SOIL MONITORING REPORT
CLANCY-UNIONVILLE PROJECT AREA

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3/25/2004 8:21 AM

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INTRODUCTION

Soil monitoring was conducted in the Clancy-Unionville Project area in proposed management activity areas, in past timber harvest units, and on grazing lands. Soil Scientists, Sue Farley, Vince Archer and Tyler VanGemert implemented this monitoring during June and July 2002.

The monitoring data gathered during summer 2002 provides a baseline for documenting current soil conditions in areas proposed for timber harvest and prescribed burning. This information can later be used to evaluate changes in soil quality following implementation of the proposed timber harvest, prescribed burning, and other management activities.

For the past timber harvest areas, data representing adjacent undisturbed forest will be used as the baseline to evaluate degree of soil impacts with past road construction and log skidding activities. This comparative information can be used to assess effects to long-term soil productivity from past harvest, and to predict cumulative effects of past harvest combined with proposed vegetation treatments in the Clancy-Unionville project area.

For the rangeland sites, no historic data exists to document past soil conditions, and no ungrazed rangeland sites have been identified to serve as an undisturbed comparison. Thus, 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).

Monitoring data will also be used to evaluate compliance with Forest Plan standards and guidelines for soil management (USDA Forest Service 1988, pages II/26 and IV/15), and National Forest Management Act direction to maintain site productivity (16 U.S.C. 1600, 1976). The Helena National Forest Plan directs that monitoring for productivity changes in sensitive soils will be implemented on 10-15 sites annually. The intent is to insure that management practices do not adversely affect soil productivity. The measure for variability, which would initiate management action, is when changes of the soil's chemical and physical properties exceed 20% following management activities.

LITERATURE REVIEW

Forest management activities, such as road construction, timber harvest, grazing, and prescribed burning can affect soil quality. A review of the scientific literature describing soil effects resulting from forest management activities is presented in the following narrative. This literature review will serve as the context for interpreting results of soil quality monitoring in the Clancy-Unionville project area.

Soil Bulk Density and Compaction

Timber harvest with heavy equipment can increase soil bulk density through soil compaction. Froehlich and others reported, "about 60 percent of the change in soil density after 20 trips is reached by the sixth trip" (1980; page 29). These same researchers found that ground-based harvest methods increased surface soil bulk density 5-20% after 20 trips with heavy equipment.

Information about soil bulk density can be useful in evaluating effects to long-term soil productivity from past timber harvest. Increases in soil bulk density, or compaction, reduces soil porosity, particularly large soil pores. Loss of large soil pore spaces can limit plant root penetration and reduce soil infiltration rates, but can increase water-holding capacity especially with sandy-textured soils (Greacen and Sands 1980).

Increased soil bulk density due to compaction can limit root penetration, but the threshold for this limitation varies by soil texture. Daddow and Warrington found bulk densities of 1.4 grams per cubic centimeter (g/cc) prohibited root growth in a clay-textured soil; "However, if this same bulk density were measured for a sandy-textured site, most likely there would be little if any adverse compaction effects on root growth" (1983; page 12).

Tree growth can be either adversely or beneficially affected by changes in soil bulk density, depending on individual circumstances. Greacen and Sands state, "There appears to be an optimal bulk density, or range in bulk densities, above and below which a decrease in plant yield occurs" (1980; page 177). For example, compaction that limits root growth will have an adverse impact on plant productivity. Whereas, compaction that increases soil water-holding capacity on drought-prone sandy soils can have a beneficial effect on plant productivity.

Researchers have documented that magnitude of soil compaction associated with ground-based timber harvest can vary with different soil textures and differing levels of soil moisture. Froelich and others reported increases in soil bulk density on skid trails traversing fine-textured volcanic soils "was nearly twice that found on granitic sites" with sandy-textured soils (1985; page 1017). Amaranthus and Steinfeld found the magnitude of compaction was substantially less, compared to other studies, because ground-based harvesting occurred during conditions with very low soil moisture levels (1997).

Researchers have also documented that the duration of soil compaction associated with ground-based timber harvest can vary. One study documented that soil compaction can persist for longer than 4 decades on the most severely compacted soils (such as on roads and log landings) following harvest activities (Vora 1988). Another study found, "Compacted soils on secondary skid trails recovered to preharvest bulk density in 2 to 4 years" (Reisinger et al. 1992). Froehlich and others reported increases in soil bulk density on skid trails traversing fine-textured volcanic soils "was nearly twice that found on granitic sites" with sandy-textured soils (1985; page 1017). Froehlich and others concluded the granitic soils would require less time to recover from soil compaction compared to volcanic soils, because the initial magnitude of impact was less on the granitic soils with sandy textures (1985; page 1017).

