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SOILS OF THE FREEMAN RANCH, HAYS COUNTY, TEXAS

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INTRODUCTION

Soil is a unique material. This finite natural resource should be of utmost concern to all of mankind. Civilizations, like individuals, are dependent on the soil. It is our moral duty to be good stewards of this resource. The soil is critical to growing plants. Food and fiber production on this media has been the focus down through the ages, but now we seek to understand a broader view of how soil impacts man and his activities. Soil quality is now measured not only by the sustainability of agricultural management systems but also by the health of humans and ecosystems that involve the soil. The future environmental quality of the soil may very well lie with the degree of education we each have as to where it is spatially located, what its unique properties may be, and what the best management practices may be for each soil body.

HILL COUNTRY SOILS

Freeman Ranch lies within the Edwards Plateau physiographic region. The topography in this area is undulating to hilly with some sections that are deeply dissected. Most is rapidly drained to less sloping stream valleys and some stony plains that are broad and relatively flat. Soils of this region are mostly stony. Some series are somewhat deeper and less stony on flat divides and in stream valleys. The underlying material of the Edwards Plateau soils is erosion-resistant limestone and limestone interbedded with clay and marl. (Godfrey, et al. 1976).

DESCRIPTIONS OF THE DETAILED MAP UNITS LOCATED ON THE FREEMAN RANCH

Detailed soil map units include one or more soil series for which the unit is named. They also include transitional areas and areas of other soils too small to separate because of the map scale. The series category in the soil taxonomic system is the most specific. Each series is defined by unique soil properties such as horizonation, structure, texture, color, reaction, consistence, and mineral and chemical composition. The name given a series is usually from some town, river, geographic area or geomorphic feature. There are approximately 19,000 series identified in the United States (Brady and Weil, 1999). The map unit symbol found on soil maps for the ranch will be given in parenthesis next to the map unit name.

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Comfort-Rock Outcrop Complex, Undulating (CrD)

This soil unit is designated as a complex because there are two or more kinds of soil in such an intricate pattern or so small in area that it is not practical to map them separately at the scale of mapping used. The topographic sequence of this complex (Figure 1) includes: Comfort extremely stony clay which makes up most of the complex (usually in excess of 70 percent); Rock outcrops and areas of soil less than 4 inches in depth; and small areas of Rumple and Eckrant as well as small areas of Anhalt in the small drainage-way valleys.

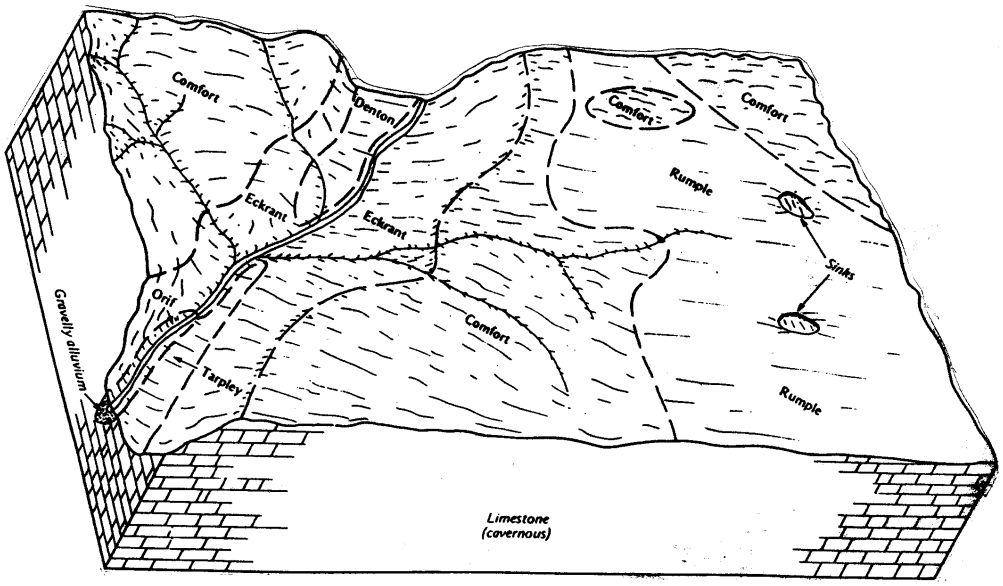

Fig. 1. Pattern of soils in the Comfort-Rumple-Eckrant general soil map unit. (Taken from the Soil Survey of Comal and Hays Counties-Texas)

