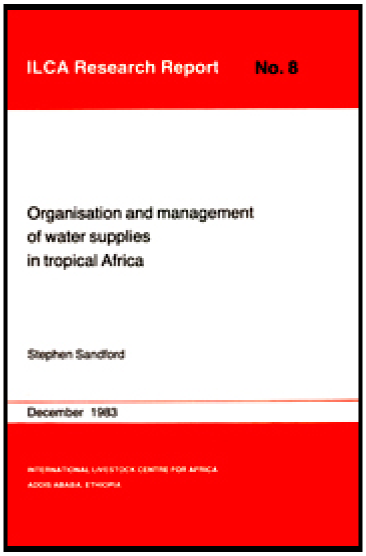
Organisation and management of water supplies in tropical Africa



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ILCA Research Report - No. 8.

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December 1983

INTERNATIONAL LIVESTOCK CENTRE FOR AFRICA

ADDIS ABABA, ETHIOPIA

ILCA PUBLICATIONS

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ORIGINAL: ENGLISH

ABSTRACT

This report, one of a series of three on livestock and water in Africa, defines the major agricultural production zones of tropical Africa with some account of the importance of land, livestock and water in each zone. Traditional and modern strategies used to overcome water shortages are discussed. The technical, administrative and environmental problems experienced in the past development of water supplies are then outlined as is the relationship between technology, equity, management and control. The implications of past experience for planning water development in the future are then considered. Proposals are made for future research which could lead to the formulation of improved policies and development programmes. An appendix gives a recommended nomenclature for the different kinds of water resources which could lead to greater precision and clarity in discussing water management.

KEY WORDS

/Tropical Africa/ /water management/ /water supply/ /land/animal production/ /traditional methods/ /research/recommendation/

RESUME

Le présent rapport qui fait partie d'une série de trots rapports de recherche sur le bétail et les ressources en eau en Afrique, définit les principales zones de production agricole de l'Afrique tropicale et présente un aperçu de l'importance relative des terres, de la population animale et des ressources en eau de chaque zone. Il étudie également les stratégies traditionnelles et modernes adoptées face aux pénuries d'eau. La suite du rapport dégage les difficultés techniques, administratives et écologiques relatives a l'approvisionnement en eau ainsi que les relations entre la technologie, l'équité, la gestion et la maîtrise des eaux. On y examine ensuite les implications de l'expérience acquise par le passe aux fins de la planification en matière de mise en valeur des ressources en eau dans l'avenir. Des propositions sont faites sur les perspectives de recherche qui pourraient conduire a la formulation de politiques et de programmes de développement améliorés. Une nomenclature classant les différents types de ressources en eau est recommandée en annexe afin que les discussions sur la gestion des ressources en eau puissant être plus claires et plus précises.

MOTS-CLES

/Afrique tropicale/ /gestion des ressources en eau/ /approvisionnement en eau/ /utilisation des terres/ /production animale/ /méthodes traditionnelles/ /recherche/ /recommandations/

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Preface

Domestic livestock need water, and unless it is provided in adequate quantities their output is reduced and they may die. The physiology of water use is discussed in ILCA Research Report No. 7 (King, 1983). How and where water can be located and developed is discussed in ILCA Research Report No. 6 (Classen et al, 1983). It will not always be possible or economic to provide water whenever it is wanted in tropical Africa and in many areas it will always remain a scarce resource of which the most effective use can only be made through good organization and management. While water scarcity is for the most part a constraint to livestock production, it can also be turned to advantage as a management tool. The theme of this report, therefore, is how the use of scarce water resources can be managed and organised to achieve the objectives of production, equity and environmental stability which human societies pursue.

Organisation and management are elastic terms and in this report they are widely stretched to include not only formal organizational structures and the details of administrative procedures, but also people's behaviour and decisions and the factors which determine these. Although this report is mainly concerned with the drier zones of tropical Africa some attention is paid to other zones and their production systems, since comparisons can throw more light on the situation in the drier zones.

Chapter 1 starts with a brief definition of the major agricultural production zones of tropical Africa and of different kinds of water supplies, with some account of the endowment of land and livestock and of the importance of water supplies in each zone. This is followed by a section which distinguishes six livestock production systems of which three are of particular interest in terms of the need for and use of water. These production systems do not coincide with the agricultural zones defined; one may straddle several zones and one zone may contain several production systems. Although production systems cannot usefully be defined precisely or narrowly, the organization and management of water supplies tend to be more homogeneous within systems than between them. Production systems represent, therefore, one (but not the only) convenient approach to this subject. In subsequent chapters examples are given of the organization and management of water use in different systems; and some of the conclusions and prescriptions in Chapter 6 are appropriate for some systems but not for others. Chapter 1, therefore is mainly concerned with clearing the ground on which subsequent analysis and prescriptions can be built.

Chapter 2 discusses the traditional strategies to overcome water shortage which have been adopted by societies in Africa without much access to external resources. The chapter distinguishes five main strategies and, focusing on these, briefly cites examples where they have been adopted. Chapter 3 describes in detail the way in which particular human societies, selected to exemplify different livestock production systems, have sought to overcome water shortage, and this illustrates how strategies are adopted. The chapter ends with a discussion of the factors that determine which traditional strategies are adopted in different societies, systems and zones.

In Chapter 4 we turn to modern strategies, which are defined as at least partially dependent on inputs originating outside Africa. Two principal strategies are discussed together with the factors which determine their adoption. In Chapter 5 the focus switches to the experience of programmes for the development of water supplies. The technical, administrative and environmental problems experienced in the past are discussed as well as the relationship between technology, equity, management and control. Chapter 6 considers the implications of past experience for planning water development in the future. Attention is focused particularly on technology, on decisions about the appropriate capacity and density of water points and on organization and management. Chapter 7 briefly lists some proposals for more research in the future which could lead to the formulation of better policies and development programmes than in the past.

The appendix to the report recommends a nomenclature for different kinds of water resources which, if generally adopted, would lead to greater precision and clarity in discussion of water management.

Acknowledgements

The author wishes to thank all those who helped in the preparation of this report, and in particular David Pratt and Peter Brumby who as Directors General of ILCA commissioned it, Robert Wood who as Director of the Overseas Development Institute in London, when the author was on the staff of that Institute, encouraged him to undertake it, Ayele Gebre-Mariam, Noel Cossins, Gudrun Dahl, Johann Helland, John King and Dick Sandford who as official and unofficial referees made substantial and helpful comments on the draft, Richard Stewart for editorial assistance and a number of other colleagues in the Overseas Development Institute and ILCA who provided other assistance.

1. Introduction

1.1 Agricultural production zones

The agricultural production zones of tropical Africa in which livestock are kept can be defined in different ways. Here we shall use a classification of four categories:

Arid zone: Rainfed crop cultivation is uneconomic, given current technology and price ratios, because of very low and unreliable rainfall. *Semi-arid zone:* Some rainfed cultivation is economic, but due to low and unreliable rainfall crop yields are generally poor and highly variable.

Highland areas of plentiful rainfall: These are mainly found in East Africa, in Ethiopia, Kenya and Tanzania. Rainfall is usually sufficient and temperatures are moderate enough for temperate zone crops to be grown.

Low-altitude areas of high rainfall: These include what are normally classified as humid and sub humid areas. High temperatures discourage the growing of temperate zone crops but rainfall is high enough to allow profitable crop production.

Different criteria and definitions can lead to somewhat different estimates of the size and importance, in terms of livestock, of the different zones. Table 1 indicates the proportions that the populations of livestock and of humans and the surface areas of these zones constitute of the totals for tropical Africa[1]. The figures for the low-altitude/high-rainfall zone combine those of what are normally called the humid and subhumid zones: this zone includes much of the land area that tsetse fly infestation renders unsuitable for most livestock.

1 The definition of the zones used in drawing up Table 1 was done in terms of the length of the plant growing period during the year. This is not identical with the classification used in the text above but yields broadly similar results.

Table 1. *Relative area and populations of different zones of tropical Africa (all figures as % of total for tropical Africa).*

Zone	Surface area of land (%)	Population (%)					Percent of ruminant TLUs[a] (%)	Percent of zone infested by tsetse fly (%)
		Humans	Camels	Cattle	Sheep	Goats		
Arid	38	5	100	21	36	39	31	12
Semi-arid	18	26	0	31	22	27	27	50
Highlands (with plentiful rainfall)	4	19	0	20	21	9	17	20
Lowlands (with high rainfall)	40	50	0	28	21	25	25	76

All zones	100	100	100	100	100	100	100	45

Source: Jahnke (1982).

[a] TLU = tropical livestock unit of 250 kg liveweight.

1.2 Water supplies

Water supplies for livestock can also be classified in a number of different ways. The most common classifications are by source of water (e.g. rivers, lakes, dams, wells), by method of extraction (e.g. direct access by animals, rope and bucket, motor-driven pump), by ownership (government, community, private) or by period of use (wet or dry season, ephemeral or permanent). The Appendix to this report sets out and recommends a classification of water points in terms of sources of water. The terms defined in the Appendix are used in the text without further explanation.

Each of the different categories of water supply, defined in terms of water source, can be found in each zone. Neither the relative number of each kind of source nor the volume of water or number of livestock supplied - even if these figures were available which they usually are not - would fully reflect each category's relative importance in each zone. Relative importance is often primarily a function of location, especially in relation to feed resources, and of reliability at critical periods in particularly dry years. However, for purposes of illustration Table 2 shows the water resources which livestock owners used to water their livestock in the dry season in the mid-1970s in the livestock zone of Tanzania. Different regions are ranked by their dryness. There is a tendency for livestock owners in the less dry regions to make relatively more use of streams and rivers and for those in the relatively drier regions to make more use of wells, boreholes and piped water supplies. The latter are all structures in which resources have had to be invested to provide water that would otherwise be absent. There is only a weak (negative) correlation between use of dams and relative dryness, probably reflecting the fact that although there may be a tendency for relatively more of these dams to be constructed in drier regions, dams often dry up before the height of the dry season. The pattern demonstrated by these regions of Tanzania probably reflects fairly well the situation in tropical Africa as a whole. Individual areas in Africa, however, are likely to show marked deviations from the average in response to local factors.

In the drier (arid and semi-arid) areas the importance of water supplies lies in their reliability at times of acute shortage, in their location in relation to supplies of forage and topographical features such as steep escarpments, and in the method by which water is extracted from its source and distributed to livestock. The reliability of supply determines whether herdsmen can keep livestock at all in an area where, in the event of breakdown or drying up, alternative supplies are not available within a 2 or 3 days' trek, and deaths from thirst therefore may occur. The location of water supplies in relation to topographical features and to the available forage determines how much time, energy and body water livestock have to expend in travelling to the water point. The method of extraction determines how much human labour and time is spent in the actual process of watering.

Table 2. ***The relative use of different kinds of water source by livestock in the dry season in Tanzania (all figures in % of livestock owners claiming this as main source).***

Region (ranked in descending order of dryness[a])	Main source of water for livestock in dry seasons (%)						Total[b]
	Stream or river	Dam	Well	Borehole	Pipeline	Spring lake or other	

		A	B	C	D	E	F		C+D+E
DRIER	Singida	12	24	58	1	5	1	101	64
	Dodoma	13	4	71	1	0	12	101	72
	Arusha	51	13	8	6	20	2	100	34
	Shinyanga	52	34	14	0	0	0	100	14
WETTER	Tabora	32	38	27	0	2	0	99	29
	Mara	59	12	6	0	0	23	100	6
	Mwanza	49	36	9	0	0	5	99	9
Value of Kendall's rank correlation coefficient between region and columns A, B and C, and C+D+E[c]		-0.524	-0.333	+0.429					+0.714

Source: Texas A and M University (1976, p.52).

[a)] Dryness is measured in terms of the proportion of a region's surface area with 80% probability of annual rainfall exceeding 500 and 750 mm.

[b)] Totals may not be 100% due to rounding up of figures.

[c)] For seven pairs the values of the coefficient required for significance are 0.56 and 0.75 at the 5% and 1% significance levels respectively.

In high rainfall areas at both low and high altitudes the main function of water supplies and water development is to distribute the already available water more evenly. This is done in order to enable high-yielding dairy animals to be watered several times a day and to reduce the risk of high-value (especially exotic) livestock being exposed to disease infection. For example, in areas where East Coast Fever is a major problem, cattle which have been subject to a rigorous tick-control regime should not have to run the risk of picking up infected ticks from other livestock while trekking across other farms to water. A water supply needs to be made available on-farm. To a lesser extent water development may be necessary in these areas to prevent soil erosion caused by thousands of animals converging on a single water source. In such high-rainfall areas it may, therefore, be appropriate to distribute water by piping it to small farm holdings or to small paddocks. In drier areas disease and erosion are usually of less importance, partly because exotic livestock are not so well adapted to the local environment and therefore less likely to be present, and partly because the lower economic value of land makes soil erosion from the tracks of cattle of any kind of less economic consequence.

1.3 Livestock production systems

In this study, six livestock production systems are distinguished and discussed. These six categories do not cover the spectrum of livestock production in Africa. Attention is focused only on those systems in which water supply and management seem to be particularly critical, and a number of important systems, e.g. all those in the high-rainfall/low-altitude zone, are not considered. Categorising particular cases into systems is a convenient way of sorting out a mass of detail drawn from different places, societies and times so that regular patterns of behaviour can be identified and analysed. The categorisation employed uses individual livestock owners, rather than areas or economic relations, as the units of which systems are composed. Hence in the same geo graphical area two or more 'livestock production systems' can coexist (for an example see Horowitz, 1972), and individual livestock owners can switch, over time, from one system to another. The evidence available about how systems work is usually drawn from a particular place, a particular society (often an ethnic group) and a particular moment in time. In using evidence which describes specific cases to illustrate systems this study uses the present tense, except where it is positively known how the situation has changed since the time when the evidence was collected.

Three of the six categories of production systems mentioned above are described in some detail as follows, as examples from them are discussed at some length later in the report.

1.3.1 Nomadic pastoralism in arid and semi-arid areas

Several species of livestock are normally kept in these systems. Crop cultivation plays, at most, only a minor role, although earnings from wage employment outside the pastoral sector or from trading or caravaneering may contribute substantially to income. Herds and families are extremely mobile; wet-season movements are opportunistic although in the dry season there is a tendency to return to the same water sources each year. Arid areas may be exploited during one season and semi-arid areas during another[2].

2 Examples are the Somali of the Haud in Ethiopia (Cossins, 1971a), of northern Somalia (Lewis, 1961) and of northern Kenya (Chambers, 1969), the Kababish Arabs of Kordofan Province in Sudan (Asad, 1970), some Tuareg of Mali (Swift, 1979) and Niger (Bernus, 1981), end the WoDaaBe Fulani of Niger (Horowitz, 1972).

1.3.2 Seminomadic pastoralism in semi-arid areas

In such systems, there is a tendency to concentrate on one species of livestock. Movement between, for example, wet and dry-season pastures takes place but it is on a smaller scale than in the nomadic system, and some members of the family, e.g. wives with children, may stay in one place throughout a year. A substantial proportion of families may cultivate some crops, although not necessarily every year. Such crop cultivation may be of equal importance as animal husbandry in terms of sales or subsistence consumption, but animal husbandry is usually accorded primacy in terms of prestige, the attention of the household head, and the allocation of adult male labour. Dwellings may be of either a mobile (tent) or a fixed (house) type[3].

3 Examples are the Karimojong of Uganda (Dyson-Hudson, 1972) and some Tuareg of Niger (Bernus, 1981).

1.3.3 Livestock husbandry in mixed farming in semi-arid areas

In these systems, crop cultivation takes precedence over livestock husbandry both in terms of the proportion of income (including subsistence) derived from it and in the allocation of family labour, including the labour of adult males. There may be some movement of livestock between seasonal pastures but, except where livestock are entrusted to the care of pastoralists who are not members of the family (and who may be from another ethnic group), such movements are usually on a small scale and may principally be undertaken in order to keep livestock away from crops during the growing period. Livestock may be of considerably more importance in terms of defining and cementing social relations (e.g. as bride-wealth) or as forms of investment than in terms of income[4]. The distinction between this system and the seminomadic pastoralism is one of degree in terms of relative mobility, allocation of labour to cultivation, and dependence on income from crops.

4 Examples are the Mangari (Horowitz, 1972), the Gogo of Tanzania (Rigby, 1969), the Berti of Sudan (Holy, 1974), and many of the Bangwaketse of Botswana (Gulbransen, 1980).

The three other groups of production systems, which are of less (but nevertheless of some) importance in terms of this study of water management, are the mixed farming systems in high-altitude areas[5], the small-holder dairy systems, and ranching. These systems will occasionally be referred to later in this report.

5 This system is particularly important in highland Ethiopia (Cossins and Yemerou, 1974).

2. An outline of traditional strategies to overcome water shortage

2.1 A definition of traditional strategies

The term strategy occurs many times in this report. A 'strategy' is here defined as a pattern of behaviour followed by individuals, groups or organizations, which seems to have a consistent, harmonious, combined and overall effect greater than and distinct from the sum of the effects of the individual actions which constitute the behaviour. Plants and animals follow strategies without being conscious of the fact. Human beings normally intend, and are conscious of, the effects of the strategies they follow but this is not always the case; differences in strategy are better revealed by actual behaviour than by statements of intent.

