Republic of Kenya

Ministry of Agriculture, Livestock Development and Marketing

Range Management Handbook of Kenya

Volume III,5

USERS GUIDE FOR THE RANGE MANAGEMENT HANDBOOK OF KENYA

Nairobi 1993

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CHAPTER I
INTRODUCTION

Lack of information is an important factor which routinely limits the effectiveness of natural resource management activities. Natural resource managers require information from a wide range of technical disciplines to make sound decisions. Some of this information is scattered in textbooks, scientific journal articles, and various types of difficult to access project reports and informal publications. Additional information is stored in the minds of the scientists, engineers, managers, pastoralists and farmers who have experience working with the land. It is obvious that no one person has the time, money, and contacts necessary to fully access the existing information base.

To solve this problem, the Kenyan Ministry of Agriculture and the German Agency for Technical Cooperation (GTZ) teamed up to compile the existing natural resource information for the districts where farming was a primary land use. Information gaps in the existing knowledge base were addressed by collecting additional data. The product of this effort was published in 1982-83 as the Farm Management Handbook of Kenya (FMH) (Jaetzold and Schmidt 1982, 1983).

Based on the success of the FMH, a similar rationale and approach was used by the Ministry of Agriculture, Livestock Development and Marketing (Range Management Division) and the GTZ to produce a series of publications collectively known as the Range Management Handbook of Kenya (RMH). The RMH provides a reference of pertinent natural resource information for the nine arid and semi-arid districts where livestock production is a primary land use. The names and locations of the districts covered in the RMH are illustrated in **Figure I.1**.

The RMH fulfils the objectives of providing a reference that is a compendium of information needed to aid natural resource management. The RMH is organized into three volumes:

Volume 1: Introduction, policy, history, status, potential and constraints to/of/on range management in Kenya.

Volume 2: Reports/maps showing range resources and environmental attributes district by district.

Volume 3: Special miscellaneous topics relevant to range ecology and management in Kenya's arid and semi-arid lands. The data is presented at the level of detail needed to assist development planning (especially within the context of the "district focus").

The emphasis of the RMH was placed on providing the types of information planners need to devise a solution or make a decision, rather than simply recommending specific development packages/activities for generic problems (some packages/activities are included as examples of potential solutions but the reader is encouraged to craft solutions that best fit the unique nature of each situation). Therefore, the information included in the RMH is helpful to a wide variety of users, ranging from administrators, planners, managers, scientists and teachers.

The information in the RMH covers a wide variety of technical disciplines. It is not uncommon for a reader unfamiliar with a particular discipline to have difficulty understanding some of the terms and information presented in the RMH. If this is the case, important information necessary to make a well-rounded decision may be ignored or under-utilized. The objective of this text is to explain the terms and management implications applicable to the information included in the RMH. These principles should help individuals work across disciplines to diagnose a variety of factors that have a bearing on a particular challenge. These principles should also help develop the type of integrated solutions necessary for effective natural resource management.

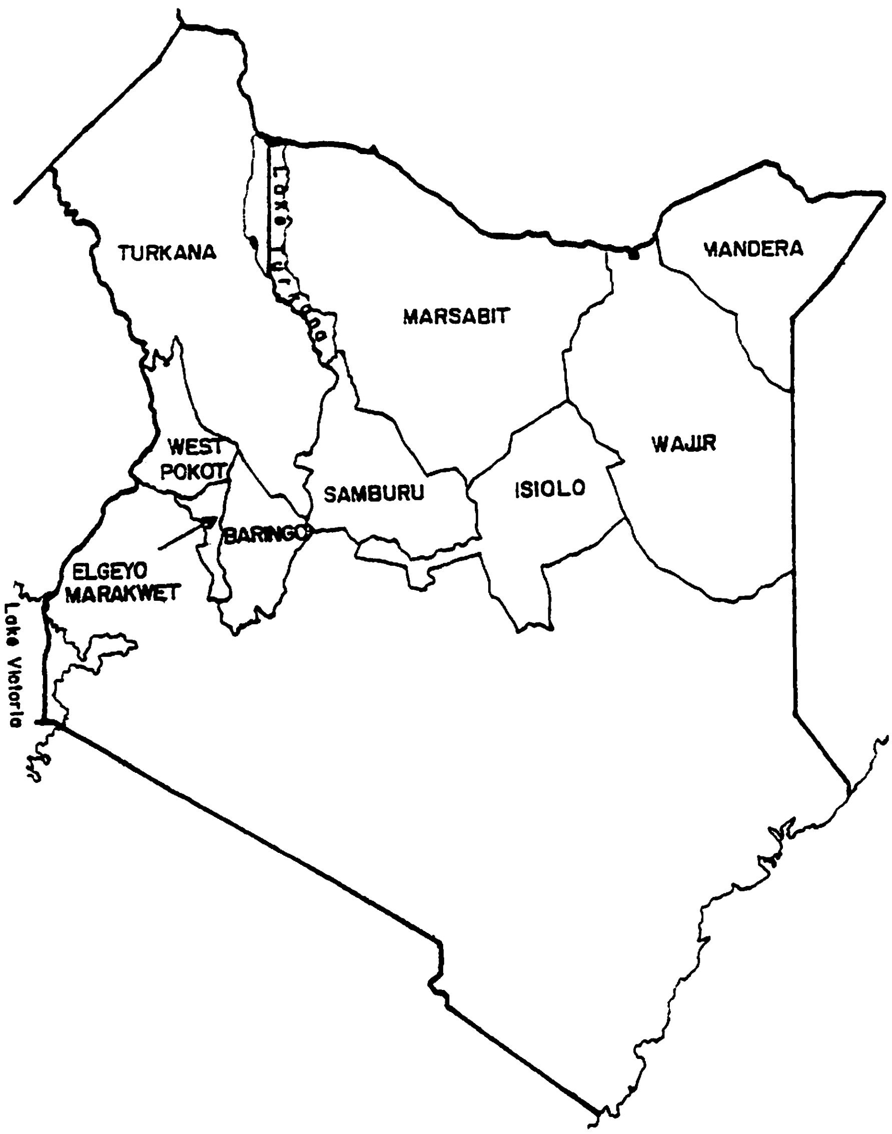

Figure I.1. Location of the districts covered by the Range Management Handbook of Kenya.

CHAPTER II
READING A MAP

Much of the accumulated information about rangeland systems can be expressed in the form of maps. In the case of the RMH, district maps reduce the pattern of a particular aspect of rangeland to a size small enough to be seen as a whole. Maps are especially important tools for natural resource managers, because the rangelands of Kenya are so vast that they cannot be viewed as a whole unless represented on a map. While each map in the RMH is supplemented by text material, the maps themselves contain information about spatial distribution that cannot be stated as fully and accurately in words or by any other means. Maps are therefore an extremely important tool of rangeland management.

Every map is made for some special purpose. The purpose is briefly summarized in the title of the map. There are two classes of data which are commonly included on maps: base data and special-purpose data. The base data which is common to all of the RMH maps includes the latitude-longitude grid, towns, boundary lines of the district and national reserves or parks, the major water bodies and the major roads. Many types of maps, such as a common road map, do not provide any more information than this. Special-purpose data conveys some other characteristics of the mapped region. This information is superimposed over the base data. For example, the RMH *RANGE CONDITION* map uses color tints to indicate the condition of the rangeland across the district. The base data provides reference points for the user of the map.

Many types of maps, such as a common road map, only depict length and breadth, but not elevation. These types of maps are known as two-dimensional base maps. Three-dimensional maps, which represent length, breadth and elevation are known as **topographic maps** (i.e. a map which shows the difference in altitude and form of the land). Topographic maps can convey the form of the land in several ways. Altitude is indicated by both the contour lines and by color tint on the RMH *PHYSICAL AND GENERAL* maps of the districts. On the other maps, the user is only provided with contour lines to indicate relief and color is used to display other types of information such as hydrography (e.g., water sources and rainfall patterns), soils (e.g., soil types and soil characteristics such as production capacity, erosion hazard, accessibility restrictions) and vegetation (e.g., range condition, dominant vegetation types).

Therefore, topographic maps can display many types of information in a way that can help a natural resource manager make a wide range of decisions as diverse as, for example: Where would be the most useful place to put a new well or road? Where are areas with sites especially susceptible to erosion? Where are rangelands that are producing less than their potential? Where are the areas most susceptible to drought?, etc. A range manager will often need to consult several maps and several chapters of the RMH text before making a decision because each may contain only a piece of the information needed to make a wise decision. Whether the rangeland manager is a life-time resident of the district or a distant administrator who has never visited the region, the RMH maps present a series of information that provides useful insights and establishes a common ground from which discussion and planning can proceed.

Topographic maps are made by conducting surveys of the area. Horizontal control in terms of distance and direction is provided by two or more points on the ground accurately fixed in position. Vertical control is provided by two or more **bench marks** (points of known elevation that serve as reference points for calculating the relative elevation of the surrounding terrain) which are in or near the area to be surveyed. These points are often marked in the field in some permanent way (e.g., a brass plaque cemented into the ground) and are sometimes shown on maps.

Contours are used to quantitatively represent hills, mountains, depressions and ground-surface undulations on a sheet of paper. A **contour** is an imaginary line passing through points which have the same elevation above sea level. Most contours are irregular lines like the closed loops for the hill depicted in **Figure II.1**. The vertical distance between two contour lines is called the **contour interval**. The contour interval selected depends on the scale of the map and the amount of relief (difference in altitude between the high and low parts of the land surface) in the area mapped. **Spot elevations** are usually given for significant points such as peaks.

Distances are plotted from the field data to a selected scale, such as 1 unit of map length is equal to 1,000,000 units of actual field length. In this case the map would be said to have a scale of 1:1,000,000. This scale is also shown graphically on the map to indicate, for example, that 1 cm = 10 km (i.e. 1 cm of distance on the map = 1,000,000 cm of distance in the field). By using the odometer in a vehicle and the mile/km scale on the map it is possible to locate the features on the map when working in the field. If traveling cross-country, a compass will also be useful. The choice of a scale depends upon the:

- Purpose and required precision of the map. The RMH maps have very broad scales of either 1:500,000 or 1:1,000,000. Broad scale maps are well suited for use in regional planning, but a manager will likely require that more site-specific information be gathered if activity is to be focused on a relatively small area within the boundaries of the map. The greater the precision required, the more detailed the scale required. For example, if the soil map was to be used to make decisions regarding specific small farms, the scale would need to be about 1:10,000 or less.

- Size of the area to be mapped and the size of the paper on which to map it. The map size must be convenient to use; this convenience will, in part, determine the degree of scaling necessary.

- Availability of information used to create the map. Detailed, precise maps can be drawn if detailed information is available. If however, information is limited, such as is the case regarding many regions of Kenya's rangelands, the scale of the maps will have to be broader. Collecting the data necessary to make a map is very

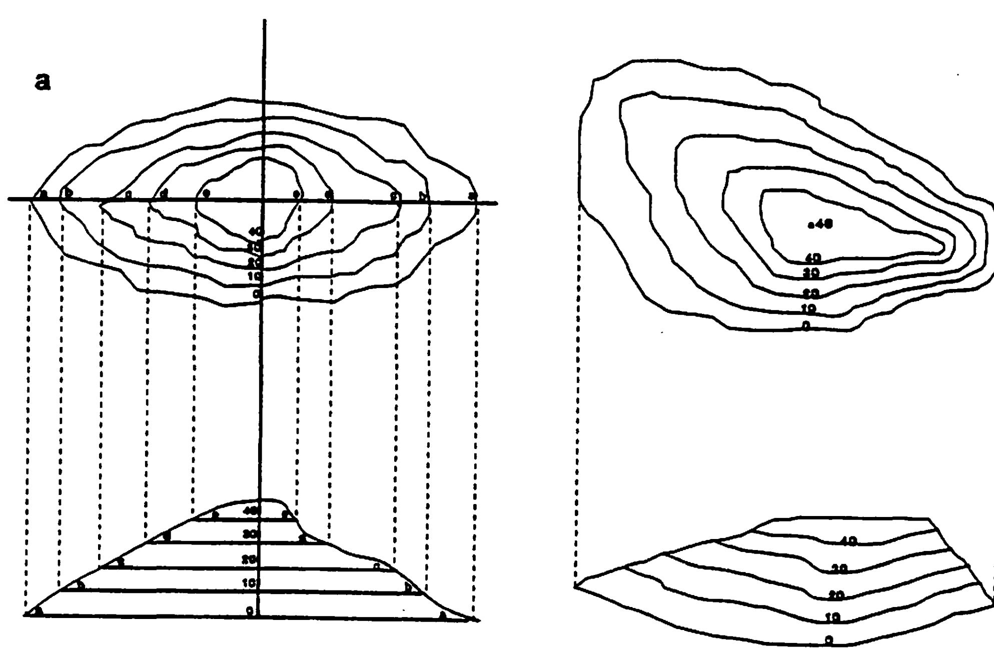

Figure II.1. The upper figures illustrate surface features as they would appear on a topographic map. Experienced topographic map users can visualize these figures as three dimensional images. The lower left drawing shows a side-view of a cross-section of the upper left drawing. The lower right drawing shows a side-view of a hill represented in the upper right drawing. Note the contour lines are closer together on the steeper right side of the hill and further apart on the more gently sloping left side of the hill. The dot in the inner circle of the hill (spot elevation) represents the highest point on the hill.

labor intensive and very expensive. The effort and expense increase dramatically as the scale becomes more specific. Field managers should ideally keep detailed notes of the natural resource characteristics for different locations that they visit within a district. This information will be a valuable aid to making more detailed and more accurate maps the next time new maps are produced.

Standard symbols are used to represent special topographic features, thereby making it possible to show many details on a single map. These symbols are explained in the **legend** which is printed on each map. The top of a map is always north, unless otherwise indicated by a direction diagram included in the legend. At the outer right (east) and left (west) edges of the map there are often numbers which indicate the latitude. **Latitude** indicates the relative position of the site between the equator (0°) and the pole (90°). For more precision, each degree of latitude is subdivided by 60 minutes. The latitude is followed by an N or S to indicate if the point you are referring to is north or south of the equator. At the outer top (north) and bottom (south) edges of the map, there are numbers which indicate the longitude. **Longitude** indicates the relative position of the site from the adopted zero longitude (meridian) which was arbitrarily chosen to pass directly north and south through Greenwich, England. There are 180° east (E) and 180° west (W) of this 0° longitude, with each degree of longitude being divided by 60 minutes for more precision. For example, Nairobi is located at 1° 15'S, 37° 10'E.

Using this method, any point on the globe can be accurately identified. If, for example, you want to communicate the location of the El Golicha borehole, you could simply say that it is located at 2° 50'N, 40° 59' E and everyone who can read a map in the entire world, whether they have been to Africa or not, could easily pinpoint the location of the well in southeastern Mandera District. This abbreviated form of communication allows an ease and accuracy in writing reports by eliminating the need to include

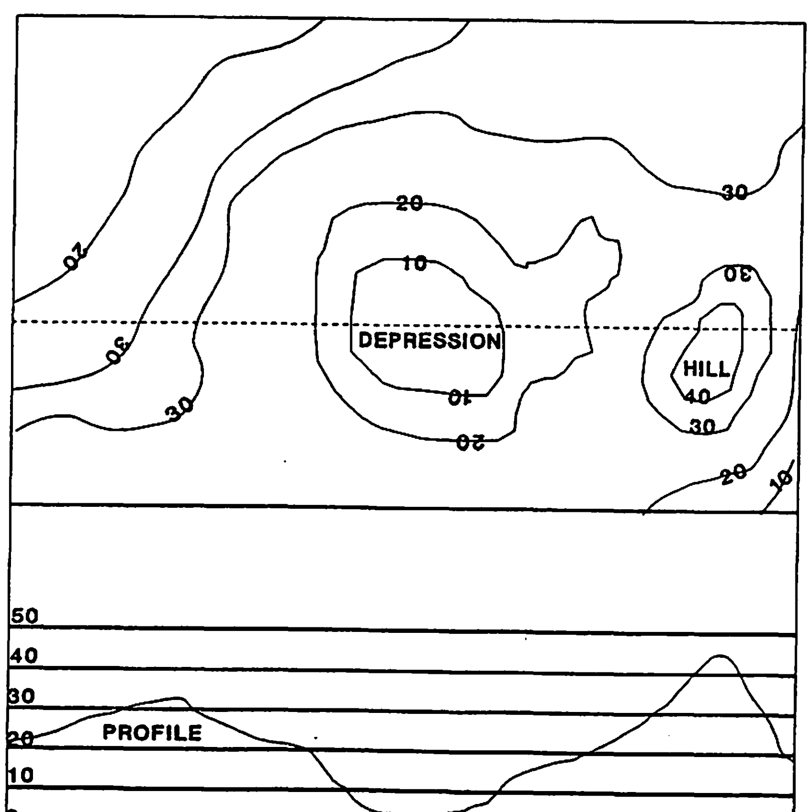

Figure II.2. The upper portion of this figure illustrates the surface features as they would appear on a topographic map. The bottom portion of this figure shows a side-view of a cross-section of the upper drawing (the cross-section is along the dashed line). By considering the elevation numbers, it is possible to distinguish between depressions and hills.

a map or written description of the location for every place you discuss.

Keeping the following characteristics in mind will help you to visualize the land form characteristics being illustrated on a contour map:

- Evenly spaced contours mean that the slope of the land is rather uniform.
- The distance between contours indicates the steepness of the slope. Wide spacing denotes gentle slopes; close spacing denotes steep slopes (left and right sides of **Figure II.1b**, respectively).
- Contours which increase in elevation represent hills. Those which decrease in elevation portray depressions. For example, if the contour (location A) indicates an elevation of 2000 feet and the next contour you encounter (location B) indicates an elevation of 3000 feet, the map is of course indicating that location B is 1000 feet uphill from location A. Contour elevations are shown on the uphill side of the lines, or are written in line breaks with the upper part of the number indicating the uphill side, to help the map reader avoid confusion in determining the direction of the slope (**Figure II.2**).
- Irregular (wiggly, jagged-shaped) contour lines signify rough, rugged country. Smooth contour lines indicate that the slope is rather even and uniform.
- Contour lines tend to parallel each other on uniform slopes.
- Contour lines never meet except on a vertical surface such as a wall or cliff. They cannot cross except in a very unusual case such as a large cliff with an overhanging shelf.
- Relatively steep valleys are usually characterized by V-shapes on a contour line (left side of **Figure II.3**) and ridges and broad, gentle valleys are usually characterized by U-shapes on a contour line (right side of **Figure II.3**).
- V-shapes on a contour line may be formed by contours crossing a drainage point upstream. Often, lines will be drawn on a map to indicate where the water courses are located (dashed lines indicate stream beds that are likely to carry water only during the rainy season, solid lines indicate the stream beds likely to have water in them most of the time). Contour lines cross

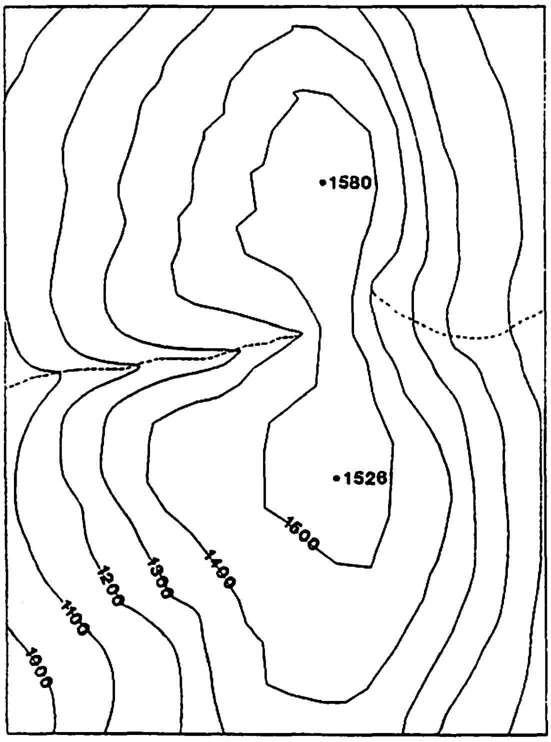

Figure II.3. This figure illustrates a ridge as it would appear on a topographic map. Note that the drainage on the left has a V- like shape to the contour lines. This indicates that the sides of the drainage are steep. The more gradual contour lines on the right indicate this drainage has a more gentle slope. The spot elevations indicate that there are two peaks on this ridge.

ridges and streambeds at right angles (**Figure II.3**).

- Contour lines tend to parallel streams and have an M-shape just above the junction of two streams.

- Contour lines are perpendicular (i.e. ⊥) to the direction of maximum slope.

- Since the earth is a continuous surface, all contour lines must close upon themselves. This closure may occur within the area being mapped, but often happens outside the area and therefore will not appear on the map sheet.

Besides the direct presentation of information on topographic maps, these maps can be used by an insightful manager to provide clues that will allow reasonable deductions about many aspects relating to resource management. For example, if the contour lines are close together (indicating a steep slope) the manager should be aware that an erosion hazard may be present. Steep sites are more susceptible to erosion because the runoff will gain momentum as it flows overland, thus enabling it to detach and carry more sediment than would be possible on a gentle slope. Another general characteristic is that as elevation and slope increase there is a greater likelihood that the site will have shallow and/or rocky soils. Extensive flat or gently undulating land tends to have much deeper soils.

Be careful not to focus on only one map trait and make a snap decision. For example, if charged with choosing a route to travel cross-country with livestock, it makes sense to look for broadly spaced contour lines on a map to find the most level route possible and thereby avoid difficult-to-traverse steep country indicated by closely spaced contour lines. But again, this is only one factor to consider. To make a wise decision, it is desirable to also consider the wide variety of information available on the other RMH maps. For example, the text tables and maps illustrating *RATINGS OF RESTRICTIONS IN ACCESSIBILITY FOR LIVESTOCK* should be consulted to see if other barriers to movement, such as rocky or sticky soil, are present. It may be a good idea to consult the maps on *RANGE CONDITION, VEGETATION TYPES* and *ECO-CLIMATIC ZONES* along with the map and accompanying text about *RANGE UNITS* to determine if sufficient forage is likely to be available. If the trip is being planned for a particular time of year, the set of *RAINFALL RELIABILITY* maps and the *PRODUCTION RISK* map may also be useful to consult since these factors are linked to forage production. The map on *TYPE AND LOCATION OF WATER SOURCES* will indicate where water can be obtained along the route.