Up to 50 percent of the surface of the Comfort soil (CrD) is covered with cobbles and stones that may reach 4 feet across. The surface layer or topsoil is typically dark brown extremely stony clay about 6 inches thick. The B2t or subsoil of the Comfort is 6-13 inches deep and a dark reddish brown extremely stony clay. The underlying material or R layer is about 13-20 inches of mostly indurated dolomitic limestone that has dark reddish brown soil material in the narrow fractures. This soil is well drained but slowly permeable to air and water. The moisture storage capacity is limited by the lack of soil depth and content of stones.

The Rock outcrop part of this complex (average of 15 percent) is typically dolomitic limestone, which is barren of soil except for some narrow fractures. Sometimes there may be as much as 3 inches of soil on the surface of flat rocks. The small inclusions of other soil series usually make up less than about 15 percent of the rest of the complex. The Rumple and Eckrant soils included in this complex will be discussed later.

Although not shown on the Ranch soil map because of its limited acreage, a short description of the Anhalt (An) series will be included here. This soil (which is part of the Comfort-Rock outcrop complex, undulating map unit, CrD) is usually above drainage valleys with complex slopes that range from 1 to 8 percent. The topsoil is dark reddish gray or dark brown clay and may be as much as 23 inches thick. The subsoil is dark reddish brown or reddish brown clay and extends to a depth of 32 inches or more. The soil identified on the ranch was more than 40 inches deep. This soil has very slow permeability and is high in shrink/swell clay. Indurated fractured limestone underlies this soil. These shallow, undulating, well drained soils are on upland positions.

Rumple-Comfort Association, Undulating (RUD)

The soil mappers felt that the composition of this unit is more variable than most others in the survey area, but has been controlled well enough to be interpreted for the expected use of the soils. The major soil of this taxonomic unit is the Rumple series which makes up about 20 percent and other soils, mainly the Tarpley and Orif series make up to 20 percent of the total. The Rumple soil is on broad ridgetops and side slopes with gently sloping topography, while the Comfort soil is on more sloping areas near rock outcrops and drainageways. The Tarpley is found on slightly concave, gentle slopes on the upland, while the Orif is a floodplain soil.

The Rumple soil (RUD) may have the surface covered with as much as 20 percent by volume of rounded chert, limestone fragments and gravels. The surface soil layer is a dark reddish brown, very cherty loam, clay loam, or clay that is bout 10 inches thick. The B21t and B22t or subsoil is a dark reddish brown very cherty clay to extremely cherty clay that may have up to 75 percent by volume of limestone fragments present in the lower part of the subsoil. The subsoil is 10-28 inches deep. The R layer or underlying material is coarsely fractured indurated limestone that has dark reddish brown soil in the crevices. The R layer is 28-36 inches in depth. The Rumple is a moderately deep, well drained but slowly permeable soil. The reaction ranges from mildly alkaline to slightly acid and it is noncalcareous throughout.

The Comfort soil series of this map unit is basically the same as that given for the Comfort-Rock outcrop complex described earlier. The only difference is the Comfort soil of this map unit does not include the Rock outcrop.

