Lewis & Clark National Forest
White Sulphur & Belt Creek
Ranger Districts

SOIL MONITORING REPORT
SHEEP CREEK RANGE PROJECT AREA

Compiled by
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12/23/2002 1:29 PM

Lewis & Clark NF
White Sulphur &
Belt Cr. Ranger
District

INTRODUCTION

Soil monitoring was conducted in the Sheep Creek Range Project area for the purpose of documenting baseline soil condition information on primary rangelands. Soil Scientists, Sue Farley, Vince Archer and Tyler VanGemert implemented this monitoring during late June and early July 2002.

MONITORING PLOT SELECTION

Soil monitoring plots were selected in the field based on several criteria:

- Representative of primary rangelands and areas known for livestock use;
- Located on as many allotments as possible;
- Distributed on both upland and valley bottom landscape positions;
- Valley bottom plots located along segments of stream rated as functioning at risk or non-functioning, and;
- Accessible by motor vehicle (because the required equipment and supplies were too heavy and numerous to carry on foot).

A total of 21 monitoring plots were evaluated during a 3-week period. Of these, 12 plots were situated on upland landscape positions, and 9 on valley bottoms. These plots were located on 11 different allotments:

ALLOTMENT NAME	NUMBER OF UPLAND SAMPLE PLOTS	NUMBER OF VALLEY BOTTOM SAMPLE PLOTS
Bald Hills	2	1
Black Butte	NR	1
Cabin Creek	1	NR
Calf & Indian Island	1	1
Copper Creek	1	1
Deep Creek Park	2	NR
Eagle Creek	1	NR
Green Mountain	NR	2
Jumping Creek	NR	1
Newlan Creek	2	1
Studhorse Creek	2	1

MONITORING METHODS

Monitoring at each plot assessed the following soil parameters:

- Standard soil profile description and soil classfication
- Extent and type of ground cover
- "A" horizon thickness, color, structure and texture
- Soil bulk density
- Soil infiltration rates
- Soil organic matter content
- Plant rooting depth and abundance.

Soil erosion was not monitored for several reasons. First, erosion is not a sensitive indicator for trend in rangeland condition. In one study, "Plant cover and plant vigor had already changed significantly before accelerated soil movement became obvious" (Passey et al. 1982, page 48). Second, the commonly accepted indicators for accelerated erosion (i.e. soil deposition, soil surface crusts, pedastalling of plants, and rock pavements on the soil surface) are natural phenomena that can occur "independent of disturbance caused by man" (Passey et al. 1982, page 47). Third, erosion is difficult to measure accurately (Wells and Wohlgemuth 1987), especially after it has occurred and the evidence has been masked by other disturbance.

Soil Description and Classification

A soil profile description was completed at each plot to document the landtype. Standard soil methods were used to describe the soil profile (Schoenberger et al. 1998). A profile description provides information on physical soil characteristics in the field, such as color, texture, structure, depth of different horizons (i.e. layers), etc. The profile description also includes information on basic site characteristics, such as slope gradient, aspect, landform, geology, etc. Information obtained with the soil profile description was used to classify the sampled soils (Soil Survey Staff 1999).

Ground Cover

The extent and type of ground cover was recorded on three transects at each plot. Ground cover was measured using a frequency frame sample method at 5 points on each 20 meter transect (Weixelman et al. 1999).

"A" Horizon Characteristics

Characterization of the "A" horizon thickness, color, structure and texture was completed with the profile description and on each of the ground cover transects. The "A" horizon was characterized using standard soil methods (Schoenberger et al. 1998).

Soil Bulk Density

Three soil bulk density samples were obtained from each plot. Soil bulk density was measured using the core sample method (Blake and Hartge 1986).

Soil Infiltration Rates

Soil infiltration rates were measured at three sites within each monitoring plot. Soil infiltration was assessed using the ring infiltrometer method (Bouwer 1986).

Soil Organic Matter Content

Triplicate samples for soil organic matter were obtained on each plot, taken from the bulk density cores after bulk density had been measured. Soil organic matter content was evaluated using the loss on ignition method (Nelson and Sommers 1982).

Plant Rooting Depth and Abundance

Plant rooting depth and abundance were recorded on three transects at each plot (e.g. the same transects evaluated for soil cover and "A" horizon characteristics). Plant rooting depth and abundance were determined using standard soil methods implemented with an auger (Weixelman et al. 1999).

LIMITATIONS FOR USE OF MONITORING INFORMATION

There are a number of limitations associated with the information obtained through these monitoring methods. These limitations must be considered when interpreting soil monitoring information, and drawing conclusions regarding effects of livestock grazing on soil conditions.

A recent review of livestock grazing studies found, "very few studies of truly ungrazed landscapes exist". Thus, "we lack a clear ecological benchmark for determining the effects of grazing" (Fleischner 1994, page 630). Consistent with this review, there are no previous soil condition monitoring data for the Sheep Creek Range Project area. Thus, there is no well-defined benchmark for determining changes in soil condition associated with past livestock grazing in the project area.