Soil Infiltration Rates

Timber harvest with heavy equipment can decrease soil infiltration rates through soil compaction. For example, one research study found that infiltration rates on skid trails were reduced 67-78% compared to undisturbed sites (Froehlich et al. 1980, page 41).

Information about soil infiltration rates can be useful in evaluating effects to long-term soil productivity from past timber harvest. Froehlich and others concluded, "Even after compaction, measured infiltration rates on skid trails remained quite high (*and*) should be able to absorb all but the heaviest rainfall rates" (page 44). Soil infiltration rates can sometimes be correlated with soil bulk density (Van Haveren 1983, page 588), and can therefore corroborate professional judgments about site productivity.

Soil Organic Matter

Forest harvest activities can remove trees that serve as source for surface organic material (such as needles, limbs and logs). Also, without the tree canopy, the site is exposed to greater solar radiation, thus increasing the rate at which organic matter within the soil is decomposed. Removal of the source for surface organic material and increased decomposition of soil organic matter may result in lower soil organic matter content following timber harvest.

Information about soil organic matter content can be useful in evaluating effects to long-term soil productivity from past timber harvest. One research study found no change in soil organic matter following clear cutting due to increases in grasses, forbs and shrubs on the site: "Litter inputs from this understory vegetation offset the losses of litter inputs from the overstory that was removed" (Liechty et al. 2002, page 47). In this case, soil organic matter was maintained in support of long-term site productivity.

Soil Cover

When evaluating ground cover, "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). An increase in bare ground generally corresponds to a decrease in infiltration rate. Thus, a large area of bare ground should coincide with slow infiltration rates.

Soil "A" Horizon

The "A" horizon information is useful in evaluating rangeland productivity. One researcher found that thickness of the dark-colored, organic rich surface layer of soil (i.e. mollic epipedon) "was significantly related to production" on grassland soils in Montana, Wyoming and North Dakota (Cannon 1983).

Plant Rooting Depth and Abundance

Plant rooting depth information is useful in assessing soil condition. When evaluating soil condition, "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).

MONITORING PLOT SELECTION

Soil monitoring plots were selected based on criteria for three sampling scenarios:

1. Sites representative of sensitive soils affected by past timber harvest within the Clancy-Unionville project area.
2. Sites representative of forest soils, typically sensitive soil types, in areas proposed for timber harvest activities.
3. Sites representative of rangeland soils, typically sensitive soil types, in areas proposed for prescribed burning activities.

A total of 21 monitoring plots were evaluated during a 4-week period. Of these, 5 plots were located in past timber harvest units, 12 plots were situated in forested areas proposed for timber harvest with the Clancy-Unionville project, and 4 plots were placed on rangelands proposed for prescribed burning. A brief description of these 21 monitoring plots is displayed in Table 1.

Table 1. Description of Soil Monitoring Plots Located in the Clancy-Unionville Project Area.

Monitoring Plot No.	Management Activity Unit Identification	Type of Management Activity	Landtype	Vegetation Community	Misc. Notes
02SF001	Timber stand no. 31501001	1971 Clearcut Harvest	56A	Forest	Granitic soils on steeper mountain slopes
02SF002	Timber stand no. 32101001	1973 Clearcut Harvest	136	Forest	Wet area soils in lower portion of unit
02SF003	Timber stand no. 32201001	1973 Clearcut Harvest	12D	Forest	Wet area soils throughout unit
02SF004	Timber stand no. 32104029	1987 Clearcut Harvest	36	Forest	Granitic soils on rolling uplands
02SF005	Timber stand no. 32104028	1987 Clearcut Harvest	36B	Forest	Wet area soils in draws & depressions
02SF027	proposed unit C-81	Commercial Thinning	12C	Forest	Charcoal at 5 cm. depth in topsoil
02SF028	proposed unit C-78	Commercial Thinning	57	Forest	Charcoal in lower part of surface litter layer
02SF029	proposed unit C-103	Commercial Thinning	36	Forest	Granitic soils on rolling uplands
02SF030	proposed unit C-103	Commercial Thinning	120	Forest	Granitic soils on glaciated mountain slopes
02SF031	proposed unit C-79	Commercial Thinning	36B	Forest	Charcoal at soil surface below surface litter
02SF032	proposed unit D-47	Commercial Thinning	260	Forest	Evidence of livestock grazing
02SF033	proposed unit C-66	Prescribed Burning	36A	Grassland	Evidence of livestock grazing
02SF034	proposed unit D-52	Commercial Thinning	36	Forest	Charcoal at soil surface below surface litter; also, evidence of livestock grazing
02SF035	proposed unit D-56	Aspen Treatment	36B	Forest	Wet area soils in draws & depressions
02SF036	proposed unit C-90	Prescribed Burning	470	Grassland	Evidence of livestock grazing
02SF037	proposed unit C-87	Seed Tree Harvest	12D	Forest	Soils formed in glacial till
02SF038	proposed unit C-86	Seed Tree Harvest	136	Forest	Charcoal at soil surface below surface litter
02SF039	proposed unit C-101	Prescribed Burning	12D	Forest	Charcoal at soil surface below surface litter
02SF040	proposed unit C-101	Prescribed Burning	360	Grassland	Evidence of livestock grazing
02SF041	proposed unit C-101	Prescribed Burning	76A	Grassland	Evidence of livestock grazing
02SF042	proposed unit C-81	Commercial Thinning	12C	Forest	Soils formed in glacial till with loess surface