We can define a 'traditional strategy' as one which has been practiced in tropical Africa and which does not require large inputs of money, equipment or skills from outside Africa. Traditional strategies to overcome shortages of water for livestock have taken a number of different forms. In this chapter we look at the nature of these forms in general, briefly quoting examples of where each has been practiced. In Chapter 3 we look in more detail at some societies which exemplify the main livestock production systems distinguished in Chapter 1 and show how each of these societies employs one or more traditional strategies to overcome water shortages.

2.2 The strategy of investing in water supplies

One strategy, the 'investment strategy', followed when the technical opportunities for it exist, is to construct new water sources in water-deficit areas. In some areas this has been done on a considerable scale and with a high degree of skill. In the arid Haud-Ogaden region of Ethiopia, for example, thousands of dams, *hafirs* and cisterns have been constructed (Cossins, 1971a, pp. 3234). In one part of this region, over an area of 33000 km^2, there are an estimated 41000 manmade water sources, i.e. 1.2 per km^2 (Watson, 1973). Traditional open wells in Niger reach a depth of as much as 90 m (Bernus, 1981, p. 46) or even 100 m or more (Swift, 1979, p. 68). In some cases the existing major water sources appear to have been constructed with technical skills which have since been lost (Helland, 1980, p. 63; Rigby, 1969, p. 57). In a number of cases the technical skills or labour force, or both, were derived from outside the society which commissioned the work, either in the form of slaves (Lewis, 1978, p. 59) or on a contract basis (Bernus, 1981, p. 342). Although the transportation of water for livestock over long distances by lorry from water source to herd is not as common in Africa as it is in the Middle East (Bahaddy, 1981, p. 261; Cole, 1979, p. 15), it does occur, e.g. in southeast Ethiopia (Cossins, 1971a, p. 44) and Somalia (Lewis, 1961, p. 44). But this is not a 'traditional strategy' as defined above. Transport of water over comparatively short distances from water source to camp by donkey or camel for the use of calves or smallstock is a common and traditional practice (e.g. see Swift, 1979, pp. 147 and 154); and this form of investment in transport of water, by allowing the location of pastoral camps at a considerable distance from existing water points, can be an important alternative to investing in new water sources as a means of gaining access to grazing in water-deficit areas.

2.3 The strategy of adjusting the species, age and sex composition of herds

Another strategy, the 'composition strategy', concerns the appropriate composition of herds. This is a question of composition partly in terms of species, and partly in terms of age and sex. It is commonly agreed that camels, because of their low water requirements, are of the main species of domestic ruminants the best adapted to water-deficit areas, cattle the least well adapted, and that sheep and goats are in between the two. Some societies, e.g. the Kababish nomads in Sudan (Asad, 1970, p.17), believe goats have lower water requirements than sheep, while in other societies the reverse is the case; for example the Berti of the Sudan water their goats in the dry season once in 3 days but their sheep only once in 6 (Holy, 1974, p. 88).

Livestock owners react to relative water shortages by adjusting the species composition of their herds. In drier areas there tend to be relatively more camels, in wetter areas more cattle. Since different species differ in ways other than their adaptibility to water shortage, e.g. in the frequency, timing and duration of their lactation, and in the amount of labour required to tend them, it is common for pastoralists' holdings to consist of more than one species in order to obtain the best mix of advantages. However, the overall balance between different species will differ between drier, more water-deficit areas and wetter ones. For example in Kenya, under an annual rainfall of 200 mm, camels and cattle each account for about 20% of the total livestock species (in terms of biomass) and sheep and goats together for about 60%; under an annual rainfall of 500 mm cattle account for 65%, sheep and goats for 35% while camels essentially do not exist (Western, 1974). Table 3 shows the relative proportions of livestock species in two Somali clans in southeast Ethiopia, one of whose base territories is relatively drier than the other and relatively less well-equipped with wells - the only reliable dry-season water point.

Livestock owners not only adjust the species composition of their total livestock holdings but also the composition of individual herds; each species within the total holding may be herded separately so that its water requirements receive appropriate attention. This point will be discussed later.

Livestock owners also adjust the age and sex composition of individual herds within their total holdings in accordance with water requirements and adaptability to water shortage. For example the Jafarabe Fulbe pastoralists of Mali like to have a proportion of elderly intelligent steers in their herds to lead more excitable, less experienced animals away from a known water source at the end of the dry season towards better grazing (Lewis, 1978, pp. 54-55). The Borana of Ethiopia and Kenya divide their cattle into two groups. The 'dry' or 'fallow' *(fora)* group of animals is able to walk further and to drink less frequently and thus can exploit more distant pastures. The 'milking' *(hawicha)* group, because of the higher water requirements of its milking cows and calves, needs to drink more frequently and to walk less far to water (Dahl, 1979, p. 42). Not only do the 'dry' herds reach better, less overgrazed pastures by travelling further afield, but by doing so they leave more of the nearer pastures for the more sensitive milking herds.

2.4 The strategy of positioning livestock and conserving feed and

water

Another strategy, the 'positioning and conservation strategy', involves two elements. One of these is the careful adjustment in space and time of the positions of different species and classes of livestock in relation to water supplies. This adjustment depends on the relative water requirements of each class and species, on the availability in space of forage in the quantity and quality appropriate to those livestock, on the location of sources of drinking water for livestock in the quantity and quality required, and on the means whereby water is extracted from its source and delivered to livestock. This strategy will be more clearly illustrated in some of the examples which follow.

Table 3. ***The relative proportions of livestock species in two Somali clans in southeast Ethiopia.***

Clan	Approx. density of dry- season water points (No. per km^2)	Proportion of total livestock (% of total biomass)			
		Camels	Goats	Sheep	Cattle
Habar Awal	0.04	72	4	15	9
Abaskul	2.57	27	9	33	31

Sources: Cossins (1971a) and Watson (1973a).

However, a few brief generalizations can be made. Where water is scarce the total livestock composite will be split up into as many herds of relatively homogeneous livestock as the amount of herding labour permits, so that each species of livestock can be managed in the most appropriate way (Swift, 1979, pp. 144-158; Cossins, 1971a, p. 45). Other things being equal (they seldom are!) milk stock will graze closer to water and dry stock furthest away from the water point, sheep and goats probably the intermediate area and cattle the nearest. However, there are differences between particular situations (e.g. see Smith, 1978, p. 85). Where calves must trek to water and are unable to cover too great a distance, most of them occupy the closest ring; but in other situations (e.g. Swift, 1979, pp. 144-158) sheep and goats occupy the nearest ring and cattle the intermediate area because calves which are too young to walk far to a water point can still have water transported to them in a camp further away.

The second element in this strategy is the conservation of the water and grazing at or around the most permanent and reliable water points ('fallback' or 'dry-season' water points). This is done for as long as possible into the dry season until the water or grazing at other less reliable water points is exhausted; coupled with this is the vacation of dry-season fullback points as soon as possible when rainfall reopens other points. The other elements in this and previously mentioned strategies are matters which essentially concern the individual livestock owner and those who collaborate with him in the labour of herding and watering (his 'herding community'). However the conservation of water and grazing at fullback water points in most of the grazing lands of tropical Africa where communal forms of land tenure prevail, is a matter where the benefit which an individual derives is dependent on many other people outside his own herding community pursuing the same strategy; otherwise the grazing around the fullback point will be used up by others before the peak of the dry season while the individual who is trying to pursue a conservation strategy is still exploiting the less reliable water points.

Conservation at fallback water points is a strategy which, according to reports, is widely practised in many arid and semi-arid parts of Africa, although seemingly to a much less extent in other zones. Among regions and societies practicing some kind of fullback conservation are: the Borana of Kenya (Dahl, 1979, p.48) and Ethiopia (Helland, 1980, p. 60); the Somali of southeast Ethiopia (Cossins, 1971a) and northern Kenya (Chambers, 1969, pp. 10-15); the

Maasai of East Africa (Western, 1973, pp. 92-94); the Kababish Arabs of Sudan (Asad, 1970, pp. 17-30); the Berti of Sudan (Holy, 1974); the Fulani of the Mopti region and Niger delta (although this is a much more complex system due to both the rise and fall of flood water and the risk of damage to cultivation) (Gallais, 1975; Lewis, 1978); the Tuareg of Mali in the central Gourma region (Bourgeot, 1981), in the southeast (Smith, 1978, pp. 83-88), and in the Adrar region in the northeast (Swift, 1979, pp. 56-60); the Tuareg and Fulani in the northern Sahelian zone of Niger (Bernus, 1971, and 1979, p. 51); and to a limited extent livestock owners in southeast and eastern Botswana (Gulbransen, 1980, pp. 192-198; Fortmann and Roe, 1981, pp. 7-15).

This list of examples could, no doubt, be greatly extended by a more complete search of the literature. What is noteworthy is the small proportion of the examples in which this conservation strategy is a formal policy of a community with community-imposed rewards and sanctions for compliance. The strategy is seldom imposed by a society's rules, formally agreed on by a community or decreed by a legitimate authority; usually it is discernable mainly in the way in which people actually behave, although that behaviour may be influenced by cultural norms expressed in acceptance or disapproval by public opinion. In part this observation may be caused by the nature of the evidence on which we rely. In most cases this evidence consists of the reports of anthropologists, many of whom may not have been particularly interested in this aspect and may simply have failed to note the mechanisms by which the community enforces its policy. Nevertheless in a number of cases social scientists have looked for rules and found none.

In the Niger Delta (Gallais, 1975) and the central Gourma of Mali (Bourgeot, 1981) rules exist and are focused on the conservation of grazing. Among the Berti of Sudan (Holy, 1974, p. 107) no one may use the dry-season well before the well-master *(agid al-bir)* has formally opened it for the season, but there is no evidence that this opening date is determined by the exhaustion of alternative pastures and water sources. Although the Somali of northern Kenya operate a conservation system, they explicitly deny the existence of customary control or sanctions over opening or closing of grazing. In some clans day-by-day communal discipline was exercised over the process of watering but not over the dates at which water or grazing were opened for use. The only grazing controls were ones imposed by the colonial power and these have now effectively lapsed (Chambers, 1969, pp. 11-16).

In many cases the reason why pastoralists in practice conserve the grazing and water at fall-back water points is simply that these water points, being deep open wells, require a lot of labour to extract the water, and pastoralists are reluctant to supply this until absolutely necessary. Swift (1979, p. 222) has shown how a herd of 50 camels watered from a deep well needs twice the number of people (i.e. two persons) as the same herd watered from sources where livestock have direct access. In Botswana a variety of water points are used as fullback points in the dry season; in the case of some dams a form of communal control prevents their use except when other sources of water have dried up (Fortmann and Roe, 1981, p. 139). However in many cases it is the relative reliability, cost and inconvenience of using some kinds of water points which leads to their being used only at the height of the dry season when no alternative source is available (Fortmann and Roe, 1981, pp. 7-19; Bailey, 1980, pp. 9-49).

A strategy of conservation of grazing around dry-season fallback points appears also to be practiced by some wildlife populations. In this case the control mechanism which moves the animals away from the fullback point as soon as rain falls elsewhere (such emigration may start within a few hours of rainfall) is not certain but appears likely to be the relatively better quality of grazing (especially in terms of protein content) away from the fullback water points (Western, 1975, p. 274; Western, 1973, pp. 50-52 and 162164).

2.5 The husbandry strategy

Livestock owners engage in some other management practices - we can call them collectively the 'husbandry strategy' - in order to overcome water shortage. In some cases selection of breeding stock, especially sires, is done in terms of characteristics associated, or thought to be associated, with ability to withstand water stress. One Somali clan in southeast Ethiopia had only white cows:

> 'They bred their own animals and selected for this colour and type - it was a light animal and reputed to be able to withstand drought conditions and a bad *Jilal* (dry season) better than coloured cows.' (Cossins, 1971a, p.70).

Some herdsmen in northern Kenya also believe that animals with light coloured coats are more drought-resistant (Lewis, 1977, p. 45). Western (1982) notes that the Maasai of East Africa recognize the relationship between the environment, productivity and coat colour, and suggests that they may be actively reinforcing prevailing selection pressures, which appear to be reflected in the tendency for the incidence of light-coat colours among cattle in Maasailand to be negatively associated with higher altitude (Finch and Western, 1977).

King (1983, pp. 34-37) has reviewed the evidence that coat colour affects the inward flow of heat to livestock from a hot environment and, thus, the degree of heat stress suffered when restriction on drinking water leads to dehydration, and has shown that in hot dry conditions light-coloured cattle are better adapted.

Maasai pastoralists also alter the hours and length of daily grazing in accordance with temperature and distance from water (Western, 1973 and Branagan, 1962, p.8). The Borana of Isiolo district in northern Kenya at the height of a drought trekked their cattle to water at night in order to reduce losses of body water in their livestock (Dahl, 1980, p. 62). Elsewhere in northern Kenya at a relatively cool time of year cattle are let out by their herdsman to graze very early in the morning and in this way are able to get all the water they need from the dew formed by the condensation of mist; as a consequence the cattle do not need to drink for up to 60 days and thus are able to graze an area that has no water point (Lewis, 1977, p. 41).

Another management variable is the duration and number of drinking episodes that take place at each visit to a watering point. When the frequency of bringing animals to the water point is restricted to once in every 3 days or more, pastoralists will often organise the routine of watering so as to allow livestock an opportunity to drink more than once at each visit (Field, 1977; Bernus, 1981, p. 30; Marty, 1972, pp. 27-29; Cossins, 1971b, p. 48[6]; Torry, 1977, p. 10), although congestion at wells and labour shortage may prevent this. King (1983, p. 18) cites evidence that livestock that have been severely dehydrated may need more than one drink to replace lost water completely.

[6] In this case watering takes place every other day.

2.6 The strategy of managing and controlling water points

Even where livestock owners and herders practice all the strategies discussed so far, there may still be a deficit between the amount of water the livestock in an area need and its supply. The final strategy we discuss is one for managing and controlling water points. By management is meant the organization of watering activities and maintenance in such a way that the minimum of time and water is wasted - through slow rates of extraction due to insufficient labour or other forms of energy to draw water, through quarrels and fighting about turns for watering, through fouling of water by animals or through losses from water sources or troughs. By 'control' is meant the regulation of access to a water source, and restricting this access to the number of people or livestock for which the water and surrounding grazing is adequate.

The rules and systems for managing and controlling water points differ from society to society and, within the same society, between different kinds of water sources, different seasons of the year, and sometimes between the same season in different years. The degree of management and control tends to vary with the scarcity of water, with the difficulty of extracting it, or with the amount of surrounding grass. Where neither water nor grass is scarce management and control are often perfunctory, becoming more strict as the dry season advances (Fortmann and Roe, 1981, pp. 142 and 145). In arid areas where communal systems of land and grazing tenure apply, it is usual for water in ephemeral natural pans to be unmanaged and uncontrolled; anyone within the society that has grazing rights in the area is at liberty to water his livestock at these pans (Asad, 1970, p. 21; Helland, 1980, p. 61). The water in the pans is likely to dry up more quickly, through evaporation and seepage, than animals drinking there can exhaust the water or surrounding grazing, so that the water is not a conservable resource to be kept from the livestock. However, access to reliable and, above all, permanent water, even when this is a 'gift of God', e.g. a lake or river, is more likely to be strictly controlled (Helland, 1980, p. 62; Cossins, 1971a, p. 34).

Where human labour or other resources have been invested in the development of a water resource, then, even if water is not scarce, some nominal control of access is likely to prevail, although in practice it is likely to be of a rather perfunctory nature (Swift, 1979, p. 70). For example, in some areas occupied by the Samburu in Kenya, water can be obtained simply by digging a water hole a few feet deep. The person who digs it can, in theory, refuse permission to any other person to use it; in practice doing this would create considerable bad feeling, except when water and grazing are in short supply (Spencer, 1965, p.5).

In high-rainfall areas there may be no formal control of access to water sources such as rivers, because water itself is not a particularly scarce resource. In practice it may be difficult to bring animals to water without trespassing on other people's pasture and crops so that *de facto* access may be controlled. On the other hand local laws and customs may prohibit riparian land owners from denying others access to water (personal observation in pre-revolution Ethiopia). In arid areas most societies regulate access to permanent water. In some cases the power to do this is vested in individuals through a concept of private property, and this power can be bought, sold or inherited. In some cases ownership is vested-in the society as a whole that grazes in that area, and in others ownership is vested in only one section of that society. In some cases within the same area and society different rules apply to different kinds of water supply. Somali pastoralists in southeast Ethiopia present an example of this (Cossins, 1971a) as do pastoralists of the same ethnic group in neighbouring northern Somalia (Mirreh, 1983), although the details of the rules differ significantly between the two areas and the account which follows applies only to southeast Ethiopia.

Particular permanent dry-season wells are usually owned by primary lineage groups (sub-clans), although several primary lineages may each have their own well or wells within a single well-field. These primary lineages will usually allow free access to members of the same clan, or occasionally the same clan family, without payment or grant of specific reciprocal rights. Members of other clans will normally have to pay in cash or kind or by the grant of reciprocal rights on a contract basis. Small *hafir* dams *(harrs)* are owned by individuals or by close family, and water may be sold from them. Large *hafir* dams were, in the past, owned by primary lineage groups, but there was a trend prior to 1975 to individual ownership or to ownership by syndicates which cut across primary lineage lines. Water is increasingly being sold to those who are not close relatives of the owners. Concrete-lined water cisterns *(birkas* or *berkads)* are also owned by individuals and water may be sold from them even to close relatives.