The Tarlpey clay (TaB) has limestone and chert fragments that cover up to 20 percent of its surface. The topsoil or A horizon is dark brown to dark reddish brown or even dark reddish gray. This upper layer is typically about 6 inches thick and clay texture. The B2t or subsoil is also clay and has a dark reddish brown color. The subsoil may be 6-17 inches in depth. (Some pedons of the Tarpley are deeper than 17 inches which is the case near the Ranch Office area). The underlying layer or R horizon is fractured indurated limestone bedrock 17-21 inches deep. This fractured rock material will have dark reddish brown soil material in the cracks of the limestone and between fractured pieces. The Tarpley is well drained on 1-3 percent slightly concave slopes. Permeability of air and water is slow and infiltration is fairly rapid when dry and cracked due to the shrink/swell clay and surface rock fragments but may be slow when wet. Soil reaction is lightly acid to mildly alkaline.

The Orif (Or) soil is associated with the floodplain of creeks and rivers and thus may be frequently flooded. On the ranch, this soil is in the floodplain of Sink Creek. The typical Orif soil has a topsoil or A horizon that is 20 inches thick and grayish brown to dark brown. It is very gravelly loamy sand and sometimes stratified layers of

rounded limestone pebbles. The underlying layer is not a B horizon but classified as a C or weathered parent material. It may be 20-60 inches deep with the depth varying somewhat. This underlying layer is brown to dark brown in color. It is very gravelly loamy sand stratified with very gravelly sand, very gravelly sandy loam and loam. The abundance of gravel reflects the alluvial or water transported history of the parent material. These deep well drained soils are usually less that 1 percent slope but may be 1-3 percent in some places.

Medlin-Eckrant Association, Undulating (MEC)

This map unit, like the Rumple-Comfort association described earlier, is variable in makeup but the mappers decided this combination was controlled enough for interpretative purposes as to the expected uses of these soils. The Medlin soil series makes up about 50 percent of this unit while the Eckrant soil series comprises approximately 30 percent of the total. Comfort soils may be less than 20 percent while the Krum soil series may comprise a much smaller percent of the total. The topographic sequence (Figure 2) finds the Eckrant soil on the upper side slopes and on the crest of the hills or ridges, while the Medlin is on the concave hillside below the Eckrant with the Krum below on the toe slope and the Comfort at the crest of ridges and narrow limestone rock ledges of the upper side slopes.

The A horizon or topsoil of the Medlin (MEC) is grayish brown stony to dark grayish brown clay about 9 to 11 inches thick. Stones may cover up to 40 percent of the surface but are usually much less. The underlying AC subsoil layers are light yellowish brown, light olive brown, olive brown, olive yellow or olive. The unique color and mottles also present are due to the very poor permeability and large amounts of shrink/swell clay present. The AC layers are 11 to 40 inches deep. The C horizon or weathered parent material is 50 to 80 inches deep and a light gray to light brownish gray shaly clay. Mottles (irregular spots of different colors) of olive yellow and yellow are common here due to the poor drainage and discontinuous oxygen content. These deep soils have formed in calcareous clay and shales with slopes of 1 to 30 percent.

The Eckrant soil (ErG) is usually very shallow to shallow well drained upland soils that may be on slopes ranging from 1 to as much as 30 percent. The topsoil is usually very dark gray or dark shades of brown or black. The top soil layer is extremely stony clay with lots of stone fragments that are 4 to 20 inches across and make up about 35 to 75 percent by volume of this surface soil horizon. This layer is maybe 10 inches deep and sits on an indurated fractured limestone layer classified as a R horizon that may extend from 10 to 20 inches. This fractured layer may have a very small amount of soil in some of the cracks. The Eckrant soil is shallow to very shallow with limited soil moisture due to the lack of soil depth and abundance of limestone rocks inside the profile. This soil is well drained and has a moderately slow permeability.

The Krum soil series (Kr), part of the Medlin-Eckrant Map Unit (MEC), is a very small acreage on the ranch and thus was not separated out as an individual map unit. This soil on the ranch is found on the gentle toe slopes below the Medlin. The topsoil, or A horizon, is a dark gray to very dark gray clay that is approximately 16 inches thick. The grayish brown to brown subsoil or B horizon is also clay and is 16 to 66 inches deep. Permeability of this layer is very slow. The C horizon or weathered parent material is a pale brown to light yellowish brown clay and is 66 to 80 inches deep. This soil is moderately alkaline throughout.