Sites Representative of Sensitive Soils Affected by Past Timber Harvest

Within the Clancy-Unionville project area, records indicate past timber harvest has occurred on 1,436 acres of soil. This harvest was implemented between 1968 and 1995, although the majority of timber cutting occurred in the 1970's:

- 80 acres were harvested in the 1960's;
- 842 acres were harvested in the 1970's;
- 253 acres were harvested in the 1980's, and;
- 261 acres were harvested in the 1990's.

In 1988, the Forest Service began consistently implementing Best Management Practices (BMPs) in an effort to improve conservation of soil and water resources with forestry practices (USDA Forest Service 1988). In 1989, the Montana Environmental Quality Council followed suit and released the state's Forestry Best Management Practices (Montana Department of Natural Resources and Conservation, Forestry Division 2000, page 3). Thus, timber harvest practices have evolved over the past 10-15 years to offer greater protection to soil resources (McIver and Starr 2000, page 16).

In 1990, the state of Montana implemented a formal auditing process for determining if these forestry BMPs were being applied correctly and if they were effective in protecting soil and water resources. State audits have demonstrated a consistent trend for improvement in implementation and effectiveness of forestry BMP's to protect soil and water quality. Bi-annual state audits have shown that implementation of forestry practices in a manner that meets or exceeds BMP requirements has improved from 79% of the time in 1990 to 96% of the time in 2000 (Montana Department of Natural Resources and Conservation, Forestry Division 2000, page 30). These audits have also shown the effectiveness of forestry practices, in a manner that meets or exceeds BMP requirements, has improved from 81% of the time in 1990 to 98% of the time in 2000 (Montana Department of Natural Resources and Conservation, Forestry Division 2000, page 31).

From these BMP audits, it can be seen that forestry practices were generally not as effective in protecting soil resources prior to about 1988. Thus, past timber harvest implemented within the Clancy-Unionville project area prior to 1988 was likely to produce greater impacts to soil resources. For this reason, the 2002 soil monitoring in past harvest areas focused on timber stands that were cut prior to 1988. By sampling areas harvested before 1988, soil monitoring should document the greatest magnitude of residual harvest impacts.

The 2002 soil monitoring also focused on sampling past harvest areas with sensitive soils. Sensitive soils are defined by having characteristics that are most susceptible to adverse impacts following disturbances, such as timber harvest. By sampling areas with sensitive soil types, soil monitoring should again document the greatest magnitude of residual harvest impacts.

Soil survey information helped to determine sensitive soil types that would be most susceptible to adverse impacts following timber harvest for areas affected by past timber harvest (Table 2). This background information was obtained from the "Soil Survey of the Helena National Forest Area, Montana" (USDA Forest Service and

Natural Resource Conservation Service 2001). In the Clancy-Unionville project area, sensitive soils are represented by landtypes 36B and 136 with wet areas that are susceptible to soil compaction during timber harvest using heavy equipment, and landytpe 56A with steep slopes in granitic material that is particularly vulnerable to erosion when site preparation activities remove protective ground cover.

Monitoring data from these previously harvested sampling sites will be used to determine effectiveness of sustaining long-term soil productivity with past timber management practices. The data can also be used to address cumulative soil effects of past timber harvest combined with proposed vegetation treatments within the project area.