The monitoring data gathered during summer 2002 provides a baseline for documenting current soil conditions. Because no historic data exists to document past soil conditions, any conclusions regarding how past livestock grazing has affected current soil conditions will be based on professional interpretation. This is consistent with recommendations by the National Research Council regarding rangeland monitoring: "evaluation of what constitutes a healthy, at risk, or unhealthy distribution of plants, bare areas, rooting depths, and growth periods will depend primarily on informed judgments" (National Research Council 1994, page 120).

Due to time and personnel constraints, a very limited number of monitoring plots and soil samples were evaluated for the Sheep Creek Range Project area. This limited number of monitoring plots and soil samples is not enough to allow for a high level of confidence in statistical analyses. Thus, statistical analyses for this soil information will be limited to simple, descriptive statistics.

Because soils are spatially variable, a point sample may not precisely represent the soils across an entire monitoring plot. Nonetheless, if surface features such as soil color and structure or plant composition and cover do not vary tremendously then it is reasonable to expect that soils should be similar across a monitoring plot. In addition, replicated samples within a plot can aid in documenting the degree of soil variability. Replicated samples were evaluated at each plot for soil cover and plant rooting depth (5 sample points on each of 3 transects), soil bulk density and soil organic matter (3), and "A" horizon characteristics (1 sample point on each of 3 transects, plus 1 sample with the soil profile description).

Because soils are spatially variable, point samples may not accurately represent the full range of soil conditions across larger landscapes, such as entire allotments or the project area. These point samples should be viewed as "spot checks", which evaluate soil health on key areas within primary rangelands. Nonetheless, the sites sampled are considered representative of areas that have experienced soil impacts due to livestock grazing. This is because the sample sites selected were located in primary rangeland areas known for livestock use, and associated with impacted streams in valley bottom landscapes.

Because integrity of the soil is disturbed with digging for the initial sample, most of these soil measurements cannot be duplicated at the same location. This circumstance creates challenges for validating monitoring results, and for future monitoring of changes in soil condition.

For the ground cover sample method, gophers, and other burrowing organisms, may cast fresh soil onto the ground surface. In this case, there may be substantial areas of bare soil. However, this does not indicate unhealthy soil conditions. On the contrary, soil mixing due to activity of burrowing organisms typically indicates healthy soil processes. This soil mixing improves distribution of organic material, and burrowing increases soil aeration and water infiltration capacity.

Soil infiltration rates may also be affected by animal burrowing. Infiltration rates may be exceptionally high, if the infiltration ring is placed directly over a burrow. In this case, the animal burrow acts as a "pipeline" to quickly funnel large amounts of water into the subsoil. These exceptionally high infiltration rates may not be representative of the entire site.

MONITORING RESULTS AND DISCUSSION

Soil Description and Classification

Information obtained through the soil profile descriptions is displayed in Table 1. Soils were classified as Ustic or Pachic Argicryolls at 16 of these sites. These soil types were found on both landscape positions sampled: upland meadows (9 sites) and riparian valley bottoms (7 sites). Ustic Argicryolls most often were found on upland landscape positions. Pachic Argicryolls were most often found in the riparian valley bottoms. These two classifications indicate the soils have a dark-colored, organic-rich surface layer, and subsoils with moderate clay accumulation and soil development. These soils are typical of meadow or grassland ecosystems found within the project area. Most of these sites had surface soil textures of silt loam or clay loam. Slope gradient ranged from 0-15 percent at these sites (except at Daisy Spring, where slope was 32%).

Soils in the riparian valley bottom at Jumping Creek and Indian Creek were classified as Typic Cryaquolls. This classification indicates these soils have a high water table and are usually saturated. These soils also have a dark-colored, organic-rich surface layer. So, these are representative of wet meadow soils found within the project area. Surface soil texture was silt loam or silty clay loam, and slope gradient was 3-5 percent.

Soils at the remaining two sites were located on upland landscape positions, and were classified as Ustic Haplocryalfs. The site in the area of Lake Creek (i.e. plot 02SF026) did not have a surface layer that was dark-colored or deep enough to qualify as a typical grassland soil. This site had evidence of relatively recent prescribed burning, which facilitated a site conversion from sagebrush shrubland to fescue grassland. The site in the area of Cabin Creek (i.e. plot 02SF015) did not classify as a typical grassland soil, because the surface soil had 35% clay content resulting in hard to very hard consistence when dry. Both sites have subsoils with moderate clay accumulation and soil development. Surface soil textures were loam or silt loam, and slope gradient was 2-8%.

"A" Horizon Characteristics

With these soil profile descriptions, 18 of the sites evaluated had dark-colored, organic-rich surface layers, or "A" horizons. "A" horizons with these characteristics are termed mollic epipedons. Soils with mollic epipedons are classified as mollisols, and are typically grassland soils. The mollic epipedon was found to a depth of 40 centimeters, or greater, on 12 of those sites. Mollic epipedons with this depth are termed pachic.