SOIL PROPERTIES

Eight soil series have been mentioned as occurring on the ranch in various map unit combinations or soil types (Figure 3). The series identified include the Anhalt, Comfort, Eckrant, Krum, Medlin, Orif, Rumple and Tarpley. Table 1 shows values (some measured and some estimated) of the more important soil physical and chemical properties (Soil Survey Lab Method Manual, 1996) that impact how each soil responds to use and management. Soil texture, which is a measure of the percent sand, silt and clay, is one of the most important properties to be identified because it has such a wide range of influence on other soil properties as well as the way the soil should be used and managed. All ranch soils, except the Orif, are relatively high in clay. The Orif is dominated by gravel and sands with less clay. A higher clay content usually means the soil is less permeable to air and water movement. Also, higher clay contents mean more moisture storage. However, most of the ranch soils with high clay content, except the Medlin and Krum, are limited in moisture storage by a lack of

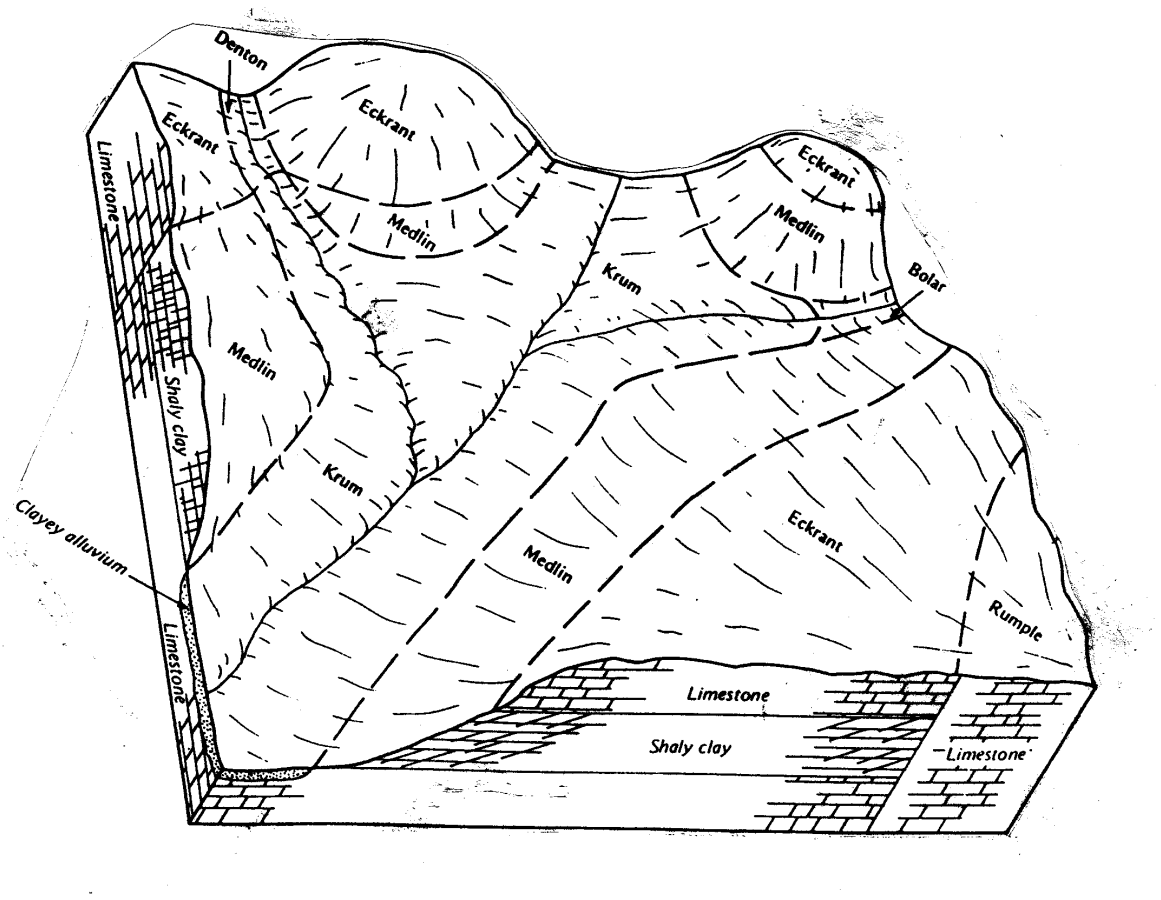

Fig. 2. Pattern of soils in the Brackett-Comfort-Real general soil map unit. (Taken from the Soil Survey of Comal and Hays Counties-Texas)

depth and a high percentage of rock and rock fragments in the profile. Soil volume taken up by rock takes away potential moisture storage by soil material. Another important clay property is the kind of clay minerals that make up the clay fraction. The dominant mineral in the ranch soil clays is smectite. This particular mineral has a tremendous shrink-swell potential when moisture content varies. This movement of soil masses causes instability for roads, buildings and fences. One positive for smectite clay is that it has a very large nutrient storage capacity. Another important clay mineral present is illite. This mica-type mineral is a good source of potassium.

Another very important physical property of soil is permeability. This is the movement of air and water through the soil. The Anhalt and especially the Medlin have very slow permeabilities. This makes internal drainage in these two soils a problem. Both have values of <0.06 inches per hour which is a severe limitation when using these soils for septic filter fields or other uses that need internal water drainage.

Available water supply is a property that is important in plant growth potential. As already mentioned, a lack of soil depth and a lack of soil volume due to rock are limiting factors for the Comfort, Eckrant, Rumple and