Sites Representative of Forest Soils in Areas Proposed for Timber Harvest

The 2002 soil monitoring focused on obtaining data on existing conditions within areas proposed for vegetation management treatments representing the greatest diversity of landtypes possible. Thus, eight different landtypes were sampled: 12C, 12D, 36, 36B, 57, 120, 136, and 260. A description of basic characteristics for these landtypes is displayed in Table 2. Monitoring data from these forested sampling sites will be used to determine baseline soil quality for comparison with post-management soil conditions.

Sites Representative of Rangeland Soils in Areas Proposed for Prescribed Burning

Four different rangeland soils were sampled to represent areas that are currently grazed and are also proposed for prescribed burning. The landtypes sampled were 36A, 76A, 360 and 470. A description of basic characteristics for these landtypes is displayed in Table 2. Monitoring data from these sampling sites will be used to evaluate effectiveness of sustaining long-term soil productivity with past grazing management practices and to address soil cumulative effects of past grazing combined with proposed prescribed burning in those areas.

12D	Moraines	Glacial Till	25-50%	Cobbly Loams	188
14B	Colluvial Basins & Toeslopes	Colluvium - Limestone, Basalt & Metasedimentary Rock	10-25%	Cobbly Silt Loams	2
14C	Colluvial Toeslopes & Basins	Colluvium - Basalt & Metasedimentary Rock	10-40%	Very Cobbly Loams	36
26	Rolling Uplands	Granites to Diorites	10-40%	Gravelly Sandy Loams to Sandy Loams	220
36	Rolling Uplands	Granites to Diorites	25-40%	Coarse Sands to Gravelly Coarse Sandy Loams	312
36A	Rolling Uplands	Granites to Diorites	10-40%	Gravelly Sandy Loams	9
36B	Mountain Slopes with Wet Draws (up to 25% of the unit)	Granites to Diorites	10-40%	Gravelly Sandy Loams	85
39	Steep Mountain Slopes	Sedimentary to Metasedimentary	40-60%	Very Channery Sandy Loams	8
56A	Steep Mountain Slopes	Granites to Diorites	40-60%	Extremely Cobbly Sandy Loams	8
57	Mountain Ridges	Basalts, Tuffs, Andesites & Breccias	10-40%	Extremely Cobbly Loams	105
76	Glaciated Mountain Slopes	Granites to Diorites	25-50%	Gravelly Loams	271
120	Glaciated Mountain Slopes	Granites to Diorites	10-25%	Gravelly Sandy Loams to Very Cobbly Sandy Loams	22
136	Moraines with Wetlands	Glacial Drift	0-10%	Sandy Clay Loams to Very Cobbly Sandy Loams	55
260	Rolling Uplands	Granites to Diorites	10-40%	Sandy Loams to Gravelly Sandy Loams	3
360	Mountain Ridges	Granites to Diorites	10-40%	Gravelly Sandy Loams	34
470	Mountain Slopes and Ridges	Basalts, Tuffs, Andesites & Breccias	10-40%	Stony Loams to Loams	10
Grand Total Acres					1,436

MONITORING METHODS

A number of soil parameters were assessed during monitoring within the Clancy-Unionville project area. However, not all soil parameters were evaluated at every sampling site. The soil parameters evaluated include:

- Soil bulk density

- Soil infiltration rates
- Soil organic matter content
- Plant rooting depth and abundance
- "A" horizon (i.e. topsoil) thickness
- Extent and type of ground cover.

Soil bulk density was measured using the standard core sample method (Blake and Hartge 1986). Triplicate soil bulk density samples were taken to aid in describing spatial variability for this soil characteristic. For the past harvest units, soil bulk density samples were obtained to compare conditions corresponding to three levels of soil disturbance:

1. Old harvest access roads (currently closed to use) were sampled to represent highly impacted soils;
2. Old harvest (primary) skid trails were sampled to represent soils with intermediate impacts;
3. Unharvested areas adjacent to, or within harvested stands, were sampled to represent soil conditions in undisturbed forest.

Soil bulk density samples were **not** obtained within areas proposed for timber harvest or prescribed burning, because the core sampling equipment was being repaired during that timeframe. Soil monitoring data for bulk density within proposed treatment units is planned for collection during summer 2003. Gathering this data in 2003 will still meet the objective to establish baseline soil conditions prior to implementation of any future management activities.

Soil infiltration was assessed using the ring infiltrometer method (Bouwer 1986). Again, triplicate soil infiltration tests were completed to aid in describing spatial variability for this soil characteristic. For the past harvest units, soil infiltration rates were tested on the same three levels of soil disturbance as described for bulk density, to compare soil impacts from past road construction and log skidding with undisturbed forest soil conditions. Soil infiltration rates were tested for soils prior to treatment within areas proposed for timber harvest or prescribed burning.