Maps must be used with some insight as to how they were constructed. Map accuracy is often not absolute because of information limitations when the maps were drawn. There is usually a discussion in the respective sections of the RMH with regard to the types of data and field sampling which was used when making decisions of how to draw the maps. Available information was used whenever possible, however the precision of this information often was quite variable. For example, the precision of soil maps available from different portions of districts ranged from very detailed maps with a 1:1,000 scale to very broad generalizations with a 1:1,000,000 scale.

The mapping approach used by the soil and vegetation consultants was:

1. Satellite images were used to identify area (land units) with similar landscape/surface features. Strategic points were selected within each land unit to serve as representative sample locations.

2. Data collected at these sample locations (ground-truthing) were used to estimate what the vegetation/soil/landscape was within the rest of the land unit.

3. The degree to which the sample location represented the rest of the land unit was checked by additional ground-truthing (additional samples were collected or visual estimates were made at other areas within the land unit). Often knowledge about one easily-observed trait was used as a guide to assess a more difficult-to-measure trait. For example, the character of soils is often related to the type of vegetation growing on it. Thus, it was sometimes possible to determine the type of soil by looking at the vegetation.

The degree of ground-truthing conducted by the map maker was often affected by practical considerations. Logistics often influenced where samples were collected. Field verification surveys were therefore usually done along the existing roads. This means that the maps are usually more accurate along roads and may be increasingly suspect as the remoteness of the area increases.

The climatological maps were based on interpolating rainfall data that had been collected from existing rain gauges which are unevenly scattered over northern Kenya. The length of time for which rainfall records are available is quite variable, with some rain gauges having been maintained for decades and others having been established relatively recently. The mapping of climatological information was also influenced by knowledge of the relationship between climate and landform and the relationship between climate and vegetation type.

CHAPTER III
LANDFORMS AND SOILS

The physical characteristics of a landscape affect many aspects which determine patterns of rangeland use and productivity. **Landforms** are natural features of the landscape (mountains, plains, etc.). Landforms are of interest to a range manager because of the wide range of environmental and managerial implications associated with them.

Geology characterizes the history of the site, especially as recorded in the type and age of rocks. The type and age of rocks influence the relative abundance of minerals at the surface of the earth. Rocks at or near the earth's surface are exposed to air and water which produce physical and chemical changes in the rocks. This process is known as **weathering**.

The unconsolidated and more or less chemically-weathered minerals and organic matter (organic refers to material from plant or animal origin) are the **parent material** from which soil is developed. **Solum** is the uppermost weathered material. The solum can usually be differentiated into a variety of different layers which lie approximately parallel to the soil surface. These layers are known as **soil horizons**, each of which has distinct characteristics produced by the soil-forming process associated with the pattern of weathering and biological activity on the site. The **soil profile** is a vertical section of the soil through all the horizons and extending into the parent material. **Bedrock** is the solid rock underlying the soil. The depth to bedrock may range from zero (where exposed by erosion) to several hundred feet.

A range manager can therefore use a knowledge of geology to deduce what the likely characteristics of the soil will be. The terms introduced above represent an interconnecting series of traits that can provide important insights regarding potential range management problems and opportunities.

The surveyors collecting information for the RMH recorded the following information during their field studies: landform, geology, slope, stoniness/rockiness, apparent soil degradation and topsoil quality (estimated by considering the amount of grass cover, the organic matter content of the soil, etc.), presence and extent of soil crusting, erosion status, soil depth, soil texture, soil color, consistence and calcareousness. Topsoils were sometimes analyzed for fertility and soil salinity. Soil profile pits were not dug due to time and labor constraints; instead, soils were characterized by examining augured cores of soil.

The *LANDFORMS AND SOILS MAP* in the RMH illustrates the location of the major landforms and the predominant geology and parent material within each district. These characteristics are represented on the maps and legends by capital letters, with the first capital letter indicating the landform and second capital letter indicating the geology and parent material. The table accompanying the *LANDFORMS AND SOILS MAP* lists a variety of other factors associated with the mapped traits. The following text describes the important terms used in the RMH discussion of landforms and soils, and discusses some of the managerial implications associated with the terms. **Figure III.1** illustrates the shape and position of landforms on the landscape.

LANDFORM

The following terms are used to characterize various landform types:

Mountains

A large land mass that rises conspicuously above the surroundings (usually rises several thousand feet above the surrounding landscape, as opposed to hills which are lower in elevation). Mountains which are grouped in a continuous series of related ridges are called a mountain range.

A change in elevation can alter the climate of an area. The windward side of mountains usually receive more rain and the leeward side usu-

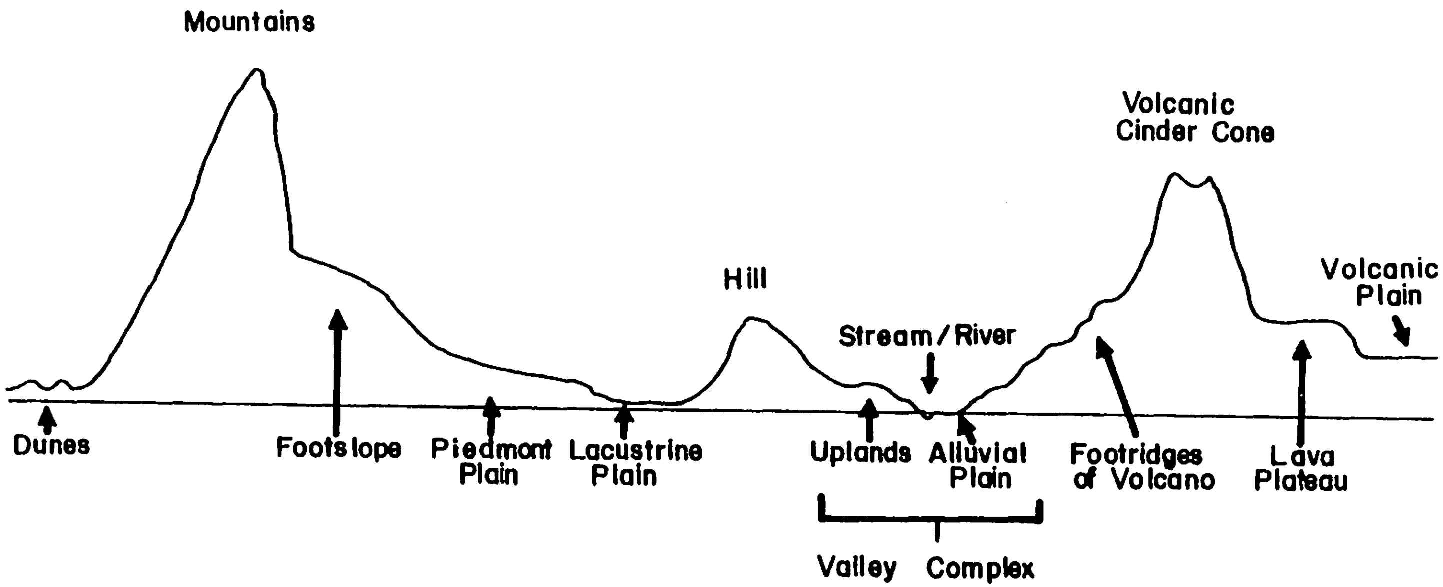

Figure III.1. Shape and position of the landform types typical of the rangeland landscape in Kenya.

ally receives less rain (see discussion of orographic storms in Chapter IV for more information on this phenomenon). Therefore, the windward sides of mountains are often important recharge areas for rivers and groundwater aquifers. Temperature also decreases with an increase in elevation (about 1°C for every 300 m). The cooler and wetter climate associated with an increase in elevation results in the formation of a gradient of vegetation types. Forest or woodland types dominate at the top of many of Kenya's mountains, shifting to shrubland, grassland or barren land at more arid lower elevations. On very high mountains, such as Mt. Kenya or Mt. Kilimanjaro, the cold temperatures near the peak cause the forest to give way to cold-tolerant dwarf shrubs.

The higher elevations of mountains are therefore important dry season sources of forage and water. Traditional pastoral systems near these locations were often structured so that livestock were grazed at the lower elevations during the rainy season. The higher elevation grazing lands were conserved for use during the dry season. Since dry season forage and water access are limiting factors in most of these regions, this seasonal movement pattern allowed a greater number of livestock to be supported on the landscape than would be possible if there was no access to these dry season pastures. Wildlife movements followed a similar pattern.

In recent decades, permanent settlement on dry season pastures for the purpose of farming or year-round ranching has changed the traditional movement patterns. Without access to the traditional dry season pastures, the livestock population using the more arid rangelands of the lower elevations must be kept smaller to survive the dry season. There are several reasons why forage, even when produced during a several month growing period, cannot be conserved for optimal use in the dry season. Termites are one of the most important consumers of forage in many arid and semi-arid rangeland environments. Therefore, much of the grass produced during the rainy season will be quickly consumed by termites, and is thus not likely to be available during the later portion of the dry season. Also, many of the perennial grasses move most of the nutrients in the above-ground tissue to their root systems before they dry out. Thus, many forage species which are quite nutritious during their early growth period have a very low nutritive value by the time the plant begins senescence.

Misuse of vegetation in mountainous terrain can result in rapid runoff of rainwater down the steep slopes, causing serious erosion and flash-flooding. For this reason, the steep slopes of mountains are best managed by conserving the trees and moderately grazing the forage. Another obvious management consideration associated with mountainous terrain is the steep, rocky land which makes overland travel difficult for both livestock and vehicles.

Hills

A well-defined natural elevation of land which is usually rounded on top. Large hills can also affect climate (with results similar to that described for mountains), but because they have a lower elevation than mountains, the climate and vegetation changes are smaller. The slopes associated with hills require that vegetation cover be carefully maintained to reduce the rainfall runoff which can cause serious erosion and flash-floods.

Footridges of Volcanos

Formed when rapidly cooling lava at the outer extremeties of lava flows solidify and block the flow of warmer lava which piles up behind. This causes an elongated crest or series of crests. The general landscape is often rolling but sometimes forms an angular, rugged terrain. The ridges or gorges often form impediments to vehicle travel (and sometimes even livestock movement) because of their rocky and steep nature.

Footslopes

A concave rise in elevation on the side of a range of hills or ridges. The characteristics of the soil at the top and bottom of footslopes may not be the same. A **catena** is a topographic sequence of soils of about the same age, derived from similar parent material, and occurring under similar climatic conditions, but having different characteristics due to variation in relief and in drainage. A series of different soils occurring from top to bottom of a footslope is a soil catena. Often there will be different vegetation species growing on different portions of a catena.

Colluvium is a deposit of rock fragments and soil material which has accumulated at the base of the slopes. This material reached this area by the pull of gravity. If the colluvium is primarily soil material, the resulting deep soils may store more water and allow plants to develop more extensive root systems. Often the vegetation growing on colluvium supports more robust or different vegetation communities than are found on the surrounding terrain.

Lava Plateaus

Formed when land covered by lava was uplifted along a broad front by pressures within the earth or when successive horizontal lava flows accumulated to produce a region of high elevation. In some cases the elevation difference is further increased by a more rapid erosion rate of the land adjacent to the lava flow. The tops of the plateaus are usually extensive land areas that have a relatively level surface. Usually the lava plateau rises sharply above the adjacent land (i.e. forms an **escarpment**) on at least one side of the plateau. Lava plateaus are characterized by a general absence of streams, rivers or surface catchments. The tops of the plateaus are often characterized as stony rises and plains, the rises marking areas of lava flow.

Uplands

A high, rolling landscape elevated above lower areas along rivers or the sea.

Piedmont Plains

A plain stretching from the base of mountains that is composed of alluvium eroded from the mountain. **Alluvium** is a general term for all loose material (such as rock fragments, soil particles or small pieces of organic matter) that is transported by overland water flow. **Alluvial soils** develop from recently deposited alluvium. There is essentially no horizon development or modification of the recently deposited materials. The soils may be quite deep and the terrain is generally flat.

Volcanic Plains

Lower in elevation than lava plateaus, volcanic plains are generally flat and have few rivers, streams or surface catchments. The plains may either be fine-grained ash or stony, depending on how the volcanic output was deposited.

Sedimentary Plains

Flat or slightly rolling plains which are the exposed parts of the former sea-floor. These plains are usually underlain by marine strata (such as limestone).

Lacustrine Plains

Very flat plains which are the sediment of deposits in ancient lakes. The plains are now exposed because either the water level of the region has been lowered or the elevation of the land has increased.

Alluvial Plains

Flat plains formed by the deposition of sediment being transported by rivers. These soils can often be quite deep. Any pre-existing relief is buried by a blanket of sediment.

Bottomlands

Low-lying land along a water course composed of sediment deposited by the river. These deep, well-watered, nutrient-rich soils are very productive and are often cleared for use as cropland. The portion of bottomland that is susceptible to inundation when the stream is at flood stage is called a **flood plain**.

Valley Complex

Flat plains that are disected by numerous streams and rivers which erode the soil to form depressions or gullies.

Dunes

Dunes are mounds or hills of sand which have been deposited by the wind. Dunes vary greatly in size and shape, depending on the velocity and direction of the wind and on the amount of sand available in the area. Dunes are formed in areas where there is a combination of strong winds and sufficient amounts of loose, unprotected soil. Dunes are usually composed of sand, although clay, salt and gypsum are also involved in some areas. Dunes are aligned in a pattern which bears some relationship with the local wind regime. Active dunes have little or no vegetation cover and move with time. Most dunes are not stationary. Instead, they slowly move as the wind blows sand up the gentle windward slope and over the crest, thus allowing it to fall down the steep leeward side. The repeated occurrence of this process results in the dune moving in a leeward direction. Although most large dunes usually move less than 8 meters a year, some are known to have moved as much as 30 meters in one year. This can create great economic problems if a well, village, road, etc. is in the path of a moving dune. The effort and cost of stabilizing a dune is great. Management should be focused on protecting the plant cover to prevent accelerated wind erosion and dune formation.

Stabilized dune fields have a rolling relief with grass or shrub cover. The soils are usually nutrient poor. If livestock are confined to grazing on stabilized dune fields the lack of some key nutrients may be so extreme that birth defects or other physiological problems result. There are few rivers, streams or surface catchments in dune fields.

Recent Lavaflows

Generally flat terrain with a blocky volcanic rock cover. There are generally few rivers, streams or surface catchments. Movement by livestock or vehicles across lava flows is often difficult.

Landscape attributes make watersheds (a surface drainage area) a logical, natural land unit for soil and water management (see Chapter VII for more information). Often there are mixed land uses within a unit which are interdependent from a watershed perspective. For example, improper management of upland sites used for wood gathering and grazing can result in flash-floods which jeopardize cultivation activities in lowland areas. This interdependence makes it desirable to plan development in the context of the watershed. If this does not occur, a good program at one site within the watershed may fail because of unsound land use on adjacent, interdependent sites. In terms of economic planning, a watershed also constitutes a useful management unit since the benefits and costs of soil and water management primarily accrue to the people within the watershed.

GEOLOGY AND PARENT MATERIAL

The minerals which compose the rocks from which soil is derived have great influence over the fertility and physical properties of the soil. Therefore, by observing the geology and parent material of the site, insight can be gained about how processes such as plant growth and water drainage will be affected.

Soil is largely composed of rock particles. The characteristics of the soil will be determined to some extent by the degree of weathering the soil has undergone. The results of weathering are determined in part by the mineral stability of the parent materials, which in turn influences the occurrence of various minerals in the soil. The varied resistance to weathering of different minerals influences the mineral composition of a soil. For example, quartz often dominates the non-clay fraction because of its resistance to weathering and because it is abundant in certain common parent materials such as granite or sandstone.

Rocks are aggregates of minerals. The wide variations in appearance and physical properties that they show depend upon the amounts and kinds of different minerals they contain, and upon how the grains of these minerals are held together. The rocks in the earth's crust are commonly classified as igneous, sedimentary or metamorphic. As these rocks weather, they are eventually broken down into the individual minerals of which they are composed. The rock parent material therefore has an influence on the characteristics of the soil in ways broadly discussed below.

Igneous Rocks

Igneous rocks are formed from molten lava (sometimes referred to as **volcanic rocks**). Although geologists have recognized many different types of igneous rocks, basalt and granite are the two most common igneous rock groups discussed in the RMH. The color of an igneous rock is dependent on the minerals from which it is formed and thus provides clues as to the characteristics of the soil derived from it.

Basalt is a black to medium gray, fine textured rock which is the world's most abundant type of **lava** (i.e. fluid rock that comes from a volcano or fissure in the earth's surface). In general, darker-colored igneous rocks are high in minerals which contain nutrients such as calcium, iron, magnesium and potassium. Therefore, the soils formed from these rocks also contain high amounts of these nutrients. The characteristics of these minerals give basaltic soils a relatively high pH. If volcanic activity has occurred within the geologically recent past (i.e. last 500,000 years) there will often be a fair degree of stoniness at the soil surface, possibly including many large rocks.

Granite is a light-colored igneous rock which contains a large amount of quartz. Soils derived from granite tend to be yellow or yellowish-brown in color because of the low iron content of the parent rocks. These soils tend to be low in nutrients and are often acidic.

Pyroclastic rocks are rock fragments thrown out of volcanoes, such as volcanic ashes or cinders. **Volcanic ash soils** generally have thick, dark soil profiles which are coarse grained, very friable and have a high infiltration rate.

The texture of igneous rock is determined by how fast the molten materials cool and how large the mineral crystals grow within the rock. Basalt is fine-textured and granite is coarse textured. Weathering of fine-grained rocks produces soils containing fine materials such as clay and silt, while coarse-textured rocks develop into sandy soils.

Sedimentary Rocks

Sedimentary rocks are formed either by accumulation of fragments of rocks, minerals, and/or organisms which are cemented together, either chemically or by compression. For example, **sandstone** is composed of cemented sand. The original sand particles accumulate in many different environments, such as at the bottom of a prehistoric water body or heaped up in dunes by the wind. Soils derived from sandstone are usually acidic. The porous sand leaches quite easily and is usually low in nutrients (**leaching** is the process of minerals being dissolved in water and then leaving the soil via seepage). **Shale** is basically hardened mud composed of silt and clay particles which are cemented together. The soils formed from shale have a wide variety of characteristics, depending on the amount of minerals present. **Conglomerate** rocks are composed of cemented gravel and sand and weather to coarse, gravelly soils. **Limestone** is composed almost entirely of calcium carbonate ($CaCO_3$) which has precipitated from water. Limestone may sometimes contain remains of marine organisms such as shells that were covered by the precipitate. Parent materials which contain calcium carbonates result in formation of basic soils (i.e. soils with a high pH) high in calcium and magnesium. **Coal** is the result of compression of partially decomposed plant material which was buried under later sediments.

Metamorphic Rocks

Metamorphic rocks are formed when igneous or sedimentary rocks are buried deep within the earth and are subjected to high amounts of heat, pressure and/or chemical activity. These conditions usually produce great changes in the rock, altering its texture, mineral composition and chemical composition. Igneous rocks are commonly modified to form **gneisses** (from granite) and **schists** (from basalt). Sedimentary rocks such as shale may be changed to **slate**, sandstone may be changed to **quartzite** and limestone may be changed to **marble**. These metamorphic rocks slowly weather to form soils with similar properties to soils derived from the corresponding igneous or sedimentary rocks described above.

A **basement complex** is an assemblage of metamorphic rocks derived from igneous rocks that were formed below the surface of the earth, and very old sedimentary rocks that lie beneath the oldest stratified rocks of a region. Many, but not all, basement rocks are of the Precambrian age (i.e. older than 600 million years) and therefore generally lack a fossil record. Soil derived from weathering of basement system rock is typically brownish colored, coarse sandy loams and coarse sandy clay loams which have a low fertility.

AGE

In general, the younger the soil the more influential the parent material. The effects of the initial parent material on the soil characteristics become less and less important as the weathering and biological processes alter the soil. As soils age, the amount of weatherable minerals is reduced, causing a drop in soil fertility. Older soils have usually lost via leaching many of the nutrients needed by plants.

The influence of parent materials on soil development is often strongly modified by other environmental factors such as the climate or vegetation changes which took place over thousands of years. For example, past climates have affected the rates of chemical and physical processes. For every 10°C rise in temperature, the rate of chemical reactions double. If precipitation and temperatures are high, the biochemical changes caused by soil organisms are also high. The climate affects the type and amount of vegetation which influences organic matter accumulation. Organic matter helps hold nutrients in the soil for later use by plants. Nitrogen is added to the soil system by microorganisms. The cover provided by the vegetation reduces natural erosion rates, thereby slowing the rate of mineral removal from the surface. The topography of the land also influences soil formation over time. As slope increases, the speed and erosive force of overland flow increases and the likelihood of deep soil formation decreases. The interaction between climate, living organisms, parent material, topography and time must be emphasized. Knowing any one of these factors can provide important clues regarding soil development, but no single factor is likely to be solely responsible for the kind of soil that develops over time.

There are occasional references in the RMH text regarding the geologic ages of the rock material from which the soil is derived. Little of the earth's surface is older than the Tertiary period and most of it is no older than the Pleistocene epoch. The volcanic activity associated with the formation of the Rift Valley started at the end of the Miocene and lasted through the Pleistocene. **Table III.1** provides a geologic time scale to provide a relative reference point for the ages of rock material cited in the text.

SOIL CHARACTERISTICS

Understanding the soil of a site provides a number of important management insights. The terms used in the RMH to describe soil characteristics are discussed, along with the implications of each of these factors regarding rangeland management.