In this example, control of access to water in order to match supply with demand is regulated by a number of administrative devices. At permanent wells, if supply in a particular season falls short of demand, members of other clan families, then of the same clan family, then of other primary lineages within the clan can successively be refused access. At water sources *(harrs* or *berkads)* owned by individuals or small groups the price of water to those who are not the owners of a source can be progressively raised until they are discouraged from coming. In the early 1970s in a bad year it cost the price of a whole sheep to water 170 sheep once[7].

> [7] On the basis of: a 30 kg sheep valued at Eth. Birr 30, water in a bad dry season sold at Eth. Birr 5 per 200 litres, sheep (50% of whom are lactating) watered every 3 days drinking the equivalent of 2.3 litres per day, i.e. 7 litres at a single watering (from King, 1983, p. 45). Cossins' assertion (Cossins, 1971a p. 69) that sheep are only given 4 litres of water every 9 days in the dry season, i.e. 0.44 litres per day, seems implausible.

Control of access to water usually only distinguishes persons with stronger or weaker claims to use a particular water point. It seldom, if ever, imposes a formal limit, by regulation, on how many stock each person may water in times of scarcity. However, other kinds of constraint may impose less formal limits. Foremost among these is the increased requirement in times of water scarcity for human labour to extract water from the source and to deliver it to livestock. At the height of a bad dry season the appetites of livestock may be relatively low and the loss of water through faeces correspondingly reduced; but this will be counterbalanced by an increased need for water for evaporative cooling necessitated both by high ambient temperatures and long treks to water (King, 1983, pp. 57-61). Livestock needs for water will, therefore, be high at precisely the time when there will be most difficulty in extracting water from wells. This difficulty arises both from the low static water level in some reliable dry-season wells (as much as 90 m below ground level in some places) and from the low yields of wells during a drought, which means that labour and livestock have to wait around for the well to recharge itself.

At some wells each herd has to produce its own labour to water its own stock. In such cases owners of herds with high stock: family labour ratios will have to make arrangements to borrow, contract, or hire labour in order to water over-large herds at peak times; alternatively they may arrange to entrust or lend their animals to be managed by people whose herds are smaller. Such arrangements can be expensive particularly in the more commercialized pastoral systems. Entrusting or lending livestock deprives the original owner of much of their products; hiring labour is not only expensive in terms of direct payments in cash or kind, but there is also the danger of incompetence or dishonesty on the part of the hired person (Bernus, 1981, p. 169; Dahl, 1979, p. 77). Rather than engage in such expense the owners of large herds may prefer to take their animals away from overcrowded water points into another region where water is less scarce and watering less expensive. For example in north Kordofan province in Sudan,

> 'Many families watering at the deep wells in Hamrat al-Shaikh have their main herds watered at the borewells in Um-Sunla about 50 miles west. Because although water from the Hamrat wells is free and from the borewell it is not, it is cheaper for exceptionally large herds to be watered at the borewell than it would be if they were watered by hired labour from the deep Hamrat wells. Watering at the borewell is of course quicker and less laborious than watering at the deep Hamrat wells[8]. But there is a risk involved: a mechanical breakdown of the borewell pump may spell disaster, as happened a year before my arrival in the geld.' (Asad, 1970, pp. 24-25).

> [8] But a Tuareg livestock owner interviewed in Niger in 1972 denied that watering camels or sheep at boreholes involved any fewer herdsmen than watering at other sources such as open wells (Marty, 1972), even though the actual raising of the

> water to the ground surface is by motorised pump in the case of a borehole and by hand power in the case of an open well.

At other wells watering livestock requires the cooperation of several relatively independent herding units. An extreme example occurs among the Borana in southern Ethiopia where some open wells require a chain (team) of up to 23 strong persons to draw water. In such circumstances the owner of a herd who is unable to provide a labour force proportionate to the size of his herd will find it extremely difficult to find other herding units with whom to form a watering unit. He would, therefore, have to distribute his surplus to friends and allies or recruit extra labour through adoption, foster parenthood or through herding contracts. He will have to spend much time, and in the end many resources, in recruiting support in the well-council *(cora ela)* to prevent his exclusion from access to the well and a place in the watering roster (schedule of users). In extreme cases the herder of too large a herd will even bribe the well-master *(abba hirega).* All these arrangements have their costs, and if the herd owner fails to meet them he will be excluded from the well and his livestock will die unless he takes them off elsewhere to less labour intensive water points (Helland, 1980, pp. 63-71).

Management of water points is designed to ensure that these are efficiently used. It includes a number of activities which require a degree of coordination and organisation of effort between different individuals or groups. Wells and, to an extent, dams and *hafirs* need annual maintenance to remove silt and sand, to repair structures and to replace the equipment, e.g. wooden frames or windlasses, by which water is drawn (Holy, 1974, p. 107). Either daily or at the watering of each herd, minor repairs must be made to watering troughs and dung and other refuse removed so that they do not contaminate the source (Helland, 1980, pp. 66-67). Watering and labour rosters have to be drawn up so that each herd or type of animal is allocated an appropriate frequency of watering and a place in the order of watering for that day, and so that adequate labour is there when cooperation between different herding units is required. Some further rules may be needed, for example to prevent the mixing up of herds (Lewis, 1978, p. 48) or trampling of smaller animals, or to segregate sick animals (Chambers, 1969, p. 15). Some authority may be required to ensure observance of the rules and to settle disputes so that they do not lead to fighting, confusion and bloodshed.

Where water is not scarce management tends to be minimal. In regions where water is relatively abundant specialist traditional institutions for water management may not exist. In regions where water is only scarce in some seasons specialist organizations may exist but only operate at the season of scarcity. In Botswana:

> 'Management (of small dams[9]) occurs but it is management under stress at that time of year when use of the dams is critical.' (Fortmann and Roe, 1981, p. 42).

> [9] It should be noted that these are not 'traditional' dams. They were mostly constructed with outside funds and earth-moving equipment.

In Ethiopia attempts by government to introduce a 'well-master' *(abba hirega)* system in areas used by the Borana pastoralists at stockponds which hold water only at the less dry times of year have been only moderately successful at best (R. Sandford, personal communication), although the system functions extremely well at the traditional dry-season permanent wells. In some regions where water is extremely scarce specialist water management institutions do not seem to have evolved. In areas used by Somali pastoralists in the Horn of Africa - areas adjacent to but more arid than the Borana areas mentioned above - no specialist institutions for water management have evolved. In southeast Ethiopia informal councils of Somali elders from among those who expect to use a well may meet to work out watering schedules (Cossins, 1971a, p.39); but amongst the Somali of northeast Kenya (except for the Borana-speaking Somali) even such informal councils appear to be lacking (Chambers, 1969).

Published information on the management of traditional water points is quite limited. There is fairly detailed information available about eastern Botswana (Fortmann and Roe, 1981), the Borana of southern Ethiopia (Helland, 1980) and the Berti of western Sudan (Holy, 1974). There is a little written information about the Somali of the Horn of Africa (Cossins, 1971a; Chambers, 1969; Lewis, 1961), the Samburu of Kenya (Spencer, 1965), and the Tuareg (Marty, 1972). For other societies our information tends to consist of a few isolated sentences in documents mainly concerned with other subjects. It is difficult to know whether lack of information about water management in societies about which good information, e.g. based on sound anthropological fieldwork, exists on other subjects is because water management is not practiced. The writer of the information may not have been interested in water management, or, although interested, he or she may not have recognized it for such. What applies to water management also applies to control of access to water. It is common to find a few sentences about the rules of 'ownership' of water points, much less common to find any information of who lays down or enforces the rules, under what circumstances the rules are rigidly enforced or relaxed, and what the word 'ownership' implies. What information we do have relates to the arid end of the ecological spectrum.

3. Production systems and traditional strategies: Some examples

This chapter takes a detailed look at some societies which exemplify the main livestock production systems in tropical Africa, and shows how each of these societies employs one or a combination of the traditional strategies discussed in the previous chapter to overcome water shortage. Since the most complex of the strategies is the one we have termed the "positioning and conservation strategy', emphasis has been given to using as examples societies which best illustrate that strategy. However, the provision of examples to illustrate strategies has a danger. Such examples, drawn from studies of whole societies rather than of individuals, tend to foster the illusion of uniformity within a society, as though all the members every year pursue the same strategy. This 'averaging' of behaviour over whole societies often obscures important differences between the way in which different individuals, or the same individual when subject to different constraints, behave[10].

10 Dyson-Hudson has drawn attention to this: 'It is the variations in individual behaviour patterns not the modal behaviour for the entire tribal group which gives the greatest insights...'(Dyson-Hudson, 1972, p. 47).

It has been easiest to find well documented examples of the application of strategies to overcome water shortage among systems of nomadic pastoralism in arid areas, then of mixed farming in semi-arid areas. With some difficulty an example has been found for a seminomadic system. These are the three production systems described in Chapter 1 of this report. No very useful information could be found on mixed farming in high-altitude areas, so no example of this is given. Ranching and small-holder dairy systems have tended to rely, in their water technology, on imported equipment and technology and are there fore, by our definition, not exponents of traditional strategies. The reader is reminded that in describing how societies employ different strategies the present tense is used in connection with evidence drawn from the past, unless it is positively known how the situation has changed since the time when the evidence was collected.

3.1 The Kababish Arabs-pastoral nomads

Among the Kababish Arab pastoral nomads of Sudan the following system operates (Asad, 1970). Kababish mainly keep camels, sheep and goats, in that order of importance in terms of biomass. The Kababish rely on grain rather than on livestock products for their main direct food, selling livestock to buy grain. Sheep and goats are sometimes herded together and sometimes separately, in which case the sheep require the more intensive herding. In the summer (hot dry season from February to June) camels need watering once in 9-10 days and sheep once in 4-5 days. Goats last a little longer without water than sheep but are normally watered at the same time. In winter (cool dry season from November to January) camels can go without watering for months and the watering frequency of other species is also greatly reduced.

Sheep are the most selective feeders and goats the least. Because it is a less selective feeder a goat needs a smaller area than a sheep to feed itself, i.e. it can use an area more intensively. As a consequence goats need to travel smaller distances from water points in the dry season in order to find enough to eat. Camels are also more intensive (i.e. less selective) feeders than sheep, but because of their lower watering frequency they can also exploit a much larger area. In normal dry seasons sheep and goats graze up to 18 miles from water and camels up to 35 miles; as a consequence in regions where there are only a few isolated water points camels can exploit an area four times larger than can sheep and goats. In bad dry seasons the radius of grazing for each species greatly increases and, as a consequence, the area livestock can exploit from a single water point almost trebles.

At the peak of summer it is usual for all household's livestock to be watered at the same well-field, although (as mentioned earlier) some camels may be sent off to water at distant boreholes so as to reduce the strain of watering by hand. At the well-field one household may 'owe' one or several wells which it may use exclusively or in cooperation with other households. Such wells have to be dug each year, and may need to be re-excavated and relined several times during a summer; they are normally less than 25 feet deep. A well is 'owned' by the household or group who dug it, but any Kababish may dig a well at any well-field and use the pasture around the well-field. Although households tend to return to the same well-field each year there is no rule which compels them to do so and some households do change from one well-field to another. Watering livestock at these impermanent wells is very labour-intensive and requires the labour of many members of the household. The tents of the household will be pitched from as little as 1/2 a mile to as much as 10 miles from the well-field. The better the year and the less dependent the household is for its subsistence on selectively grazing sheep (which need to roam further afield than goats in order to meet their feed requirements), the closer will be the household's tents to the well-field.

Towards the end of the summer dry season, especially if it has been a bad one, those livestock, especially camels and sheep, which are not required for the direct subsistence of the family, may be driven south accompanied by just a few herders, to an area where rain has already fallen. This exodus greatly eases the work of watering animals at the wells and relieves pressure on the grazing around the summer well-fields. When the rains come further north the families and family herds also move away from the well centres in a westerly direction to the rainy-season (July-September) grazing area, where they are subsequently joined by the main herds coming up from the south. The move away from the summer well-fields is not dictated by regulations or even, in most years, by the exhaustion of the summer pasture, but primarily by the desire to end the backbreaking job of watering livestock from wells. During the rainy season the herds drink from surface pools; if from small pools then frequent shifts of camp are required as these pools are exhausted and only small concentrations of the human population are possible. If livestock drink at larger pools then higher concentrations of human population are possible, allowing wider social contacts, but the surrounding pasture is correspondingly over-used, the water becomes foul, and there is more opportunity for thefts, quarrels and the spreading of livestock disease.

After the rains end in September to October the Kababish delay the return to the summer well-fields for as long as possible. The families and their accompanying herds (mainly goats for milk) stay at the big pools in the rainy-season grazing area until those pools dry up between November and January. The reluctance to return to the wells is (again) not imposed by regulations but by the desire to evade the arduous tasks of watering from wells and the long treks to and from well-fields for as long as possible. At this time the main herds, with just a few accompanying herdsman, may move off further northwest to the desert margin for a period. The sheep of the main herds will have to return to the wells earlier, as soon as the exiguous water resources in these areas dry up. The camels will stay out longer, relying on the succulence of vegetation to satisfy their water requirements in this winter time, and their herdsmen will in turn rely only on the camel's milk for their water intake. In good years camels may be able to stay away from the wells up to as late as March.

The Kababish practice most of the strategies already outlined, but to varying extents. From the evidence available they do not appear to put much emphasis on investment in new water supplies (in contrast, for example, to the Somalis of Ethiopia mentioned in the previous chapter), or on adjusting the age and sex composition of their flocks, or on the management and control of water points. Their main emphasis is on the positioning of herds and herders in relation to water supply and in using their summer water points and grazing for as short a time as possible. Given the nature of their water source, and their reliance on human labour to build and maintain the water point and to extract water from it for delivery to livestock, the main factor that influences their activities is the supply of labour. It is the labour constraint that induces them to send some camels off to water at boreholes throughout the summer and to send their main herds off south towards the end of the dry season. Similarly it is the desire to save labour that drives them away from the wells at the end of the summer and delays their return for as long as possible after the end of the rains.

3.2 The Berti - Mixed farmers in a dry area

The Berti are Arabic-speaking mixed farmers who live in the west of Sudan in an area where 300-350 mm of rain falls during the 3 months from July to September (Holy, 1974). The Berti practice hoe cultivation, the collection of gum arabic and animal husbandry. Their main source of cash income is gum arabic and of food the crops of millet, sorghum, sesame and melons which they grow themselves. They keep goats, camels and sheep as well as their main livestock, cattle, which they value mainly for their milk. The Berti live in permanent houses in villages around which they plant their crops.

During the rainy season livestock are kept near the villages, watering, where necessary, from temporary sources. They have to move near the villages at this time because all the available labour is required for weeding the crops and it can not be spared to herd livestock in distant pastures. During the long dry season only a few head of cattle are kept in the villages to supply milk for the inhabitants. If the dry-season water points are not more than 2 to 3 hours' walk from the village, the village livestock will be trekked to these water points on watering days. If the water points are further away, water for the village livestock as well as for human use will be transported by camels and donkeys.

The other livestock are kept, during the dry season, in special dry-season camps, in areas that provide better grazing than is available around the villages and which are nearer the dry-season water points. These dry-season water points are of two kinds; sandy river wells and open wells up to 40 m deep. The sandy river wells are used earlier in the dry season and then, when they dry up, to 40 m deep. The sandy river wells are used earlier in the dry season and then, when they dry up, recourse is made to the deeper open wells. Sandy river wells are 'owned' by particular villages and a village may have between one and three such wells. Each well has a 'well-master' *(agid al-bir)* who is an inhabitant of the village owning it. The well-master organises the communal redigging of the well each year and is responsible for the orderly use of it. People from the village owning the well have a preferential right to use it and people from other villages may only use it if members of the owning village are not doing so[11]. The well-field (i.e. the sandy river or *wadi)* in which particular wells are located has a 'well-field-master' *(rais al-bir)* who is a member of the major lineage in whose territory the well-field is situated. The well-field-master, at the beginning of each dry season, assigns the rights to dig wells in the well-field.

11 It is not clear in the source document (Holy, 1974, p. 109) whether members of other villages are only able to use a well *at particular moments in a day* when it is not being used by the owning village, or whether their access depends on the owning village not using it at all in that day/week/month.

Open wells *(sani)* are owned by the maximal lineage in whose territory they are situated. Rights over a well are exercised by a dwell-master' *(agid al-bir),* who is also responsible for organising the communal work of cleaning and repairing the well. The right to use the well is tied to the payment of a fee at the end of the rainy season following the use of the well. Clearly someone who fails to pay the fee will be debarred from subsequent use of the well, but it is not clear how the right to use it on the first occasion is obtained: the well may be used by tribal aliens and members of other lineages as well as by the lineage owning it. Watering at these open wells is on a 3-day cycle and for each day in the cycle there is a separate 'roster-master' *(rais al-dima)* who is- responsible for maintaining order at the well on his day in the cycle, a day on which 'water is always drawn by members of the same household'.