Tarpley. Even though these four soils may average 0.12-0.15 inches of water storage per inch of soil, the average soil depth is only 12 to 28 inches.

Soil reaction is a measure of the acidity or alkalinity of the soil. Most of the ranch soils are slightly below neutral to mildly alkaline. The higher pH or alkaline soils have more carbonate material present. Sometimes the mildly alkaline soils may be somewhat deficient in phosphorus for plant growth due to the effect of higher pH values on the availability of this element.

Erosion hazard depends upon several factors including climate, erosiveness of the individual soil, slope gradient and length, the type and amount of vegetation and the erosion control measures in place. The "K" factor in the Universal Soil Loss Equation (USLE) used by the Natural Resource Conservation Service (Troeh, et al., 1999) is a measure of an individual soil's erodibility. The K value ranges from 0 to 1.0. The values for Comfort, Eckrant, Orif, and Tarpley all are from 0.10 to 0.17 which means they are less erosive while Medlin, Anhalt and Krum are all 0.32 which means they are somewhat more susceptible to erosion. However, slope will override the good erodibility factor in soils such as the Comfort and Eckrant increasing the erosion hazard. Probably equally important to slope on the ranch soils is the influence of ground cover ("C" factor in the USLE). Overgrazing in some areas of the Hill Country is a major contributor to increased soil erosion.

Nutrient status of most of the ranch soils is fairly good. Calcium and magnesium are naturally present due to the abundance of limestone and dolomitic limestone. Potassium is also usually present in adequate amounts due to the presence of mica-like minerals in most of the soils. However, phosphorus is generally lacking in the soils, as is the case with nitrogen. Soils with a dark gray, dark brown or black topsoil usually have more than 2 to 3 percent organic matter. Organic matter is a good indicator of nitrogen supplying power of the soil. In clay soils, an organic matter content of 2-3 percent would mean that it has a low nitrogen supplying power. The Medlin and Orif soils probably have the least amount of organic matter making them have a very low nitrogen rating. Recycling of vegetative and organic materials resulting from good management such as controlled grazing and wildlife management help to maintain the nutrient status of the soils. Supplemental fertilization is usually not recommended on rangeland soils.