Pedology is the study of the origin, classification and description of soil in the natural environment. This information can provide fundamental knowledge of a site that is needed by a wide range of professionals (e.g., farmers, pastoralists, construction engineers, planners and administrators). Without using information about the soils of a site, it is difficult to make wise decisions regarding development and management of the natural composed of silt and clay particles which are cemented together. The soils formed from shale have a wide variety of characteristics, depending on the amount of minerals present. **Conglomerate** rocks are composed of cemented gravel and sand and weather to coarse, gravelly soils. **Limestone** is composed almost entirely of calcium carbonate ($CaCO_3$) which has precipitated from water. Limestone may sometimes contain remains of marine organisms such as shells that were covered by the precipitate. Parent materials which contain calcium carbonates result in formation of basic soils (i.e. soils with a high pH) high in calcium and magnesium. **Coal** is the result of compression of partially decomposed plant material which was buried under later sediments.

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Table III.1. The geologic time scale (Holmes 1965).

Era	Period	Epoch	Beginning of Interval (millions of years)
Cenozoic	Quaternary	Holocene (Recent)	<3
		Pleistocene	3
	Tertiary	Pliocene	12
		Miocene	25
		Oligocene	40
		Eocene	60
		Paleocene	70
Mesozoic	Cretaceous		135
	Jurassic		180
	Triassic		225
Paleozoic	Permian		270
	Carboniferous		350
	Devonian		400
	Silurian		445
	Ordovician		500
	Cambrian		600
Precambrian			>600

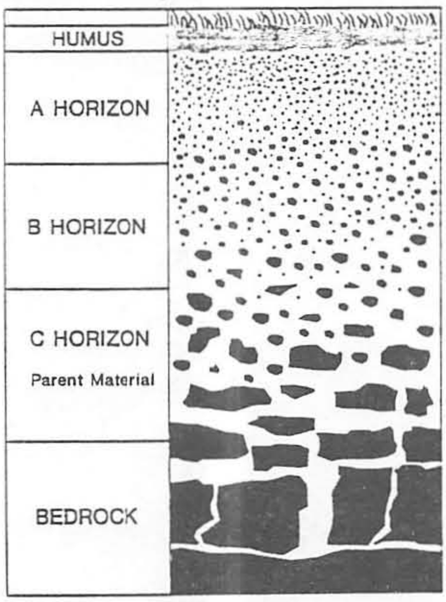
resources of the area. **Edaphology** is the study of the soil in relation to the vegetation that can grow on the site. It considers the various properties of soils that relate to plant production. Soil information within the RMH is discussed both in terms of chemical and physical properties and in terms of how the soil will influence vegetation growth.

Soil classification is the systematic arrangement of soils into groups or categories on the basis of their characteristics. Broad groupings are based on general characteristics and subdivisions on more detailed specific properties. The soil classifications applicable here (in descending order of subdivision) are family, series, class and type. **Soil families** are defined largely on the basis of physical and mineralogical properties important to plant growth. **Soil series,** the basic units of soil classification, consist of soils that are essentially alike in all major profile characteristics. **Soil classes** are groups of soils having a definite range in a particular property such as acidity, degree of slope, texture, structure, land-use capability, degree of erosion, or drainage. **Soil types** are the most detailed, site-specific units of soil classification, and consist of soils that are alike in all characteristics including the texture of the A horizon.

A **soil survey** is the systematic examination, description, classification and mapping of soils in an area. Describing a soil is usually done in the context of the **soil profile** (e.g., a vertical section of soil). The more or less distinct individual horizontal layers encountered within the soil are called **horizons (Figure III.2)**. The upper portion of the soil is the most weathered portion of the profile and is known as the **solum**. The solum is composed of the A horizon (i.e. the layer in which most of the organic matter has accumulated and in which there is the most biological activity) and the B horizon (i.e. the layer beneath the A horizon which has some different characteristics, such as a blocky or prismatic structure and/or a different set of soil constituents). On heavily degraded rangeland, the top horizon is not necessarily the A horizon because in areas of high erosion the A horizon soil may have been completely washed away, exposing the B horizon to the surface (see plate 11, Volume III.7 of exposed B horizon soils in West Pokot District). In such instances the production potential of the site has been substantially reduced because the soil of the B horizon is less developed, which means that it will likely have less water-holding capacity and less plant available nutrients.

The C horizon is relatively little affected by biological activity and is composed of unconsolidated (i.e. loosely arranged, not stratified) and somewhat chemically weathered rocks known as the **parent material**. Every well-developed, undisturbed soil has its own distinctive profile characteristics which are used in soil classification. The combination of these characteristics give each soil type a unique set of properties which are important considerations for people who use that land. A brief

Figure III.2. Typical soil profile showing the A-, B-, and C- horizons.



overview of how to recognize the major soil characteristics used to classify soil is discussed below.

Texture

Soil texture is defined as the relative proportion of three size classes of individual particles in the soil material. **Clay** is defined as individual soil particles that are less than 0.002 mm diameter, **silt** particles range in size between 0.002 and 0.05 mm in diameter and **sand** particles range in size between 0.05 and 2.0 mm in diameter. Almost all soils contain a mixture of each of these three size classes. The textural description for a particular soil is based on the relative percentage of the three size classes as diagramed in **Figure III.3**. Do not be confused by the fact that the words "clay", "silt" and "sand" are used both for the size fractions (where for example "sand" means sand size) and for the textural names (where "sand" means soil of sandy texture). In addition to the textural group determined from the proportion of particles less than 2 mm in diameter, the textural name will be prefaced by the term **gravelly** when 20 to 50% of the profile material is between 2 to 76 mm large, **cobblely** if 20 to 50% of the profile material is between 76 to 250 mm large, and **stony** if 20 to 50% of the profile material is greater than 250 mm in diameter. For example, a "stony clay" designation refers to the fact that 20 to 50% of the material in the sample is stone size and the remaining portion falls on the soil textural triangle within the clay designation.

When considering soil texture in land use and soil management decisions, be sure to evaluate the total soil profile rather than just the soil surface. Often the surface soils are underlain by soil of a quite different texture. Remember that the composition of a soil refers to a vertical sample of the solum (i.e. the A and B horizons), not simply what is laying on the surface exposed to the air. This means that a pit will have to be dug or auger sample extracted to get an accurate characterization of the soil.

If more than 50% of the surface of the soil is in the stone size class, the site is simply referred to as stony or rocky. In some regions the soil surface may be naturally covered with rocks. In others, extreme erosion may have taken place, washing away the lighter clay, silt and sand particles and leaving the surface covered with rocks. If the surface material is predominantly stony it may impede livestock movement across the area (especially camels and cattle), a fact that must be considered with regard to planning and administration of pastoral development programs. The stoniness, along with steep slopes/rugged topography which can also limit livestock movement, are the considerations used when developing the map which shows the *PERMANENT, NON-SEASONAL RATINGS OF RESTRICTIONS IN ACCESSIBILITY FOR LIVESTOCK.* Although this map is primarily designed with regard to livestock accessibility, slope and stoniness considerations are also of great concern when attempting to travel overland in a vehicle, when determining the feasibility and cost of a road or pipeline project, etc. This map is therefore important to consult for any activity that has an overland logistic component.

The texture of the soil is an extremely important factor influencing a host of soil properties. Therefore, the soil texture information in the RMH can be used in many practical ways by a range manager. For example, the large pore spaces which form between sand particles allow water to pass into and through sandy soil quickly. This means that it is unlikely that significant runoff will occur on sandy soils. Therefore, water harvesting reservoirs are unlikely to be successful on sandy textured soil. Likewise, water erosion is unlikely to be a serious concern on sandy soils. The small pore spaces which form between clay particles allow water to pass into and through clayey soil very slowly. This means that surface runoff from clay sites is likely. It also means that the overland flow will pose an erosion hazard. Water harvesting on clay sites is therefore possible, but if the vegetation is overgrazed the soil will be easily eroded and will silt up the reservoir. Clay fields may require terraces and strip cropping to prevent erosion.

Once water gets into the small pores of clay, it

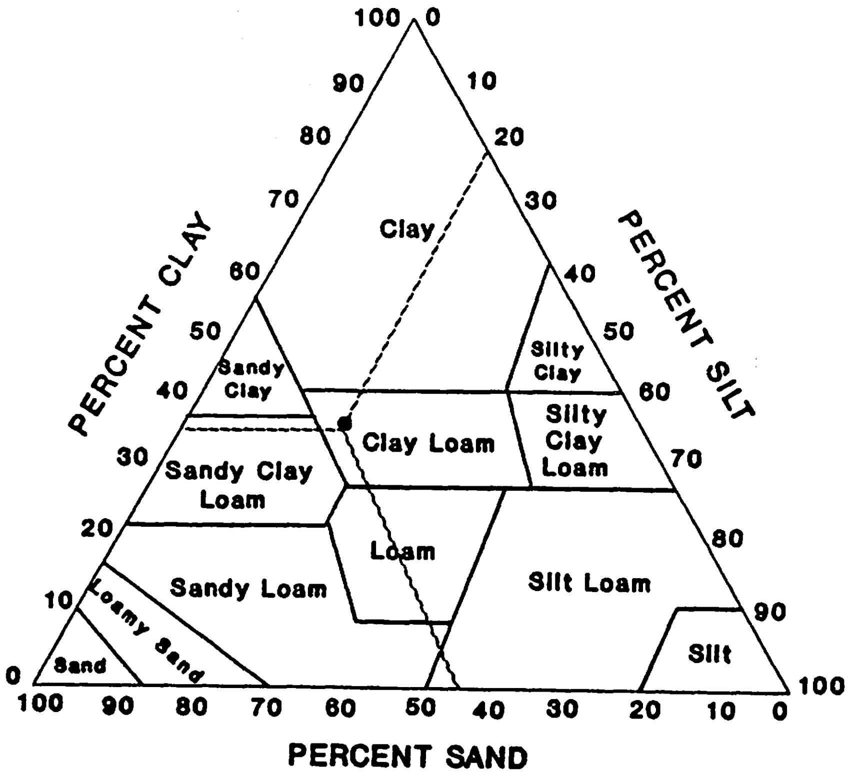


Figure III.3. Relationship between the class name of a soil and its particle size distribution. To use this diagram, the line originating on the silt axis should run parallel to the clay axis, the line originating on the sand axis should run parallel to the silt axis, and the line orignating on the clay axis should run parallel to the sand axis. For example, a soil with a texture listed as 35% clay, 20% silt, and 45% sand would be classified as a Clay Loam (shown by the intersection of the dashed lines).

will drain out more slowly than from the large sand pores. Therefore, clay soils have a much better water holding capacity than sandy soils. This is why grass and forbs will stay greener longer into the dry season on clay sites than on sandy sites. Another implication is that when roads on clay become wet, they will be impassible much longer than roads on sandy sites.

As the water rapidly passes through sand, it transports some of the available nutrients with it. Sandy soils therefore often have problems storing nutrients. This implies that if fertilizer is being added to coarse-textured soils it should be frequently applied in small amounts. Usually clayey soils tend to be more fertile than the sandy soils, but this broad generalization is qualified by many other factors which can affect fertility, such as the climate and age of the soil. If the area around a well is sandy and livestock are allowed to congregate there, the animal waste products will percolate through sand quite easily. Little filtration and purification may take place and the groundwater may become contaminated. At the other extreme, fine-textured soils such as clays, sandy clays and silty clays may hold water and nutrients so tightly that they are unavailable for plant growth.

Clay soils are quite difficult to till without becoming cloddy. Clays are susceptible to crusting which may result in poor seedling emergence. In terms of construction, sandy soils do not pack well and thus are poor roadbed and fill materials. Clay soils may shrink and swell and, in the process, break foundations. Often sandy soils will be underlain by more clayey horizons. Because of the wide range of implications associated with soil texture, this term is the basic descriptive factor from which almost all aspects of soil property discussions proceed.

Texture is best determined in a laboratory where it is possible to use procedures to accurately separate the different size classes of soil. However, it is possible to use the following characteristics to estimate the textural class of a soil while in the field (Sopher and Baird 1982). The characteristics described below are only applicable for soils which are moist. If the soil is dry, add water until the soil is moist (i.e. do not add more water then the soil can absorb -- there should be no water dripping from your fingers when the soil is squeezed).

Sand: Loose, single-grained soil. The individual grains are readily visible. When the soil is squeezed, a cast forms that will fall apart when your hand is opened.

Loamy sand: Loose, single-grained soil. The individual grains are readily visible. When squeezed, a cast will form which will not fall apart when your hand is opened but will break easily when handled.

Sandy loam: Loose, single-grained soil. The individual grains are readily visible but the grains will appear coated with finer-grained particles. When squeezed, a cast will form that can be carefully handled without breaking.

Loam: A mixture of different size soil particles which feels gritty but is clearly not dominated by sand grains. When squeezed, a cast will form that can be handled freely without breaking.

Silt loam: The feel of the soil may range from gritty to floury, depending on size of the sand particles. The sand grains appear coated with finer-grained particles. When squeezed, a cast will form that can be passed from hand to hand without breaking. When pressed between your thumb and finger, the soil will not hold together.

Silt: No sand grains are visible. The soil feels like flour. When pressed between your thumb and finger, the soil may come close to holding together but usually breaks.

Sandy clay loam: Some sand grains are visible. When pressed between your thumb and finger, the soil forms a ribbon which can barely supports its own weight when lifted from the finger.

Clay loam: Very few sand grains are visible. When pressed between your thumb and finger, the soil forms a ribbon which barely supports its own weight when lifted from the finger.

Silty clay loam: The soil has a rough appearance when rubbed between your thumb and finger. When pressed between your thumb and finger, a ribbon forms which will barely support its own weight when lifted from the finger.

Sandy clay: Some sand grains are visible. The soil will feel gritty when rubbed between your thumb and finger. When pressed between your thumb and finger, a ribbon forms that is capable of supporting its own weight when lifted from the finger.

Silty clay: The soil will appear rough or broken when rubbed between your thumb and finger. When pressed between your thumb and finger, a ribbon will form that is capable of supporting its own weight when lifted from the finger.

Clay: The soil will feel either slick or sticky when rubbed between your thumb and finger. When pressed between your thumb and finger, a ribbon will form that is capable of supporting its own weight when lifted from the finger.

Organic Matter

Soil organic matter is the component of the soil composed of partially decayed plant and animal residues. This material is broken down by microorganisms living in the soil. Organic matter is thus a soil constituent that must be renewed constantly by the addition of new residues such as dead plant tissue (**litter**). Organic matter represents only several percent by weight of topsoil. However, its influence on soil properties and plant growth is far greater than this small percentage would indicate. Organic matter is the substance which binds soil particles together to make the soil loose and workable. It is a major source of phosphorus and sulfur and is essentially the sole source of nitrogen. Organic matter is the main source of energy for soil microorganisms which are necessary for the biochemical activity in the soil. Therefore, the topsoil organic matter content information presented in RMH can be used as a rough estimate of the fertility of the soil. In addition to its role as a nutrient supply, organic matter helps provide soil pore structure which increases infiltration and increases the amount of water a soil can store for later use by plants. In tropical environments such as Kenya, a soil organic matter content of 2% or more is considered high, 1 to 2% as moderate, 0.5 to 1% as low and below 0.5% as very low.

Consistence

Consistence is a general term which refers to a combination of soil properties which indicate the soil's response to pressure. The following discussion describes how consistence characteristics can be determined (Boul et al. 1973) and discusses some of the management implications of the consistence information presented in the RMH.

<u>Stickiness:</u>

Moisten the soil (no water should drip from the soil when it is squeezed) and pinch it between your finger and thumb. The degree of stickiness is then determined by how the soil responds as your fingers are pulled apart:

Nonsticky: Almost no soil sticks to your fingers.

Slightly Sticky: Some soil sticks to one finger but not to the other.

Sticky: The soil stretches somewhat and some soil remains stuck to both of your fingers.

Very Sticky: The soil strongly adheres to both your thumb and finger, requiring a little extra effort to pull them apart.

Sticky soils have high water-holding capacities and high nutrient-holding capacities. If the soil is classified as sticky or very sticky there will be severe limitations to livestock and vehicle movement during the wet season (e.g., the region around Logologo in Marsabit District). This factor, along with flooding potential, was used to make the map of *RATINGS OF RESTRICTIONS IN ACCESSIBILITY FOR LIVESTOCK DURING THE WET SEASON.* Any activities (e.g., livestock or vehicle movement, construction activities, etc.) that involve overland travel should consider the information presented on this map as part of the planning process.

__Plasticity:__

Moisten the soil and rub it between your hands. The degree of plasticity is then determined as follows:

Nonplastic: Unable to form a cohesive thin roll when rubbing the soil between your hands.

Slightly Plastic: Thin rolls form and break into sections less than 1 cm long when rubbing the soil between your hands.

Plastic: Long thin rolls greater than 1 cm long can be formed when rubbing the soil between your hands.

Very Plastic: Much pressure is needed to mold the soil in your hands.

A soil classified as plastic or very plastic will hold water quite well; however, they may or may not hold large amounts of nutrients (this depends on the type of clay present). The pore space between the soil particles can be much reduced on plastic soils if it is plowed or driven on or walked on. A reduction of soil pore space makes the soil relatively impervious to air and water. If the soil is compressed over a large area a **fragipan** (i.e a dense, brittle layer of extremely compacted soil) can form below the soil surface. This dense soil layer can be a severe barrier to root penetration and water movement and therefore can greatly limit vegetation production. Where fragipans are present, water quickly puddles on the surface because the soil pores by which water would pass through the soil have been compressed. If the land has some slope, concentrated water flow will likely occur which can cause rills and gullies to form. When a soil in this condition dries, it usually becomes hard and dense and can inhibit germination and establishment of seedlings. Plowing of plastic soils and movement across plastic soils by vehicles or livestock must be carefully timed. If these activities occur when the soil is wet, the soil pores are compressed and cause a great erosion and runoff hazard. At the other extreme, if the soil is plowed when too dry, great clods are turned up which are difficult to work into a good seedbed.

Cracking clays, composed of types of clays with a propensity to shrink and swell, are one of the most difficult soils to work with because they are highly plastic and sticky and have a great capacity to shrink when dry and swell when wet. After prolonged dry periods, these soils are criss-crossed by wide, deep cracks which at first allow rain to penetrate rapidly. However, as precipitation continues, such soils are likely to close up (swell) and become very impervious to water, causing ponding. It is very costly to build a road or a foundation for a building on such soils because, unless an extra investment is made to do the job correctly, shrinking and swelling soils will cause the structure to eventually break apart.

__Friability:__

Moisten the soil and press it between your thumb and finger. The following categories can thus be described:

Loose: Soil material is composed of single grains.

Very Friable: Soil aggregates crush easily between thumb and finger.

Friable: Gentle thumb and finger pressure is required to crush the aggregates.

Firm: Moderate thumb and finger pressure is required to crush aggregates.

Very Firm: Strong thumb and finger pressure is required to crush aggregates.

Extremely Firm: Aggregates cannot be broken by thumb and finger pressure.

Another way to determine the same general properties is to take air dry soil into your hands. The categories with this test are described as:

Loose: Soil material is composed of single grains.

Soft: Aggregate easily breaks into single grains in the hand.

Slightly Hard: Gentle thumb and finger pressure is required to crush the material.

Hard: Aggregates are barely breakable by thumb and finger.

Extremely Hard: Aggregates cannot be broken with both hands.

These categories refer to the workability of the soil. Friable or soft soils are most easily tilled.

<u>Cementation:</u>

Pick up a big chunk of soil. The degree of cementation is described as:

Weak: The clod can be broken by hand.

Strong: The clod is brittle but can easily be broken by a hammer or by heel pressure.

Indurated: The clod is brittle, requiring a strong hammer blow or strong stomping by the heel to break it. If immersed in water, pieces of the clod will not slake (i.e. crumble).

Indurated (i.e. cemented) soil forming a layer in the soil profile is referred to as a hardpan, claypan, duripan, or caliche. Indurated soils are formed when soil particles are cemented with materials such as calcium carbonate or silica. Indurated soils are a barrier to root growth and downward water movement and can therefore strongly inhibit vegetation production. The barrier to water movement into indurated soils can result in ponding and, if there is even a slight slope, can contribute to much overland flow, greatly increasing flash-flooding and erosion hazard downslope.

Depth

Depth of the soil is important because it reflects the volume of soil available for retaining water and nutrients. The amount of storage space for water and nutrients affects the production potential of the vegetation growing on the site. Soil depth is classified as follows:

Deep: Greater than 80 cm.

Moderately Deep: Between 40-80 cm.

Shallow: Between 20-40 cm.

Very Shallow: Less than 20 cm.

The depth of the soil profile naturally decreases as soil is lost via erosion. This actually explains an apparent paradox. Pastoralists or farmers often say that droughts are increasing in frequency and severity. Yet, rainfall records for the region may show no conclusive pattern of rainfall change over several decades. How can these opposing observations be reconciled? One factor may be that if large amounts of soil are lost via erosion, there is less soil in which to store water and nutrients. This means that the plants which are growing on the site will exhaust the stored water sooner and produce less forage or grain. Thus, droughts occur sooner and with greater frequency.

Another common comment by pastoralists or farmers is that rocks are "growing" out of the ground on their fields, hence the site is becoming more rocky than when they first came to the area. Of course, rocks do not grow out of the ground. What is happening is that the topsoil covering the rocks is being washed away. Most of the erosion which occurs is undramatic (see the interrill (sheet) erosion portion of this chapter for more information on this subject), thus over one or two decades the change is so gradual that the local inhabitants don't even realize that it is happening (shrub encroachment also falls into this category of an insidiously gradual but serious degradation of a site).

Soil Moisture Storage Capacity

Soil moisture storage capacity (SMSC) depends mainly on the depth of the soil (effective soil depth, rooting space) together with the available water capacity (AWC) of each soil horizon. The AWC is expressed as a percent or in terms of millimeters of water per meter of soil. It depends on a number of soil physical properties such as soil texture. Approximate values are given below for homogeneous soils one meter in depth that have no rocks or hardpans.