The "A" horizon information is useful in evaluating rangeland productivity. For rangeland soils in Montana, Wyoming and North Dakota, one research study found mollisols with pachic epipedons denoted the most productive sites (Cannon 1983, page 13). Thus, the majority of soils sampled within the Sheep Creek Range Project area represent highly productive rangeland sites.

Plant Rooting Depth and Abundance

Information obtained through evaluation of plant rooting depth and abundance, ground cover transects, bulk density samples, soil infiltration testing, and soil organic matter content is summarized in Table 2. The "raw" monitoring data for these soil parameters is contained in the Appendix.

The monitoring data for plant rooting depth and abundance, showed the depth of "many" roots (i.e. greater than 100 very fine or fine size roots within an area of one square decimeter) ranged from 0-2 centimeters. The depth of "common" roots (i.e. 10-100 very fine or fine size roots within an area of one square decimeter) ranged from 5-15 centimeters.

These roots represent the "sod mat" typically found in the topsoil on grasslands. These roots are critical in maintaining organic matter and contribute to nutrient cycling in the topsoil, as the roots die and decompose. These roots also aid in maintaining soil structure, bulk density, porosity and infiltration capacity.

The health and biomass of plant roots closely depends on plant photosynthesis for production of carbohydrates. Disturbance that significantly decreases the amount of plant leaves capable of photosynthesis will also decrease the root mass. Grazing reduces the amount of plant leaves. If overgrazed, the plant will not be able to produce enough carbohydrate reserves to maintain root mass.

Drought can also impact plant growth and root biomass, particularly when combined with grazing. Researchers found that soils grazed moderately during drought were able to recover following the dry period. Whereas, heavily grazed soils were not able to recover, and the trend in soil condition "followed a stair-step pattern typified by decreasing condition during drought, and an inability to recover to pre-drought level during periods of above-normal precipitation" (Thurow et al. 1988, page 296).

When evaluating plant rooting depth information, "The healthy end of the continuum consists of...plants that fill the soil profile with roots". And "The unhealthy end of the continuum probably consists of...plants that fill only a small portion of the soil profile with roots" (National Research Council 1994, page 120).

On all but 2 of the monitoring plots (i.e. plots 02SF024 and 02SF025), the root mat did not fill the entire "A" horizon (i.e. topsoil). This condition is most pronounced on 3 sites where the root mat fills less than half the "A" horizon: plots 02SF008, 02SF011, and 02SF020. Based on professional judgment, the depth and abundance of roots appears to be lacking in vigor, especially on those 3 sites, compared to what is expected in healthy native grasslands (National Research Council 1994, page 120).

The exact cause for decline in plant rooting vigor on these monitoring sites has not been quantified. It is likely that both grazing and 4 years of drought have combined to reduce plant root vigor. The extent that plant-rooting vigor will be able to recover on these sites, once the current drought has subsided, is uncertain.

Ground Cover

When evaluating ground cover information, "The healthy end of the continuum consists of an unfragmented distribution of plants and litter with few bare areas", and "The unhealthy end of the continuum probably consists of a fragmented plant cover with many large bare areas" (National Research Council 1994, page 120). A research study on fescue grassland ecosystems in Alberta found that increased bare ground was "of practical significance since hydrologic changes such as reduced infiltration and increased runoff occur in this ecosystem when bare ground is approximately 15%" (Naeth et al. 1991, page 11).

Soil cover information can also be used to corroborate interpretations of soil conditions derived from other monitored parameters. For example, one study documented, "Total organic cover was the most important factor determining infiltration rate" (Thurow et al. 1988, page 296). Thus, a large area of bare ground should coincide with slow infiltration rates.

The monitoring data for ground cover showed that bare ground ranged from 2-64 percent of the area within plots. Contrary to the research study cited above (Thurow et al. 1988), the monitoring data did not show any apparent relationship between ground cover and infiltration rates.

Of the 19 plots evaluated for ground cover, 12 had bare ground on greater than 15 percent of the area. Of these 12 plots, gopher activity was noted along ground cover transects on 2 sites (i.e. plots 02SF017 and 02SF022). For comparison, gopher activity was noted on 4 other sites, where bare ground did not exceed 15 percent of the area (i.e. plots 02SF012, 02SF018, 02SF024 and 02SF026). Plot 02SF020 was located in an area of concentrated livestock use, adjacent to a water development, where bare ground is expected to be high. Based on professional judgment, the amount of bare ground appears to be high on these 12 plots compared to what is expected in healthy native grasslands (National Research Council 1994, page 120). Both grazing and effects from 4 years of drought may have combined to increase bare ground at these sites.

Soil Bulk Density

Soil bulk density data can be used in evaluating effects of livestock grazing. For example, soil trampling from concentrated livestock traffic can increase soil bulk density. One research study found, "On heavily grazed range, bulk densities increased 7% (*in the surface layer*), 4% (*at the 6 to 10 inch depth*), and 2% (*at the 12 to 16 inch depth*)" (Duvall and Linartz 1967, page 245).