DISTRIBUTION AND USE OF RANCH SOILS

Land Capability Classification

There are several ways of categorizing soil. The taxonomic classification which includes identifying soil at the series level has already been discussed. Another general method of classifying soil is by Land Capability Classification (I, II, III, IV, V, VI, VII, VIII) (Miller and Gardiner, 1998). This allows soils to be grouped according to their suitability for a particular use. Low Roman numerals mean the soil is well suited for most uses while a high number means that the soil has severe limitations. The Anhalt series (included in the Comfort-Rock complex, undulating map unit-CrD) would be a capability class I, II or III depending upon slope, permeability and erosion as would the Krum series (included in the Medin-Eckrant association, undulating map unit-MEC). These soils are suitable for crop production or improved pasture, however both are less than an estimated 5 to 10 acres in size on the ranch which would also limit those kind of uses. The Tarpley (TaB) series which occupies about 27 acres around the ranch headquarter area is classified as a Class III or improved pastureland although due to the small acreage and lack of water storage and stoniness it is typically managed as a rangeland.

The Orif (Or) series is a Class V unit because of being subject to frequent flooding, or Class VI because of stoniness. Flooding and the high content of gravel limits this soil to certain uses which would exclude cropping. The Orif occupies an estimated 98 acres which lies along the floodplain of Sink Creek within the ranch.

The Rumple series which is part of the Rumple-Comfort association, undulating (RUD) is a Land Capability Class VI. Shallowness, slope, stoniness and in some cases rapid surface water runoff are severe limitations for the Rumple which eliminates its use for cropping and improved pastureland. The RUD map unit occupies an estimated 2056 acres on the ranch, especially on the perimeter areas (see Figure 3). The Comfort series part of the Rumple-Comfort association, undulating (RUD) is also rated in the Class VI category for the same reasons as

the Rumple series. The Comfort series part of the Comfort-Rock outcrop complex, undulating (CrD) is a Class VII due to their very shallow nature and stoniness. These severe limitations limit this soil to mainly wildlife use. The CrD map unit occupies an estimated 1997 acres mostly on the hilltops and ridgetops within the ranch. The Medlin series of the Medlin-Eckrant association, undulating (MEC) is capability class VI because of very slow permeability and erosiveness. Because of these severe limitations it is best used for rangeland and wildlife. The Eckrant series part of the MEC map unit is rated Class VII. The shallow, stony nature of this soil as well as the slope present some serious limitations for its use. The MEC map unit with the Medlin, Eckrant, and Krum series occur northeast from the First Christian Church on Ranch Road 12 (Figure 3).

Rangeland Classification

The five soil types identified on Figure 3 will be discussed in this section They include: Comfort-Rock outcrop, undulating (CrD); Medlin-Eckrant association, undulating (MEC); Orif soils (Or); Rumple-Comfort association, undulating (RUD); and Tarpley clay (TaB).

Range Sites. Soils are grouped together in relation to their ability to produce grass and other plants for grazing by livestock. Those soils within a given range site have similarities as to the kind and amount of plant forage material they typically will produce. The plant community produced in each site is unique. However, keep in mind that there are several soil types lumped together to form the aggregate map unit in many cases. Thus, the range site given for a particular map unit may have small inclusions of soil series that are very different in their ability to grow certain vegetation. For a more complete assessment of range sites and condition classes one should consult the Soil Survey of Comal and Hays Counties (Batte, 1984). Another reference with detailed information as to these range site descriptions can be found in Field Office Technical Guides USDA-SCS, Section II-E, 1994.

