, with special reference to fodder resources. Land resource study, 8. LRDC, Surbiton.

Walsh RPD, Hulme M and Campbell MD 1988. Recent rainfall changes and their impact on hydrology and water supply in the semi-arid zone of Sudan. The Geographical Journal Vol 154, No 2, 181-198.

Watson JP 1964. A soil catena on granite in Southern Rhodesia. I - field observations, II analytical data. Journal of Soil Science 15, 235-257.

Webster R 1965. A catena of soils on the northern Rhodesian plateau. J. Soil Science, 16, 31-43.

Whitlow JR 1980. The morphology of two different vleis on the highveld of Zimbabwe Rhodesia. Zimbabwe Rhodesia Agricultural Journal 77 (2). 71-79.

Whitlow JR 1983a. Hydrological implications of land use in Africa, with particular reference to Zimbabwe. Zimbabwe Agricultural Journal 80, 5, 193-212.

Whitlow JR 1983b. Vlei cultivation in Zimbabwe. Zimbabwe Agricultural Journal Vol 80 (3).

Whitlow JR 1985. Dambos in Zimbabwe: a review. Zeitschrift fur Geomorphologie; Supplementband 52, 115-146.

Whitlow JR 1988. Land degradation in Zimbabwe: a geographical study, Natural Resources Board, Harare.

Whitlow JR 1989. Gullying within dambos with particular reference to the communal farming areas of Zimbabwe. PhD thesis, University of London.

Whitlow JR 1990. Conservation status of wetlands in Zimbabwe: past and present. GeoJournal 20.3, 191-202.

Wilding LP and Rehage JA 1985. Pedogenesis of soils with aquic moisture regimes. In: Wetland soils: characterisation, classification and utilisation. Proceedings of a workshop held 26 March- 5 April 1984, IRRI, Los Banos, Philippines, 139-160.

Young A 1976. Tropical soil and soil survey. Cambridge University Press.

IIED'S DRYLANDS PROGRAMME

The Drylands Programme at IIED was established in 1988 to promote sustainable rural development in Africa's arid and semi-arid regions. The Programme acts as a centre for research, information exchange and support to people and institutions working in dryland Africa.

The main fields of activity are:

- Networking between researchers, local organisations, development agents and policy makers. Networks help exchange ideas, information and techniques for longer term solutions for Africa's arid lands.

- Support to local organisations and researchers to encourage sharing of experience and ideas, capacity building and establishing collaborative links.

- Action-oriented research in the practice and policy of sustainable development in Africa's drylands, focusing on the variability of resources and incomes on which populations depend, development-oriented research *methodologies*, and natural resource management systems.

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