High AWC: >180 mm/m Very fine sandy and silty textures

Moderate AWC: > 120-180 mm/m Clayey soils, silty clay loams, sandy loams

Low AWC: < 120 mm/m. Sands, loamy sands and coarse sandy loams.

A small SMSC implies that plants will run out of water quickly. On such sites with a small SMSC, the frequency of rain storms may be more important than the amount of rain. This is because most of the water from large storms would not be stored (it would either run off or drain through the soil).

Color

Soil color is probably the most obvious feature of the soil and is easily described by the layman. Color will to some extent be influenced by the parent material and the subsequent chemical reactions associated with weathering of this material. An experienced observer can often relate soil color to specific chemical, physical and biological properties of the soils in that area. Some broad generalizations are possible. Black or dark brown soil color usually indicates the presence of organic matter, which means the soil has a high capacity to hold water and nutrients. Small amounts of **humus** (the relatively stable portion of the organic matter that remains after decomposition of plant and animal residues) can have a very substantial influence on the vegetation production associated with a soil. Red to yellow-brown colors result from the presence of iron oxides and hydroxides. These minerals furnish iron needed for plant growth. These colors in the subsoil indicate the soil is well supplied with oxygen necessary for microorganism activity and good plant growth. Soil which is gray, blue or which has a mottled appearance may indicate insufficient oxygen often associated with imperfectly drained soils. These conditions result in suppressed plant growth. White or light-gray colors above the B horizon suggest that there has been extensive nutrient leaching. White or light-gray colors below a B horizon are usually due to high concentrations of calcium carbonate.

Dark-colored soils absorb more heat; thus, they warm up more quickly and reach higher soil temperatures. In cold climates, an advantage of dark-colored soils is earlier initiation of plant growth. In warm climates, a disadvantage of dark-colored soils is higher soil temperatures that cause more rapid soil water depletion and increased chance of heat-induced mortality of seeds and seedlings.

Drainage

Percolation is the movement of water downward through the soil profile. Drainage of soil primarily depends on the texture of the soil. In general, clays are poorly drained, loams are moderately drained and sands range from moderately to excessively drained. **Percolation** results in the loss of soluble salts (**leaching**), thus depleting soils of certain nutrients. Soil properties have a definite effect on nutrient leaching losses. Sandy soils generally permit greater nutrient loss than do clays, not only because of the lower rate of percolation in the finer-textured soils but because of the nutrient-absorbing power of these soils. For example, nitrates react with iron and aluminum. For this reason, nitrates are less prone to leach from soils which have red subsoils (indicating the presence of iron in the soil).

When working on well to excessively drained soil, a laboratory nutrient analysis of the soil may be very useful. Often these soils will be deficient in some of the macronutrients (e.g., nitrogen, phosphorous, potassium etc.) or micronutrients (e.g., copper, zinc, etc.). Nutrient deficiencies in the soil can result in poor vegetation growth. Nutrient deficiencies can also affect animal growth or behavior. A high incidence of thin or deformed horns of gazelles, stunted growth or deformities in animals, livestock consuming bones, etc. are clues that there are some nutrient deficiencies on the rangeland. In such cases, nutrient supplements for livestock or fertilization of crops can yield dramatic production responses.

In well to excessively drained soils there are several things that can be done to minimize nutrient losses. To the extent feasible, vegetation should be kept on the land. This will help to keep the nutrients bound within the roots and foliage. The plants will also be using water, thus limiting the amount of soil water that can leach nutrients through the soil beyond the root system. If fertilizer is being used on these sites, it should be added as close as feasible to the time of nutrient utilization by the plants. Even by following these suggestions, some leaching losses will occur.

Salinity and Sodicity

Where the amount of rainfall exceeds evaporation, the surplus rainwater leaches mineral salts from the soil. Where evaporation is greater than rainfall, mineral salts are not washed from the soil and may actually accumulate at the surface. This is particularly true in areas that have waterlogged soils or areas where floodwater ponds and stagnates. On these sites, salts are concentrated and left behind as the evaporation occurs. This is the case, for example, in the Chalbi Desert located in Marsabit District. Soils of high salt content are toxic to plants, hence many of these areas are barren or are sparsely vegetated with species uniquely adapted to high levels of salt.

Soils that have a large salt accumulation are called **halomorphic**. Halomorphic soils are classified under three headings, determined to a large extent by the pH of the salt compounds. pH is a scale (ranging from 1 to 14) based on the hydrogen ion activity in the soil or water. A substance with a low pH is considered acidic, a substance with an intermediate pH is considered neutral, and a substance with a high pH is considered alkaline. If the pH of soil or water is below 5.5 or is greater than 8.5, there will be increasing problems regarding plant and animal production. For example, activities of soil organisms that fix nitrogen or break down organic matter are reduced in an acidic or alkaline soil environment.

A high concentration of salts, regardless of their pH, generally disrupts a variety of metabolic processes within the cells of organisms and thus inhibits growth. In extreme circumstances, a large salt concentration will result in death of the organism attempting to live in that environment. In soils with a large salt concentration, there usually are specialized plant species which have developed adaptations that allow them to tolerate a higher salt content. The presence of these species can be used as an indicator of high salt concentrations in the soil. Examples are the various types of "salt bushes" (e.g. *Suaeda*, *Lagenentha*, *Salsola*, etc.) and grass species such as *Sporobolus spicatus* (see Volume II.1 plates II.23-24 for pictures of these distinctive plant communities).

The three types of salt dominated soils are described as follows:

Saline soils contain a concentration of neutral soluble salts (i.e the pH of the salts are 6 to 8). The high concentration of these salts is sufficient to seriously interfere with the growth of most plants. Saline soils often have a surface incrustation which is light in color. Because of the neutral nature of the salts, it is possible to leach them out of these soils with no appreciable rise in the pH if fresh water is available.

Sodic soils do not contain many neutral soluble salts. Rather, they contain salts that are very alkaline, with the soil pH ranging between 8.5 and 10. The detrimental effects on plants is largely due to the toxicity of the sodium. Because of the extreme alkalinity, the surface of sodic soils usually is discolored by the dispersed humus carried upward by evaporating water. This gives the soil a black appearance. These soils are often located in small areas called "slick spots" surrounded by soils that are relatively productive.

Saline-sodic soils contain large quantities of both neutral soluble salts and alkaline salts so that plant growth is inhibited. In both the sodic and the saline-sodic soils, leaching will markedly raise the pH of the soil because of some of the chemical reactions in the soil associated with the sodic salts. Therefore, irrigation of such soils is not advisable unless soil amendments are added to lower the pH. Gypsum ($CaSO_4$) is often applied (usually several tons per acre are necessary) to convert the caustic alkali substances in the soil to a more neutral pH. When gypsum is applied it should be lightly mixed with the surface soil (not plowed under) and the soil should be kept moist to hasten the chemical reaction.

Infiltration

Infiltration is the process by which water moves into the soil. **Infiltration rate** is the quantity of water passing through the soil surface per unit of time (this is different from percolation which refers to water movement through the soil profile). The rate of water movement into dry soil is faster than into wet soil. This is because the soil pore spaces are empty when the soil is dry, thus allowing water to flow in faster. When the soil is wet, water can not flow in as fast, thus forcing the excess water to flow overland. When the soil surface is saturated, infiltration stabilizes at a rate known as the **terminal infiltration rate or infiltration capacity**. The terminal infiltration rate is influenced by a variety of soil and vegetation characteristics. It is important that land managers understand these characteristics so that they can understand how land use practices which affect the vegetation and soil will affect the infiltration rate.

For water to enter the soil, it must flow through the open spaces between the soil particles. Water can flow more quickly through large pores than small pores. Soil texture is an important factor influencing the infiltration rate because the relatively large particles which characterize sand texture cannot pack together as closely as the relatively small particles which characterize clay. Therefore, sand has larger pores than clay and this explains why the infiltration rate on sand sites is usually greater than the infiltration rate on clay sites.

Texture is not the only consideration in infiltration rate, however. Large soil pores can also occur if the individual particles are stuck together into clusters (called **aggregates**) which create large pores between the clusters. **Soil structure** is the term which describes the arrangement of soil particles and the intervening pore spaces. A well aggregated soil structure has a high infiltration rate because the soil particles are physically bound together by roots, microscopic fungi and sticky microscopic byproducts of organic matter decay which then become cemented together into stable units by humus. For this reason, soils which have a high organic matter content usually have a high infiltration rate. A well aggregated soil has a granular texture and thus has large pores which allow water to pass through it quickly. For this reason, well aggregated clays and silts can also have a high infiltration rate. The stability of the aggregate when wetted is an important characteristic of humus bound aggregates, as opposed to aggregates which stick together when dry but fall apart as soon as they are wet.

Where is the most granular soil usually found within a range landscape? Usually it is associated with permanent vegetation such as bunchgrasses, shrubs or trees standing above a ground cover of accumulated dead leaves. On these sites, there is a steady supply of organic matter which is needed to form aggregate bonds. Soil temperature and moisture content is usually more stable under vegetation, which creates a favorable habitat for microfauna such as worms and insects. This microfauna is important for mixing the organic matter into the soil and producing waste products which help to cement the soil particles together into aggregates. The removal of vegetation as a result of overgrazing adversely affects exposed soil by causing an increase in soil temperature that can cause the humus of the topsoil to be consumed by oxidation. Therefore, management that helps establish permanent vegetation such as perennial grass helps improve the infiltration rate of the site.

Heavy grazing tends to remove palatable perennial grasses from the site. Therefore, if there is a shift in species composition from perennial grasses to annuals, there is likely to be less cover throughout the year. A decrease in above ground vegetation is also eventually mirrored by a decrease in root biomass. Roots help to hold the soil together and create avenues for rapid water movement into the soil. The combined result of all of these factors is a decreased infiltration rate which means an increased runoff rate and an increased erosion rate. If less water is entering the soil, and soil nutrients are carried off the site via runoff, it means that much less of these key components will be available to grow forage. Therefore, there will be less forage to feed livestock and therefore less milk, meat and profit for the pastoralist.

Aggregate bonds can be broken by anything that applies energy to the surface of the soil. Examples are trampling by livestock and operation of heavy vehicles. For this reason, compacted trails have little pore space and consequently have a low infiltration rate. This results in concentrated runoff which eventually can create gullies along trails. Another important energy impact is associated with falling raindrops. The removal of vegetation cover as a result of heavy grazing also removes the protection that cover provides to the soil in terms of dissipating the energy of raindrops before striking the soil. The impact of these activities breaks the bonds holding the aggregate together. Detached soil particles are then carried away by runoff to lodge in the remaining pores, thus making the pores smaller or clogging them up completely. This is one way in which **soil crusts** are formed. A "washed in" layer, where clay particles have clogged soil pores to form a crust, may reduce infiltration rate by as much as 90%. In such an instance, a productive 1000 mm/yr rainfall zone may produce forage in an amount typical of a 100 mm/yr desert (i.e. plants, of course, cannot use water that does not enter the soil and reach their roots). Besides substantially reducing the water entering the soil and increasing the risks of erosion, crusts can also be a severe barrier to seedling emergence, thus limiting the recuperative potential of vegetation cover.

If a crust is formed, churning it into a dust is not going to help infiltration because as soon as the soil becomes wet the pores will clog again. To effectively address a soil crusting problem, livestock grazing management must concentrate on addressing poor aggregate stability which is the cause of the crusting. Livestock grazing management systems that promote an increase in plant and litter cover and an increase in organic matter produce the only lasting effect in reducing soil crusts. Soil crusting is an important attribute used in the survey method for classification of degraded range condition (see Volume III.7 of the RMH).

Not all types of crusts are bad. Some types of crusts formed by lichens, moss, and algae play an important role in arid environments by stabilizing soils otherwise susceptible to wind erosion. These plants may make the surface of the soil appear blackish, grayish, pinkish, etc. and are known as **cryptogamic crusts**. The reduction of water infiltration associated with cryptogamic crusts may be offset by the benefits they provide in slowing runoff and evaporation, leading to a net water benefit. Cryptogamic crusts are prone to deterioration resulting from trampling or air pollution.

Another way degraded soils are manifest is when under special circumstances the soils become water repellent. Soils which repel water are called **hydrophobic**. On some sites degraded soils do not crust but instead become very "fluffy". The soils are fluffy because there are few effective aggregate bonds holding the fine soil particles together. The fine, fluffy texture of the soil actually repels water, causing raindrops to bead up on the surface and runoff. This is especially true on relatively recent, volcanic ash soils. Hydrophobic soils can also be formed if an intense fire consumes certain types of shrublands. When shrubs that have waxy or oily foliage burn, the waxes and oils in the leaves are volatilized. Most of these substances are consumed in the fire, but some move into the soil where they cool and coat the soil with a water repellent surface. Hydrophobic soils are thus very erosive and subject to flash-flooding.

Water Erosion

Water erosion is typically characterized by stages of progressive concentration of runoff. The first stage, **interrill erosion** (sometimes referred to as sheet erosion), combines the detachment of soil resulting from raindrop splash and its transport by a thin flow of water across the surface. This thin flow of water is highly turbulent as a result of raindrop impact and has a high erosive capacity. Extreme interrill erosion is evident when, for example, soil pedestals are formed by erosion around an area covered by a resistant material such as rock or plant. The fact that the surrounding material is eroded without undercutting the soil under the rock or plant illustrates that raindrop splash is the major erosive mechanism, rather than the surface flow.

Other indications of severe sheet erosion are the exposure of grass or shrub roots to the air, soil-stained grass leaves after a rain, and the accumulation of litter into little dams on the soil surface. See RMH Volume III.6&7 for pictorial examples of these erosion indicators. Therefore, even though no running water is observed, serious water erosion may have taken place. The fact that raindrop splash is the primary erosive agent illustrates the great advantage of maintaining vegetation cover that will reduce the impact of the falling raindrop upon the soil, making it less likely that soil particles will be detached. Intense storms at the beginning of the rainy season are potentially very serious erosion events if the plant and litter cover have been depleted during the dry season. If this is likely to be the case, special plantings of erosion resistant grasses and shrubs or construction of structures to retain or disperse the water may be desirable.

The amount of interrill erosion varies depending upon the type of grass that is providing cover. Bunchgrasses accumulate litter at the base of the bunch which provides an effective obstruction to overland flow. By slowing or diverting the course of overland flow, the energy of the runoff is reduced, resulting in decreased sediment transport capacity. Bunchgrass clumps which are mounded above the level of the surrounding soil indicate erosion. Grasses that grow as erect single stems or grow along the ground surface as single-stemmed runners, generally do not have the capacity to catch and hold sediment. Consequently, while runoff is typically related to the amount of cover, interrill erosion is more strongly related to the growth form of the cover. **Desert pavement** refers to a situation when the soil material is eroded away primarily by wind or interrill erosion, leaving behind a soil covered by small rocks (Volume II.1 plate II.17).

Rill erosion begins as the diffuse water movement causing interrill erosion to concentrate into discrete flow paths. Signs of rill erosion indicates that the land use pattern has negatively changed the natural equilibrium between soil and the environment. If signs of rill erosion are present, it is urgent that management action be taken to prevent runoff and erosion from getting completely out of control. **Gully erosion** is generally defined as the point when rills increase in size to the point they can no longer be driven across by a truck. In areas where severe gully erosion has occurred, a "**badland**" topography is formed which is characterized by many steep, deep gullies. **Streambank** erosion is defined as soil displaced from the banks of rivers or streams. See RMH Volume III.7 for pictorial examples of these different stages of erosion.

Wind Erosion

Wind erosion is usually confined to arid and semi-arid climates because the soil must be dry to be detached and transported by the wind. In Kenya, where annual rainfall is concentrated into part of the year, the remaining portion of the year is likely to be dry enough so that the soils are vulnerable to wind erosion. This situation may result in water erosion and wind erosion both being major problems in the same area. Some soil types are particularly susceptible to wind erosion (e.g., dry sands with poor soil structure and little cohesion cannot resist movement).

In general, the factors which affect the likelihood of wind erosion are the soil characteristics, the moisture content of the soil and the vegetation. Since wind erosion is restricted to dry soils, and the amount of erosion is dependent upon wind velocity, wind erosion control techniques are designed to lower the wind velocity at the soil surface during the dry season. This can be done by pursuing management practices that maintain as much dry season cover as possible. In areas of frequent human habitation, such as around villages and well sites, perennial woody species that will slow the wind and help to reclaim a site are planted to serve as windbreaks. Usually this can be accomplished by planting vegetation that will not only slow the wind but provide some useful product such as fuelwood.

Wind erosion and subsequent deposition is part of the natural equilibria in many regions of northern Kenya. An example of natural (geologic) wind erosion is the strong winds which blow across the arid Chalbi Desert and create sand dunes in the vicinity of North Horr at the western end of the desert. Man-induced (accelerated) wind erosion occurs around many of the villages or well sites in northern Kenya where the rangeland vegetation has been removed by heavy grazing and fuelwood harvesting.

Wind erosion, like gully erosion, is very much a case of prevention being better than the cure. The process of wind erosion is self-generating and, once started, becomes progressively more difficult to stop. It is especially difficult to establish plant seedlings on sites with active wind erosion because of the abrasion associated with the soil movement. The degree of erosion is an important attribute used in the classification of range condition. Refer to the following publications of the RMH for photographic examples of different types and degrees of soil erosion: A Survey Method for Classification of Range Condition (Vol III.7) and Pictorial Guidelines for Identifying the Type and Degree of Soil Erosion (Vol III.6).

Accelerated rates of runoff and erosion resulting in a gradual diminution or destruction of the biological potential of the land (i.e. **desertification**) is a growing problem throughout many semi-arid regions of the world. The threat that this trend poses to ecological stability and sustainable economic development has highlighted the need to develop sustainable resource management practices that are compatible with increasing human demands. Soil loss cannot be effectively restored through management since topsoil formation in semi-arid regions occurs at an extremely slow rate. Stopping the deterioration spiral is usually not economically viable on marginal lands; therefore, it is vital that management be sensitive to maintenance of the soil resource and hydrologic condition, so that the deterioration process is never initiated. These efforts form the foundation of sustained long-term productivity.

CHAPTER IV
CLIMATE

Climatic factors such as rainfall, temperature and radiation determine, to a large extent, the ecological potential and the resulting productivity of a region. Because Kenya is located near the equator, there is little seasonal variation in temperature and solar radiation. The reason most rangelands are used for grass production (which is converted by livestock into useful products for humans) is because they receive too little rain or the timing and amount of rain is too unreliable to produce substantive timber or grain yields. Because rainfall is usually the single most important variable influencing production, it is important to precisely understand the different ways rainfall statistics can be used to help a manager make informed decisions.

AVERAGE RAINFALL

One common way to analyse and present rainfall is to present data as the "average" amount of rain likely to fall within a season or year. Each district publication of the RMH (Volume II.1-9) includes a map showing MEDIAN ANNUAL RAINFALL and a series of maps showing MEDIAN SEASONAL RAINFALL for each district. This information is very important to a resource manager because it represents the middle point of rainfall that has occurred for the sample period and thus provides a reference for planning. There are several different ways to calculate "average" (Table IV.1, location #2). The decision regarding which method to use may have great implications with regard to how that information is used.

Mean

The most common usage of "average" refers to a mean. To calculate the mean, values are simply added together and divided by the total number of values (Table IV.2). It is only appropriate to use a mean when the data are normally distributed (i.e. when graphed, the data form a bell-shaped curve, as shown in Figure IV. 1). Annual precipitation at many sites on arid or semi-arid rangelands is often characterized by many years of low precipitation and a few years of high precipitation. In such cases, using the mean is inappropriate because it will give an "average" value that is going to be greater than the actual precipitation of most years. At Location #1, the mean would give a value which is too high 67% of the time.

Table IV.1: Three different results associated with different methods of calculating "average".

Year	Annual Precipitation (mm)	
	Location#1	Location#2
1	300	400
2	400	300
3	800	500
4	300	300
5	500	400
6	200	200
7	700	500
8	1000	600
9	300	400
MEAN	500	400
MEDIAN	400	400
MODE	300	400

Median

Median is determined as the mid-point of the data set. For the data introduced in Table IV.1, the method illustrating the selection of the mid-point years of the precipitation records are shown in Table IV.3. The median indicates that precipitation for half of the years will be equal to or greater than the median amount and for half of the years will be equal to or less than the median amount. The median is the most appropriate and useful expression of "average" for a manager because the annual rainfall data on most arid and semi-arid lands does not have a bell-shaped distribution. For this reason, the data is expressed as a median on the precipitation maps included in the RMH.

Table IV.2: Method for calculating the mean.

Year	Annual Precipitation (mm) Location#1	Location#2
1	300	400
2	400	300
3	800	500
4	300	300
5	500	400
6	200	200
7	700	500
8	1000	600
9	300	400
Total	4500	3600

4500mm/9yrs = 500mm/yr
3600mm/9yrs = 400mm/yr

Table IV.3: Method of calculating the median.

Year	Annual Precipitation (mm) Location#1	Year	Location#2
6	200	6	200
1	300	4	300
4	300	2	300
9	300	1	400
2	**400**	9	**400**
5	500	5	400
7	700	3	500
3	800	7	500
8	1000	8	600

Mode

The mode indicates which amount of precipitation occurred most frequently. For the data introduced in Table IV.1, the method illustrating the selection of most frequent precipitation amounts is shown in Table IV.4. Also see the section on Climatology in Volume I.2.

Table IV.4: Method for calculating the mode.

Location #1	Location #2
200 mm for 1 year	200 mm for 1 year
300 mm for 3 years	300 mm for 2 years
400 mm for 1 year	**400 mm for 3 years**
500 mm for 1 year	500 mm for 2 years
700 mm for 1 year	600 mm for 1 year
800 mm for 1 year	
1000 mm for 1 year	

STORM CHARACTERISTICS

Water molecules in the air begin to bond together when moisture-laden air is cooled. As this coalescence process continues and the microscopic droplets grow, they become visible; these are called clouds. If the microscopic droplets continue to bond together, the droplet eventually begins to weigh more than the air can support, resulting in the droplet falling as rain, or if cold enough, as snow or hail.