With the soil core samples, average bulk density for each plot ranged from 0.71-1.56 grams per cubic centimeter (g/cc). Of the 21 plots evaluated for bulk density, 18 had average soil bulk densities lower than 1.1 g/cc. The remaining 3 plots had an average soil bulk density greater than 1.1 g/cc (e.g. 02SF020, 02SF021 and 02SF022).

Plot 02SF020 had the highest average bulk density value of 1.56 g/cc. This plot was located in an area of concentrated livestock use, adjacent to a water development, where bulk density was expected to be high due to soil compaction from animal trampling. This soil compaction was corroborated by visual evidence of platy soil structure with evaluation of "A" horizon characteristics at this site.

Plots 02SF021 and 02SF022 were located in the same general area as plot 02SF020. It is uncertain if these two plots had high bulk density values solely due to soil compaction resulting from livestock use. Soils in this area may have naturally higher bulk density because they are derived from different geologic materials (i.e. sandstone and shale compared to limestone for other sites). Perhaps the higher bulk density at these 2 sites is due to a combination of these factors.

Soil Infiltration Rates

Soil infiltration data can be used in evaluating effects of livestock grazing. For example, one research study found, "Grazing was generally detrimental to water infiltration and percolation" (Duvall and Linartz 1967, page 246). Research studies have found that soil infiltration data can sometimes be correlated with, and therefore corroborate, data from other monitored soil parameters (Van Haveren 1983, page 588).

For the soil infiltration tests, water filtered into the soil at average rates ranging from 3.1-120 liters in 32.5 minutes (L/32.5 min.). These data represent exceptionally high variability for infiltration rates between the various soils sampled. With this monitoring, infiltration data did not display any strong correlation with other data, such as bulk density or ground cover. However, trends for infiltration did appear to correspond to the landscape position sampled: valley bottom riparian sites generally had higher infiltration rates compared to upland sites (Figure 1).

The highest average infiltration rate, 120 L/32.5 min., was recorded on plot 02SF006. Gopher activity was noted at this test site, and it seems likely this affected the infiltration test results.

The lowest infiltration rate for one test, 0.5 L/32.5 min., was recorded at plot 02SF020. Soil compaction, due to concentrated livestock use at a water development, was documented at this plot. This soil compaction likely accounts for the low infiltration rate.

Soil Organic Matter Content

Information about soil organic matter can be used in evaluating effects of livestock grazing. For example, one research study found, "Heavy intensity and/or early season grazing had greater negative impacts on litter and soil organic material than did light intensity and/or late season grazing" (Thurow et al. 1988, page 296).

Soil organic matter ranged from an average of 6 to 24 percent in the samples analyzed. This data showed a relationship to bulk density values: as soil organic matter decreases, bulk density tends to increase (Figure 2).

The site with the highest value for soil organic matter (i.e. plot 02SF009) had the lowest bulk density value. The sites with the three lowest values for soil organic matter (i.e. plots 02SF020, 02SF021, and 02SF022) had the three highest bulk density values.

The site with the lowest organic matter content (i.e. plot 02SF020) was located in an area of concentrated livestock use, adjacent to a water development. Negative impacts on soil organic matter in this area of heavy intensity livestock traffic is consistent with the research study cited above (Thurow et al. 1988).

SUMMARY AND CONCLUSIONS

In summary, the majority of soils sampled on primary rangelands within the Sheep Creek Range Project area represent highly productive rangeland sites. On all but 2 of the sites, the depth and abundance of roots does not completely fill the "A" horizon and appears to be lacking in vigor, compared to what is expected in healthy native grasslands. This condition is most pronounced on 3 sites where the root mat fills less than half the "A" horizon: plots 02SF008, 02SF011, and 02SF020. The amount of bare ground appears to be high on the 12 plots where bare soil exceeds 15 percent of the area, compared to what is expected in healthy native grasslands. Drought over the past four years, combined with grazing, has likely played a role in affecting both plant-rooting vigor and amount of bare ground.

Three plots had an average soil bulk density greater than 1.1 g/cc (e.g. 02SF020, 02SF021 and 02SF022), which may indicate compaction due to concentrated livestock use. Based on professional judgment, the highest average bulk density value does indicate soil compaction due to concentrated livestock use. This highest bulk density value coincided with the lowest infiltration rate for a single test: 0.5 L/32.5 min. recorded at plot 02SF020. Otherwise, infiltration data showed exceptionally high variability between the soils sampled, and did not display any strong correlation with other data, such as bulk density or ground cover. Soil organic matter data showed a relationship to bulk density values: as soil organic matter decreases, bulk density tends to increase. The site with the lowest organic matter content (i.e. plot 02SF020) was located in an area where negative impacts on soil organic matter occurred due to heavy intensity livestock traffic.