Cattle, goats and donkeys are watered every third day in the dry season and camels and sheep every sixth day. Water is drawn by hand, using a leather bag and rope, and then poured into troughs. At the height of the dry season this work requires a team of three or four people of whom all but one (who is supervising the animals as they drink) must be physically very fit. Watering livestock is, therefore, labour-intensive and households which are short of labour, either because they cannot field the minimum team needed to operate the well at all or because their herds are too large for the number of people in the immediate household, have to enter into cooperative agreements with other households in order to provide enough labour. On watering days members of the family who are resident in the village come out to the wells to assist in watering, but there is a conflict between the requirement for labour to water animals at the height of the dry season and the need for the same labour to be clearing new fields for planting.

There is some movement of dry-season livestock camps in relation to water points, in terms both of moving from dependence on one kind of water source, i.e. sandy river wells, to another, i.e. open wells, and of relocating camps into different positions with better access to pasture while still depending on the same water source. But the Berti, because they are tied to permanent villages and the fields around these and to the requirement of providing labour for cultivation, do not have the same flexibility to adjust the positioning of their herds to the availability of pasture and water as do pastoral nomads such as the Kababish. Not only are the Berti more constrained in space but also, because of the competing demand by crop cultivation for labour, they are not able to split up their herds to the same extent as do pastoral nomads. The latter often split up their herds into different species and different types (age, sex, lactation, pregnancy) within species, with each herd receiving the management, in terms of watering, trekking and grazing, best suited to it. Indeed the Berti's livestock receive rather little herding and may, for example, stray off to the watering point on days outside their proper cycle (Holy, 1974, p.88). In any case, cows and goats are expected to go of their own accord to the well on the proper day. Possibly it is because of these limitations on their ability to practice a positioning and conservation' or a 'husbandry' strategy that the Berti seem to have invested more effort into a 'management and control of water points' strategy and into the evolution of a comparatively complex set of water institutions.

3.3 Seminomadic Tuareg

Many of the seminomadic groups, occupying areas on the margin between the purely cultivation and purely grazing zones and basing their livelihood on both crop and animal husbandry, have been subject to the greatest changes in their modes of life during the last 30 years as a consequence of demographic pressure, of development programmes which introduced new water supplies, and of political change. The account which follows of seminomads in southern Niger draws principally on Bernus (1981) and Eddy (1979) and refers to the Iullemeden Kel Dinnik Tuareg whose cultivation and dry-season grazing areas-their home base - are located in the Tchin Tabareden Arrondissement. In addition to keeping livestock these seminomads also cultivate millet, sown on sandy soil often on the side of sand dunes, and, to a lesser extent, sorghum cultivated on heavier soils often in valley bottoms. Tuareg society was traditionally divided into a number of social classes, the complexity and functions of which can not be discussed here but are described in Bernus (1981). The social system gave Tuareg 'warlords' the power to control access to the range-lands (Eddy, 1979, p. 384).

The home base of these seminomadic pastoralists is in an area relatively well watered with pans, open wells and, more recently, boreholes (Bernus, 1981, pp. 342-353). In the past in general the migrations of these seminomads followed the same general north-south oscillation as that of the pure nomads also occupying parts of southern Niger, but there were important differences due to the different circumstances and constraints under which they operated.

The most important determinant of the direction of migration for both pure nomads and seminomads was the need to have access during the rainy season to the minerals ('cure salée') in the water of ephemeral pans and in the soil and vegetation 250 km away to the northeast outside the seminomads' home base, as well as the need to conserve the grazing in their home bases for use during the dry season when water supplies further north dry up. The seminomads' main migration was actually longer than that of the pure nomads because the seminomads needed to retreat further south to less dry areas where crops could be grown.

The timing of migration was also different. Pure nomads moved when the relative abundance of water and grazing in different areas dictated this; seminomads were constrained by the crop timetable. Except in the case of the larger or richer families the labour of their herdsmen was required for planting and for weeding at least once after the beginning of the rains before they departed north, and again for harvesting soon after the beginning of the dry season when it hastened their return south once more. In between these times their livestock needed to move out of the home base not only in search of minerals and to conserve dry-season grazing, but also to avoid trampling on the growing crops. Often only young people, especially young men, went on the annual migration, leaving other members of the families to keep an eye on the fields (Eddy 1979, p. 32). In contrast pure nomads moved with their whole families earlier on the onset of the rains and returned later in the dry season.

The herds of seminomads were both smaller than those of pure nomads and less diversified in species -both features reflecting their relatively greater scarcity of labour for herding consequent on the need for it in crop cultivation. In this system in the past neither pasture nor drinking water were particularly critical scarce resources. For these seminomads the main constraint seems to have been shortage of labour for herding and cultivation and the rather complex forces in the Tuareg social structure which limited the rights of subordinate classes to accumulate livestock.

In recent years the pattern has changed as a result of three main factors. Demographic pressure has pushed both cultivating Hausa and nomadic pastoral Fulani northwards into these Tuaregs' home base. The relatively high rainfall years of the 1950s and early 1960s made the expansion of cultivation - especially by the Hausa - possible, although this expansion was checked by the drought of 1968-73 and further encouraged thereafter by the need of previous pastoralists who had lost their livestock during the drought to find an alternative livelihood. The opening of government-operated water points has allowed an enormous influx of livestock, largely but not only belonging to the Fulani, into an area where, in more distant pre-colonial times, Tuareg ascendancy and subsequently private ownership of private wells restricted livestock numbers (Eddy, 1979, p. 133). The number of livestock owned by the Tuareg themselves fell severely during the 1968-73 drought. Whether as a result of greater population pressure and a consequent removal of protective vegetation or of the 1968-73 drought, the surface water sources of the area seem to have deteriorated. Pans dry up earlier in the year and shallow wells no longer last throughout the dry season.

As a result of these factors the previous pattern of land use by these Tuareg seminomads has changed in recent years. For the most part they no longer migrate out of their home base in the rainy season in search of mineralised water and pasture; instead salt is imported and fed to livestock. To migrate out would not, now, as it did hitherto, conserve the grazing for later use in the dry season, since immigrant Fulani herds would eat it in the rainy season instead. Moreover the Tuareg seminomads need as many of their household members as possible to be present in the crop areas during the rainy season to prevent crop damage by other people's herds (Eddy, 1979, pp. 133-134 and 181). There has been some tendency for Tuareg seminomads to give more emphasis recently to crop production than hitherto, partly because loss of livestock during drought has made them more dependent on cropping, and partly because only by planting an area of land to crops can some rights over it be maintained (Eddy, 1979, p. 137); otherwise it is likely to be occupied by an immigrant. Paradoxically the introduction into the area of additional water points, in the form of government-operated boreholes and concrete-lined open wells, has probably worsened the access to water and grazing of the original Tuareg people who used the land. Some of their previous water sources have dried up while grazing needs to be sought further afield at the end of the dry season as a consequence of its early exhaustion by the immigrant herds. Both these processes have been facilitated by the new water supplies at which control of access is not exercised.

In this example both traditional positioning/conservation and management/control strategies were exercised in the past; investment, composition and husbandry strategies were, in comparison, less important. Political events, i.e. on the one hand the suppression by the French colonial power of the Tuareg social system and the pattern of control of access to grazing and water which derived from it, and, on the other hand, the opening of new government-operated water supplies, were the main causes of the collapse of the old system. Nothing has yet grown up to take its place in providing a system for coping with shortages of grazing and water. A main reason for this is probably that the area is now occupied by three main ethnic groups, Tuareg, Hausa and Fulani, of whom the Hausa are in the dominant political position (Eddy, 1979, p. 137) and probably have the least interest in increasing the efficiency of livestock production. Given the inter-ethnic competition for resources and the inter-ethnic strife that the imposition of a new system for controlling access to water and grazing would likely arouse, it is, perhaps, not surprising that the politically dominant group have not thought it worth investing effort in evolving a new system.

3.4 Factors influencing the adoption of traditional strategies

The detailed examples given above show some of the ways in which different factors influence the extent to which particular strategies are undertaken; further evidence comes from other studies whose details are not reported here. The ensuing paragraphs discuss the influence of the main factors.

Foremost among these is the supply of labour for herding and watering in relation to competing demands for its use. As already pointed out the optimum spacing of livestock in relation to sparse water supplies requires that there be sufficient herding labour available for it to be possible to split up a person's or a household's total livestock holding into separate specialised herds (in terms of species, age, etc.), each with its own system of grazing, watering and management. Where the separate herds have to be reunited daily, e.g. to be enclosed at night in stockades for protection from predators, or so that milking animals can suckle stock, this requires a careful spacing of the encampment. On the one hand, the encampment must not be so far from water that young stock cannot be trekked there or water be brought to them by beasts of burden (Smith, 1978, p. 85) or that members of the household cannot walk to and from the water point to assist in the task of watering. On the other hand, the encampment must be sufficiently far from the water point that mature stock grazing out from the camp can get access to the relatively ungrazed outlying pastures. The camp site will need to be changed from time to time in response to the changing availability of pasture.

Some of the elements in a husbandry strategy, e.g. night grazing or extended grazing hours, also require abnormally high amounts of labour. Some elements in an investment strategy, e.g. constructing and maintaining dams, *hafirs* and wells of different kinds, are also labour-intensive. The greater the supply of labour available for these purposes the greater the extent to which livestock-owning households or societies will be able to implement these strategies effectively. When the supply of labour is inadequate to carry out the strategies properly for the existing number of animals, either the performance of livestock will suffer as they fail to overcome the problems inflicted by water shortage, or else the number of animals will have to be reduced to match the labour available.

Competing demands for labour may divert this labour supply. In some societies a substantial part of the labour force which would otherwise have herded livestock has, in recent years, attended school (Gulbransen, 1980, p. 173), or migrated outside the area where livestock are kept to earn income as wage-labourers elsewhere (Dahl, 1979, p. 85; Bonte, 1975, pp. 254-259; Fortmann and Roe, 1981, p. 143). In other cases labour is needed for crop cultivation inside the area. The consequences in all these cases tend to be the same - the livestock get less attention. For example the livestock of sedentary Fulani farmers in Nigeria have a 'grazing day' (i.e. time spent outside the cattle enclosure or camp) 20% shorter on average over the year as a whole, than those of their (semi) nomadic wholly pastoral counterparts. In the critical dry season (January to May) 'sedentary' cattle start their grazing day almost 2 hours later than 'nomadic' ones and their grazing day is up to 33% (in April) shorter (Van Raay, 1975)[12]. When labour is tied to permanent habitations or fields of crops it can probably not be optimally positioned in a camp between water supply and pastures. Many settled livestock owners in West Africa get round this competition between the demands for labour from cultivation and herding by entrusting their livestock to nomadic herders.

12 Van Raay does not give data for allocation of human labour. Data from a region in Upper Volta (Delgado, 1979) at the same latitude as Van Raay's sedentary farmers show that from the end of March onwards farmers are engaged in land preparation for the coming season's crop, an activity which reaches a peak in May (Delgado, 1979, p. 111). Van Raay himself came to the conclusion that the livestock management system of settled cattle is *more* efficient (by the criterion of the ratio between protein intake and requirement) than the nomadic system in the dry part of the year; but he reached this conclusion on the basis of arbitrarily allocating to the Fadama (lowland) herbage, which makes up 50-80% of settled livestock diets (and from which nomadic livestock are excluded) in the dry part of the year, a protein content double that which has been actually measured.

Watering livestock is another important competitor with herding for a scarce labour supply. In this case the type of water source at the water point can be of crucial importance. In Mali one herder can herd up to 50 camels during the dry season if they drink from a dam or river where livestock have direct or near-direct access to the water source; but if water has to be laboriously raised by rope and bag from 20 m deep open wells, an extra adult (probably a man) is required for half a day every 5 days to help in watering (Swift, 1979, Ch. 5). In the case of cattle two men can cope with 100 head, except for watering at these open wells when an extra two adults will be required for several hours every other day. In watering from open wells there are both economies of scale and diseconomies, e.g. where different herds and species get intermixed, and confusion, and sometimes injury to animals, results (Marty, 1972, p. 33 and Annexe p. 42; Swift, 1979, p.203). In cases where a certain minimum size of watering team is required to draw any water at all (Holy, 1974, p. 88; Helland, 1980, p. 66) there can be very substantial decreases in labour requirements (per head of livestock) for watering as herds are increased up to the optimum size, because once the team has taken the necessary time to assemble at the well it requires proportionately little extra time to water an extra animal.

We can illustrate this with a composite example that uses realistic technical coefficients from various sources (Holy, 1974; Swift, 1979; Torry, 1977; Bernus, 1981). A minimum team of four persons is required and they have to walk 2 hours from camp to well and 2 hours back again; the well yields 500 litres per hour from a depth of 20 m and cattle drink just over 30 litres at a single watering, i.e. 16 cattle can drink per hour; watering is hard work and a team cannot do it for more than 5 hours maximum per day. For a herd of only 10 cattle the labour input (walking to the well and then watering) would be 1.85 man-hours per head of cattle on a watering day; for a herd of 80 cattle it would be 0.45 man-hours per head; but for a herd of 90 cattle an additional watering team would be required and overall (i.e. over all the 90 head) the labour input would rise again to reach 0.61 man-hours per head on a watering day.

The large requirement for human labour to water livestock from open wells, and from many sandy river wells, has had important effects, primarily in terms of limiting the total number of livestock kept, but also in respect of determining the opportunities for advancement of those whose herd sizes are greater (i.e. the rich) or less (i.e. the poor) than the size of herd which is optimal for watering at open wells. Substituting either boreholes, where water is extracted and delivered to the livestock by mechanical pump, or permanent reliable dams and *hafirs,* where livestock have direct or near-direct[13] access to the water source, in place of labour-intensive wells sometimes greatly increases the number of livestock which can be kept in an area (e.g. the case of Niger - see Marty, 1972, p. 82). Labour released from watering duties can then be employed (although it may not be) in carrying out better herding and husbandry. It also makes it possible for the rich to accumulate bigger herds than would otherwise have been the case, by removing the need to take on extra labour to water their herds at wells and the steady drain on resources to pay this labour that is the usual result[14]. Boreholes, either because they are usually government owned and therefore outside the traditional community controls, or because their technology puts power to control them in the hands of technicians who can then be threatened or bribed, may also give advantages to the rich and powerful who can get priority for their own herds at the expense of others (Marty, 1972, p. 34). Probably, however, such privileges due to power and position always exist at water points.

13 'Near-direct' access covers instances where herders ladle water from the water source more or less horizontally into water troughs, without great expenditure of human energy, in order to prevent livestock fouling the water source.

14 In some societies, however, slaves or near-slaves watered (and continue to water) the livestock of the powerful for little reward.

Boreholes and dams, however, may also benefit the poor by making it possible for them to carry on other income-earning activities in addition to livestock raising without the total absorption in watering that labour-intensive wells require. In Niger (Marty, 1972, pp. 82 and 92) the poor who are thus able to pursue other occupations are among the strongest proponents of boreholes. In Botswana female-headed households are significantly less frequent users of sandy river wells than male-headed households, possibly because of the high annual labour requirements for redigging such wells (Fortmann and Roe, 1981, p. 73). Providing new labour-sparing water sources to poor or weak households may help them to continue to be stock raisers.

To an extent obstacles to carrying out the various strategies that are caused by labour shortage can be overcome by social institutions that facilitate cooperation between households and other groups, so that labour and livestock can be pooled in such a way as to achieve optimum combinations. Herding groups constitute one such institution, as do well-councils and well-masters (Helland, 1980; Holy, 1974), and lead to the formation of teams to maintain and operate wells. Other institutions permit the adoption of children from labour-surplus by labour-deficit households or the entrustment of livestock by farmers or large herd owners to pastoralists with the capacity to take on more animals. Some societies possess such institutions while others do not. It is difficult to tell how much 'social structure' is an independent factor in this, encouraging or inhibiting cooperation, or how much it merely reflects the degree of need for cooperation. Certainly in some cases it seems to be an independent factor. In the central highlands of Ethiopia, for example, so intense is suspicion of neighbours that the size of flocks which are herded independently are quite remarkably small; 20% of all sheep and goat flocks (i.e. herding units) consist of five or less animals and 35% consist of 10 or less. This occurs because, in spite of general complaints about shortages of shepherds, no one is prepared to entrust their livestock to someone else (Cossins and Yemerou, 1974, p. 14; Watson, 1973b, Table 7).

Reliability, both of water supply and of the surrounding pasture, may be an important element in determining to what extent one strategy is followed rather than another. The societies which have developed the most complex institutions for managing and controlling water supplies, e.g. the Berti (Holy, 1974) of Sudan and the Borana of Ethiopia, are either sedentary[15] or at least fairly regular in their use of water and pasture. Water is in scarce supply (or at any rate it is difficult to extract from deep open wells) but both water and pasture vary comparatively little from year to year in contrast to neighbouring areas. Thus settlement and moderate regularity provide the opportunity to develop complex social institutions. Helland (1980) emphasizes the time and effort that an individual needs to invest in social and political relations if he is to maintain and strengthen his watering rights at the important Borana wells. That kind of continuous maintenance of social relations inside a group with a more or less fixed membership is exceedingly difficult in a highly fluctuating and unpredictable environment, where groups are liable to have to form and disperse at short notice in response to the need to adapt human and livestock densities to local and temporary variations in grazing. Moreover, even if the required investment in social relations can be maintained in order to establish efficiently functioning institutions at particular water points, there will be no guarantee that the investor will reap the fruits of his investment; a bad season may force him to go and seek grazing elsewhere where the rainfall in that year has been better.