In Kenya, there are three common ways that air is cooled, thus causing clouds to form and eventually rain to fall. Each of these storm types have implications for managers.

Thermal Lifting

As the earth's surface heats during the day, the temperature of the air begins to increase. Warm air is lighter and thus begins to rise, carrying water vapour with it. As the altitude increases, the temperature of the air cools, causing the water molecules to coalesce and create rain. There are two general types of storms that are generated from thermal lifting.

Thunderstorms

Sometimes thermal lifting causes the rapid formation of isolated groups of tall, billowy clouds. Rain from these clouds tends to be intense and the storms tend to be isolated. This may result in one area receiving a large amount of rain in a brief, intense shower but a short distance away no rain falls at all. The rapid lifting of the air causes great turbulence as the clouds form, hence thunder and lightening are often associated with storms caused by thermal lifting. Regions that receive most of their precipitation in the form of thunderstorms are likely to have large variations in amount of rain and forage from one area to another because of the localized nature of the rain. One advantage of communal land ownership is that it gives the pastoralists the flexibility to move their livestock to where the rains (and subsequent forage growth) have occurred.

The intense nature of the thunderstorms increases the risk of runoff and erosion. Vegetation and litter cover must be managed carefully so that the cover can protect the soil when the intense rains occur. On extremely overgrazed land susceptible to thunderstorms, a centimetre of soil that may have taken 500 years to form may be lost in one hour of intense rainfall. The nutrients and water holding capacity of that soil is lost forever (at least from a societal perspective). The production potential of the land decreases each time a disaster like this occurs. Many areas of the world that were once fertile rangelands have been converted to deserts by this process. Building reservoirs in drainages to capture the runoff resulting from these intense storms can help improve the amount and distribution of water available for livestock. However, since the runoff from these storms often carries a lot of sediment, siltation problems may shorten the life of the reservoir.

Engineers must consider the type of storm when designing structures because the intense nature of thunderstorms can create flash-flood hazards. For example, culvert size is often larger in regions that get most of their precipitation as thunderstorms than in regions that receive the same amount of rain from ITCZ or orographic storms.

Intertropical Convergence Zone (ITCZ) Storms

Global atmospheric circulation patterns strongly influence the amount and distribution of precipitation. In the tropics, rainfall is especially linked to convergence of global wind patterns (which create the southeast and northeast monsoons in Kenya) and the convection currents generated by solar heating. Rainfall is associated with the zone where the winds converge and cause the air to rise in a broad band. The location where the global winds converge (ITCZ) moves north or south with the sun. The sun is at its farthest point north (23° 20'N) on about 21 June and its farthest point south (23° 20'S) on about 21 December. The sun must pass directly overhead all points in between these two extremes twice annually. This means that the ITCZ passes over Kenya twice a year. The time when the ITCZ passes over a particular location is complicated somewhat by yearly changes in the location and temperature of ocean currents and by surface features of the earth, such as mountain ranges, large land masses, etc.

The ITCZ passes over Kenya approximately in April and again in November. In April, the ITCZ is moving north, therefore the predominate winds are from the southeast. These winds often carry large amounts of moisture that was picked up over the Indian Ocean. Therefore, clouds readily form as the moist air rises over the warm land. The influx of moisture from the ocean causes the band of cloud formation associated with the ITCZ to be broader. Hence, the rainy period lasts longer than if moisture was less available. In November, the ITCZ is moving south, therefore the predominate winds are from the northeast. These winds often carry less moisture than the April-May monsoon because they pass over arid Somalia before reaching Kenya. Thus, the rain period generated from northeast winds is likely to be more variable, produce less rain, and cover a briefer period of the year than the rain period generated from the southeast winds. Unlike thunderstorms, the thermal lifting associated with the ITCZ produces broad bands of clouds. Rain therefore tends to occur over a large area and may last for several days at a time.

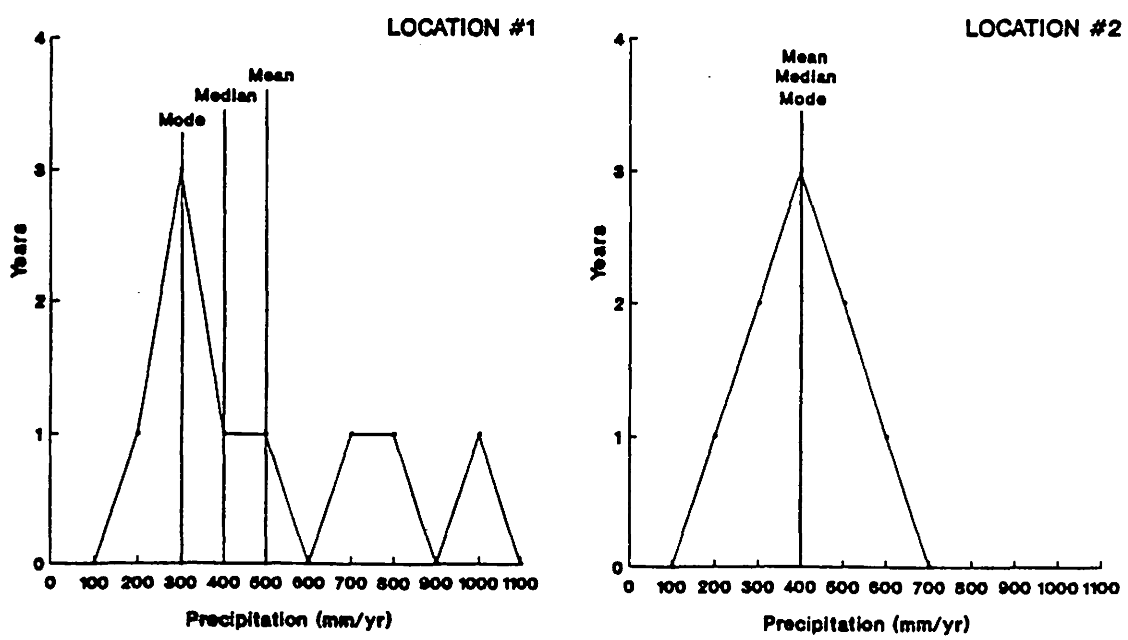


Figure IV.1. Mean, Median and Mode of annual preciptiation (mm) for two different locations.

Orographic Lifting

Orographic storms are associated with changes in topography. The air currents must rise when they strike a mountain. This causes the air to cool and form rain. In Marsabit District, for example, precipitation increases dramatically around Mount Marsabit, Mount Kulal and the Huri Hills. The side of the mountain the wind strikes first tends to receive more rain over a broader area than the leeward side of the mountain which may be quite arid at the lower elevations. The pattern of less rain falling on the leeward side of a mountain is known as a "rain shadow". Thus, the eastern side of Mount Marsabit gets more rain than the western side. Rain caused by orographic lifting tends to be slow and steady and is much more reliable than ITCZ storms and thunderstorms.

SEASONALITY OF RAINFALL

The distribution of rainfall is an important consideration when using precipitation data. Much of the precipitation in the tropics is seasonal for the reasons mentioned in the above discussion of the ITCZ. Therefore, some periods of the year may have ample precipitation whereas other times of the year rainfall may be rare. This seasonality of precipitation creates great challenges for land managers. If the rainfall distribution is bimodal (i.e. two rainy seasons), the rangeland production potential is much higher than in areas where an equal amount of rain falls during one long rainy season only. This is because there will be a period of growth accompanying each of the rainy seasons that will produce nutritious forage for livestock, and the dry seasons will be shorter. In contrast, many regions of subsaharan Africa have only one rainy season (rains last about four months, followed by a dry season that lasts eight months) or one reliable rainy season and one very unreliable rain season (e.g., the November rains are very unreliable in northwest Kenya). In this case, rangeland production potential is less because livestock must subsist for long periods on dry and decomposing forage. As human population densities increase, people will often try to grow crops in regions which receive one long rainy season. This is a very risky strategy in Africa because of the erratic year to year variation in total amount. The chance for failure of a grain crop in such regions is relatively high, while native grasses can be produced with a fair amount of reliability.

The maps of the median precipitation for each of the rainy seasons can be used to help the manager plan for the characteristic seasonality of precipitation. The normal times that rainy seasons are expected to occur can also be obtained from figures showing average start and end of the rainy seasons in the climatology report in the RMH Volume II.10. Such information is important when anticipating the pattern of annual production for the area. This can influence decisions regarding the livestock breeds selected, types of range plants used in re-seeding operations, types of crops recommended for agriculture, etc.

RELIABILITY OF RAINFALL

The above discussion has dealt with the annual amount and distribution of rainfall within the year. The annual and seasonal values provided on the rainfall maps are derived from information collected at weather stations located throughout the districts. Unfortunately, long-term weather records are often not available for large areas of Kenya rangelands. This has forced the scientists who drew the maps to make educated guesses of rainfall patterns for the areas far removed from rain gauges.

Understanding the reliability of rain is extremely important because it allows the manager to factor in the risk associated with these data. As already discussed, by knowing the median, the manager knows that over the long-term, half of the time more rain will fall and half of the time less rain will fall. However, this information does not help the manager in anticipating the spread of possibilities on either side of the median. The risk of this spread is illustrated in **Table IV.5.**

Table IV.5: A simple way of calculating rainfall reliability.

Year	Annual Precipitation (mm)	
	Location #3	Location #4
6	390	560
2	450	600
7	510	610
9	520*	620*
3	630	630
1	640	640
4	690	650
8	860	660
5	980	700
Median	630	630
Mean	630	630
66% Reliability	520*	620*

At Location #3 rainfall is very erratic, whereas at location #4 rainfall is very reliable. As the erratic nature of precipitation increases, the risk of not getting the amount of rain you need for a particular management action is increased. For example, Rhodes grass (*Chloris gayana*) grows best if it receives at least 600 mm/yr. At location #3 at least 600 mm/yr occurred only 56% of the time (5 ÷ 9 = 56%) but at location #4 at least 600 mm/yr occurred 89% of the time (8 ÷ 9 = 89%). The RMH includes maps which show the 66% reliability of rainfall for the first or second growing season. *This 66% reliability number should not be* interpreted to mean that the rainfall will equal or exceed the amount 2 out of every 3 years; rather it should be interpreted to mean that in any particular year the amount will have a 66% chance of being equalled or *exceeded.* This is a subtle but important difference. For example, when a coin is flipped there is a 50% chance that it will come up heads and a 50% chance it will come up tails. If your coin lands as heads 5 times in a row, what is the likelihood of the next flip being heads? 50%. Each flip has a 50% chance regardless of what came before. Likewise, each year has a 66% chance of receiving at least the rainfall amount indicated on the map, regardless of what came before. Over the long-term, this probability would yield an expected result of 66% of the years (e.g., 20 out of 30 years) receiving precipitation at or above the listed figure.

It is true that there tends to be periodic wet or dry cycles that last for several years. These periods are related to variations in global air circulation patterns which are not well understood. Therefore, since these types of cycles cannot be predicted, the probability calculations described above are the best we can do for now. These maps should therefore be used with an understanding of how they were developed. The rainfall probability maps provide information that can help planners assess risk; the planner must understand that risk assessment is different from rainfall forecasting, which these maps do not do. Even though the timing of a dry cycle cannot be predicted, the fact that dry cycles will occur is a certainty! The probability of an extended dry cycle is discussed latter in this chapter.

For the two sites in **Table IV.5**, location #3 has a 66% reliability of getting at least 520 mm/yr and location #4 has a 66% reliability of getting at least 620 mm/year. The RMH maps would therefore tell the manager that at location #3, the Rhodes grass plantation would receive optimal rainfall for less than 66% of the time, but location #4 would receive optimal rainfall more than 66% of the time. This might indicate to the manager that he would be well advised to seed the pasture at location #3 with another forage species such as Masai love grass (*Eragrostis superba*) which can do well at locations which receive 500 mm/yr.

The names of the months on the rainfall reliability maps of Marsabit District (Volume II.1) and in the text of Volume II.10 for the other districts indicate when most of the rains are likely to occur within a season. This information can be used in several ways. Sometimes the seasonal rains begin early and managers wonder whether the early rains are likely to continue. If the first rains occur significantly earlier than the dates on the map, there is a good chance that a dry period may resume prior to the onset of the other rains within the season. Thus, if you begin planting seed at the onset of these early rains, there is a good chance that the seeds will germinate and then die because the rains have not continued. Planting during the time listed on the map provides the best chance that the rains will be reliable enough to enable seedling establishment.

Another way to use the dates is to begin to implement a drought management plan (such as selling off some livestock). **Drought** is a vague term that can mean different things to different people. Part of the term's emphasis is on an unusual lack of precipitation and part of the emphasis is on the resultant decreased forage/crop production. A definition which combines both considerations identifies a drought as a shortage of rainfall such that production from the land use under consideration is reduced below what can be expected on average. There has often been indecision and/or inaction on the part of managers and policy makers regarding drought because it is hard to define. Disagreement as to when a drought has occurred, when it began or when it ended is common. Part of the confusion is that "water shortage" is a relative term depending upon a variety of factors other than amount of rainfall. For instance, factors such as expectation influence the size of the shortage relative to the planned use.

Long-term rainfall patterns are naturally erratic on many rangelands throughout the world. Therefore, wise management must consider climatic variability and have some built-in ability to cope with normal fluctuations resulting in below average rainfall availability. Using this reasoning, a manager would consider a drought to be a water shortage that overwhelms his contingency plans for dealing with a dry period (see Volume II.10 to learn how to calculate what constitutes a "meteorological" drought). Decisions regarding livestock species selection, stocking rate, etc. depend on the expectation of rainfall availability (e.g., stocking rate and kind/class of animal are decisions that consider the amount of forage likely to be produced by expected rainfall). The perception and consequences of drought are based on these production decisions (e.g., a heavily stocked range shows signs of drought stress before a moderately stocked pasture; a cattle herd shows the effects of drought before a camel herd, etc.).

By using the rainfall reliability maps, a manager can get some feeling for what is normal (i.e. how much rain is likely to occur at least 66% of the time). The manager can also know that if it has still not begun to rain well into the time period outlined on the map or as shown in Volume II.10, it is increasingly unlikely that the median rainfall will occur during that season. Under such conditions, implementing a drought management plan early enough will protect the range condition and will allow the livestock owner to benefit from early action (i.e. selling while the price is still relatively high rather than waiting until all the forage is gone and livestock prices have crashed).

The information included on the RMH maps illustrating the *66% RELIABILITY OF RAINFALL* should be considered in conjunction with the information on the RMH maps entitled *66% RELIABILITY OF THE LENGTH OF THE GROWING SEASON* which show the length (in terms of 10-day periods) that the growing season is likely to last. The length of the growing season integrates not only precipitation amount and distribution, but also takes into account other important climatic factors such as the temperature, wind and humidity which combine to determine the rate of evaporation as well as the ability of soils to store water useable by vegetation. The variation in the median length of the growing season or the median amount of precipitation becomes more critical when considering application of these data in arid regions.

For example, a 20% shortfall in the length of the growing season or amount of rainfall will still result in a fair amount of production in an area that normally receives 1000 mm/yr, such as on Mount Marsabit. A 20% shortfall in an area that receives only 200 mm/yr may mean that many forage plants may not even break dormancy. The margin between survival and disaster becomes sharper as the livestock and human populations increase; as the reserve capacity of the system is pushed to the maximum, the inhabitants become more and more vulnerable to downside variation in precipitation. For this reason, areas in subsaharan Africa which were able to sustain a prolonged drought with little livestock and human mortality a century ago now have livestock dying and people starving if the rains are only delayed several weeks beyond normal.

The RMH also includes information regarding the longest period without significant rainfall over a 30 year period (RMH map entitled *PRODUCTION RISK DUE TO LACKING RAINFALL*). This information is useful when devising drought management strategies and when assessing risk of a particular enterprise. For example, the amount of food that should be stored in emergency reserves should consider the period of time a serious dry period is likely to last. The length of the dry period is also important when selecting which types of enterprises will be viable over the long-term. For example, a dairy cow operation is likely to end in disaster if it is located in an area that has a history of long dry periods. In such areas, camel or goat production would perhaps be more practical and secure over the long-term. Another example is an area with a history of 8-11 months with no significant rain in a 30-year period that is being used to grow crops. A young 20-year old farmer living in the area should be made aware that if he expects to survive to 50-years old, he should always have enough cash or food reserves to feed himself and his family for at least a period of that length (i.e. 8-11 months).

ECO-CLIMATIC ZONES

Because eco-climatic zones combine both rainfall and temperature they are much better indicators of land use potential than rainfall maps alone. The sub-zones are subdivisions of those eco-climatic zones with potential for grazing based on the length of the grass growing season. The amount, distribution, and reliability of rainfall affects key ecological properties, such as the length and certainty of the growing season and the likely production potential for the area over the long-term. These precipitation characteristics, combined with some consideration of temperature, are used to formulate the RMH map entitled *ECO-CLIMATIC ZONES* (see Volume II.1 and Volume II.10). By considering the median number of days in the growth period, or alternately, the number of periods per year with poor growing conditions for grass (i.e. the period when there is not sufficient soil moisture to allow the plant to grow) the manager will get some insight into how the range is likely to be used. If the period with poor growing conditions is long, it is likely that forage will be a severe limiting factor and will likely force a short period of use by livestock. The growing season is defined in the context of grass growth because grass is the primary forage for most livestock (which is the primary use of most rangeland). The shrub growing period is usually longer than grass because shrubs are often able to access deeper soil water with their more extensive root system.

The mix of climatic considerations discussed above combine to affect the plant ecology, animal ecology and human ecology of the area. Using the *ECO-CLIMATIC ZONE* map in conjunction with the RMH information on traditional pastoral land use strategies may help develop an insight into why these traditional strategies developed. This indigenous knowledge of the pastoralists should not be ignored when formulating land use plans for the region. Often, the pastoralist will not be able to clearly explain the rationale for what they do, simply stating that this is the way it has always been done. In risky production environments, pastoralists are justifiably very cautious about changing the way they have used the land. The precipitation amount and reliability maps in general, and the *ECO-CLIMATIC ZONE* map in particular, may help the manager to understand current use practices and thus allow the manager to build upon the strong points of the existing system as new development opportunities occur. The *ECO-CLIMATIC ZONE* map also provides insight necessary to help understand the relationship between these factors and the occurrence of vegetation types shown on the RMH *VEGETATION* map. The vegetation types do not exactly match the eco-climatic zones because soil is also an important factor to consider. By simultaneously considering the information on the RMH *RATED LEVELS OF PRODUCTIVE CAPACITY* (Volume II.1) or *MINERAL RICHNESS* (Volume II.2-9) map (which is based on soil characteristics alone) and the *VEGETATION* and *ECO-CLIMATIC ZONE* maps, an experienced manager will be able to formulate a rough expectation of site potential, which is an important step in being able to determine range condition (see CHAPTER VI).

The fact that many of the rangelands in Kenya have very short and unpredictable grass growing conditions is a primary reason why communal grazing is common in the region. With communal access, pastoralists have the flexibility to move their livestock to take advantage of the short growing conditions that result from thunderstorms which are erratic in space and time. This flexibility allows the sustainable carrying capacity of the rangeland to be much greater than if movement was restricted.

Another option, more commonly used in the U.S. and Australia, is to form private ranches that are large enough to allow flexibility of livestock movement within a single ranch. The viability of ranch size is based to some extent on the area of land needed to ensure a high probability that rain will fall somewhere on the land and provide sufficient forage. Optimal ranch size increases as the erratic nature of precipitation increases. For example, in a 1000 mm zone, viable ranches may average 1,000 ha in size while in a 300 mm zone, viable ranches may average 100,000 ha in size. In countries with a large pastoral population, modern privatized ranching may require a substantial reduction in the existing population making their living as pastoralists. For example, Jahnke (1982) estimated that if the land use in Somalia was re-organized in the form of modern ranching, the pastoral population would have to be educed by a factor of 50. Such an approach in many regions of subsaharan Africa is currently unfeasible since unemployment in the cities is already chronically high. Creation of private ranches that are too small to accommodate the need for flexibility imposed by erratic rainfall is likely to result in a production disaster when an inevitable dry period occurs.

CHAPTER V
VEGETATION TYPES AND RANGE UNIT INVENTORY

Physiognomic description is a classification of the form and structure of plant communities. This description should help anyone familiar with the classification criteria to visualize a site with specific attributes, thereby aiding communication between range professionals. A descriptive physiognomic approach is used because regions which have similar environmental conditions often have climax plant communities that have the same physiognomy. There are many different criteria scientists use to classify physiognomy. The procedure used in the RMH is the classification system developed for East Africa (Pratt and Gwynne 1977). The attributes of the physiognomic classes are described in the VEGETATION TYPES chapter of the RMH district descriptions (Volume II. 1-9). These attributes are outlined below:

Forest: Most trees are 7-40 m or taller with the crowns often interlocking. Evergreen forests are characterized by individual trees that may shed leaves, but the canopy as a whole remains green throughout the year (e.g., composed of trees such as *Olea africana*). Deciduous forests are characterized by trees that lose their leaves during the dry season (e.g., *Acacia* and *Combretum* spp.).

Woodland: Most trees are approximately 20 m in height. Crowns usually do not touch, but canopy cover is over 20%. There is usually a well-developed herbaceous and/or dwarf shrub understorey. Riparian woodlands occur along seasonal or permanent watercourses.

Bushland: Bushlands consist of woody plants which often have multiple stems, most of which grow to not more than 10 m. Crowns are often interlocking and canopy cover is over 20%. Trees are scattered but conspicuous. The herbaceous understorey is usually sparse.

Shrubland: Shrubland consists of woody plants about 6 m tall without a significant presence of trees. Canopy cover is more than 20%. The herbaceous understorey is usually sparse.

Dwarf Shrub Grassland: Woody plants less than 0.7 m tall dominate this plant community and compose over 2% of total cover.