In conclusion, soil monitoring completed for 21 sites located on primary rangeland documented that soil health is currently impaired for at least one soil parameter on 19 of those sites. This monitoring data suggests healthy soil conditions exist at the remaining two sampling sites (i.e. plots 02SF024 and 02SF026).

It is possible that some of these soil effects remain from historic grazing. Soil recovery under semi-arid climatic conditions can require decades before improvement occurs, particularly if grazing continues during the recovery period. Researchers found that on severely degraded soil where moderate grazing continued, "more than 55 years were required for soil to return to native range standards" (Dormaar and Willms 1990, page 456).

It is likely that the current grazing regime, perhaps combined with the effects of 4 years drought, has contributed to impaired soil health and may have perpetuated residual effects from historic grazing.

The monitoring site that showed the greatest magnitude of soil degradation was located at a livestock water development (i.e. plot 02SF020). This site had the least amount of the "A" horizon filled with plant roots (24%), a large area of bare ground (29%), the highest average bulk density (1.56 g/cc) with platy soil structure due to soil compaction, the slowest soil infiltration rate for one test (0.5 L/32.5 min), and the lowest soil organic matter content (6%). This site showed obvious soil impacts due to grazing for every parameter monitored. Based on professional judgment, the magnitude of soil degradation at this monitoring site (i.e. plot 02SF020) constitutes detrimental soil disturbance (USDA Forest Service 1999). Detrimental soil disturbance implies that the site has exceeded an ecological threshold where long-term soil productivity is significantly impacted by current conditions.

This data demonstrates that the greatest soil impacts from livestock grazing occur in areas of highly concentrated use, such as at water developments, locations of salt placement, and animal trailing corridors along fence lines. The (i.e. plot 02SF020) data obtained at this site is considered representative of soil conditions at other areas of highly concentrated livestock use within the project area.

The data also documents that the magnitude of soil impacts seen at the other 18 monitoring sites, most notably in riparian areas, is less pronounced than impacts at plot 02SF020 (i.e. the area of concentrated livestock use). Based on professional judgment, the monitoring data at the majority of other sites suggests that there is adequate soil organic matter to sustain nutrient cycling, infiltration capacity for water absorption and retention, and soil bulk densities that will allow root penetration (Daddow and Warrington 1983).

The primary parameters that may affect soil productivity over the long-term are the high amounts of bare ground, and lack of plant-rooting depth and abundance. If these sites have opportunity to regain plant-rooting vigor and soil cover provided by plants, soil conditions should provide the capability to sustain the current level of soil productivity over the long-term. This implies that long-term soil productivity is not significantly impacted by current conditions on these other 18 sites, if these areas can recover vegetative vigor.

Table 1. Summary of Site-specific Soil Characteristics For Primary Rangelands Within Sheep Creek Range Analysis Project Area (USDA Forest Service 2002).

PLOT NUMBER	AREA LOCATION	SOIL CLASSIFICATION	LANDFORM	SLOPE GRADIENT	TOPSOIL TEXTURE	DEPTH (cm) OF MOLLIC EPIPEDON
02SF009	Copper Crk.	Ustic Argicryolls	Upland Meadow	5	Silt Loam	37
02SF012	Lake Crk.	Ustic Argicryolls	Upland Meadow	0	Silt Loam	32
02SF014	Williams Park	Ustic Argicryolls	Upland Meadow	5	Silt Loam	22
02SF015	Cabin Crk.	Ustic Haplocryalfs	Upland Meadow	8	Silt Loam	NA
02SF017	Indian Crk.	Ustic Argicryolls	Upland Meadow	12	Silt Loam	32
02SF019	Newlan Crk.	Ustic Argicryolls	Upland Meadow	12	Silt Loam	30
02SF020	Daisy Spring	Pachic Argicryolls	Upland Meadow	32	Very Fine Sandy Loam	45
02SF023	Robertson Spring	Pachic Argicryolls	Upland Meadow	5	Silt Loam	48
02SF024	Deep Creek Park	Ustic Argicryolls	Upland Meadow	3	Silt Loam	27
02SF025	Abbott Gulch	Pachic Argicryolls	Upland Meadow	5	Silt Loam	40
02SF026	Lake Crk.	Ustic Haplocryalfs	Upland Meadow	2	Loam	NA
02SF006	Studhorse Crk.	Pachic Argicryolls	Valley Bottom-Riparian	5	Clay Loam	105
02SF007	Miller Gulch	Pachic Argicryolls	Valley Bottom-Riparian	5	Silt Loam	55
02SF008	Copper Crk.	Pachic Argicryolls	Valley Bottom-Riparian	5	Silt Loam	72
02SF010	Pistol Crk.	Pachic Argicryolls	Valley Bottom-Riparian	5	Silt Loam	82
02SF011	Allen Gulch	Pachic Argicryolls	Valley Bottom-Riparian	5	Clay Loam	48
02SF013	Jumping Crk.	Typic Cryaquolls	Valley Bottom-Riparian	5	Silty Clay Loam	40
02SF016	Indian Crk.	Typic Cryaquolls	Valley Bottom-Riparian	3	Silt Loam	46
02SF018	Black Butte Crk.	Pachic Argicryolls	Valley Bottom-Riparian	5	Silt Loam	82
02SF022	Daisy Creek	Pachic Argicryolls	Valley Bottom-Riparian	15	Loam	45

NOTES:

A mollic epipedon is the dark-colored, organic-rich surface layer of soil that is used in soil taxonomy to classify grassland soils (i.e. Mollisols).