15 The Borana have the system of 'dry' or 'fallow' herds already referred to, in which the dry herds and their few herdsmen are much less sedentary than the 'milking' herds and other humans. Although the dry herds are fairly opportunistic in their movement, this does not invalidate the present argument since the herders of the dry herds are not usually the heads of households who need to develop and cooperate in social institutions.

Next door to the Borana of Ethiopia but in a much more unreliable environment are the Somalis of the Horn of Africa. Because of this unreliability they have a highly opportunistic land-use system in which large sections of the population may switch even their fallback dry-season watering points from year to year. In contrast to the Borana they have much less complex institutions for the management and control of water points. However, their manipulation of livestock and people in space and time is much more complex. This is well illustrated by Cossins (1971a).

Other kinds of uncertainty (as well as that due to the natural environment) can also effect the extent to which livestock owners are willing to invest time and energy in institutions to carry out a strategy of managing and controlling water points. Where different ethnic groups use the same territory and watering facilities, and where one of these ethnic groups is not clearly superior in power and status to the others, it is extremely difficult to decide upon, by consensus of all the users, and then to enforce, the regulations for management and control. In northern Kenya, Borana efforts to manage the efficient use of water at dams broke down when the government ceased to enforce the previously strict restriction of pastoralists within tribal areas -Somali pastoralists came to water at the same dams (Dahl and Sandford, 1978, p. 41). Thereafter not even the Borana observed the regulations because they were sure the Somalis were not doing so. In general when governments construct or take control of water points, the uncertainty caused by fluctuations in government policies prevents the growth of the kind of management system found at non-government water points in the same areas. Both ethnic mixing and government ownership have combined in Niger to produce a situation in which the management of the water at boreholes is extremely poor (Marty, 1972, pp. 33 and 43).

Another important factor influencing the choice of strategy is the extent to which crop cultivation spreads into areas previously used exclusively by nomadic pastoralists. When water supplies are sparse and investment in multiplying them is expensive, and where nomadic pastoralism is the only system of land use, livestock owners will probably prefer a strategy - of the kind illustrated by the example of the Kababish Arabs - of carefully positioning different species and classes of livestock in space and time so that each has an optimum balance between access to feed and access to water. But this strategy often becomes infeasible where the spread of cultivation, often by an immigrant ethnic group, around the fallback water points prevents grazing of this area by the livestock with the highest water requirements, or involves pastoralists in constant disputes over damage done to crops while bringing their livestock to water. The spread of cultivation may involve the abandonment of one strategy in favour of another.

The factors already mentioned, labour supply and alternative demands for it, the unreliability of the natural and social environment, and the extent to which crop cultivation extends into areas previously reserved exclusively for nomadic pastoralists, largely explain why some strategies are pursued more in some production systems than in others.

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4. Modern strategies

'Modern' strategies can be contrasted to 'traditional' ones; the latter have been defined principally in terms of their not requiring large inputs of skills, equipment or money from outside Africa. Modern strategies are, therefore, by implication ones which do require these exogenous inputs. The fundamental element in modern strategies is the new ability to place water points where one wants them to be rather than where, by accidents of nature, it is relatively easy to identify a local source of water and to extract it for use by livestock. This new ability depends on exogenous technical skills (hydrology, mechanical and civil engineering), equipment (drilling rigs, earthmovers, metal or plastic piping) and capital resources (e.g. loans from banks or donor agencies). An important determinant of whether this new ability is exercised is the balance between the costs and benefits of investment in water points. The economic considerations which touch on this balance are not discussed to any significant extent here, but may be reviewed by ILCA in a subsequent report.

Two main modern strategies exist. The first is to increase the spatial density of water points, so that the energy expenditure involved in trekking to and from water is minimised and so that the species, breed, and class of livestock kept can be determined by their relative productive ability rather than by their ability to cope with water shortage. The second strategy is to use the location and density of water points, and the dates at which they are opened and closed to use, as a principal means of controlling the intensity, the evenness (in space) and the period of grazing in the interests of optimal pasture productivity. The second strategy may involve the use of fencing to control the movement of livestock around water points. It is also related to the availability and amenability to direction of herding labour. In situations where herdsmen are hard to obtain the provision of a water point in each of many small paddocks may be an alternative to close herding for ensuring that pasture is used properly. Where herders are disinclined to heed verbal instructions on pasture rotation, the opening and closing of water points, by such means as removing parts of machinery or locking taps or access gates to dams or *hafirs,* may be a way of compelling the herdsmen's compliance. The technology involved in modern, as opposed to traditional, water points makes control by a centralized management over recalcitrant herdsman technically more feasible although in practice social pressures (e.g. bribery and coercion) often overrule technology. One observer of government water points in Niger has commented:

> 'Practically, herders and herd owners coerce the managers of pumping stations into opening the stations whenever the herders find them more convenient.' (Eddy, 1979, p. 168).

4.1 Reducing the waste of energy in trekking to water

It is very difficult to quantify in a satisfactory way the benefits which increasing the density of water supplies will bring through changes in the species, breed and class of livestock[16]. It is however possible, in a highly simplified model (explained in the notes to Table 4) to quantify the effects, for particular classes of animals, in terms of the extra energy made available for production, of reducing the energy expenditure on trekking long distances to water. The details of the calculations for lactating cows are shown in Table 4. The key assumptions, coefficients and parameters are drawn from King (1983, especially Ch. 5). Simplification is introduced by assuming that water frequency does not increase with greater density of water supplies and that body weight remains constant, i.e. that cows do not sacrifice body tissue in order to maintain milk output. Relaxation of these simplifications will not substantially alter the general picture, which is that a reduction in the spacing of water supplies (spacing = twice the maximum radius of the grazing circle), for example from 26 km to 20 km nearly trebles output (milk supply); but further reductions (in spacing of water supplies) lead to smaller proportional results, so that finally decreasing the spacing from 10 km to 4 km increases output by only an additional 9%.

16 For a review of some of the literature see Squires (1978b).

Table 4. *Relationship between density of water points and energy available for production.*

Density of water points (D) (No. per 1500 km^2)	1	3	5	10	20	100
Maximum radius of grazing circle (R)[a] (km)	22	13	10	7	5	2
Average walk to and from water per day (G)[b] (km)	15.5	9	7	5	3.5	1.5
Average daily energy intake[c d] (MJ ME)	24.1	42.4	48.0	50.1	50.1	50.1
Mean daily expenditure on maintenance at rest[e] (MJ ME)	28.2	28.2	28.2	28.2	28.2	28.2
Mean daily expenditure on feeding[f] (MJ ME)	1.0	1.7	1.9	2.0	2.0	2.0
Mean daily expenditure on walking while grazing[g h] (MJ ME)	4.5	4.5	4.5	4.5	4.5	4.5
Mean daily expenditure on walking to water[h] (MJ ME)	7.0	4.1	3.1	2.2	1.6	0.7
Subtotal mean daily expenditures listed above (MJ ME)	40.7	38.5	37.7	36.9	36.3	35.4
Balance of energy available for production (MJ ME)	(-16.6)[i]	3.9	10.3	13.2	13.8	14.7
Milk yield (litres) equivalent of energy available for production[j]	0	0.6	1.7	2.2	2.3	2.5

a $R = \sqrt{1500/D\pi}$ rounded to nearest km.

b $G = \sqrt{\pi R^2/(2/\pi} = R/\sqrt{2}$, rounded to nearest km; assumes watering every other day for all densities of water points. This is the formula for determining the radius of the inner ring where a circle of radius R is divided into two rings, an inner and outer, and where the surface area of the two rings is the same. This is a simplifying approximation to the correct formula for estimating average daily distance walked to water according to one model of how livestock will progressively utilise the grazing around a central water point.

c Assumes intake varies with daily distance walked with a maximum intake (in DM) of 2.5% of body weight; the gross energy content of intake is 18 $MJ.kg^{-1}$ DM; digestibility 55%; metabolisability 81%. See King (1983, Equations 5.01 and 5.02).

d ME = metabolisable energy.

e $0.343W^{0.73}$/efficiency of conversion; where W = liveweight = 250 kg and efficiency of conversion for maintenance is 0.68.

f Prehension, tearing, eating at 40 $kJ.MJ^{-1}$ ME of intake.

g Assumes that animals walk 10 km per day, on average, while grazing in excess of the daily average distance walked to water.

h Energy cost of walking is 1.8 kJ $ME.km^{-1}$ $.kg^{-1}$ of liveweight.

i

At this spacing of water supplies the animal loses weight at the rate of about 0.5 kg per day and will soon stop lactating.

[j] At 3.6 MJ net energy per litre, with a conversion efficiency of 0.6, thus requiring 6 MJ ME to produce 1 litre of milk.

Table 5 shows the same general pattern in a different way. Using exactly the same assumptions as for Table 4 it shows in summary form how successively quadrupling the number of water points increases output as a consequence of the reduction in energy wasted trekking to water. Of course at the higher densities of water points some of the original assumptions, e.g. about distance walked while grazing, about watering frequency, about food intake, are no longer realistic. For example,

Table 5. ***How multiplying the number of water points increases output by saving energy spent on trekking water.***

Spacing between water points (km)	20	10	5	2.5
Implied size of square paddocks (ha)	10000	2500	625	156
Increase in output per beast compared to next largest size of paddock (%)[a]	-	34	5	2

a Output per head of livestock (beast) in paddock size (A) less output in next largest paddock (B) as a proportion of output in paddock B is given by

$$\frac{A - B}{B} x100$$

Squires (1978b)[17] has shown, for sheep, that food intake declines with increasing distance between food and water[18], as does drinking frequency and, above a distance of about 5 km, total water intake. Moreover, the simplified model here ignores many of the trade-offs between intake, loss of weight, metabolic rate and distance walked (and the seasonal variations in these) contained in the more complex model used by King (1983). It represents, therefore, only a first approximation to reality on which we must rely until more direct empirical evidence, derived from pastoral systems, becomes available on the relation between distance and water and economic output. It is, nevertheless, illuminating in showing how initially large proportionate returns to reducing the spacing between water points (i.e. an increase of 34% in output as a consequence of halving the spacing from 20 to 10 km) rapidly falls off for successive proportionate reductions in spacing; so that the final halving in spacing from 5 to 2.5 km yields only an additional 2% in output.

17 Drawing on Squires (1970b), Squires and Wilson (1971) Squires et al (1972), Daws and Squires (1974).

18 A decline not closely associated with decreased time for grazing caused by wastage of time trekking to water.

4.2 Controlling the intensity, evenness and period of grazing

The second main modern strategy is to use water points as an instrument in controlling grazing and trekking in such a way as to increase the productivity of pasture and to minimise soil erosion. The density of water points, their location in relation to natural features such as hills, and the periods of the day or year in which they are open, influence the distribution and movement of livestock in space and time. On unfenced rangeland in Australia unherded cattle can be redistributed between different areas simply by closing one water point and opening another (UNESCO, 1979, p. 469). Where livestock are herded, the opening and closing of water points, and limitations on the supply of water from them, can be used to enforce pasture rotations and stock limitations against the wishes of the herdsmen. However, as we have already seen, and as is experienced frequently, a central management body's decisions about the operation of particular water points may not always be respected by their operators in the face of local pressures.

Livestock, with their attendant trampling and grazing pressures on soil and vegetation, are seldom evenly distributed across the landscape. Where water points are sparse, trampling and overgrazing normally occur in concentric rings of increasing intensity the closer one approaches to the water point. The relationship between distance to water and pressure may best be represented, diagrammatically, by a curve which is sigmoid in shape - not much change in pressure in the first band, then a very sharp change, tailing off further out - rather than simply linear (Graetz and Ludwig, 1978). One example of this spatial distribution of pressure in relation to the location of a water point is given in Table 6.

Similar data can be quoted to show how palatable vegetation is replaced by unpalatable vegetation as one approaches a water point.

A spatially more even distribution of pressure on vegetation and soil can be brought about by increasing the number of water points - although this may lead to an overall greater, albeit more evenly distributed, pressure - and by fencing or careful herding. Some livestock, e.g. sheep in mountainous areas, distribute themselves, unherded, more evenly than others, e.g. cattle (Stoddart et al, 1975, p. 285). Naturally the distance which livestock will graze out from an isolated water point varies by species and class of livestock, from place to place and season to season, and according to vegetation type and whether the animals are herded or not[19]. For example, around one water point (Mount Capitor Bore) in Central Australia the grazing distance from the water point of the majority[20] of cattle (unheeded) varied from 1 km to 13 km depending on season and grazing abundance (Hodder and Low, 1978). At another water point (Sandy Bore) in the same general area, faced with similar conditions of feed scarcity, at no time did the majority graze more than 8 km. In contrast, Table 7 shows the distribution of nomadic flocks in the dry season in arid Mali.

19 For a further analysis of factors affecting the spatial distribution of livestock see Squires (1976).

20 In the original paper the expression 'majority' is not defined. Presumably it refers to a cumulative frequency of ^{3} 50% of cattle at all distances up to the one quoted; but some of the language of the paper suggests otherwise.

Table 6. ***The effect of gross overgrazing around a wet-season water point (Mare d'Arodouk) in Mali.***

Distance from water point (km)	1	2	3	4	5
Bare soil as % of surface area	36	22	14	20	9

Source: Boudet (1977, p. 191).

Table 7. ***The spatial distribution of nomadic livestock in an arid zone in Mali.***

Species	**% distribution of flocks/herds at different distances between pasture and wells**					**No. of flocks/herds in sample**
	10-19 km	**20-29 km**	**30-39 km**	**40+ km**	**All distances**	
Camels	25	23	39	13	100	56
Cattle	19	66	15	0	100	62
Sheep	30	54	16	0	100	37
Goats	64	36	0	0	100	14

Source: Swift (1979, p. 154).

The evidence is not conclusive, but it suggests quite strongly that herding is an alternative to extra water points as a way of obtaining a more even distribution of livestock across the landscape. No direct evidence is available to compare, other things being equal, the impact of such a livestock distribution on soil and vegetation resources in circumstances where herding is practised in contrast to those where it is not.

In smallholder dairy systems fencing and installing water supplies in fenced paddocks is primarily aimed at preventing disease-susceptible stock, on the way to water points, from entering land where they may pick up infections or parasites (Goldson, 1980). We could call this a third modern watering strategy. In drier areas fencing is another alternative to herding as a way of obtaining both a rotation of pastures and a more even spread of grazing pressure. Often fencing into paddocks will also require the installation of extra water points so that each paddock has its own supply and no trekking between paddocks in search of water is required. In Australia, Squires (1978a, quoting Squires, 1970a) suggests that sheep normally concentrate their grazing within a 3 km radius of water, and this would imply a maximum paddock size of about 3600 ha for a water supply centrally located in a square paddock[21] (or 900 ha if located in a corner). The data already referred to in suggesting a sigmoid relationship between distance to water and grazing pressure (Graetz and Ludwig, 1978) suggest that about one tenth, in a ring at the centre of such a 3600 ha paddock, would be heavily used and the remainder would be under even pressure. For cattle, especially for Africa's relatively long-legged rangeland cattle, we can presume that a bigger paddock size would be appropriate. Squires (1978b) suggests that 4000 ha may be grazed by sheep, in Australian conditions, from a single water point, but 17000 hectares - a square paddock of 13 x 13 km - by cattle, a maximum radius of about 7 km.

21 The implication is that about 20% of the paddock in the corners outside the circle of 3 km radius would be underused.

Constructing separate water points for each paddock of 4000 ha involves very substantial capital cost per ha in water development. As an alternative to this, fencing can be used to channel livestock away from single water points further than they will normally graze of their own accord. Kilgour (1974) - quoted by Squires (1978b) - has suggested fenced lane-ways radiating out from permanent water and widening out into funnel-shaped fenced lanes ending beyond the normal grazing range of the livestock being managed. In southern Africa, in connection with the so-called Savory system of short-duration grazing, up to 30 or more fenced wedge-shaped paddocks radiating, like the spokes of a wheel, from a single water point have been advocated (Savory, 1975; Farmer's Weekly, 1976) for the ranching of cattle. However, it is not clear from these sources that more than 8000 ha can be served in this way from a single water point, although very even use of pasture and up to three times the normal safe stocking rate are claimed for this system.

4.3 Factors that determine the appropriateness of adopting modern strategies

It is evident from the previous discussion that the main factors that determine whether and to what extent one of the modern strategies reviewed here should be adopted will be the relative costs and prices of modern water technology (which is the key to adopting a modern strategy), economic output from livestock, fencing and herding labour. The first strategy discussed was an increase in the density of water supplies in order to reduce energy wasted in trekking to water. Successively quadrupling the number of water points (i.e. halving the distance between them) produces successively smaller proportionate (and absolute) increases in output. The cut-off point at which it will no longer be worthwhile to increase further the density of water points will be determined by the cost of additional development relative to the price at which the additional output can be sold. Similarly the second strategy, to ensure optimum intensity, period and evenness of grazing pressure, involves a careful weighing of the relative costs of water development, fencing and labour - all of them partly complementary, partly alternative means whereby grazing pressure can be controlled to increase economic output.

There are, however, some complicating factors that need to be taken into consideration in both the main modern strategies. One of these is that topography and the spatial distribution of soil and vegetation in Africa are seldom so uniform that livestock (or their herders) are indifferent about which direction they head away from the water point; nor is the distance they trek from water solely determined by the availability of metabolisable energy in the grazing. On the contrary, livestock feed very selectively and roam purposefully to areas where the vegetation they prefer grows. In Botswana:

> 'Significant portions of almost untouched pasture can be observed less than 1 km from water points even in the crowded eastern areas.' (Gulbransen, 1980, p. 199).