The Comfort-Rock outcrop complex, undulating (CrD), the Comfort part of the Rumple-Comfort association, undulating (RUD) and the Eckrant part of the Medlin-Eckrant association, undulating (MEC) are in the Low Stony Hills range site. The Eckrant series is the main soil in the unit. This site is characteristically low in soil moisture holding capacity due to the lack of soil volume because of the shallow nature (from 6 to 20 inches) of the soils and abundance of rocks (35 percent or more of soil volume). The rocky nature of the soils can in some cases "protect" animal-preferred grasses and forbs from being overgrazed or grazed too close to the ground. Soil in rock fissures provides for plant root water and nutrients. Fertility is adequate to produce climax vegetation but grazing management is critical to maintain a healthy ecosystem.

The Medlin series of the Medlin-Eckrant association, undulating (MEC) is in the Blackland range site. The Medlin occurs as narrow bands on concave slopes. Good forage production is possible under careful management. The soil is typically low in phosphorus and has very slow permeability. Although the soil is deep, there is some problem with root penetration due to the dense clay nature of the soil. Because the Medlin is so low in water permeability it is often used as a site for a farm pond. There is a small pond on the Medlin that is located on the ranch. Careful livestock management is critical to reduce the high erosion potential of this soil.

The Rumple series part of the Rumple-Comfort association, undulating (RUD) makes up the Gravelly Redland range site. This soil has a depth of 20 to 30 inches which helps some in water storage although it still lacks completely adequate supplies of soil moisture and may be moderately droughty. Chert and limestone fragments on the surface and within the soil profile limit the plant productivity somewhat. Internal drainage and permeability are fairly good for this clay soil allowing root penetration and growth.

The Tarpley soils (TaB) make up the Redland range site. Infiltration of water into this soil is sometimes hindered when it does not have shrink/swell cracks for water to run into if the soil is more moist and the cracks are swelled shut at the time of the rainfall event. Overharvest of vegetation and decreased organic plant residues may cause surface soil deterioration and a buildup of impermeable crusts, reducing water intake into the soil. The ameliorating effect of surface rock (up to 25 percent) can help infiltration and protect palatable grasses. Fertility is generally good and this site can produce nutritious forage.

The Orif soil (Or) is part of the Loamy Bottomland range site. This range site has good internal drainage but has low available moisture capacity and low natural fertility. Forage yields are moderate at best. A major problem is potential flooding from high stream flows and runoff from higher adjacent sites Seasonal and deferred grazing on this and all range sites should be practiced to ensure a desirable plant community.

Wildlife Classification

When considering wildlife today there are both consumptive uses such as harvest of deer and non-consumptive use such as bird watching and wildlife photography. Whatever the use may be, the one underlying issue critical to wildlife is habitat. Habitat and vegetation are strongly affected by soil resources. Soils are rated as good, fair, poor and very poor as to their potential for wildlife habitat. A fair or poor rating means there are increasingly severe limitations that must have very careful management systems in place for those soils to be effective in habitat production. The rating of very poor should exclude the use of that particular soil as a habitat. Provision of food, water and cover are elements of a desirable wildlife habitat. A detailed rating for soils (some of which are the ones found on the ranch) can be found in the Soil Survey of Comal and Hays Counties (Batte, 1984).

The Comfort-Rock outcrop complex, undulating (CrD) is a low forage producer due to its shallow and stony nature. It does have some smaller trees, shrubs and wild herbaceous plants that provide food and cover for deer, turkey and quail. The Medlin-Eckrant association, undulating (MEC) does not rate very well for wildlife, especially the Eckrant series part of the map unit. The Eckrant soil is too shallow and stony for grass, legumes and seed plants. The Medlin does sometimes provide for water collection in depressions and ponds. These soils can provide for cover and some food for wildlife making them fairly well suited for upland wildlife. The Orif (Or) soil is fairly well suited because of its location near creek channels and drainageways. Shrubs and herbaceous plants found on the Orif soil provide mainly cover but also some food supplies. The Rumple-Comfort association, undulating (RUD) is fairly well suited to wildlife due to the presence of shrubs and herbaceous plants. The Rumple produces some forage grasses since it is somewhat deeper and more productive than the Comfort. The Tarpley (TaB) is generally rated at least fair for most habitats associated with upland, and rangeland wildlife due to the fertility present.