Soil organic matter content was evaluated using the standard loss on ignition method (Nelson and Sommers 1982). Triplicate samples for soil organic matter were obtained to aid in describing spatial variability for this soil characteristic. The soil organic matter samples were taken from the bulk density cores after bulk density had been measured. For the past harvest units, soil organic matter was evaluated on the same three levels of soil disturbance as described for bulk density, to compare soil impacts from past road construction and log skidding with undisturbed forest soil conditions.

Soil organic matter samples were **not** obtained within areas proposed for timber harvest or prescribed burning, because the core sampling equipment was being repaired during that timeframe. Monitoring data for soil organic matter content within proposed treatment units is planned for collection during summer 2003. Gathering this data in 2003 will still meet the objective to establish baseline soil conditions prior to implementation of any future management activities.

Plant rooting depth and abundance were determined using standard soil methods implemented with an auger (Weixelman et al. 1999). Plant rooting depth and abundance were recorded at five intervals for each of three 20-meter transects within plots (i.e. the same transects evaluated for soil cover and "A" horizon characteristics). Again, multiple measurements were made within monitoring plots to aid in describing spatial variability for this soil characteristic.

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 intervals on each of three 20-meter transect (Weixelman et al. 1999).

The topsoil, or "A" horizon, was characterized using standard soil methods (Schoenberger et al. 1998). Characterization of the "A" horizon thickness, color, structure and texture was completed on each of the three 20-meter transects.

Soil erosion was **not** measured for several reasons. First, erosion is difficult to measure accurately, especially after it has occurred and the evidence has been masked by the passage of time, and re-establishment of vegetation or plant litter cover (Ranger and Frank 1978; Wells II and Wohlgemuth 1987). 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 not a sensitive indicator for trend in soil condition, particularly within rangelands. In one study, "Plant cover and plant vigor had already changed significantly before accelerated soil movement became obvious" (Passey et al. 1982, page 48).

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 past timber harvest or livestock grazing on soil conditions.

Due to time and personnel constraints, a limited number of monitoring plots and soil samples were evaluated for the Clancy-Unionville 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 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 soil conditions across larger landscapes, such as the entire Helena National Forest. These point samples should be viewed as "spot checks", which evaluate soil health on key areas within the Clancy-Unionville project area.

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.

MONITORING RESULTS

Soil Bulk Density

Soil bulk density data was collected in past timber harvest areas. Three levels of soil disturbance were sampled within these past harvest units: 1) highly disturbed (D) sites represented by old harvest access roads that are currently closed; 2) intermediate disturbance (I) sites represented by primary skid trails within the harvest unit, and; 3) undisturbed forest (U) sites adjacent to, or within, the harvest units.

Soil bulk density is measured in grams of soil weight per cubic centimeter of whole soil volume. The whole soil volume includes both pore spaces and soil particles, or aggregates of particles, in a core sample. Complete results of this bulk density sampling are displayed in Table 3.

For the old roads, bulk densities ranged from 1.22 to 1.76 grams per cubic centimeter (g/cc). The average bulk density value is 1.58 g/cc for all samples taken from old roads (n=6). For the primary skid trails, bulk densities ranged from 0.94 to 1.56 g/cc, with an average value of 1.22 g/cc (n=12). For the undisturbed forest sites, bulk densities ranged from 0.8 to 1.4 g/cc, with an average value of 1.17 g/cc (n=9).

Table 3. Results of Soil Bulk Density Sampling, Clancy-Unionville Project Area 2002.