In Australia:

> 'Both cattle and sheep have been shown to walk long distances to reach preferred plant communities, often passing through abundant forage on the way.' (Squires, 1978b, p. 433).

Carefully planned spacing of water points that assumes tidy concentric circles of grazing pressure can lead to locating water points in a way that increases rather than reduces energy spent on trekking. Secondly, with this asymmetry in where livestock prefer to graze is an asymmetry in where it is cheapest to find water. Modern technology may make it possible to put in a water point almost anywhere - by piping in a supply if necessary; this does not alter the fact that it may be far cheaper to put a modern water point alongside a sandy river bed than 2 km away on a ridge, where symmetry may demand that it be placed.

The third complicating factor is that nowhere does a planner of water development (or fencing) start with a clean sheet. In almost all cases he will be faced with an existing pattern of spatial distribution of water points (this also applies to fencing). If they are evenly spaced so as to be in the right position for the present policy for locating water points, e.g. that they should be a certain distance apart, they will almost all of them be in exactly the wrong position for any new policy of more closely spaced water points; unless the new policy is to halve the distance between water points, which means quadrupling their number-an enormous investment. That may seem a very theoretical point but it is one that ranchers also find in practice, in respect of both water points and fences. In Australia:

> 'Management is often severely constrained by the siting of fences and water points. Paddock size, once determined, is not easily altered. Unless a fire removes a fence the next unit of subdivision is to split it in half; this may provide a second best approximation to optimum paddock size...' (Squires, 1978a).

In Zimbabwe the introduction of a short-duration grazing Savory system has been hampered where attempts have been made to graft it on to an existing layout of water points and fences (Savory, 1975) and complete replanning of existing ranches may be preferable (Savory, 1978), although it is obviously extremely expensive. Water points and fences cannot be uprooted and replanted in fresh places as easily as seedlings in a garden.

We can see, therefore, that as well as relative prices both the homogeneity of the landscape, in terms not only of the palatability of the vegetation but also of the cost of developing water in different places, and the extent to which new water developments are being imposed on an existing pattern that is at variance with a new policy, will be important in determining whether and to what extent the modern strategies will be taken up. Finally, part of our definition of a modern strategy is that it is dependent on exogenous inputs. Not only is the availability of such exogenous inputs unreliable, both in the development and in subsequent operating stages, but where they are introduced into traditional societies it is particularly difficult to predict how the benefits which will accrue from their introduction will be distributed between different interest groups. We return to this point in the next chapter.

5. The experience of water development

5.1 The popularity of water development

In arid and semi-arid areas the development of new water supplies has been, and for the most part still is, overwhelmingly the form of development most sought after by pastoralists. In a few cases this enthusiasm has been tempered by experience. In southeast Ethiopia in the early 1970s pastoralists said:

> 'Put in wells a long way from here otherwise people will come and the grass will be finished... All we need is enough (water) for our own people and we don't mind walking for a day to get it.' (Cossins, 1971a, p.45).

In Niger in 1971/72, in roughly the same area as the example of Tuareg seminomads used in Chapter 3 - an area where a number of factors including government water development had caused the collapse of the previous land-use system nearly three quarters (73%) of livestock owners surveyed wanted a further increase in the number of open wells, although somewhat less than a half of them (43%) wanted a further increase in the number of boreholes (Marty, 1972, p. 91). In some cases pastoralists in this region requested the government administration to close boreholes already in operation because of the disruption they cause (Bernus, 1981, p. 429). In many, even most, pastoral areas, however, enthusiasm for new water development remains strong. We shall return subsequently to the question of which pastoralists, within a group or area, are most enthusiastic and receive the most benefit from water development, and which the least.

5.2 Water development in the past

Water development in the past has undoubtedly had a very important impact on livestock output from the dry (arid and semi-arid) regions of Africa. Although there must have been some effect in terms of a reduction in the amount of energy wasted in trekking to water, it seems probable that the main impact has been through opening up for more intensive use areas which, prior to water development, could only be used for short periods in the year and by a few livestock, or which could not be used at all. For example, between 1965 and 1976 the area of land in Botswana accessible to domestic livestock approximately doubled as a consequence of borehole drilling programmes financed from both public and private sources (Sandford, 1977, p.B. 16). In Sudan the number of watering sites for livestock was allegedly quadrupled between 1957 and 1968 by constructing nearly 1000 water yards equipped with boreholes, reservoirs and dams (Ministry of Agriculture and National Council for Research, 1976). In both countries these measures were accompanied by tremendous increases in the livestock population able to take advantage of the feed resources made accessible by these developments. According to government estimates the cattle population in Botswana increased by 73% between 1965 and 1975 (Sandford, 1977, p.25) and in Sudan by 55% between 1957 and 1968 (FAO Production Yearbooks). As is usually the case with such statistics, not much confidence can be put in these figures.

5.3 Negative aspects of water development - Technical problems

In spite of the popularity of water development among pastoralists in dry regions and of the impressive scale on which it has taken place in some countries, there have also been several negative aspects to it. In many cases the technical efficiency of construction, operation and maintenance has been low, and a few years after construction many water points are no longer in use. In Kenya in 1976 only 12 out of 54 boreholes drilled in the northeast after 1969 were still operating (Kenya Ministry of Water Development, internal reports). In Botswana 40% of boreholes drilled never operate, and in a survey of the Botswana Western Sandveld region only 65% of water points (85% of these were boreholes) were found to be operating at the time of the survey, 19% had been completely abandoned[22], and 16% were not functioning for more temporary reasons - usually mechanical failure of some kind (Hitchcock, 1978, pp. 143-157). In Niger out of 23 boreholes installed between 1961 and 1969 about 15 (65%) were still functioning by 1969 (Bernus, 1977, pp. 56-57). In Sudan, out of 145 boreholes in one area of Southern Darfur Province, 28 had broken or malfunctioning pumps in the mid-1970s and 44, although constructed, had never operated (Huntings Technical Services and Sir M. Macdonald and Partners, 1976, pp. 13 and 61). In one part of southeast Ethiopia in 1974 only 9 out of at least 17 boreholes known to have been drilled were still functioning (Livestock and Meat Board, 1974, Annex II).

22 Although this is not expressly stated it seems that boreholes which had never operated, because 'cry' or otherwise unsuccessful at first drilling (i.e. the 40% already referred to), are excluded from these Western Sandveld figures.

Boreholes probably have a worse performance than other types of water source but other kinds also have problems. Of 100 *hafirs* or *hafir* dams built in the northeast of Kenya in the 1970s 'many are silted in, some completely' (Axin et al, 1979, pp. 29 and 55) due to heavy rainfall causing unexpectedly high erosion, unrestricted access to the actual dam and side wells by livestock and damage consequent on this, and the absence of maintenance. In 1977 someone who had known Tanzania Maasailand for over 20 years commented:

> 'Most of the former permanent water supplies of Maasailand such as boreholes, dams and improved spring catchments and water pipes are either broken down, clogged up, working at reduced capacity or in need of hardware and repair to permit them to work effectively.' (Jacobs, 1977).

A large range development project in this area in the early 1970s constructed or rebuilt about 25 major dams (USAID/Tanzania Government, 1977, pp. 18-20).

> 'Unusually heavy rains in the spring of 1977 breached and destroyed <u>all</u> of the earthen dams constructed during the previous 7 years, all of which - according to the new hydrologist - had been built without proper subsoil and watershed assessment and without adequate wetting or compaction.' (Jacobs, 1980).

There are many causes for this poor technical performance. In some cases it is simply inadequate technical skills, measured by any yardstick, on the part of those designing, constructing and operating water points; in other cases the professionals, although well-trained and motivated, have too little local hydrological or geological information, or there simply has not yet been adequate local experience with different kinds of equipment or structures for sound designs to be drawn up. In such circumstances risks have to be taken and inevitably the failure rate is high. In some cases information might have been available if adequate administrative sources had existed to retrieve or extract it from archives or technical literature. In other cases quite inappropriate techniques and equipment have been used, either from a misplaced faith in the most recent technology or, far more often, because development was financed from external aid funds and these are all too often biased towards the use of complex technology imported from the country supplying the funds. Often complex imported equipment cannot cope with the local roads and no adequate system exists or can be quickly put in place for ordering, storing and supplying spare parts or other inputs.

5.4 Administrative and financial problems

Very often financial and administrative problems lie behind technical breakdowns. Broken equipment is not repaired because there is no money with which to do so, and even where there is, administrative procedures may act as glue in the bureaucratic machinery to prevent the work being done. It is not easy to collect watering fees in pastoral areas. For short periods at the height of the dry season very high rates of watering fees can be charged and collected, as the example from southeast Ethiopia quoted in Chapter 2 shows (Cossins, 1971a, p.44). But faced with high fees over an extended period, pastoralists will quickly move to alternative cheaper sources while these are available - only returning to the source charging a high fee at times of emergency. This makes the steady recovery of overhead costs for water development particularly difficult. Collecting fees for watering livestock is difficult for both private entrepreneurs and government. The data in Table 8 show how much, in 1979-1980, livestock owners in Botswana actually paid to use water at other people's or government boreholes.

Table 8. *Costs of providing water and fees paid at public and private boreholes in Botswana (1979-1980).*

	Private borehole	Government borehole
Watering fees paid (in cash and kind)[a] per m^3 (Pula[b])	0.38	0.55
Average cost of providing water per m^3-Total[c] (Pula)	2.65	2.39
of which: recurrent costs (labour, fuel, repairs) (Pula)	1.01	0.93
capital charges (Pula)	1.64	1.46

Source: Bailey (1980, Tables 11 and 26).

[a] This assumes that, on average, one 'livestock unit'- equivalent to an adult bovine - drinks 0.85 m^3 of water per month throughout the year. This figure can be justified from Bailey (1980), Table 13.

[b] 1 Pula = approx. US$ 0.90.

[c] All figures are averages for many boreholes, and capital charges are at 'replacement' not 'historic' cost and include 12% interest on capital.

The data in Table 8 show how very much less than the average cost of providing water was paid by these livestock owners. In the case of privately-owned boreholes the average amount paid is almost exactly the same as the cost of the average amount of fuel used - an approximation to the marginal cost of water supply. Ties of friendship, fear of offending an important person, a desire to help the poor, ignorance of what the cost of supplying water actually is, all combine to make it difficult to charge the full-cost rate. In the case of both governments and private entrepreneurs not only are the rates for watering fees set too low, but even those set are not collected. Fortmann and Roe (1981, p. 24), for example, recount how they counted an average of about 300 cattle per day watering at a government borehole in a month where the total receipts for watering indicated only about 100 cattle watered; given a 2-day watering interval, this means that only about one fifth of the fees due were collected.

In many cases government financial procedures stipulate that money collected at a particular water point is not earmarked to meet the expenses incurred at that point but is paid into general government revenue and the expenses are met by a separate allocation. As a consequence users of the water point have absolutely no incentive to pay the fees, nor the employee operating the water point to collect them. The result of all these factors is that watering points in dry regions are constantly starved of funds for their operation, maintenance and repair. Such funds as are available in the responsible ministry for running water supplies will be allocated to regions of greater political priority.

Shortages of funds to run government water points are often compounded by administrative procedures for procurement and contracting. For example, in one African country funds were avail able to repair government open wells scattered over a huge area. Official procedures, however, required that the contract for the repair be awarded only after the receipt of three competitive tenders for the work. No contractor would tender for the work without inspecting each well to see precisely what repairs were required. But travailing round the wells and entering each would account for, by far, the largest part of the actual cost of repair, and for three contractors to be required to do this and for only one (the successful tenderer) to be paid, and then only for a subsequent trip on which to do the work, guaranteed that three bids were not received.

This is an extreme case but nicely illustrates the point that government procedures drawn up to fit the needs of a different set of circumstances are quite inappropriate for running livestock water supplies in dry areas. As a consequence operators are not paid their salaries, fuel for pumping runs out and is not replaced, and essential repairs and maintenance do not take place. The results are most dramatic in the case of boreholes because they either function or they do not. In the case of dams and *hafirs* the result is more usually a steady diminution in effectiveness over a period of time rather than the kind of instant catastrophe recorded above for the Tanzanian Maasai Range Project's dams.

5.5 Environmental problems and land use

The negative impact of water development on the environment has often been stressed in recent years. It is the counterpart to the increased livestock populations, and consequent increased livestock output already referred to. The 'last word' on the environmental impact of water points on African rangelands is still a long way from being written. An initial unrealistic optimism assumed that new water points would spread a finite grazing pressure more evenly and more widely; in practice the grazing pressure increased, in total, to fill the new niches made available by water development. The subsequent ultra-alarmist fears about the rapid spread of barren deserts around water points are now being replaced by more cautious assessments, as detailed attempts to measure change are revealing the complexity of the interactions between new water supplies, grazing pressure, climate, soil nutrient status, and the composition and productivity of the range vegetation.

The subject is beyond the scope of this study (for some reviews see Bernus, 1981, pp. 437-451; Breman et al, 1979/80; Horowitz, 1979, pp. 27-42; Warren and Maizels, 1977) except to note that the ill effects of new livestock water supplies on the range vegetation are more local in space, more circumscribed in time and less certain than has often been claimed. The timing, in the year, of the use of vegetation is often more important than the degree of grazing pressure. However, whereas previously the main concern was with the physical effects of trampling and grazing by animals on the soil structure and vegetation, more recently there has been a shift towards greater emphasis on the chemical effects of overgrazing on soil nutrient status (Penning de Vries and Djiteye, 1982). With this change in emphasis on the mechanism for degradation, it seems possible that new water supplies will be accorded a less prominent role.

Even if the environmental effects of new water supplies are still uncertain they have, nevertheless, had important effects on land-use systems. In part this is because, as intended, they reduced the distance livestock had to trek to water; and in part because they disrupted traditional patterns of management and control. Sometimes the new supplies are built by entrepreneurs, often with capital generated from outside the pastoral society, and these entrepreneurs' commercial and political contacts with non-pastoral society enable them to evade traditional social pressures, which might have made the use of the new water point conform to the traditional pattern. In most cases (Botswana presents an exception) the new supplies in dry regions 'belong' to government, i.e. government overtly claims the right to control access. Inevitably this means that additional people who would otherwise have been excluded from water points giving access to certain grazing areas are now allowed in.

In Botswana the number of livestock watering in the dry season at government or group owned or managed water points is significantly larger, even after allowing for differences in type of water supplies, than at private ones (Fortmann and Roe, 1981, pp. 88-120). Interestingly, the condition of the livestock at the private points is better while that of the grazing is worse, aptly illustrating the complexity of the issues involved. On government boreholes in Niger, Bernus has commented:

> 'To give good quality water to some and to refuse it to others has always been an insurmountable obstacle in principle and in practice. The choice is always difficult, because of the risk of favouring important chiefs and the richest pastoralists who reserve for themselves exclusive use of boreholes near their camp... The government... did not see how discriminatory regulation could be applied in such a vast area; neither did it want to run the risk of favouring some groups over others and causing disputes around the boreholes; for water is always the crucial point in rivalries between ethnic groups or between tribes.' (Bernus, 1977, p. 63).

In practice, although governments wish to evade the odium of such discrimination, failure to discriminate excites the resentment of the group that sees itself as being the rightful user of the area around the water point; and fighting between groups often forces a government's intervention in any case.

Changes in the pattern of control and management of water points have consequences for both efficiency and equity. In terms of efficiency, to the extent that control of access to water previously also regulated the grazing pressure, the governments' more relaxed attitudes to access are likely to increase this pressure. In many cases it also permits a change (and not always an environmentally or even, in the long term, an economically desirable change) in land use (see for example Fortmann and Roe, 1981, pp. 114-115). As a report on Tanzanian Maasailand puts it:

> 'And once a potentially stable, clean water supply is introduced into an area it almost automatically introduces a new population centre composed of representatives of modern society. At times (sic!) agriculturalists as well as outside pastoralists are attracted to the water.' (Hatfield and Ole Kuney, 1975/76, p. 18).

In many countries governments, at new government water points, are reluctant to enforce ethnic discrimination between members of on tribe or clan and another. The consequence is an increase in quarrels and fighting by those using the water point and a decline in the discipline of water use (Marty, 1972, pp. 33 and 43; Dahl and Sandford, 1978, p. 41). At the same time governments face a dilemma over the efficient management of water points. Efficient management, as we have seen in Chapter 2, requires rules about watering order (rosters), control of animals and cleaning up after they have drunk, and about day-to-day and less frequent maintenance. In some traditional societies these rules are adjudicated and enforced, with penalties where necessary, by 'well-masters', who bear ultimate responsibility to their own community. To decentralise such powers to a government employee in charge of a water point, and who is not responsible to the community, is an invitation to corruption. Not to decentralise but to retain the powers at some higher level in the official hierarchy may (or may not) reduce corruption but will certainly make management too remote to be effective.