Bush Grassland: Bush grassland consists of grassland with scattered trees and shrubs having a combined canopy cover less than 20%.

Shrub Grassland: Shrub grasslands are grasslands with scattered shrubs which have a canopy cover less than 20%.

Grassland: Grasses or sedges dominate these communities. Woody plants are either lacking or are dwarfed and inconspicuous. Woody plants compose less than 2% of the canopy cover.

Barrenland: Vegetation is quite sparse and frequently occurs in strips.

Pictures of the common physiognomic vegetation types within each district are included in the RMH Volume II publications. **Figure V.I** shows a schematic appearance of some of the various vegetation type strata.

The primary components of the physiognomic characterization procedure are growth form and vegetation cover. These two characteristics are useful to managers because both cover and growth form change along environmental gradients in a relatively understandable and predictable fashion. **Growth form** is a description of a plant based on a number of plant characteristics, such as height, stem form, leaf characteristics, whether it is woody or herbaceous (non-woody), etc. Some examples of growth form descriptors include grass (annual/perennial), dwarf shrub, shrub or tree. The vegetation cover classes used in the RMH classification

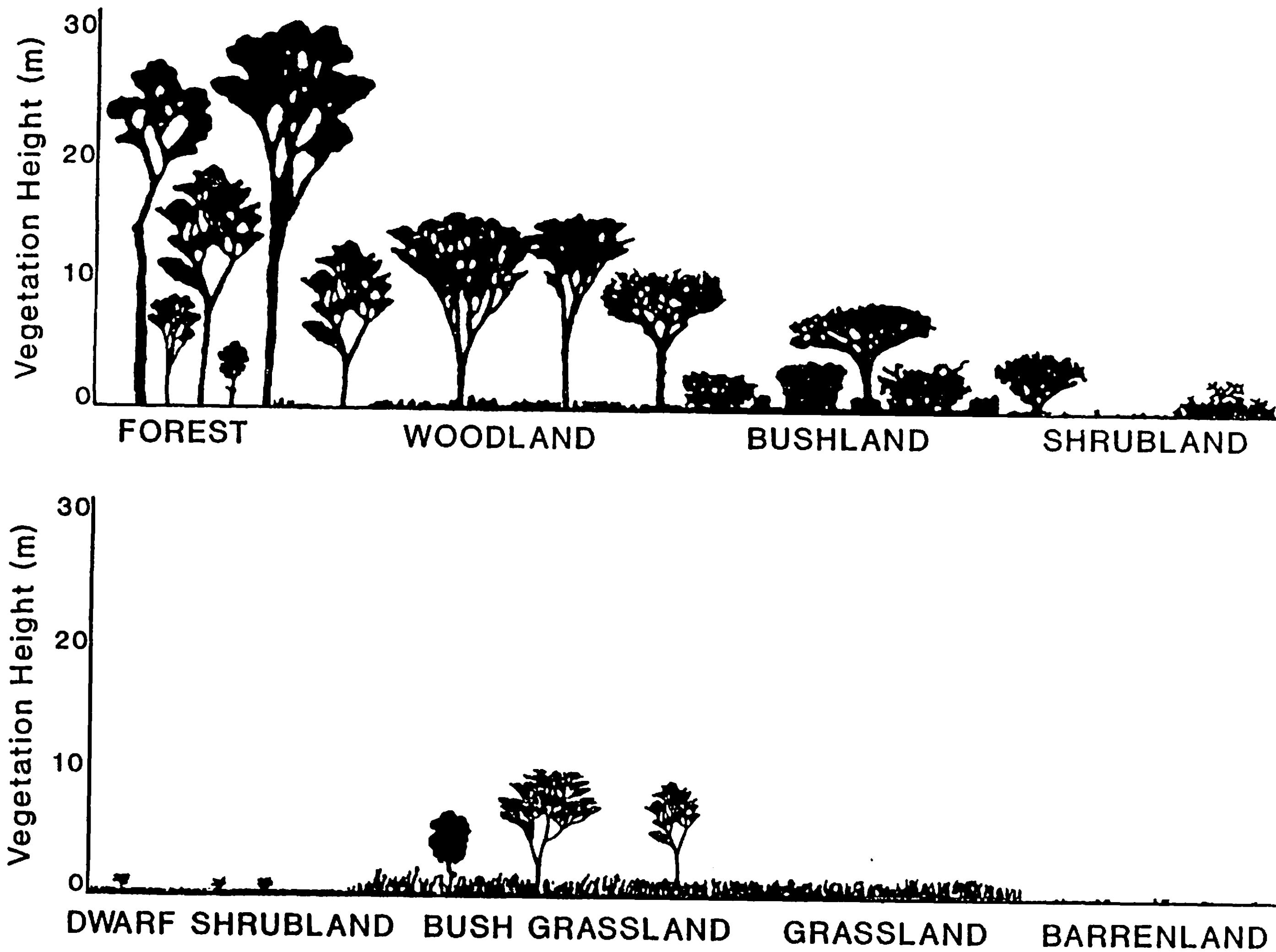


Figure V.1. Schematic representation of the physiognomic vegetation types typical of Kenya.

system are 0-2%, 2-20%, 20-70%, and >70%.

One problem in using cover classes is that many individuals find it difficult to accurately estimate the canopy cover of rangeland communities. The angle gauge (**Figure V.IIa**) is a useful tool to help standardize these estimates. An angle gauge is very simple to construct, but it is important that the length of the long piece be five times greater than the length of the short piece. To use the gauge, a person should select a representative location within the plant community. Hold the gauge with the short cross piece away from your eye and the long piece parallel to the ground. Count the number of shrubs that meet the conditions illustrated in **Figure V.IIb** as you rotate in a circle (360°). Tally the number of times these conditions were met and that will indicate the canopy cover. This procedure is based on geometric principles. Refer to a text on vegetation measurement procedures (for example, Bonham 1989) to get more information regarding the theory behind this procedure.

Physiognomically defined classes of vegetation are referred to in the RMH as **vegetation types**. The distribution of the vegetation types are illustrated on the *VEGETATION* map included in each of the RMH district publications. They are the coloured units on the maps. Within each physiognomic vegetation type are numbers that are associated with specific physiognomic and compositional features. These numbers are defined in the map legend and in the corresponding RMH text and are identified by the names of the dominant species. They are expressions of prevalent adaptations of the mix of species which compose the community. For example, there are four types of bush grassland subdivisions identified in Wajir District (Volume II.3): a *Sporobolus-Cordia-Acacia* spp. bush grassland (vegetation type #15.1), a *Sporobolus-Chrysopogon-Acacia reficiens* bush grassland (vegetation type #15.2), a *Tetrapogon-Sericocomopis-Cordia-Commiphora* bush grassland (vegetation type #16.1), and an *Aristida-Acacia seyal* bush grassland (vegetation type # 16.2).

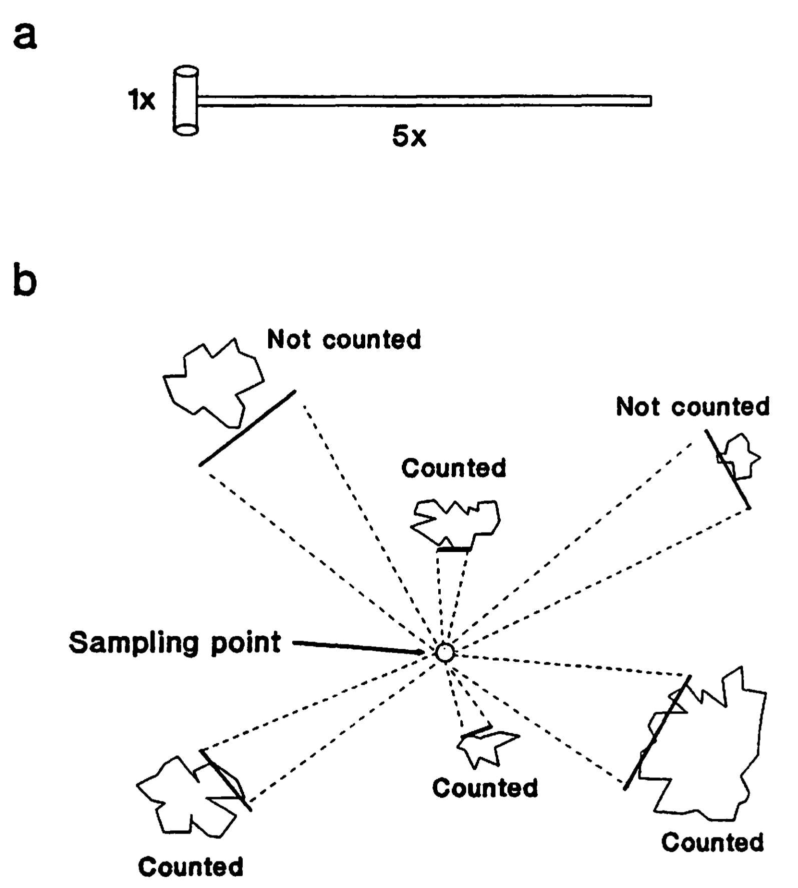


Figure V.2. The top illustration (a) depicts an angle gauge used to estimate canopy cover. The bottom figure (b) shows how plant canopies are counted using the angle gauge (Bonham 1989).

Identifying these subdivisions by the names of the dominant species helps an experienced range ecologist to form a more clear understanding of the site. The name of the vegetation type indicates both its physical structure and relative species dominance. In the case of the *Sporobolus-Cordia-Acacia* spp. bush grassland, the vegetation type is primarily a perennial grassland dominated by one or more *Sporobolus* species but which also includes one or more *Cordia* shrub species and two or more *Acacia* species which may be either shrubs or trees. If all are shrubs then there is at least one tree species present which changes the physical appearance of the vegetation type enough to justify use of the term "bush" rather than "shrub". The total canopy cover of shrubs and trees in this vegetation type is between 2 and 20%.

The physiognomy of a plant community is an integrated reflection of a wide range of climate, soil and land use characteristics. Therefore, many inferences about a variety of environmental factors can often be made from the nature of vegetation types. For example, forests indicate there is a large amount of moisture available. Annual grasslands indicate that the availability of moisture is low and probably erratic. If the physiognomic type occupies a large area, this probably reflects the prevailing climate. Vegetation types which occupy relatively small areas reflect a special local condition. For example, slender long bands of woodland or forest often indicate moist soils along a drainage. Small forest or woodland pockets may also indicate tops of a mountain (e.g., Mount Marsabit, Ndoto Mountains) where greater amounts of rainfall are generated by orographic storms (see CHAPTER IV). Usually, there will be concentric rings of vegetation around a mountain associated with different elevations. These patterns correspond to increases in precipitation as elevation increases (a result of orographic storms) and lower amounts of evaporation and transpiration associated with the cooler temperatures of increased elevation. Small vegetation type pockets may also indicate the influence of special soil conditions (e.g., saline, poorly drained, extremely rocky).

The growth form and canopy cover characteristics and the mapped location of physiognomic vegetation types can convey important clues regarding a wide range of management considerations likely to be associated with each site. There are many examples of how vegetation type information can be used to gain very specific insights:

- Vegetation dominated by *Jatropa*, *Calatropis* and *Cassia* shrub species are indicators of heavy grazing and fuelwood harvest pressure.

- *Aristida-Acacia seyal* bush grassland mentioned above is usually associated with poorly drained, heavy clay soils. The poorly drained soils imply that the site may be periodically inundated with water. These soils are also very sticky, which means there will be severe limitations to livestock or vehicle movement during the wet season. This type of species composition usually represents a steady-state climax because *Acacia seyal* is especially adapted to living on heavy clay soils that are inundated with water for short periods of the year but dry for long periods. The annual grasses, such as *Aristida* spp., are often associated with *Acacia seyal* for the same reasons. Since the grasses are annuals, they will grow quickly when the rain begins and die quickly when the rains stop. Therefore, nutritious herbaceous forage will only be available for a short time, a time when the area is difficult to enter because of soil conditions. These considerations make the *Aristida-Acacia seyal* bush grassland logistically difficult to utilize effectively, requiring a very flexible grazing strategy. Range improvement methods are unlikely to make the site substantially better; scarce financial resources would be put to better use in a different vegetation type.

- *Acacia elatior* bushland is a useful indicator of shallow groundwater in northern Kenya.

- Sites dominated by *Acacia reficiens* (a shrub with low palatability) are typically poorer habitat for livestock than sites dominated by *Cordia* spp. or *Grewia* spp. shrubs which are substantially more palatable. Grass cover under *Acacia reficiens* is also typically low to non-existent and the erosion hazard is high.

- In areas (such as Marsabit District) the dwarf shrub species *Indigofera spinosa* and *Duosperma eremophilum* both occur as dominant species. Sites dominated by *Indigofera spinosa* provide excellent quality browse. The presence of this species is an indication that the soils are likely to be coarse, sandy and well-drained. Such sites dry out quickly. Sites dominated by *Duosperma eremophilum* usually have silty or clay soils that hold moisture well into the dry season. The browse remains green longer into the dry season but is less palatable than *Indigofera spinosa*.

- A vegetation type dominated by a single woody species is less likely to be good camel habitat than one with several co-dominants (which indicates the likelihood of a diverse mix of potential browse species).

- A vegetation type that supports a mix of vegetation/wildlife habitats will likely be attractive for tourists.

The above examples demonstrate how an experienced ecologist can utilize a vegetation map. Range professionals should constantly be observing the environment in which they work to learn about these relationships. Much can be learned from the pastoralists who often have a keen knowledge about plant/soil/climate/land use relationships. This information, combined with a formal education, provides a better understanding of why the relationships exist and can help the range professional deduce and infer much about the opportunities and constraints associated with management of that resource.

The information included on the *VEGETATION* map and the *LANDFORMS AND SOILS* map, and to a lesser extent *CLIMATIC ZONES* maps, were used as the primary basis for delineating range units identified in the RMH. A **range unit** is an arbitrary planning designation used to define an area that is a meaningful management unit. It is a way to break up a district into smaller areas that are more convenient to use for land evaluation and resource management planning. The size and criteria used to identify a meaningful management unit varies depending upon the objectives and the resources of the project. In some cases, a range unit may already be in use as an administrative unit due to its association with an existing settlement. In one way or another, because of its particular mix of location, topography, climate, soils and vegetation, each range unit has some unique characteristic or potential significance to the resource manager. The area included in a range unit varies from about 1,000 km^2 to 10,000 km^2. In most cases, recognizable topographic features such as a hill range or a watercourse were chosen as boundaries.

The intent of the range unit classification shown on the RMH *RANGE UNITS* map was to group regional characteristics in a way that would highlight specific considerations regarding rangeland livestock production (e.g., the maximum stocking density and optimal number of grazing days, based on vegetation production potential and rainfall). However, the application of range units is not solely restricted to range management. For example, range units dominated by rugged topography or extensive areas of heavy clay soils indicate areas that preclude road construction or well drilling.

The range unit inventory section of the district reports (Volume II.1-9) summarizes the important environmental, ecological and management attributes of each range unit within the district. This information can be used to give the range manager some insight into the production potential and probable management constraints for each range unit. Details regarding how forage production and recommended stocking density were calculated are included in the presentation of this information in each RMH district publication. These same principles could be applied for calculating recommended stocking density if you choose to make a different type of range unit based on other considerations better suited to your needs. For example, the range units in the RMH do not consider the information included in the *TRADITIONAL PASTORALISTS: CULTURE AND LAND USE STRATEGIES* section. Traditional livestock migration routes or traditional clan/tribal controlled grazing areas may be a rational way to construct range units when tailoring a project designed to work with particular pastoralist groups. This might best be done by combining existing range units into larger units.

CHAPTER VI
RANGE CONDITION

Range condition is a classification of the current condition of a range site relative to the potential condition of the range site. A **range site** is "a distinctive kind of rangeland, which in the absence of abnormal disturbance and physical site deterioration, has the potential to support a native plant community typified by an association of species different from that of other sites. This differentiation is based upon significant differences in kind or proportion of species, or total productivity" (Society for Range Management 1974). RMH users can identify range sites by overlaying the RMH *VEGETATION TYPES* map and the RMH *LANDFORMS AND SOILS* map to identify the unique, relatively homogeneous vegetation/soil associations within a district.

Essentially, range condition is a broad description of the state of health of the range site. Observations regarding vegetation composition and soil degradation are the primary criteria used to determine range condition. Volume III.7 of the RMH discusses the survey methods used to classify range condition. Range condition is an important piece of information for a manager because it gives an indication of what type of vegetation the site is capable of supporting relative to what it is currently supporting. A site rated in "good" condition indicates that the site is supporting what it is capable of supporting. A site rated in "poor" condition indicates that the vegetation community and soil has somehow been harmed and is not supporting what it is capable of supporting. This is especially the case with regard to the range condition classes shown in Volume II.1-9 or when the RMH range condition is related to forage and livestock productivity.

Range condition alone conveys only part of the information needed by a manager. For example, if a site is rated in fair condition a manager would naturally find it useful to know if it has been recovering from poor condition, if it has been deteriorating from good condition, or if it is maintaining about the same status. The subsequent management decisions by the manager would likely be quite different in each of these three cases. **Range trend** is a descriptive term which indicates whether the site is improving or getting worse relative to its potential (i.e. the direction of change in range condition). Range trend is determined by studying the change in status of the soil and vegetation indicators measured in range condition surveys. Changes in aspects such as vigour and plant reproduction are particularly important indicators of trend. Range trend is therefore a useful tool to assess the long-term effect of management programs.

VEGETATION CHARACTERISTICS

A key premise in determining the potential condition of a site is based upon the theory that vegetation is a product of the environment. The composition of the plant community and the characteristics of the species are dependent on a host of environmental parameters (e.g., climate, soil, grazing animals "naturally" present, fire frequency). In Africa, light to moderate livestock grazing is part of the "natural" environmental characteristics. Under these "natural" conditions, the plant species best adapted to utilizing the resources of a specific range site would dominate that range site. The species composition of the plant population under these conditions would be used to define the **range site potential**.

The concept of range site potential is an important consideration when using the range condition information presented in the RMH. It is important to understand that *range sites with high production potential that are characterized as being in poor condition may actually be more productive than range sites with low production potential that are characterized as being in good condition.* Remember that range condition is a ranking relative to the potential of that particular range site. It is therefore not uncommon that some of the areas marked on maps as good condition are in lightly used deserts characterized by very low productivity. They are rated in good condition because they are in as good of shape as they are ever likely to be. Some of the areas marked on maps as poor condition are on very productive, heavily used lands. They are rated in poor condition because under different management they could support different and even more productive vegetation. The information provided in the range condition classification is therefore a useful management tool only if it is used in conjunction with data that will provide clues regarding range site potential, such as information on soil and climate.

As land use pressure increases, the density and composition of the plant species will change to types that can better cope with the disturbance. In the case of overgrazing, species that have some resistance to grazing are likely to replace species that do not. There are many plant adaptations to resist grazing. For example, the point of growth initiation for bunchgrasses is above ground and thus can be more easily harmed by heavy grazing than sodgrass species which have a creeping growth form with the point of growth initiation at or under the soil surface. Thus, sodgrasses tend to dominate under heavy grazing. However, in the absence of heavy grazing pressure the bunchgrass growth form will overtop the sodgrass and out-compete it for light.

Another growth form adaptation to cope with heavy grazing pressure or erratic climate is a short life cycle during which the plant grows very quickly for a brief period, produces seed and then dies. This enables the plant to avoid the stress of trying to stay alive while being grazed during the dry season. In contrast, bunchgrasses live for many years and develop extensive root systems which enable them to have better access to water and nutrients. This gives them a competitive advantage if they can maintain their leaf structure, but they usually cannot do so under intense grazing pressure. For this reason the shift from bunchgrasses to sodgrasses to annuals is usually an indication of deteriorating range condition. There are varying degrees of palatability among species with a particular growth form. Since herbivores tend to put the most grazing pressure on palatable species the shift from palatable to less palatable/unpalatable is also an indication of deteriorating range condition. Combining these two sequences, palatable bunchgrasses are usually among the first species to be lost from a plant community subjected to heavy grazing. At the other extreme, unpalatable annuals are usually the most hearty survivors associated with heavy grazing.

The Barsalinga-Wamba-Barsaloi area of Samburu District is an example of a marked shift in the composition of the herbaceous community as a result of heavy grazing pressure. This area was once very productive rangeland with the plant community being dominated by *Chrysopogon plumulosus*, a perennial bunchgrass. Due to long-term overgrazing, perennial bunchgrasses have disappeared and annual grasses, forbs and bare soil dominate the landscape. Perennial bunchgrasses remain the dominant type of grass on many of Kenya's semi-arid rangelands when grazing pressure has been limited for some reason (e.g., poor security (as along the border with Uganda and southern Sudan in Turkana District), lack of permanent water (southeastern Wajir District), sound management (as on some private ranches in Laikipia District)).

In addition to causing shifts in growth form, plants which have a survival advantage under heavy grazing pressure are likely to have mechanical deterrents to grazing (e.g., thorns (the dwarf shrub *Indigofera spinosa*), sharp seeds (*Aristida* spp.), waxy leaves, tough leaves (containing large amounts of silica such as *Eleusine jaegeii*, a highland bunchgrass) or biochemical deterrents (e.g., compounds which make the plant poisonous, difficult to digest, or taste bad, such as the bunchgrass *Cymbopogon* spp. or the dwarf shrub *Duosperma* spp.)). Producing these defense mechanisms costs the plant energy, therefore they are often at a competitive disadvantage with plants that do not have these defenses if there is light grazing, but they are at a competitive advantage if grazing is heavy. For this reason, if a large number of plants in a particular area bear these defense mechanisms, it is usually an indication of deteriorated range condition. This same reasoning applies to defense mechanisms in shrubs. Palatable shrubs such as some *Grewia* spp. may show signs of heavy browsing (hedging) and eventually die out, to be replaced by shrub species that are endowed with more defense mechanisms, thus making them less palatable. For example, the palatable grass and shrub species around heavily grazed well sites (e.g., Korr in Marsabit District or Wajir Town in Wajir District), are typically replaced by unpalatable species, such as *Jatropa* spp..