NA = Not Applicable

Table 2. Summary of Site-specific Soil Monitoring Data For Primary Rangelands Within Sheep Creek Range Analysis Project Area (USDA Forest Service 2002).

PLOT NUMBER	ALLOTMENT NAME	DEPTH (cm) MANY ROOTS (>100 fine & v. fine)	DEPTH (cm) COMMON ROOTS (10-100 fine & v. fine)	DEPTH (cm) "A" HORIZON	BARE GROUND (% area)	Avg Of BULK DENSITY (g/cc)	Avg of INFILTRATION (L/32.5 min)	Avg Of ORGANIC MATTER (Percent)
02SF006	Studhorse	2	15	24	NR	0.94	120.0	12
02SF007	Newlan Crk.	1	11	20	9	0.97	20.0	13
02SF008	Copper Crk.	0	10	28	3	0.89	11.1	15
02SF009	Copper Crk.	1	15	30	28	0.71	4.2	24
02SF010	Green Mtn.	0	11	17	17	0.88	71.1	12
02SF011	Green Mtn.	1	11	29	57	0.92	57.3	18
02SF012	Studhorse	2	11	13	2	0.79	7.2	17
02SF013	Jumping Crk.	1	9	12	31	0.96	22.4	15
02SF014	Eagle Crk.	1	11	14	22	0.77	3.1	16
02SF015	Cabin Crk.	0	7	12	64	1.02	14.4	18
02SF016	Calf & Indian Island	0	9	14	7	1.01	24.7	13
02SF017	Calf & Indian Island	0	7	14	50	0.89	18.8	15
02SF018	Black Butte	0	10	14	13	0.99	47.2	14
02SF019	Newlan Crk.	2	10	11	36	0.94	9.4	15
02SF020	Bald Hills	0	5	21	29	1.56	3.6	6
02SF021	Bald Hills	NR	NR	NR	NR	1.22	NR	11
02SF022	Bald Hills	0	6	12	24	1.33	NR	8
02SF023	Deep Crk. Park	0	8	16	22	1.07	13.0	14
02SF024	Deep Crk. Park	2	7	7	7	0.91	4.3	16
02SF025	Newlan Crk.	1	10	12	22	0.87	5.5	12
02SF026	Studhorse	2	10	8	6	1.04	11.8	12