PLOT_ID	SURFACE TEXTURE	DISTURBANCE	SAMPLE NUMBER	BULK DENSITY	Avg. Bulk Density by Disturbance Class	Std.Dev. Bulk Density by Disturbance Class
02SF001	sandy loam	D	1	1.60		
02SF001	sandy loam	D	2	1.76		
02SF001	sandy loam	D	3	1.64	1.67	0.08
02SF001	sandy loam	I	1	1.56		
02SF001	sandy loam	I	2	1.35		
02SF001	sandy loam	I	3	1.37	1.43	0.12
02SF001	sandy loam	U	1	1.23		
02SF001	sandy loam	U	2	1.17		
02SF001	sandy loam	U	3	1.40	1.27	0.12
02SF003	loam	D	1	1.69		
02SF003	loam	D	2	1.22		
02SF003	loam	D	3	1.58	1.50	0.25
02SF003	loam	I	1	1.03		
02SF003	loam	I	2	0.94		
02SF003	loam	I	3	1.06	1.01	0.06
02SF003	loam	U	1	1.27		
02SF003	loam	U	2	0.80		
02SF003	loam	U	3	1.08	1.05	0.23
02SF004	sandy loam	I	1	1.19		
02SF004	sandy loam	I	2	1.33		
02SF004	sandy loam	I	3	1.11	1.21	0.11
02SF004	sandy loam	U	1	1.25		
02SF004	sandy loam	U	2	1.05		
02SF004	sandy loam	U	3	1.25	1.18	0.12
02SF005	loamy sand	I	1	1.31		
02SF005	loamy sand	I	2	1.04		
02SF005	loamy sand	I	3	1.31	1.18	0.16

Soil Infiltration Rates

As with bulk density monitoring, soil infiltration rates were tested on old roads (D), primary skid trails (I), and adjacent undisturbed forest (U) for past timber harvest areas. Soil infiltration rates were also monitored on undisturbed areas (N) prior to implementation of proposed vegetation treatments in forested areas.

Soil infiltration rates are measured in liters of water that filter into the soil over a prescribed time frame, in this case 32.5 minutes. Complete results of this soil infiltration testing are displayed in Table 4.

For the old roads, soil infiltration rates ranged from 0.0 (yes that's zero) to 4.9 liters of water per 32.5 minutes (L/32.5 min.). The average infiltration rate is 1.9 L/32.5 min. for all samples taken from old roads (n=12). For the primary skid trails, infiltration rates ranged from 1.4 to 20.9, with an average value of 9.7 L/32.5 min. (n=8). For the undisturbed forest sites, infiltration rates ranged from 2.3 to 42.6 L/32.5 min., with an average value of 15.1 L/32.5 min. (n=30).

Table 4. Results of Soil Infiltration Monitoring, Clancy-Unionville Project Area 2002.

PLOT_ID	DISTURBANCE	SAMPLE NUMBER	Soil Infiltration Rates (L/32.5 min)	Average by Disturbance Class (L/32.5 min)	StDev by Disturbance Class (L/32.5 min)
02SF001	D	1	2.4	1.8	0.7
02SF001	D	2	2.1		
02SF001	D	3	1.0		
02SF001	U	1	20.2	14.0	5.4
02SF001	U	2	10.7		
02SF001	U	3	10.9		
02SF002	D	1	0.0	0.0	0.0
02SF002	D	2	0.0		
02SF002	D	3	0.0		
02SF002	I	1	2.0	1.8	0.3
02SF002	I	2	1.4		
02SF002	I	3	1.9		
02SF002	U	1	31.2	20.1	12.8
02SF002	U	2	6.2		
02SF002	U	3	23.0		
02SF003	D	1	0.1	1.7	2.7
02SF003	D	2	0.1		
02SF003	D	3	4.9		
02SF003	U	2	24.2	NA	NA
02SF004	I	1	14.8	14.1	1.0
02SF004	I	2	13.4		
02SF004	U	1	12.8	15.5	3.8
02SF004	U	2	18.2		
02SF005	D	1	5.9	4.3	2.6
02SF005	D	2	1.2		
02SF005	D	3	5.7		
02SF005	I	1	14.1	14.8	5.7
02SF005	I	2	20.9		
02SF005	I	3	9.6		
02SF027	N	1	9.6	20.0	14.6
02SF027	N	2	30.3		
02SF029	N	1	37.0	36.5	0.7
02SF029	N	2	36.0		
02SF030	N	1	2.5	3.7	2.2
02SF030	N	2	2.3		
02SF030	N	3	6.1		
02SF032	N	1	42.6	NA	NA
02SF033	N	1	5.2	6.2	1.5
02SF033	N	2	7.3		
02SF034	N	1	18.9	19.9	1.3
02SF034	N	2	20.8		
02SF035	N	1	6.3	8.2	1.8
02SF035	N	2	9.9		
02SF035	N	3	8.5		
02SF039	N	1	9.7	6.8	2.5
02SF039	N	2	5.7		
02SF039	N	3	5.1		
02SF040	N	1	12.6	10.5	2.0
02SF040	N	2	10.2		
02SF040	N	3	8.6		

Soil Organic Matter Content

As with bulk density and infiltration monitoring, soil organic matter content was measured on old roads (D), primary skid trails (I), and adjacent undisturbed forest (U) for past timber harvest areas.