In savanna regions where fire is an important component of the ecosystem, woody plants have difficulty establishing if the savanna grassland is in good condition. Woody plant seedlings must compete with the established grass for light and water, thus many of the seedlings die. Most of the remaining seedlings that have managed to become established are killed in periodic fires. Overgrazing may result in woody encroachment because the seedlings of some of the invading woody species are not very palatable compared to grass, thus the grass is eaten and the seedlings are left behind. The heavy grazing also removes much of the grass biomass which makes it more difficult for a hot fire to burn through the area and kill the shrub seedlings. When the shrub seedlings have grown above the grass height, they shade out grass species and have developed an extensive root system which gives them a competitive advantage for procuring water and nutrients. For this reason, encroachment of unpalatable woody plants in what once was a stable open savanna is considered an indication of deteriorating range condition (e.g., much of Baringo District or central Samburu District). However, this particular criteria was not used to determine the range condition patterns shown in Volume II of the range management handbook.

The long history of livestock grazing on many of Kenya's rangelands has resulted in plant communities evolving which are in equilibrium with the use. There are several examples of rangeland productivity deteriorating following cessation or significant reduction of use of an area by pastoralists. For example, the relatively low palatable shrub/small tree *Acacia reficiens* now dominates extensive areas in low-lying sites of West Pokot District; *Acacia reficiens* and *Commiphora* spp. dominate parts of northern Isiolo and eastern Samburu Districts. The banditry associated with these areas in the 1980's resulted in a significant reduction of normal pastoral use for several years. This reduced shrub cutting (for fenced paddocks and fuel), reduced browsing pressure on newly germinated young shrubs and resulted in fewer fires started by the pastoralists. The result was that these shrub/tree species gained a dominant position relative to the grasses. Once these shrubs were able to develop a canopy and an extensive root system, they were able to outcompete the grasses for light and water. The result has been a substantial decrease in livestock carrying capacity.

Retrogression is the process of a stable vegetation community shifting to one with a species composition better adapted to the new/increased disturbance conditions. Retrogression is usually used in the context of vegetation response to grazing. For example, if a new borehole is installed in a lightly used plant community and grazing is not controlled, a gradation in plant community composition and structure will develop which correlates with distance from the borehole. This gradation from the pre-existing stable community to different species group assemblages (manifest along the gradient of increasing grazing pressure) is considered a retrogression sequence. In general, productivity and/or palatability of vegetation decreases along a retrogression sequence (e.g. toward a borehole). The pattern of species compositional change is not fixed; there are many different types of retrogression manifestations possible, just as there are often numerous stable communities possible on a particular site.

The type of plant species present are very useful for providing an indication of the type and degree of disturbance (e.g., some species are very intolerant of grazing and quickly disappear while other species are only present if the site is heavily grazed). Pastoralists commonly use these species as indicators of the past use of the site. Subsistence farmers often watch for the appearance of indicator species to let them know when it will be desirable to bring fallow fields back into cultivation. Likewise, range managers use plants to inform them about the status of the rangelands. This information is then a major basis for making a decision with regard to the status of range condition. Indicator groups of plants are commonly grouped as: decreasers, increasers, and invaders.

Species that dominate under light disturbance are known as **decreasers** (because they decrease as the disturbance pressure rises). As previously discussed these species usually have poorly developed mechanisms to protect themselves from increased disturbance pressure. On rangelands, increased grazing pressure is a common disturbance. The lack of defensive mechanisms contribute to making these decreaser species more palatable, so they are most vulnerable to heavy grazing and thus rapidly disappear. If the crowns (i.e. the tussock or clump-like growth form where the roots and stems merge) of palatable bunchgrasses are hollow or closely cropped, this is a sign that these decreasers are being hurt. Not all bunchgrasses are decreasers; some bunchgrasses have mechanisms that protect them from grazing (e.g. sharp seeds of *Heteropogon contortus* or *Aristida* spp., high silica content in leaves of *Pennisetum schimperi* making them tough and unpalatable, and chemical repellents such as the substance that gives *Cymbopogon* spp. their "lemony" smell). The process by which decreaser species become a more common component of the total plant community is termed **succession**.

The species that fill the niche vacated by the decreasers are known as **increasers** and **invaders**. The difference between these two groups is that increasers are part of the stable plant community that existed prior to disturbance (**climax**) and invaders are new arrivals not part of the climax community. The relationship of the composition of these three broad plant classes relative to range condition are shown in **Figure VI.1**.

Using vegetation in this way, the manager is able to look beyond the immediate greenness of the vegetation and assess the health of the overall plant community. *Greenness, or short-term growth response triggered by good rains, has nothing to do with assessment of range condition.* A common mistake of inexperienced rangemanagers is to focus on the temporary appearance of the range, instead of looking for symptoms that give a more accurate picture of range community health. Also, it should not be assumed that rangeland in good condition (in that it is in or near the climax state) is always the best condition for producing livestock. Often increaser species may have traits better used by livestock. For example, the sod growth form of a nutritious increaser such as Kikuyu grass (*Pennisetum clandestinum*) will be more easily managed than a bunchgrass decreaser such as *Hyparrhenia rufa* which may become rank/sour and rapidly lose nutritional value if not intensively managed.

Unfortunately, information on plant indicator species of range condition for northern Kenya grasslands is limited. A "first approximation" of the position of some key species has been made in the vegetation section of the RMH for parts of some districts. The determination of plant indicator species for specific vegetation types would be a valuable contribution/activity/effort for range management division personnel.

SOIL CHARACTERISTICS

Soil structure and evidence of erosion provide information that complement the vegetation information used to determine range condition. If a rangeland is as "healthy" as possible there will be no signs of accelerated erosion (see discussion in CHAPTER III on Landforms and Soils and Volume III.6&7 for further discussion of soil erosion hazard and the field traits that indicate accelerated erosion is taking place). Soil formation is a very slow

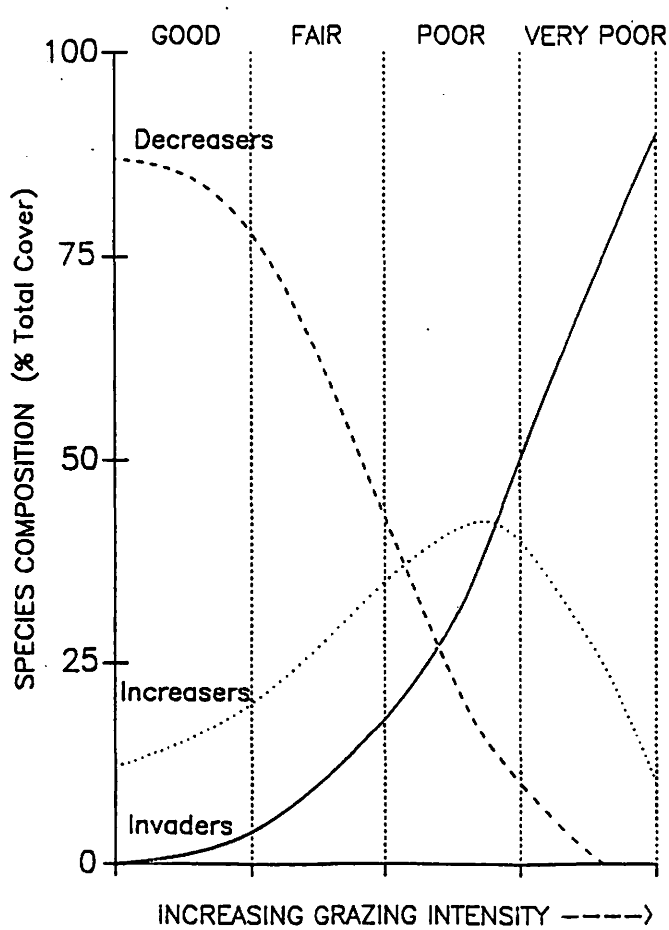


Figure VI.1. Changes in the relative abundance of species groups as grazing intensity increases. The relative abundance of the species groups is related to the rangeland condition classes.

process; on the rangelands of Kenya, 500 years or more may be required to create 1 cm of new soil. Soil accumulates on a site over time when there is a net positive balance between the formation of new soil and the loss of soil associated with the natural/ geologic rate of erosion. Changing the environment (e.g., removal of natural cover due to long-term heavy grazing pressure) may result in shifting the balance to one in which more soil is being lost than is being formed. If this is occurring, the site is experiencing a net loss in nutrients and water holding capacity, thus lowering the site potential and therefore lowering the potential condition of the range relative to what it previously was. Clues indicating that accelerated erosion is occurring include:

- Evidence of many livestock trails (compacted soil and no cover on these paths are a beginning point for concentrated overland flow which has great erosion capability).

- Low amounts of litter on the soil. Litter cover is important for breaking raindrop impact and obstructing overland flow. Litter also adds organic matter to the soil which is necessary for improving aggregate structure that forms the soil pores by which water enters the soil. This is most relevant in semi-arid rangelands where the higher rainfall and presence of perennial grasses provide an opportunity for the build-up of litter. In arid areas, the lower productivity of annual grasses and frequently high winds generally act against a significant build up of litter.

- Soil crusts (which indicate that the structure of the soil necessary to allow water to pass into the soil has deteriorated).

See the discussion on soil erosion in CHAPTER III for more detail regarding causes and indicators of erosion. See the RMH Volume III.7 (*A SURVEY METHOD FOR CLASSIFICATION OF RANGE CONDITION*) for a more detailed discussion regarding range condition and how to determine it.

CHAPTER VII
WATER RESOURCES

Rangeland managers must consider a variety of factors when devising plans that require access to water. One obvious consideration is to know the location, quality and quantity of the existing water sources. This information can be obtained from the RMH maps entitled *TYPE AND LOCATION OF WATER SOURCES AND RUN-OFF REGIONS, DISTANCE TO PERMANENT WATER* and *DISTANCE TO SEASONAL WATER*. Detailed information on the amount and quality of the water is provided in the text of the handbook that accompanies the maps (RMH Vol. II.1-9).

The *TYPE AND LOCATION OF WATER SOURCES AND RUN-OFF REGIONS* maps (RMH Vol. II.1-9) illustrates the broad-scale drainage basins (i.e. run-off regions) because a watershed basin approach may be an appropriate management unit for some types of regional management concerns. Landscape attributes make watersheds a logical, natural unit for soil and water management. Often there are mixed land uses within a unit which are <u>interdependent</u> from a watershed perspective. For example, improper management of upland sites used for wood gathering and overgrazing can result in flash-floods which jeopardize other activities in lowland areas. This interdependence necessitates development planning at a watershed unit level of management. If this does not occur, a good program at one site within the watershed may fail because of unsound land use on adjacent, interdependent sites. In terms of economic planning, a watershed also constitutes a useful management unit since the benefits and costs of soil and water management primarily accrue to the people within the watershed. A management unit must be carefully selected based upon the objectives, scope and resources of the manager. There is no universal rationale for selecting a management unit. What is appropriate for one type of project may be completely inappropriate for a different project (see CHAPTER V discussion on Range Units). Some of the interior drainage systems indicate that brackish lakes and salt pans are likely.

The amount of water available is an important consideration when planning a variety of activities. The amount of water yield at various well sites is either shown on one of the water maps or in a table in the text of the water resources report. The daily water yields are expressed as cubic meters/day (m^3/day). One m^3 = 1000 liters or 220 Imperial gallons. The maximum capacity of existing reservoirs in terms of m^3/day are listed in the appendix of the Water Resources chapter in the RMH. A major problem concerning surface water sources (pans and dams) is that they can fill to various levels with silt over time, thereby reducing their capacity and usefulness. This is especially true in areas where the surrounding watershed has been misused (overgrazed, heavy fuelwood harvest, poorly farmed, etc.) Monitoring the status of these surface water catchments is important because: 1) it will enable the manager to know when to repair/maintain the water source, and 2) the amount of sediment that washes into the catchment can be used as a very rough indicator of rangeland trend. If the runoff carries a lot of sediment it is an indication that the existing land use is not sustainable (i.e. the production potential of the land is being degraded by the loss of soil which results in loss of nutrients, loss of water holding capacity, etc.).

The chemical quality of water must also be considered since this may restrict the type of livestock that can drink the water and/or may influence the production potential of the livestock. Appendices within the Water Resources chapter of the RMH district reports (Vol. II.1-9) show water quality levels at the time of the survey. The mineral water content of water in reservoirs and some shallow wells tends to rise as the dry season advances and sometimes may reach a point were it is unsuitable for drinking. Most livestock can adapt to moderate ranges in the condition of the water and become comparatively tolerant of highly mineralized water. However, use of highly mineralized water may have a considerable effect on the mineral metabolism of animals. The specific effects depend on the mineral composition of the particular water source. **Tables VII.1-5** show recommended quality considerations for humans, irrigation and livestock use (see also the section on water resources in Vol. I.2).

VARIABLES INFLUENCING LIVESTOCK WATER REQUIREMENTS

There are a variety of factors to consider when estimating how much water livestock will need. These factors include: 1) kind of stock, 2) water content of the forage, 3) weather conditions.

Kind of Stock

The difference in physiological adaptations of domestic livestock determines their ability to utilize semi-arid and arid rangelands. The order of adaptability to increasing dry climates is as follows: European cattle breeds to Indian cattle breeds to wool sheep to hair sheep to goats to camels. Animals with low water turnover rates excrete less urea, enhancing their nitrogen efficiency and allowing better use of the dry, low-protein forage of arid areas. The water efficiency of some antelope, such as the oryx which does not need to drink water, is much superior to that of domestic animals.

Livestock have some ability to adjust to water deficits, but this is done at the expense of production. Forage intake begins to decline as the number of days after watering increases. Long intervals between watering is likely to impair performance of the livestock, particularly impacting growing and lactating animals. To avoid water-induced production declines, the amount and frequency of water that is listed in **Table VII.6** should be provided. These allowances are applicable for water containing not more than 2000 mg/L total soluble salts (TSS). For each 1000 mg TSS/L in excess of 2000 mg/L, the need for water by sheep increases by about 3% and increases by about 6% for cattle.

Water Content of the Forage

Grazing livestock for relatively long periods without visiting a well or reservoir is a common practice during the growing season when forage is green and succulent. Sheep, goats and camels can also do well on non-succulent forage if they can obtain moisture in the form of dew. Range plants may contain over 80% water during the rapid growing period of the rainy season, whereas in the dry season the moisture content of range plants is usually less than 40%. A low water content of forage increases the animals demand for water at a time when surface water resources are diminishing and the animal has to walk further to obtain both feed and water. Additional walking raises food and water demand.

Table VII.1. Guidelines for quality of drinking water with regard to maximum concentration of inorganic constituents with human health significance (World Health Organization 1984).

Constituent	Unit	Guideline Value
Arsenic	mg/L	0.05
Asbestos	---	No guideline value set
Barium	---	No guideline value set
Beryllium	---	No guideline value set
Cadmium	mg/L	0.005
Chromium	mg/L	0.05
Cyanide	mg/L	0.1
Fluoride	mg/L	1.5
Hardness	---	No guideline value set
Lead	mg/L	0.05
Mercury	mg/L	0.001
Nickel	---	No guideline value set
Nitrate	mg/L	10
Nitrite	---	No guideline value set
Selenium	mg/L	0.01
Silver	---	No guideline value set
Sodium	---	No guideline value set

Table VII.2. FAO guidelines for evaluating the quality of water for irrigation (Food and Agriculture Organization of the United Nations 1985, Kandiah 1987).

Potential Irrigation Problem	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
Salinity (affects crop water availability)[1]				
EC_w	dS/m	<0.7	0.7-3.0	>3.0
or				
TDS	mg/L	<450	450-2000	>2000
Infiltration (affects infiltration rate of water into the soil) Evaluate using EC_w and SAR together)[2]				
SAR = 0-3 and EC_w =		>0.7	0.7-0.2	<0.2
SAR = 3-6 and EC_w =		>1.2	1.2-0.3	<0.3
SAR = 6-12 and EC_w =		>1.9	1.9-0.5	<0.5
SAR = 12-20 and EC_w =		>2.9	2.9-1.3	<1.3
SAR = 20-40 and EC_w =		>5.0	5.0-2.9	<2.9
Specific Ion Toxicity (affects sensitive crops)				
Sodium (Na)				
surface irrigation	SAR	<3	3-9	>9
sprinkler irrigation	me[3]/L	<3	3	
Chloride (Cl)				
surface irrigation	me/L	<4	4-10	>10
sprinkler irrigation	me/L	<3	<3	
Boron (B)	mg/L	<0.7	0.7-3.0	>3.0
Miscellaneous Effects (affects susceptible crops)				
Nitrogen (NO_3-N)	mg/L	<5	5-30	>30
Bicarbonate (HCO_3) (overhead sprinkling only)	me/L	<1.5	1.5-8.5	>8.5
pH		Normal range 6.5 - 8.4		

1 EC_w means electrical conductivity, a measure of the water salinity, reported in deciSiemens per meter at 25°C (dS/m) or in units millimhos per centimeter (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per liter (mg/L).

2 SAR means sodium absorption ratio. SAR=Na/(Ca+Mg)/2.

3 The unit "me" stands for milliequivalent. This represents one-thousandth of the atomic weight of an ion that will combine with or displace this amount of hydrogen.

Table VII.3. FAO-recommended maximum concentrations of trace elements in irrigation water (Food and Agriculture Organization of the United Nations 1985, Kandiah 1987).

Element	Recommended Maximum Concentration[1] (mg/L)	Remarks
Aluminum (Al)	5.0	Can cause non-productivity in acid soils (pH<5.5), but more alkaline soils at >pH 7.0 will precipitate the ion and eliminate any toxicity.
Arsenic (As)	0.10	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice.
Beryllium (Be)	0.10	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans.
Cadmium (Cd)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/L in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Cobalt (Co)	0.05	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Chromium (Cr)	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Copper (Cu)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solutions.
Fluorine (F)	1.0	Inactivated by neutral and alkaline soils.
Iron (Fe)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Lithium (Li)	2.5	Tolerated by most crops up to mg/L; mobile in soil. Toxic to citrus at low concentrations (0.075 mg/L). Acts similarly to boron.
Manganese (Mn)	0.20	Toxic to a number of crops at a few-tenths to a few mg/L, but usually only in acid soils.
Molybdenum (Mo)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Nickel (Ni)	0.20	Toxic to a number of plants at 0.5 mg/L to 1.0 mg/L; reduced toxicity at neutral or alkaline pH.
Palladium (Pd)	5.0	Can inhibit plant cell growth at very high concentrations.
Selenium (Se)	0.02	Toxic to plants at concentrations as low as 0.025 mg/L and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.
Tin (Sn)		Effectively excluded by plants; specific tolerance unknown.
Titanium (Ti)		Effectively excluded by plants; specific tolerance unknown.
Tungsten (W)		Effectively excluded by plants; specific tolerance unknown.
Vanadium (V)	0.10	Toxic to many plants at relatively low concentrations.
Zinc (Zn)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH>6.0 and in fine textured or organic soils.

[1] The maximum concentration is based on a water application rate which is consistent with good irrigation practices (10,000 m/ha/yr). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10,000 m^3/ha/yr. The values given are for water used on a continuous basis at one site.

Table VII.4. Guide to the use of saline water for livestock and poultry (U.S. National Academy of Sciences, 1974).

Total Soluble Salts (mg/L)	Comments
Less than 1,000	These waters have a relatively low level of salinity and should present no serious problem to any class of livestock or poultry.
1,000 - 2,999	These waters should be satisfactory for all classes of livestock and poultry. They may cause temporary and mild diarrhea in livestock not accustomed to them or watery feces in poultry (especially at the higher levels), but should not affect their health or performance.
3,000 - 4,999	These waters should be satisfactory for livestock, although they might cause temporary diarrhea or be refused at first by animals not accustomed to them. They are poor waters for poultry, often causing watery feces and (at higher levels of salinity) increased mortality and decreased growth, especially in turkeys.
5,000 - 6,999	These waters can be used with reasonable safety for dairy and beef cattle, sheep, swine, and horses. It may be well to avoid the use of those approaching the higher levels for pregnant or lactating animals. They are not acceptable waters for poultry, almost always causing some type of problem, especially near the upper limit, where reduced growth and production or increased mortality will probably occur.
7,000 - 10,000	These waters are unusable for poultry. For all livestock these waters will almost always cause some type of problem, especially near the upper limit, where reduced growth and production or increased mortality will probably occur.
More than 10,000	The risks with these highly saline waters are so great that they cannot be recommended for use under any conditions.

The temperature also usually increases during the dry season, causing further increase in the animal's water requirements.

Environmental Conditions

Various environmental conditions can influence appropriate water spacing. The distance that a particular type of livestock can travel from water depends on the topography of the site. If the terrain is very steep or rough, livestock, particularly cattle, cannot travel as far. As the distance between water sources increases, the energy expenditure of travel increases and can result in reduced weight gains. Free-ranging grazing which allows the livestock to move at their own pace can reduce water demand in areas where water is inadequate.

Temperature is another important factor that influences water requirements. **Table VII.7** shows how water demand is associated with increasing temperatures. The information in this table is expressed on the basis of dry matter forage intake because the amount of forage intake and forage water content are such important variables influencing water requirements. Access to shade can make a very big difference in water demand and animal performance. Cattle average daily gain may be 50% less in the tropics on pastures without shade. In Australia, lamb mortality was reduced by 50% in pastures with shade. Heat stress brought on in part by lack of water and shade can negatively affect embryo and fetus development. It can also negatively affect male fertility, female ovulation rate,

Table VII.5. Water quality criteria for livestock. These criteria provide a general guide to quality of water acceptable for most livestock. Water of different quality may be acceptable because of nature, age, or condition of species being raised or because of special rearing conditions or feed components (Ontario Ministry of the Environment 1984).