Note: NR = No Record

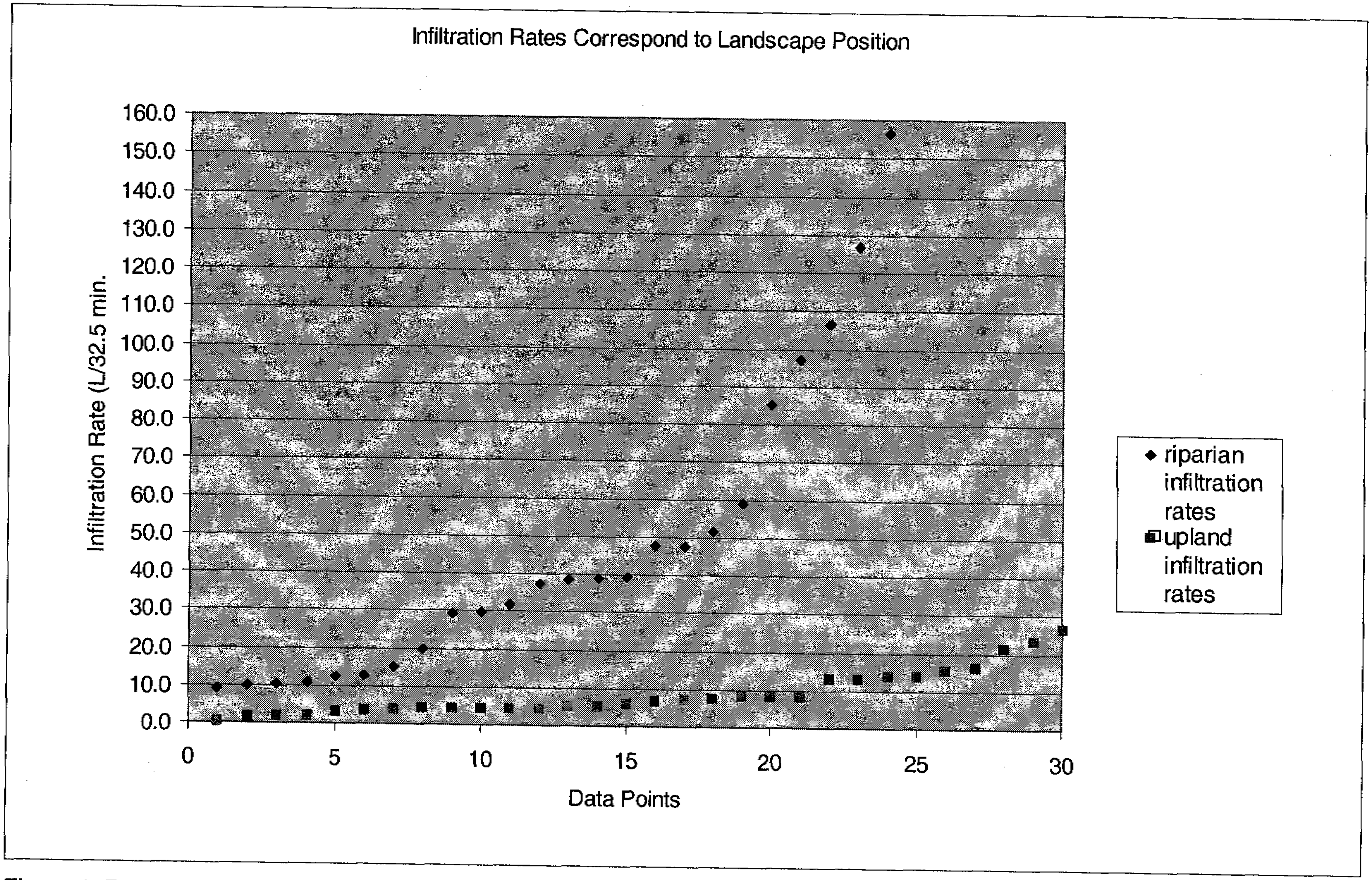

Figure 1. Relationship Between Infiltration Rates and Landscape Position (USDA Forest Service 2002).