Recreation Classification

Soils are rated as to degree of limitation when considering recreational uses. The ratings include slight, moderate and severe which means that a slight rating is desirable while moderate and severe indicate more and more problems will have to be overcome with special designs, planning or maintenance. The more severe the problem, the more costly and limited a given recreation use may become. For camping areas, picnic areas, and paths and trails the ranch soils present some significant limitations although the unique scenic qualities could make overcoming some of these limitations a desirable option. The Orif (Or) soil can be frequently flooded, thus camping and picnic uses should be avoided. Limitations for the Comfort-Rock outcrop complex, undulating (CrD) include stoniness and boulders as well as slopes that would make any shaping and leveling difficult for camping and picnic areas. The Medlin-Eckrant association, undulating (MEC) is a problem particularly in the Medlin due to the clayey surface texture and very slow permeability. The Eckrant part of the map unit is sloping and has large amounts of stones and boulders which would make any recreational use difficult. The Rumple-Comfort association, undulating (RUD) has severe limitations mainly due to the abundance of small stones on the surface of both the Rumple and Comfort and the presence of large rocks in the Comfort. The Tarpley (TaB) has limitations of shrink/swell clay and depth of soil to rock but can be overcome with good design and maintenance.

Building Site Classification

Soils can be rated as slight, moderate or severe as to their limitations when considering a building site. Foundations, septic filter fields, roads, and landscaping are considerations when rating a soil's limitation. The Orif (Or) soil is severe because of flooding while the other ranch soils are severe mainly because of a lack of depth, stoniness, high shrink/swell clay and slow percolation. With this in mind, the soils found on the ranch

would be unlikely sites for buildings were it not for the aesthetics. Because of the beauty of the area, the severe limitations of the soils involved require costly designs and increased maintenance in order to use these soils for building sites.

REFERENCES

Batte, C. D. 1984. *Soil Survey of Comal and Hays Counties-Texas.* U.S. Gov. Print. Office, Washington, D.C.

Brady, N. C. and R. R. Weil. 1999. *The Nature and Properties of Soils*. 12th ed. Prentice-Hall, Inc., Upper Saddle River, New Jersey.

Godfrey, C. L., C. R. Carter and G. S. McKee. 1976. *Land Resource Areas of Texas.* Texas Agricultural Experiment Station, College Station, Texas.

Miller, R. W. and D. T. Gardiner. 1998. *Soils in Our Environment*. 8th ed. Prentice-Hall, Inc., Upper Saddle River, New Jersey.

Soil Survey Staff. 1994. *Range Site Descriptions.* Field Office Technical Guides: Section II-E. San Marcos, Texas.

Soil Survey Staff. 1996. *Soil Survey Laboratory Methods Manual*. USDA-NRCS Soil Survey Investigations Report No. 42, Version 3.0 U.S. Gov. Print. Office, Washington, D.C.

Troeh, F. R., J. A. Hobbs and R. L. Donahue. 1999. *Soil and Water Conservation: Productivity and Environmental Protection*. 3rd ed. Prentice-Hall, Inc., Upper Saddle River, New Jersey.

SUGGESTED READINGS

Bolen, E. G. and W. L. Robinson. 1995. *Wildlife Ecology and Management*. 3rd ed. Prentice-Hall, Inc., Upper Saddle River, New Jersey.

Loynachan, T. E., K. W. Brown, T. H. Cooper and M. H. Milford. 1999. *Sustaining Our Soils and Society*. American Geological Institute, Alexandria, Virginia.

Owen, O. S. and D. D. Chiras. 1990. *Natural Resource Conservation: An Ecological Approach*. 5th ed. McMillan, Inc., New York, New York.

White, R. E. 1997. *Principles and Practice of Soil Science: The Soil as a Natural Resource*. Blackwell Science, Inc., Malden, Massachusetts.