5.6 The question of equity

Water development has equity as well as efficiency implications. By equity implications we mean the extent to which particular individuals or groups benefit relatively more than, or at the absolute expense of, others. We have already seen that some kinds of water source, i.e. open wells and many sandy river wells, require much more labour (per head) for watering livestock than do others, such as boreholes or dams. In circumstances where labour-extensive (i.e. non-intensive) types of water source abound, the demand for labour to water livestock will be low and the economic position of those whose only resource is their labour will be, in this respect, weak in relation to those with capital in the form of livestock. Cash wages will be low and non-cash institutions for redistributing livestock from labour-deficit to labour-surplus households relatively undeveloped or defunct. In contrast, in circumstances where labour-intensive types of water source abound, the position of those with much labour relative to capital in the form of livestock will be correspondingly strong. But demand for labour to water animals is only one source of demand for labour, and other sources of demand (e.g. for labour to work in the mines, as in Mauritania or Botswana) may be much more important. Given the general level of demand for labour, it may be advantageous for those with small herds below the size which can enjoy economies of scale in watering at labour-intensive sources (see earlier discussion in Chapter 3) to water these small herds at labour-extensive sources, thereby freeing as much as possible of their own labour for use in activities where returns are higher. We have already noted this phenomenon with boreholes in Niger (Marty, 1972, pp. 82 and 92) and with the avoidance of sandy river wells in Botswana (Fortmann and Roe, 1981, p. 73).

There is another aspect of water technology with equity implications. Traditional water sources, using resources and skills either endogenous to the society concerned or obtainable fairly easily from neighbouring societies, do not provide many opportunities for individuals to use their technical knowhow or their key positions in a technical post as a source of monopoly power or profit. In contrast, some kinds of modern water sources, particularly boreholes but also, to a lesser extent, large dams and*-hafirs,* do provide such opportunities. Although livestock owners may coerce borehole operators into opening up boreholes at times when they are not supposed to (Eddy, 1979, p. 168), conversely borehole operators in their turn are often able to extort bribes for doing the job for which they received a salary in any case. Their position as 'the men with the keys', either literally with respect to the engine or fuel store, or metaphorically as the only people who know how to operate the pumps, gives them considerable power. In Mali,

> 'The drilling of wells would not lessen the pressure on the ponds. Furthermore there is the problem of pulley devices often being controlled by security officers (guards). Quite frequently nomads cannot gain access to those 'monopolised' wells without resorting to threats or graft... Social control over access to subterranean waters is a real problem.' (Bourgeot, 1981, p. 174).

This problem of social control over modern technology also exists at a higher level. Where development programmes are heavily dependent on a particular form of technology for water supplies, the key technicians, the hydrologists, the drillers and the engineers in charge of heavy earth-moving equipment, are able to command salaries and influence out of all proportion to what they can obtain in an economy in which their skills are not in such short supply and the technology which they command is not such a key element. In Botswana, Kenya, Sudan and Tanzania, in theory it is the community, the politicians, the project managers and the land-use planners who control where and when water development takes place; in practice it is the technician in charge of the survey team or of the machine, whose judgement about what is feasible nobody else can challenge[23].

23 There is a discussion of this issue in Shepherd (1981).

Technology is important in a further and unexpected way. Water development is so popular in dry regions because it is so important to pastoralists' way of life. Those who control water points, be they private individuals or communities, reap monopoly profits from doing so, and when new supplies are developed the position of these monopolists is threatened. Some modern forms of water points are particularly susceptible to sabotage. In Niger boreholes were rendered useless by pastoralists who had thrown stones into the tubing (Bernus, 1977, p. 56); the same thing happened in southeast Ethiopia and to pipelines in Tanzanian Maasailand (source: discussions with range management officials).

The location, the density, the management and control of water points all have equity implications. Locating a new water point in an area that belongs to one group (A) of people rather than to another (B) may either benefit group A - because it gives them better access to water than group B or it may harm them because the livestock of group B now invade group A's grazing land since the new water point is open to all. It is very difficult to predict in advance what will happen. Livestock owners who demanded and welcomed a new water point in their area may subsequently come to regret this bitterly when they find that the assumptions they made that they would have privileged access turn out to be unfounded. If the density of water points is increased, this may help those whose households suffer a shortage of labour because, for example, they no longer have to decide whether to grow crops on the farm or herd livestock around a distant water point; with closer water points they can do both. Increasing the density of water points favours cattle, sheep and goats at the expense of camels, by opening up to grazing by all stock areas which previously only camels could reach; hence it also favours those people-ethnic groups or members of the family - who specialise in cattle rather than in camel husbandry.

Obviously the system of control over access to, and management of, a water point - including the system for deciding on its location and technology - has important implications for equity as well as efficiency. One can categorise systems in terms of the degree of centralization or decentralization of decision-making and of the extent to which users or operators of water points participate in this; or in terms of management style, whether it is authoritarian, liberal or contractual; and so on. Especially in dry areas, where access to water often also determines access to grazing, it is extremely important to potential users of a water point what system is adopted - for this in turn will influence, for example, the criteria by which eligibility to use a particular water point are decided, who adjudicates whether a particular person meets these criteria, and on what conditions, as to payment or participation in the labour of operation or maintenance, use is permitted[24]. Procedures are also important; the procedures, for example, for claiming rights to water or for determining the order of watering on a particular day. Different systems will deal with these things in different ways. Consciously or unconsciously when new water points are developed choices are made which set up particular systems for management and control.

24 For further discussion of these issues, see Sandford (1983), especially Chapters 3, 4, 6 and 7.

There is not space here to explore all the implications for equity of different systems of management and control, nor to establish precise guidelines for different circumstances. The appropriate system will depend partly on whom one wants to be 'fair' to or to favour (e.g. the poorest, a particular tribe, women), partly on the local political and social structures, and partly on the local physical environment which may determine, for example, whether particular kinds of participatory institution are viable. In one part of Niger government ownership of new boreholes worked to the disadvantage of local Tuareg, because it allowed access to water (and so to grazing) to Fulani pastoralists in an area from which they had previously been largely excluded (Eddy, 1979, p.383). In Botswana, even before the adoption of the Tribal Grazing Lands Policy, which favours exclusive rights being granted to individuals to graze some areas, a policy of favouring ownership of new boreholes by private individuals or syndicates, and which even allowed the transfer of ownership of some existing boreholes from public to private hands (Hitchcock, 1979, p. 192), has

> 'Opened up new grazing and access to those who could afford the fees. Those who could not afford the fees had to remove their cattle to 'free' water supplies which were surrounded by heavily used grazing areas. The borehole owners in the process of drilling boreholes do become *de facto* owners of the grazing land surrounding them.' (Fortmann and Roe, 1981, p. 63 quoting Peters, 1980).

In northeast Kenya the fact that the 'grazing committees of pastoralists' who are supposed to advise government, inter alia, on the management of water supplies, conduct their meetings in Swahili - a language not understood by most pastoralists - and that attendance at these meetings is not paid, means that the 'pastoralists' who attend the meetings are predominantly traders in adjacent townships whose advice is heavily slanted towards their own interests (Helland, 1980, pp. 136-169; and the author's own observations).

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6. Some pointers to the future

While the scope of this study includes all parts of tropical Africa, and all the livestock production systems therein, by far the greatest part of the experience gained in the past, or at least of that which has been recorded and analysed in publications and reports, was gained in arid and semiarid regions. This is not surprising in that it is in those regions that the physiological demand for water is greatest, that most of tropical Africa's domestic livestock live, from which their output comes, and where the supply of water is most limited. It does, however, make it difficult to prescribe for the future development of other regions on the basis of past experience. Most prescriptions that follow apply therefore primarily to the dry regions.

Much of the discussion and planning of water development in the past has revolved around the optimum location and spacing of water points and their capacity, in terms of the number of livestock they can water. The focus has been on the objectives of increasing livestock output and avoiding environmental degradation. However from the present study, several other points have emerged as requiring at least equal attention in the future. Some of these points have causal linkages between them. One of the points is that equity considerations - who benefits or suffers from water development - should rank at least equal with the other objectives. Another is that the effect of a new water supply in reducing the amount of labour required for watering is as important to some livestock owners as its effect in reducing the distance livestock trek to water. A third point is that the failure and breakdown rates of water points are high - too high for sophisticated calculations about optimum location to be valuable unless they specifically take these high failure rates into account. Technical, financial and administrative reasons all lie behind the failure rates and each needs to be given specific attention. Systems and procedures of control and management both interact with technology and have independent effects of their own. Finally, water development is often attended by unexpected and unintended changes in land use. This chapter provides some pointers/to future development in respect of water technology and its organisation and management, as well as of land use and location and spacing of water points.

6.1 Water technology

The decision to develop water supplies in an area involves not only deciding how many supplies there should be and where they should be located, but also what the source of water should be and how it should be extracted from the source and distributed to livestock. In some areas technical factors, e.g. rainfall, run-off coefficients and soil porosity which affect the viability of dams and *hafirs,* or geology which affects the prospects of finding underground water, strongly influence the choice in one direction or another. In other areas the options are more evenly balanced. Even where for technical reasons one kind of source, i.e. underground or surface, is strongly indicated, there are options about how the water point is to be constructed and how water is to be extracted from the water source and distributed to livestock. Up to depths of 100 m it is possible to dig open wells by hand labour instead of drilling a borehole, and it is possible to raise water from this depth by human or animal rather than by mechanical power. Similarly it is possible to build dams and to excavate *hafirs* - and to clean them of silt from time to time - by human and animal rather than by mechanical power. In the same way options also exist between different kinds of drilling devices, between different kinds of mechanical power and between different combinations of human labour, animal power and machinery or tools. Options exist - and the choice between them needs to be based on technical, economic, environmental and social considerations, not just on one of these alone.

An important element in the choice to be made is the requirement for human labour. Water extraction from open wells by human power is extremely labour intensive, requiring up to twice the labour force at peak times compared to some other extraction methods (Swift, 1979, Ch. 5), and animals waste much time at well heads waiting for water. On the one hand if the incomes of both livestock owners and herders are to be substantially improved in the long run, increases in labour productivity will be required. On the other hand high labour requirements for watering are the most effective limit currently available on the size of the livestock population; and unless alternative employment opportunities can be found for those displaced by less labour-intensive watering techniques, the effect of these techniques, rather than to increase aggregate income, will be to reduce the drudgery of watering, to increase leisure time and to redistribute income in favour of those with large herds and little family labour at the expense of those with labour but not enough livestock.

In principle the argument about labour-intensive water extraction is the same in all zones, for all production systems and for all species of livestock. In practice it is with the large herds of nomads and seminomads in the arid and semi-arid zones that it is of significant importance. There is a little evidence (Swift, 1979, Ch. 5) that watering camels from wells leads to sharper relative peaks in labour requirements than in the case of other livestock. Much labour can also be used in constructing water supplies, especially dams and *hafirs.* In this case the arguments probably indicate that more emphasis should be given to labour-intensive techniques of construction in the high-rainfall zones and their associated production systems, partly because the productivity of manual labour in such zones tends to be higher than among the pastoralists of dry regions, and partly because it is much easier in the more densely populated high-rainfall zones to collect a labour force of adequate size to be effective without totally disrupting family life and economy. To the extent that requirements for male labour in the dry season are particularly high for herding camels it is especially difficult to raise a labour force big enough to be useful for constructing a water supply from a camel-herding system.

The very high breakdown and failure rates for water supplies constructed under livestock development programmes in dry zones indicate the need and scope for substantial improvements in technical efficiency. However, it should be noted that <u>all</u> components, not just water development, have a very high failure rate in livestock programmes in dry regions (which indicates a particularly difficult physical and social environment) and that comparable figures for water supplies in other zones are not available, so it is not possible to assess, on the basis of firm data, to what extent the problem is peculiar to these dry zones. General impressions are that it is, and the known greater climatic variability of the dry regions over the more humid would indicate that, for surface water resources at least, more problems are likely to occur due to miscalculation about dam and spillway capacities. The low technical efficiency stems from inappropriate technology, inadequate training and information, and defective organisations and management, including financial and administrative procedures.

Given the high breakdown rate, priority in choosing the technology of water development should be given to answering the questions 'What can be done when something goes wrong?' and 'How will this water point be serviced and maintained?' All rural regions in Africa have acute problems with the availability of technical skills, with stocks of spare parts and consumables (e.g. diesel fuel) and with transport systems; the dry rural regions in Africa suffer these problems to an extreme degree. The choice of technology should not only be determined - as it largely is now - by which form of initial construction is cheapest, quickest and can be most easily financed (e.g. from foreign aid sources), but also by which technology can be kept going with the resources of the local area where it is based. These considerations are likely to indicate that open wells, even very deep ones, should much more often form part of water development programmes than they do now.

Part of the reason for the high failure rate is lack of adequate personal experience by design and site engineers and locally tested and adapted model designs. For example, in southern Ethiopia in the 1980s dams and *hafirs* were being modelled on those featured in an Australian publication because there was no African - far less an Ethiopian one - available. Not only are relative skill endowments and prices likely to differ systematically between Australia and Africa but soils, climate and other physical factors differ as well.

Experience will come with time and the problem of African-adapted designs could relatively easily be solved. But there is also a lack of site-specific information on hydrology and hydro-geology, and this will not be so easily solved, both because of the cost of acquiring this information and because, in many cases, it is only when it has been collected over many years that it yields useful results, e.g. on peak flood levels. In some cases inadequate efforts are made to use or collect information which is available in the memory of local inhabitants, and a greater willingness by design engineers to collect this information is required. This will increase the length of time it takes to design individual water points. But given the present high failure rate, it seems likely to lead to more water points that actually operate.

More attention needs to be paid to training local people in the area concerned in construction, operation and maintenance of water points. Often water points break down because of simple mistakes made out of ignorance; often technicians (and machinery) have to be brought in over huge distances and at great expense, either to do very simple jobs (e.g. replace a washer, mend a crack with some cement) for which a minimum of equipment, training and confidence are required, or to repair equipment that is unnecessarily complex in the first place. Often it is not formal training that is needed but familiarity acquired from being allowed to handle and strip down equipment (Hitchcock, 1979, p. 171).

It is not only the inefficiency of over-complex equipment or of the absence of training for local people on how to do repairs themselves which is important. It is also the fact that it makes local production systems so dependent on outside help, help which may demand onerous terms and whose income will not then be recirculated within the area to foster the growth of a locally diverse economy. Local technicians or craftsmen may exploit their neighbours - but at least the incomes gained from this exploitation will, in part at any rate, be locally spent. Complex technology requires highly skilled technicians who command high rates of pay. Sometimes even when technicians with the requisite skill can be recruited from local sources this will not be done because the rewards of the job are set by political, not by market forces, and the jobs represent prizes to be given to those economic or ethnic groups most closely related to central government's political support. Less complex technology does not require skills so highly rewarded as to form part of government's patronage[25]

> [25] This point can usually be demonstrated by looking at the origins of vehicle drivers and unskilled labourers in government pastoral development projects. Unskilled labourers usually come from the local area's ethnic group(s). Drivers, even though there are unemployed drivers from local ethnic groups available who want employment, usually come from ethnic groups closer to central government.

There is an equity element about the choice of technology which needs to be kept in mind, and these problems are most likely to arise in arid and semi-arid zones which are often both politically and geographically marginal to the nation state that incorporates them.

6.2 The capacity and density of water points

The capacity of water points - expressed in terms of the volume of water they can supply in a given period of time - and their density - which we can express in terms either of water points per km^2 or in the distance (km) between water points - will influence the species, breed and age/sex composition of the herds, as well as the yield of useful products per animal and the nature and intensity of pressure exerted on the soil and vegetation. This section considers issues of capacity and density in relation to the different production systems distinguished in Chapter 1.

In high-rainfall areas closely spaced water supplies are a precondition for the emergence of a smallholder dairy system, both because of the disease problem and because plentiful water is needed to allow high-yielding dairy stock to express their genetic potential. Where good markets for fresh milk exist and water supplies are adequate in number, cattle will form a high proportion of the total livestock composite, and cows of breeding age, probably containing a high proportion of exotic blood (often Friesian), will constitute a large part of the cattle population - as much as 50% (Goldson, 1980).

In highly productive smallholder dairy systems water supplies need to be sufficiently numerous that disease-susceptible stock of high value do not need to leave the boundaries of their farm to water at places where they may be exposed to infectious disease, parasites (especially liver fluke) or injury. This may justify the provision of water points - which may be piped supplies - at a density as high as one point to 10 ha or less. Where the disease problem is not paramount, the high productivity of selected dairy animals may, nevertheless, justify, in terms of energy and time saved in trekking to water, a spacing between water points of as little as 5 km, so that no animal has to trek more than 2.5 km to water. Table 5 in Chapter 4 shows that a 5 km spacing between water points could lead to yields per dairy cow 5% higher than a spacing of 10 km. For a dairy cow yielding on average 2000 litres per year at US$ 0.30 (at farm gate prices) per litre, that represents a US$ 60 increase (gross before deducting the expenses of increased water supplies) in value of milk output per cow per year[26]. That would justify, on the basis of a 12% interest and 15 years amortisation, an investment of up to about US$ 26000 per additional supply if the cattle population of high-yielding dairy breeds is about 10 per km^2 the Kenyan highland average in the 1970s[27]. A further increase in density reducing spacing between water points from 5 km to 2.5 km would justify an investment per additional water point of up to only US$ 2600.

[26] These figures are compatible with data contained in ILCA (1981) with some allowance for inflation in prices. The calculations of Table 5 are based on particular assumptions which may not be realistic for smallholder dairy systems.