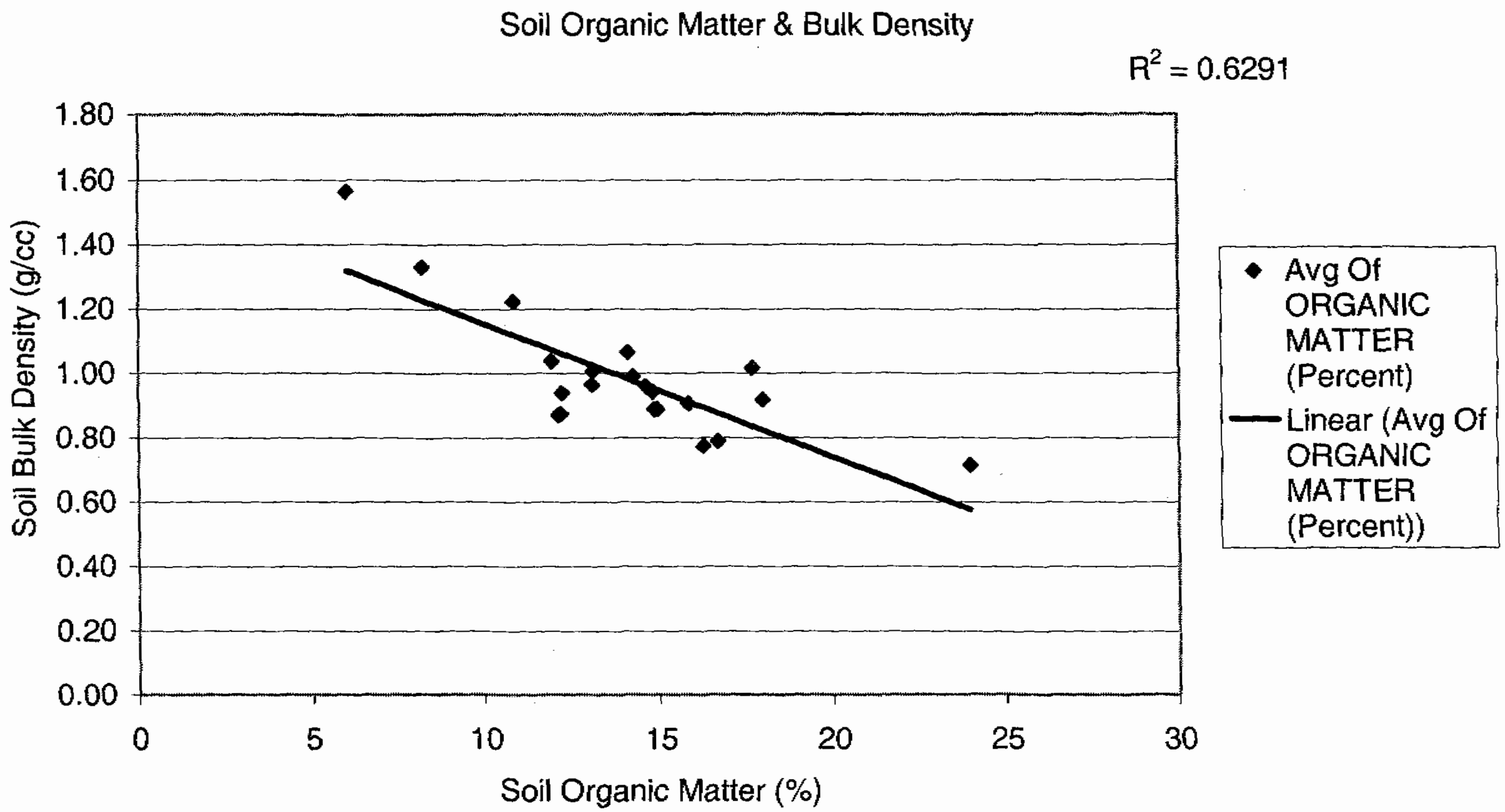

Figure 2. Relationship Between Soil Organic Matter and Bulk Density (USDA Forest Service 2002).

BIBLIOGRAPHY

Blake, G.R. and K.H. Hartge. 1986. Bulk density. In Methods of soil analysis, Part 1 – physical and mineralogical methods. Second edition. Published by American Society of Agronomy, Inc. and Soil Science Society of America, Inc. Madison Wisconsin. Pages 363-375.

Bouwer, Herman. 1986. Intake rate: cylinder infiltrometer. In Methods of soil analysis, Part 1 – physical and mineralogical methods. Second edition. Published by American Society of Agronomy, Inc. and Soil Science Society of America, Inc. Madison Wisconsin. Pages 825-843.

Cannon, Mary Ellen. 1983. Estimating range production from thickness of mollic epipedon and other soil or site characteristics. A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils. Montana State University, Bozeman, Montana.

Daddow, Richard L., and Gordon E. Warrington. 1983. Growth limiting soil bulk densities as influenced by soil texture. WSDG Report WSDG-TN-00005. Watershed Systems Development Group, USDA Forest Service, Fort Collins CO.

Dormaar, Johan F. and Walter D. Willms. 1990. Effect of grazing and cultivation of some chemical properties of soils in the mixed prairie. Journal of Range Management 43(5), pages 456-460.

Duvall, Vinson L. and Norwin E. Linartz. 1967. Influences of grazing and fire on vegetation and soil of longleaf pine-bluestem range. Journal of Range Management, Volume 20, No. 4. Pages 241-247.

Fleischner, Thomas L. 1994. Ecological costs of livestock grazing in Western North America. Conservation Biology, Volume 8, No. 3. Pages 629-644.

Naeth, M.A., A.W. Bailey, D.J. Pluth, D.S. Chanasyk and R.T. Hardin. 1991. Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. Journal of Range Management 44(1), pages 7-12.

National Research Council. 1994. Rangeland health, new methods to classify, inventory, and monitor rangelands. National Academy Press, Washington, D.C.

Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. In Methods of soil analysis, Part 2 – chemical and microbiological properties. Second edition. Published by American Society of Agronomy, Inc. and Soil Science Society of America, Inc. Madison Wisconsin. Pages 539-577.

Passey, H.B., Vern K. Hugie, E.W. Williams, and D.E. Ball. 1982. Relationships between soil, plant community, and climate on rangelands of the Intermountain West. U.S.D.A. Technical Bulletin No. 1669.

Schoenberger, P.J., D.A. Wysocki, E.C. Benham, and W.D. Broderson. 1998. Field book for describing and sampling soils, version 1.1. USDA Natural Resources Conservation Service, National Soil Survey Center, Lincoln Nebraska.

Soil Survey Staff. 1999. Keys to soil taxonomy, 8th Edition. Soil Conservation Service, USDA. Pocahontas Press, Inc. Blacksburg VA.

Thurow, Thomas L., Wilbert H. Blackburn, and Charles A. Taylor, Jr. 1988. Infiltration and interrill erosion responses to selected livestock grazing strategies, Edwards Plateau, Texas. Journal of Range Management 41(4). Pages 296-302.

USDA Forest Service, 1999. Forest Service Manual, FSM 2500 – Watershed and air management, R-1 Supplement No. 2500-99-1. Effective November 12, 1999. Chapter 2550 – Soil Management, Section 2554 – Soil quality monitoring.

Van Haveren, Bruce P. 1983. Soil bulk density as influenced by grazing intensity and soil type on a shortgrass prairie site. Journal of Range Management, Vol. 36, No. 5, Pg. 586-588.

Weixelman, Dave A., Desiderio C. Zamudio and Karen A. Zamudio. 1999. Eastern Sierra Nevada riparian field guide. USDA Forest Service, Intermountain Region, Publication No. R4-ECOL-99-01. Pages 3-24 through 3-26.

Wells II, Wade G. and Peter M. Wohlgemuth. 1987. Sediment traps for measuring onslope surface sediment movement. Research Note PSW-393. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, CA.