Soil organic matter content is measured as a percentage, by weight, of a soil sample. The results of this soil organic matter content sampling are displayed in Table 5.

For the soil samples taken from old roads, organic matter content ranged from 2.2 to 5.3 percent, with an average value of 4.2% (n=10). For the samples from skid trails, soil organic matter content ranged from 3.0 to 11.3 percent, with an average value of 5.9% (n=16). For the undisturbed forest samples, soil organic matter content ranged from 3.7 to 7.0 percent, with an average value of 5.1% (n=12).

Table 5. Results of Soil Organic Matter Content Measurements, Clancy-Unionville Project Area 2002.

PLOT_ID	DISTURBANCE	SAMPLE NUMBER	Soil Organic Matter Content (%)	Average OM (%) by Disturbance	Std. Deviation OM (%) by Disturbance
02SF001	D	1	4.8	4.8	0.5
02SF001	D	1	5.0		
02SF001	D	2	4.1		
02SF001	D	3	5.3		
02SF001	I	1	3.5	5.2	2.5
02SF001	I	2	8.2		
02SF001	I	3	4.1		
02SF001	U	1	7.0	5.4	1.4
02SF001	U	2	4.8		
02SF001	U	3	4.4		
02SF002	D	1	4.5	4.2	1.2
02SF002	D	2	5.3		
02SF002	D	3	2.9		
02SF002	I	1	9.2	7.9	4.1
02SF002	I	2	11.3		
02SF002	I	3	3.4		
02SF002	U	1	3.7	4.5	0.7
02SF002	U	2	4.6		
02SF002	U	3	5.1		
02SF003	D	1	3.7	3.3	1.0
02SF003	D	2	2.2		
02SF003	D	3	4.1		
02SF003	I	1	7.2	7.7	0.0
02SF003	I	2	7.3		
02SF003	I	3	8.6		
02SF003	U	1	4.7	5.0	0.2
02SF003	U	2	4.9		
02SF003	U	3	5.2		
02SF004	I	1	6.2	5.2	1.0
02SF004	I	1	5.8		
02SF004	I	2	4.1		
02SF004	I	3	4.7		
02SF004	U	1	5.2	5.7	0.5
02SF004	U	2	6.0		
02SF004	U	3	6.1		
02SF005	I	1	3.0	3.8	0.9
02SF005	I	2	4.8		
02SF005	I	3	3.5		

Plant Rooting Depth and Soil "A" Horizon

For the sampling sites in past harvest areas, plant rooting depth in relation to the depth of the soil "A" horizon was measured only on the primary skid trails. Plant rooting depth and "A" horizon were also sampled in areas proposed for vegetation management activities, including both forest and rangeland sites.

Evaluation of plant roots measures depth of the dense mat of very fine and fine sized roots typically associated with grasses, forbs, and small shrubs. Evaluation of the "A" horizon measures the depth of the dark-colored, organic-rich surface layer of soil, where soil particles are typically aggregated, or clumped together, in the shape of small granules (i.e. granular soil structure). Complete results of monitoring plant-rooting depth in relation to the depth of the soil "A" horizon are displayed in Table 6.

For all sampling sites, depth of the dense mat of very fine and fine sized roots ranged from 5 to 16 centimeters (cm.). Depth of the "A" horizon ranged from 6 to 23 cm. For all sampling sites, the percentage of "A" horizon filled by the dense root mat ranged from 52 to 182 percent. When the percent value is greater than 100, this indicates the dense root mat is deeper than the dark-colored topsoil.

Table 6. Results of Monitoring Plant Rooting Depth and "A" Horizon, Clancy-Unionville Project Area 2002.

PLOT_ID	TRANSECT	SAMPLE NUMBER	Depth (cm) MANY ROOTS (>100 fine & very fine per square decimeter)	Depth (cm) COMMON ROOTS (10-100 fine & very fine per square decimeter)	"A" HORIZON DEPTH (cm)	Rooting Depth & Abundance % of "A" Horizon Filled
02SF001	Average	Values	3	12	23	52%
02SF002	Average	Values	3	13	7	182%
02SF003	Average	Values	3	13	10	131%
02SF004	Average	Values	2	13	17	76%
02SF005	Average	Values	1	8	21	41%
02SF027	Average	Values	0	9	12	77%
02SF028	Average	Values	1	7	9	78%
02SF029	Average	Values	0	5	6	74%
02SF030	Average	Values	0	6	7	84%
02SF031	Average	Values	2	14	17	83%
02SF032	Average	Values	1	11	14	75%
02SF033	Average	Values	4	11	12	88%
02SF034	Average	Values	1	12	17	67%
02SF035	Average	Values	1	15	16	94%
02SF036	Average	Values	3	12	11	110%
02SF037	Average	Values	0	8	9	82%
02SF038	Average	Values	1	12	15	80%
02SF039	Average	Values	2	15	16	95%
02SF040	Average	Values	2	12	12	96%
02SF041	Average	Values	4	16	17	96%
02SF042	Average	Values	0	15	17	91%