[27] Assumes a cow: follower ratio of 1:1; this is compatible with data in Goldson (1980).

We do not possess adequate evidence to make the same sort of calculations for mixed farming systems in high-altitude areas. Here the most valuable form of economic output may be draught power from oxen. It is difficult both to quantify the effect of more plentiful water supplies on this and also to give it a unit value, since it is not a final output for consumption with a market value but a factor of production whose marginal product it is difficult to estimate. In the case of both smallholder dairy and mixed farming systems in high-altitude areas, in both of which the individual herd size tends to be low, an alternative to building additional water supplies is to transport water e.g. on donkey back, from the water source to the livestock which need it. An additional element to be taken into consideration in both smallholder dairy and mixed farming systems in the highlands is the impact on soil erosion of large numbers of livestock trekking to water points. The livestock population density in the highlands of Africa, at an average of about 20 to 25 livestock units (250 kg) per km^2 (ILCA, 1981), is 3 to 5 times that of the arid and semi-arid areas, and the topography of the highlands, their relatively high and intense rainfall, and in many cases also their soils, make them inherently more erodible. If water points in the highlands are at 5 km spacing this implies an average of 500 livestock units per water point. With cattle having to trek along narrow paths between fields, that is a sufficient number to cause serious erosion. In practice in highland areas water sources are normally much denser than the 0.05 and 0.20 per km^2 implied by these trekking radii of 2.5 and 1.25 km. For example, in the central highlands of Ethiopia the average water point density is 0.87 per km^2 (of which flowing streams and rivers account for 0.57), and in only 20% of this whole area of 100000 km^2 does the overall density fall below 0.2 (Watson, 1973b, p. 23 and Table 8A).

In the arid and semi-arid zones the factors affecting the appropriate density of water supplies are probably more numerous and more complex than in the highlands. One factor is that in many semi-arid areas where crop cultivation exists and where cultivators and herdsman are from different ethnic groups, the damage done to crops by livestock on their way to water, and the way in which access by livestock to water is barred by the position of cultivated fields, is an important source of inter-ethnic conflict. In these areas, although the amount of labour required to water livestock may be an important constraint on livestock numbers, the actual number of water points is probably not. Extra water points may be justified in order to reduce conflict rather than in terms of extra production. They may cause environmental degradation, but this is more likely to be as a result of the extra spread of cultivation that they permit rather than the increase in livestock numbers.

In arid areas water points are important not only in terms of the grazing which they permit in their vicinity, but also as transit points for animals on migration from one general grazing area to another. Such permanent and reliable transit water points can be extremely important in permitting the movement of livestock (in pastoralists' breeding herds as well as in the herds of traders), especially in times of drought, from poor to good grazing areas. In the absence of such water points herds can be cut off and suffer great losses. Along migration corridors of this kind reliable water points at intervals of about 20-30 km are suggested[28]

> [28] Lewis (1978) reports 'weaker members' (the *beedi)* of transhumant cattle herds trekking 50 km without water and 'stronger' (*garti*) 90 km. But, especially in a drought year, very few waterless stages of this extent could be completed without huge losses.

Where other methods of controlling livestock numbers (e.g. government regulation, voluntary decision or agreement of livestock owners) are ineffective, the spacing and capacity of water points can be used as an alternative control. Some areas are unsuitable for dry-season grazing, either because only ephemeral vegetation grows there or because hydrological and geological conditions make the provision of water prohibitively expensive. In such areas *hafirs* and dams can be built to provide a temporary source of water during, and for a short period after, the rainy season. In a number of countries (e.g. Ethiopia, Kenya) such points have been designed so that the volume of water conserved there is no more than enough to water livestock for whom the area's feed sources are sufficient without risk of overgrazing.

The theory of this device for controlling grazing pressure is attractive; but in practice it is difficult to implement. Firstly both the yield of annual grasses and the quantity of stored water available for drinking each year fluctuate with variations in annual rainfall. However, they may not fluctuate in close proportion to each other, especially in the light of the effects of evaporation and seepage; either water or forage may be inadequate in relation to the other. Secondly rainfall in arid Africa tends to vary tremendously within seasons over quite short distances. The water catchment that feeds a *hafir* or dam is unlikely to be coterminous with the grazing area that is served by it; the rainstorm which makes the grass grow may not fill the dam, and vice versa. Thirdly dams and *hafirs* silt up over time; the right capacity just after construction will be too small 5 years later; and so on. In principle this is a good system but any kind of precision in calculation is inappropriate because of these uncertainties.

It has to be accepted that in most years either the water points will be too few and too small and not all the available forage will be used, or they will be too large and too many and some overgrazing will occur. Also, in the case of annual grasses, overgrazing is much more serious during the growing period before seed has formed than later in the dry season; with perennials it is the other way round (Breman et al, 1979/80), so that a further element of uncertainty is introduced as to exactly when the livestock will have access to this grazing. Different grazing pressures, and so different watering capacities, will only be appropriate for a particular season of use. A final problem is that there are economies of scale in constructing *hafirs* and dams. Normally, the bigger the capacity the lower is the cost per unit of capacity. It is extremely difficult to persuade water engineers of the wisdom of constructing many high-cost low-volume stock ponds when the technical possibilities exist for larger ones which can be used for a longer period each year. The moment the range planner's back is turned the water engineer will dig a deeper longer-lasting pond because, by his criteria, it is more efficient to do so (Shepherd, 1981, pp. 7-8). The pastoralist will normally support the engineer.

Where other methods of regulating livestock numbers are ineffective, the ultimate control over them in arid zones is exercised by lack of water or of forage within range of water at the height of the dry season in a drought year; at this time livestock die of starvation or of thirst or of exhaustion from seeking feed and water. In principle it would be far less damaging to the vegetation if livestock were to die of thirst rather than from starvation after they have grazed the range bare. Again, in practice, it is exceedingly difficult to design water supplies which match exactly the availability of water with the amount of forage which can be safely grazed. The main reasons for these difficulties in the case of *hafirs* and dams have already been discussed in relation to wet-season grazing areas. Many of the same arguments apply also to wells and boreholes, although the availability of water at the latter is less dependent on current rainfall in the area. It never seems to be possible to restrict the quantity of water supplied by formal administrative orders, i.e. to supply only enough water for a given number of livestock even though the physical capacity exists at that time to supply more. Intimidation of the water point operator by livestock owners and overruling of technical departments by higher political authorities always occur when livestock start dying.

Once more there are great difficulties in regulating the volume of water supplies by physical limitations or the capacity of the equipment. If one believes that the safe grazing capacity of an area is such that only 480 animals should be watered every day, then it is foolish to arrange for the physical capacity of the equipment to be only enough to deliver water for 20 animals an hour (20 animals x 24 hours = 480) with no storage reservoir. The pumps will be under too much strain and there will be no flexibility and room for manoeuvre in the event of mechanical breakdown. If, on the other hand, the equipment is sufficient in capacity to water the safe number of animals with only 6 or 10 hours' operation each day, then there will be irresistable political pressures to operate for more hours each day, and so to water more than the safe number of animals in an "emergency", i.e. when livestock owners want to bring in more animals than the area served by the water point can safely sustain. In fact the most effective physical constraint on capacity is when hard human labour by the livestock owners is required to extract water from its source. Some increase in physical capacity can be achieved by people working longer and harder, but the direct cost to the livestock owners, in terms of physical effort, is such that they re-evaluate the desirability of keeping so large a herd. The result may, however, be very inequitable between different households.

These difficulties in controlling livestock numbers by regulating the physical capacity of water points have directed attention towards regulating the number of water points and their consequent spatial density. As a consequence one often comes across recommendations or policies that permanent water points in arid areas should not be less (more) far apart than, for example, 8 km in Botswana (Hitchcock, 1979, p. 178), 10 km in Sudan (Shepherd, 1981, p. 16), 20 km (Bernus, 1977, p. 54) or even 50 km or more (Marty, 1972, p. 97) in Niger. The appropriate spacing of permanent dry -season water points will partly depend on whether one is mainly interested in economic output or environmental protection. It will also depend on the kind of output (milk or meat) in which one is most interested, the species (camels, cattle, sheep or goats) which can be kept in the area, the breeds *(Bos indicus, Bos taurus),* and on whether the livestock are herded or free-ranging.

Where animal numbers are otherwise uncontrolled (and the range is not fenced into paddocks), regulating the density of water points will not materially affect overgrazing close to the water point, only further away. Whether under free-ranging or herded management the-first 0.5 to 1 km around the water point will be severely overgrazed. Where camels are kept, grazing may occur up to 100 km away from water, even in the dry season; with cattle, sheep and goats that are in milk the range for herded animals is normally up to about 15 km from water, and for 'dry' animals up to about 30 km, although in drought conditions they will go as far as 50 km (Asad, 1970, p. 28). With all livestock grazing pressure will decrease with distance from water, but with herded animals the gradient of the decline is likely to be less than with free-ranging animals. In hot conditions Zebu cattle will probably be able to range further than *Bos taurus* breeds.

Given this set of interacting variables there can be no uniquely correct spacing of dry-season water points. If very high priority is given to environmental conservation, the water points will have to be spaced 100 km or more apart; then if the area is otherwise unsuitable for camels large portions of it will be only very lightly grazed by other domestic livestock; but there will be a corresponding large reduction in economic output. If camels are present then even in outer rings around each water point there will be notable grazing pressure; but this should be compensated by greater output. If a large proportion of the herds is females in milk - because males are slaughtered young or sold off early - then total cattle numbers are likely to be kept at a lower level because of the milking cows' inability to range so far. Restricting the density and number of water points is a very costly method, in terms of lost output, of restricting livestock numbers and so grazing pressure.

6.3 Organisation and management

In future, for reasons of both efficiency and equity, more attention needs to be given to questions of organisation and management than has been given in the past. In this section we deal with three points of paramount importance: the control of access, the ownership of water points, and financial and administrative procedures.

In the arid zone, and to a lesser extent in the semi-arid zone, where water points are few and far between and communal systems of land tenure often prevail, control over access to water is tantamount to control over access to grazing land. The development of new water points is not, therefore, simply a technical matter but also a political one concerning questions of equity to different groups. This needs to be recognized at the outset of a water development programme so that decisions can be made on appropriate political grounds. The criteria for eligibility to access to a new water point, and the adjudication process by which eligibility is decided and enforced, need to be clearly laid down.

The question of ownership of new water points affects partly rights of access, partly the way in which management decisions are made and implemented, and partly financial and administrative procedures. For example, it is possible for a government or the local community to lay down rules on who may or who may not have access to privately owned water points in a certain area, and under what conditions, but in practice it may be infeasible to impose these rules on someone who has already invested his own labour or capital in building a water point in a remote area and who wishes to recoup his money from as many well-off people as possible. It will be difficult enough even to regulate the season of the year in which privately owned water points may be used. In areas where water points are plentiful, usually high rainfall areas or along large sandy rivers where water can easily be found by digging in the bed, it is unlikely that the owners of private wells will be able to reap monopoly profits from their control of a scarce resource or from the access to grazing that this control determines. In areas of dense, settled population land is usually under some form of individual tenure, and the closure of water points by regulation is not an appropriate tool to enforce rotational grazing. In these two kinds of areas private ownership of water points does not carry heavy drawbacks and often has the great advantage of a decentralised form of management and the facility for procuring goods and services for repair and maintenance without being strangled by red tape in the way government departments often are. It may, therefore, be the most appropriate form of ownership in these cases. However, a survey of private water points in the Central District of Botswana (Hitchcock, 1978, Ch. 7) revealed that nearly half are owned by people who own more than one water source and about 99% had absentee owners; in these cases some of the defects of 'centralised' management must be in evidence.

In areas where water points are very scarce and where they provide a useful tool for public management of grazing and access to grazing, private ownership may have severe disadvantages and some form of public ownership, either by local community or by government, may be more appropriate. Community ownership - implying control of access to a water point by a particular social group, possibly a village or a kinship group, and some fairly participatory form of management may be the best arrangement in areas where the human and livestock populations are fairly sedentary. The same may be true even where populations are nomadic, provided that their movements are predictable and regular from year to year and that there is no significant intermingling of different communities at the same watering place (comprising one or several water points within a short distance of each other). If however, nomadic movements are highly irregular and unpredictable, then participatory forms of management of permanent water points become unviable due to lack of continuity of decision-making or of commitment to the long-term success of that point. If different communities water at the same point, or within a very short distance of each other, inter-community competition will probably need to be regulated by government interference. Community ownership of water points is also unlikely to lead to equitable access to water in societies where power and other resources are unequally shared, and government ownership may, in such cases, be less inequitable than ownership by the community.

Where government ownership of water points is required, for one of the reasons already given, two procedures need to be followed. The first is to provide a system whereby the information which local people already have, about hydrology, about the location of preferred vegetation at different times of year, about migration patterns in good and bad years, about the location, size and type of facilities required, can be incorporated into a government's planning processes. The second is to establish financial and procurement procedures suitable for the operation and maintenance of water supplies in remote areas. At the moment few, if any, countries in Africa have these. It is beyond the scope of this study to analyse or specify the matters in detail; but they are a major cause of current inefficiency, and rectification is a precondition to improving the supply of water to livestock in much of tropical Africa. The problems are particularly acute in arid and semi-arid zones where the low population density, long distances, and low political influence of the users of government water supplies make the conventional government procedures least appropriate.

7. Postscript on research priorities

The previous chapters of this study have revealed a number of matters on which the present level of information and analysis is defective, and where more research could lead to better policy formulation and development.

In all zones we need more information about the spacing of livestock and grazing pressure in relation to water points. There is a small amount of information about this for the arid zone, mainly in terms of vegetation composition and denuded areas; there is virtually no information for other zones. We need to know more about the impact of herding, in contrast to free-ranging or paddocking, in obtaining an even spread of grazing pressure.

We know very little about traditional watering practices in semi-arid and higher potential areas. What information we have, on frequency and amount of watering, and on distance trekked, comes from the arid zone. Similarly in the higher potential zones we know very little about the control of access to water points and their management, or about other 'strategies' for coping with water shortage.

Although there is a considerable literature for the arid zones about watering 'norms', i.e. what people think practices are or should be, there is very little that actually records what individual animals do. It is possible that 'norms' diverge from 'actual practice' substantially (in the way, for example, that they do for migration patterns), and that a study of these deviations would throw useful light on animal requirements and on constraints that prevent these being met.

The very high failure/breakdown rate for water points suggests that design standards being used are inappropriate. There appears to be a lack of suitable guidance based on local experience. Although this is not exactly 'research', the production of appropriate design manuals could be useful.

The collection of water fees is important for the successful operation and maintenance of water points. A cross-country study could be useful in throwing light on satisfactory methods for assessing fees, collecting them, and channelling the money into ensuring the efficient operation of water supplies.

Appendix: Recommended nomenclature for water sources

(Mainly derived from Fortmann and Roe, 1981)

Name	*Description*
River; stream; canal	A seasonal or perennial flow of; water along a defined water course. A linear rather than a 'point' source of water. There is no definite distinction between 'rivers' and 'streams', but in general rivers are larger than streams; both flow in natural water courses. The water courses of canals are constructed by human agency
Lake	A large, permanent, standing body of water (with or without an outlet) which does not dry up except in abnormally dry sequences of years.
Pan	A low spot or depression in which water collects seasonally but does not normally last a complete year before drying up.
	Comment
	The words 'ponds' or 'pools' may be used either for small lakes (permanent standing water) or for pans (impermanent standing water).
Springs	A spontaneous flow of water out of the ground. The volume typically varies with the season, and it may dry up at some times of the year.
	Comment
	Usually livestock can obtain direct access to drink at rivers, lakes and pans and no further methods of extraction are required to distribute water to them. At springs and canals direct access is sometimes possible but troughs and lifting devices may be necessary in order to pre vent damage to the water source by livestock
Dam	In a dam the dam wall holds back the water, and more than half of the water, at full storage, lies above the ground level that existed before the dam was built.
Hafir dam	In a *hafir* dam the dam wall holds back the water but less than half of the water at full storage lies above the ground level that existed before the *hafir* dam was built.
Hafir	In a *hafir* the wall (if any) is just a convenient place to put the soil taken out of the hole. It does not hold back standing water. All of the water, at full storage, lies be low ground level in a hole or pit.
	Comment
	The words 'stockpond' or 'tank' can be used for dams, *hafirs* and *hafir* dams. Livestock may have direct access to all of these but are liable to damage the facilities if they do so. The word 'cistern' is often used for *hafirs* or *hafir* dams which have rock, masonry or cement linings
Borehole	A machine-drilled hole of less than 300 mm diameter, often lined with casing pipe
Open well	A shaft deeper than it is wide, usually dug by hand. It may be lined in whole or in part with timber, masonry or concrete to prevent cave in. Open wells may achieve a depth of 100 m or more.
Sandy river	A shallow well penetrating to well groundwater in sandy rivers. Sandy river wells are often unlined and usually have to be reconstructed after every rainy season
Seep well	A pit, often wider than it is deep, or pit usually unlined and tapping groundwater which lies above an impervious layer. It may also collect surface run-off
	Comment
	The word 'waterhole' is also used to refer to both sandy river wells and seep wells/pits. The expression 'shallow well' is sometimes used of open wells, even when they are quite deep, in order to distinguish them from boreholes

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Printed by ILCA, Addis Ababa, Ethiopia