Quality Factor	Limiting Threshold (mg/L)
Aluminum	5.0
Arsenic	0.2
Boron	5.0
Cadmium	0.05
Chromium	1.0
Cobalt	1.0
Copper	0.5
Fluoride	2.0
Lead	0.1
Mercury	0.01
Nickel	1.0
No_3-N+NO_2-N	100.0
NO_2-N	10.0
Selenium	0.05
Vanadium	0.1
Zinc	25.0
Salinity (total soluble salts)	3000.0
Toxic algae	no heavy growth

oestrous duration, conception and milk production. Breeds of livestock differ in the speed with which they become stressed, but once the stress occurs, the physiological changes are consistent across all livestock kinds and breeds.

ISSUES REGARDING WATER DISTRIBUTION

Poor water distribution is probably the chief cause of poor distribution of livestock on the range. Without a water source, it is difficult to keep livestock in the area long enough to achieve proper utilization of forage. If available watering points are infrequent, large numbers of livestock are forced to use a single water point which leads to heavy grazing pressure and trampling of soil within several kilometres of the well. This results in a retrogression of the plant communities to a dominance of less palatable species and often is associated with widespread erosion.

The distance livestock are able to move in a day is termed an **action radius.** This movement is influenced by the type of livestock and by surface conditions/accessibility of the site. Livestock movement will be severely restricted if the region has a rugged or steep topography and/or the land surface is covered by sharp rocks or boulders. These permanent, non-seasonal restrictions are illustrated on the RMH *RATINGS OF RESTRICTIONS IN ACCESSIBILITY FOR LIVESTOCK REGARDING LANDFORMS AND SOILS* maps. The characteristics of the soil when wet will also affect the action radius estimate. Some soils become very sticky and stay muddy for prolonged periods which can be a great hinderance to livestock movement. Soils prone to these conditions are illustrated on the RMH *RATINGS OF RESTRICTIONS IN ACCESSIBILITY FOR LIVESTOCK DURING WET SEASON* maps. Another restriction on the livestock action radius is the type of vegetation cover. Thick bushland makes it difficult to herd animals and thus reduces the action

Table VII.6. Daily intake and frequency needs of range livestock during the dry season to prevent water-induced production declines (Baudelaire 1972).

Animal	Daily Intake (liters)	Frequency of Drinking
Goats	4-5	Once a day
Sheep	4-5	Once every 2 days
Asses and Donkeys	10-15	Once a day
Horses	20-30	Once or twice a day
Cattle	30-40	Once every 1-2 days
Camels	60-80	Once every 4-5 days

radius. Therefore, the RMH *VEGETATION* maps should also be consulted.

After these factors have been considered, the RMH maps showing the *DISTANCE TO PERMANENT WATER* and maps/tables showing daily water yield can be consulted to provide a reference point for water relative to distance. There are two different radii illustrated on the maps. The 0-10 km well-site radius represents the approximate distance that cattle will graze from water when grazing conditions are favourable (i.e. forage is growing and reasonably abundant). The 10-15 km well-site radius shows the distance cattle will graze from a well when forage is sparse and dry. Routinely forcing cattle to walk over 15 km from a well site to graze is impractical given the physiology and water needs of this type of animal.

Adding water on a permanent basis may not lead to proper use; it merely becomes a new focal point for increased use by livestock and possibly will prompt other difficult to control changes in land use (e.g., permanent settlement which may lead to increased fuelwood harvesting, attempts at subsistence agriculture, etc.). Historically, water availability in the dry season was the critical factor that limited livestock populations and pasture access. Traditional water sources often had well-defined rules governing access. Disease also limited human and livestock population build-up. These natural checks prevented intensive land use and environmental degradation which would cause a reduction of the overall carrying capacity. The role of disease as a controlling population factor has been reduced through the introduction of drugs. Boreholes, which provide a source of water throughout the year, eliminate water availability as a factor limiting population build-up. Unfortunately, in the absence of sound management, the new factor that replaces disease and water as a control to population build-up is lack of forage. A lack of forage results from a retrogression of the plant community and eventually leads to severe erosion and eventual desertification (see Chapter VI).

It must be the responsibility of the community to manage the land around a water source so that it does not become a new centre of resource deterioration. Many of the pastoral societies have never developed mechanisms to control livestock numbers because there was no need (water shortage and disease would naturally keep the populations in check). Thus livestock would die off before the population could ever increase to the point that it could contribute to permanent deterioration (from a societal perspective) of the resource via accelerated erosion. Therefore, an increased responsibility to control livestock populations must accompany use of technology for treating disease and installing boreholes.

Planners must realistically recognize that this type of management responsibility, unfortunately, is not in place in many regions. It does not make sense to limit access to forage that could improve the production potential of rangeland by not putting in wells that would open these areas to more efficient use. However, it also does not make sense to put in a borehole as a major water source if there is a strong likelihood that the long-term result will be massive resource deterioration. Therefore, to avoid future natural resource disasters, new boreholes should be located in areas capable of supporting grazing and should be sized so that yield from the well will not permit more animals at the site than can be sustained by the forage base.

Using the information discussed above, it should be clear that there is much more involved in deciding where to site a new borehole than simply looking at the RMH *DISTANCE TO PERMANENT WATER* maps and maps/tables of daily water yields. The

Table VII.7. Estimates of total water (combination of water that is in forage and water that is drunk) needed for cattle and sheep at various mean temperatures expressed as l/kg dry matter intake (Australian Agriculture Council 1990).

Water Need (L/kg of dry matter intake)	Mean air temperature (°C) ≤15	20	25	30	35
Weaned cattle:					
European cattle breeds (*Bos taurus*)	3.5	4.0	5.5	7.5	10.0
Indian cattle breeds (*Bos indicus*)	3.0	3.5	4.5	6.0	8.0
Calves	6-8	6-8	9+	9+	9+
Weaned sheep	2.0	2.5	3.5	5.0	7.0
Lambs	5-7	5-7	8+	8+	8+

Pregnancy: Water need increases by 30% for the last 4 months of a cows pregnancy and the last 2 months of a sheeps pregnancy.

Lactation: Water need increases by 1 liter for every kg of milk produced.

RMH maps on *RANGE CONDITION* should be consulted to determine if the area is already overused or not. The RMH maps on *RATINGS OF SOIL EROSION HAZARD* should be consulted to determine if extra use by livestock is likely to quickly destabilize the soil resource. The RMH maps on *VEGETATION* and the accompanying text on the dominant species should be consulted for several reasons. The type of forage will determine seasonality of the forage base. For example, if the dominant grasses are annuals it makes no sense to put in a well for improving livestock access during the dry season because there won't be any forage there during the dry season for the livestock to eat. The action radius of the livestock will be limited if the area is thick bush. The action radius will also be limited during the dry season by the factors included on the RMH maps illustrating *RATINGS OF RESTRICTIONS IN ACCESSIBILITY FOR LIVESTOCK REGARDING LANDFORMS AND SOILS*. It may also be useful to consult the series of RMH maps on rainfall probability if a consideration in siting water sources is influenced by the desire to help reduce risk.

CHAPTER VIII
TRADITIONAL PASTORALISM AND LIVESTOCK MARKETING

Devising technical solutions that address the technical aspects of environmental problems is often not the most serious obstacle to range management. Rather, the challenge lies in devising technical solutions that can be successfully implemented in the context of the constraints imposed by participant interests and project resources. Addressing the needs and perspectives of the participants in a program must, of course, be an important component of any solution. The information in the TRADITIONAL PASTORALISTS: LAND USE STRATEGIES chapter of each RMH district publication provides an overview of the customs, seasonal movement patterns of livestock, etc. that are characteristic for the district.

In most cases, Kenya's rangelands already have an existing population with established patterns of pastoral use already in place. In many areas there are socioeconomic and political forces at work that are essentially beyond the control of the range manager (e.g., conversion of dry season grazing areas that were communally used to fenced, cultivated, private land or the transition from communally used lands to group ranches to private rangeland ownership). A primary responsibility of a range manager is to help the inhabitants of the region adapt to the new conditions in ways that are compatible with optimizing sustainable production. In some cases, this may involve the development of new resources (e.g., helping choose the best location for a new borehole, new road, new cattle dip, etc.). In other cases, this may involve devising creative solutions that will stop the misuse of land (e.g., overgrazing, excessive fuelwood cutting) and eventually aid recovery and enhance production potential. Regardless of what activity the range manager is engaged in, a key question will be how to ensure that benefits of sound management are returned to people who adopt the practices, thus promoting community participation.

One way the RMH can help the interaction with people is to provide a foundation of information that can help a manager make a sound decision. Without the insight provided by the RMH text and maps, a manager may not have the full range of information necessary to make a wise decision. Lack of information can lead to implementation of management practices on an ad hoc or a trial and error basis. Activity without insight is time consuming, costly and increasingly intolerable given the urgent need for solutions to resource management problems. Technical mistakes are not readily forgiven by those who must suffer the consequences of a poor administrative decision. This is especially true for subsistence pastoralists or farmers who have few resources to buffer them from bad times. This vulnerability understandably reenforces cautious behaviour and minimizing risks. Subsistence pastoralists and farmers are often accused of being hard to work with because they are slow to adopt change. This caution is often based on a perceived risk associated with change. This is why, for example, demonstration projects can play such an important role in facilitating change.

Information provided about traditional pastoralist land use strategies can help the manager be aware of the cultural concerns of the region's inhabitants and make the manager aware of how those people are currently making use of the resource. Knowing how and why pastoralists utilize rangelands provides a better understanding of the resultant constraints and opportunities that the range manager must either deal with or take advantage of. For example, the Boran have a traditional organization of social groupings called "olas" which correspond fairly closely to specific units of land along the Ewaso Ng'iro River. Each "ola" has a leader, the "aba arega" who makes vital decisions regarding use of the ola. This traditional structure provides an excellent pre-existing organization through which rural development activities can be planned and implemented. Another example is that of Somali and Boran pastoralists, who recognize environmental/resource units within their rangelands, which they identify by the nature of the soils. These units have fairly specific time-tested and ecologically proven types and periods of land use which reflect the specific nature of the soils/vegetation/climate. Knowledge of the nature of these land units will give the range manager some insight regarding how and why the Somali pastoralists use these units. This insight can be used to influence decisions on development practices designed to ease existing production constraints (e.g., mineral deficiencies are associated with some units). By possessing this knowledge, the manager will be able to converse more knowledgeably with the pastoralists about their rangelands using their own terms and thereby aid communication and facilitate development of mutually agreeable plans. Maps of locally named soil units are provided for Wajir, Mandera and Isiolo districts and descriptions of the important characteristics of each unit are given in the relevant district report of the RMH.

Where there are no traditional organizations governing land use and/or the range is used by more than one (essentially competing) tribe, it will be much more challenging to develop a procedure for sustainable, equitable, cooperative use of the area. Mis-steps can create substantial social upheaval with serious consequences. There are many examples which illustrate how socio-political problems combine with resource constraints to create challenges for a range manager. For example, the Turkana land use strategies which have maintained livestock production for hundreds of years are threatened by a variety of factors. Water from the Turkwell River and products from the *Acacia tortilis* trees (particularly the highly nutritious seeds) which grow along the river are important to the traditional land use strategies of the Turkana. The trees are so important to the Turkana production system that many of them are individually owned by Turkana families. People from other groups are cutting the *Acacia tortilis* trees for charcoal production. The new Turkwell Dam is changing the nature and flow of water in the river. This may affect the ability of *Acacia tortilis* to grow downstream of the dam. Political unrest in Uganda and Sudan has severely restricted use of traditional grazing lands in these countries. This increases pressure on the rangelands within Kenya's Turkana District that might otherwise have been rested. All of these factors are beyond the control of the Turkana people and affect the livestock/human carrying capacity of Turkana District. An important goal of range management activities in such a region is to help the local production systems evolve environmentally sustainable strategies to cope with the changes.

Besides the general concerns of the group, each individual within the group is certain to have personal perspectives. Land use practices and the concern for resource conservation varies greatly depending upon whether the time horizon of the individual is focused on short-term gain or long-term sustained yield. This perspective is affected by a variety of factors such as land tenure, custom, need, age, size of family, etc. For example, traditional economic theory asserts that conservation of a resource will occur when the future profit potential outweighs the returns from consuming the resource today. If the individual is barely able to meet the subsistence needs of his/her family, the need for immediate survival outweighs consideration of future productivity. Consequently, such individuals may indeed understand that the land resource is deteriorating, but they are not in a position to change their use pattern since their immediate concern is to produce enough to stay alive, even if that may jeopardize sustained future production.

The challenge is to provide technology <u>options</u> that will meet the varying needs of the individuals within the population. Each of these options should balance the pastoralists needs with the strengths and constraints of the project resources. One option is not likely to meet the needs of everyone. For example, if soil erosion is a problem, it would be desirable to have several management options to present to the group. All individuals might not choose the same option, but as long as all of them choose one, the goal may be achieved. Simply giving orders is not likely to work; a viable solution must create an environment whereby both the individual and the manager can improve their situation.

In addition to use strategies of rangelands, the type of livestock marketing infrastructure will be an important influence in the region. The LIVESTOCK MARKETING chapter in the district publications of the RMH provides information on the constraints and opportunities regarding this issue. The livestock marketing infrastructure is important because it provides a mechanism for improving the price obtained by the pastoralist for sale of livestock. This helps to provide an incentive for pastoral communities to work for programs that will enhance the future quality of both the rangeland and their livestock. Marketing systems that improve the profit of the pastoralist provide a mechanism for destocking and a powerful incentive for focusing on quality instead of quantity. The focus on quality is necessary because livestock in poor condition yield meat that does not appeal to an overseas trade market. A good country-wide marketing system can also provide a means to reduce volatility in price. Without a good marketing system, livestock cannot be marketed at a regional level at a reasonable price during a local drought, nor can livestock herds be rebuilt in good years since at that time productive females are rarely available in local markets.

Successful livestock marketing also requires development of an infrastructure that provides for quarantines, inspections and vaccinations. A good transportation network can help control spread of disease because it provides a means to get the livestock to market quickly without contracting diseases along the way. This implies that the animals being transported must be disease free to prevent the spread of disease along the route. The transportation network can also prevent weight loss associated with long walks to a market and can assist rapid turnover of money. See the INFRASTRUCTURE and PASTORAL ECONOMY sections in Vol.I.1 and refer to the chapters on TRADITIONAL PASTORALISM AND LIVESTOCK MARKETING in the district publications of the RMH.

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APPENDIX
EXAMPLES OF HOW TO ORGANIZE THE INFORMATION IN THE RMH TO HELP MAKE PLANNING DECISIONS

The RMH contains a tremendous amount of information that is important to consider when devising management plans. However, the sheer volume of information on the maps and in the accompanying text may initially bewilder the user, thereby limiting use of the RMH in an integrated, organized, logical fashion.

The best way to approach a problem is to ask yourself two questions regarding the criteria for success of the proposed activity:

What are factors that will make success of the proposed activity likely?

What are factors that will prevent the proposed activity from being successful?

This RMH Users Guide should raise your awareness of the different components of the environment that might influence a particular task. Write out a list of factors you must consider to fully address these two questions. The simplest way to proceed is to compose the list as a series of questions that you can answer with a simple yes (acceptable) or no (unacceptable).

Once you have made a list of the pertinent factors that can influence success of the proposed activity, begin to check the information in the RMH to determine whether a particular site is a suitable location for the activity. To avoid confusion use one map at a time to check the factors that will allow or prohibit success of the activity. As you proceed through the RMH information you may find that the site is not compatible with the proposed activity (i.e. you get a no (unacceptable) answer to one of the questions you asked). In such a situation you will either have to select a new location, alter the proposed activity, or abandon the idea. Of course, even if it appears that the proposed activity is acceptable, given the information in the RMH, a field visit should be made to assess the situation in person.

Remember that the decisions being made by using the information in the RMH are "technical" (not political). It is understood that many development activities are based largely on non-technical/political reasons. However, the technical officer (i.e. the professional charged with managing range, forest, agriculture, water, etc.) should always be prepared to provide the technical reasons for or against a proposed activity.

There have been a variety of examples presented in the text regarding how to use a particular map or particular series of maps. The following text provides additional examples of how the wide variety of information included in the RMH can be applied to address the planning needs of a proposed activity.

EXAMPLE 1

You are approached by an agency with money to put in a new borehole in your district for the primary purpose of increasing water to enhance livestock production in the region. A proposal is made to install the borehole at a particular site. Is this site a good location at which to install the borehole?

What are factors that will make it likely that the proposed activity will be successful?

What are factors that will prevent the proposed activity from being successful?

1. Is an additional water source needed in the area? YES or NO

2. Is the vegetation of the area likely to be able to support increased livestock use? YES or NO

3. Will the livestock have reasonable access to the borehole? YES or NO

4. Will the site be accessible to the drilling rig and maintenance personnel? YES or NO

Next, proceed to the RMH maps and text to answer each of these questions.

1. Is an additional water source needed in the area? YES or NO

   Check the maps and text information regarding the type, location, volume/output and water quality of the existing water sources near the proposed activity. If your answer to the question is NO, there is no need to check other information. You should suggest that the well site would be better located elsewhere in a place that it is needed. If your answer is YES, the site is short of water and you can proceed to your next question.

2. Is the vegetation of the area likely to be able to support increased livestock use? YES or NO

   If the vegetation is forest, dense bushland or shrubland, annual grassland, or barren land the forage base is usually unsuitable for long-term use by livestock. Therefore the answer to the question is NO; there is little reason for a new borehole because the surrounding vegetation cannot support the increase in livestock use that the borehole would enable.

   Check the map on VEGETATION TYPES and the accompanying information in the RMH text regarding the vegetation types and range unit inventory. If the vegetation is relatively open shrubland or bushland, dwarf shrubland, or grassland there is a chance that the area will provide a good forage base for livestock. But is the range site producing near its potential or is it degraded? Check the map on range condition. If the site is in poor or very poor condition the area is too degraded to support the increased use that would follow placement of a new borehole. Therefore the answer to the question is NO and there is no need to pursue further consideration of the site. If the answer is YES, the site has a forage base sufficient for livestock use and you can proceed to your next question.

3. Will the livestock have reasonable access to the borehole? YES or NO

   Check the maps and text information pertinent to indicating whether there will be year round access for livestock. If access is poor or very poor, then the answer is NO. There is no need to pursue further consideration of the site because livestock use of the area will be seriously constrained. If it is important that livestock have access to the borehole during the wet season but the RMH text and maps indicate that the nature of the soils prevent use of the area when wet, then the site would not be a good place for a borehole and the answer is NO; there is no need to pursue further consideration of the site. If the site does allow moderate or good access by livestock to the borehole whenever access is needed, the answer is YES and you can proceed to the next question.

4. Will the site be accessible to the drilling rig and maintenance personnel? YES or NO

   If there is no road near the site it will difficult, if not impossible, to get the drilling rig to the site and it will be difficult to maintain the well. Unless the project includes funds for road construction to the borehole, the answer is NO and the site should not be chosen. If the roads are simply graded soil, access to the site may be limited to only certain times of the year. Check the information on the nature of the soil and the rainy season restrictions on livestock use. If livestock are going to have a difficult time accessing the area, vehicles and heavy machinery will also. This may pose serious problems in the drilling and long-term maintenance of the borehole and pump. Therefore the answer will be NO and the site should not be chosen. If the site does have a road nearby that will allow access throughout the year the answer would be YES. To get to this point, all of the above questions have been answered YES. This means that the questions you posed have all been satisfactorily answered. Therefore, the proposed location is likely to be technically suitable.

Clues regarding divisive socio-political issues, such as whether the borehole site is in an area that is contested between pastoralist groups, may be found in the RMH information on the traditional pastoralism. This information should be considered when the non-technical/political aspects of the study are examined by the administrators.

EXAMPLE 2

You are approached with a plan to convert some of the existing dry season pasture to maize production. Do you think that this is a sound development program?

What are factors that will make it likely that the proposed activity will be successful?

What are factors that will prevent the proposed activity from being successful?

1. Is the rainfall amount suitable? YES or NO
2. Is the rainfall seasonal distribution and reliability suitable? YES or NO
3. Are the soils of the site suitable for sustained production? YES or NO
4. Will conversion of the area to crop production disrupt the existing livestock production activities? YES or NO

Next, proceed to the RMH maps and text to answer each of these questions.

1. Is the rainfall amount suitable? YES or NO

    By checking with an agronomy text or an agriculture extension officer you learn that maize requires about 600 mm/yr. If the median rainfall in the area is less than 600 mm/yr the site is clearly not suitable, so the answer is NO and the project should be discouraged. If the answer is YES, proceed to the next question.

2. Is the rainfall seasonal distribution and reliability suitable? YES or NO

    Check the maps on the reliability of precipitation. The answer should be NO if there is a wide range in the timing of rain or a significant chance that median rainfall will not occur. Either of these factors would lead to a high likelihood of periodic failures of crop production.

3. Are the soils of the site suitable for sustained production? YES or NO

    The RMH Users Guide discusses a variety of soil factors that should be considered (i.e. depth, soil moisture storage capability, salinity, consistence, texture, fertility, etc.). Some of these factors can be checked in the RMH maps and text. Others, such as consistency, can be checked in the field using the criteria outlined in the Chapter III of this publication. If any of these soil factors are not conducive for working the soil or growing crops, the answer is NO and the project should be discouraged. Check the maps and text discussion on soil erosion hazard to determine whether the site will be susceptible to erosion. The information in the RMH is based on the site being vegetated with native species. If the area is ploughed for crop production, the chance for erosion problems would be significantly increased. If the erosion risk is high, the planned farming activities would not be sustainable, therefore the answer should be NO.

4. Will conversion of the area to crop production disrupt the existing livestock production activities? YES or NO

    Check the information included in the RMH regarding traditional pastoralism. If the seasonal migration routes of the pastoralists are dependent on the proposed site, removal of access to these dry season pastures could substantially lower the livestock carrying capacity of the range unit. This could also have significant negative impacts on the seasonal movement of wildlife. These impacts may offset the anticipated benefits of crop production on this site and should prompt further inquiry to assess the degree of negative impacts that would likely result.

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