Extent and Type of Ground Cover

For the sampling sites in past harvest areas, soil cover was measured on the primary skid trails and within the harvest units. Soil cover was not measured on the adjacent undisturbed forest or on the old access roads for the past harvest areas. Soil cover was also measured in areas proposed for vegetation management activities, including both forest and rangeland sites that are currently grazed.

Soil cover measures the amount of bare soil, and the amount of soil cover in different categories, such as plant litter, rock fragments or woody material. The amount of bare soil and soil cover within the area measured is expressed as a percent of the area sampled. Complete results of soil cover monitoring are displayed in Table 7.

The amount of bare soil was zero on 9 of the sites sampled. On the remaining 12 sites, bare soil ranged from 3 to 20 percent of the area monitored. The relatively low amounts of bare soil mean that protective soil cover is provided on 80 to 97 percent of the area sampled for all monitoring sites.

The amount of soil cover provided by plant litter or duff was zero on the 4 rangeland sites: on rangeland soils, plant litter typically decomposes quickly and is incorporated into the topsoil. For the remaining 17 forest sites, plant litter or duff provided soil cover on 13 to 55 percent of the area sampled.

There were no rock fragments found on the soil surface on 8 of the sites sampled. On the remaining 13 sites, rock fragments provided soil cover on 1 to 17 percent of the area sampled.

Six sites had no woody material providing soil cover: four of these sites were rangelands where no source for woody material exists. Woody material (from all size classes combined) provided soil cover on 12 to 37 percent of the area on the remaining sites.

Live plants, such as grasses, forbs, shrubs and small trees, provided soil cover on 13 to 92 percent of the area on sites sampled. Rangeland sites had the greatest amounts of soil cover provided by live plants: 80 to 92 percent.

Table 7. Results of Monitoring Soil Cover, Clancy-Unionville Project Area 2002.

Monitoring Plot No.	Number of Sample Points	Plant Litter and Duff	Rock Fragment (>2 in.)	Woody Material (<1 in.)	Woody Material (1-3 in.)	Woody Material (3-6 in.)	Woody Material (6-12 in.)	Woody Material (12-24 in.)	Live Plant	Moss or Lichen	Bare Soil	Total
02SF001	33	33%	3%	0%	0%	0%	0%	0%	61%	0%	3%	100%
02SF002	101	32%	1%	1%	3%	3%	6%	0%	30%	22%	3%	100%
02SF003	100	35%	1%	0%	2%	8%	6%	1%	33%	2%	12%	100%
02SF004	99	21%	4%	3%	2%	12%	1%	0%	53%	0%	4%	100%
02SF005	50	18%	0%	10%	2%	4%	6%	0%	52%	2%	6%	100%
02SF027	30	33%	10%	0%	0%	0%	0%	0%	57%	0%	0%	100%
02SF028	33	30%	0%	6%	3%	6%	0%	0%	55%	0%	0%	100%
02SF029	30	20%	3%	10%	10%	0%	3%	0%	53%	0%	0%	100%
02SF030	40	55%	15%	5%	0%	5%	8%	0%	13%	0%	0%	100%
02SF031	30	20%	0%	7%	3%	3%	3%	17%	47%	0%	0%	100%
02SF032	30	20%	10%	0%	3%	20%	3%	0%	40%	0%	3%	100%
02SF033	100	0%	0%	0%	0%	0%	0%	0%	89%	0%	11%	100%
02SF034	30	20%	0%	3%	17%	7%	7%	3%	43%	0%	0%	100%
02SF035	30	13%	10%	0%	20%	7%	3%	3%	40%	0%	3%	100%
02SF036	100	0%	0%	0%	0%	0%	0%	0%	94%	0%	6%	100%
02SF037	30	30%	17%	3%	7%	7%	3%	7%	27%	0%	0%	100%
02SF038	30	13%	13%	0%	13%	7%	13%	3%	37%	0%	0%	100%
02SF039	30	23%	3%	3%	3%	3%	3%	0%	60%	0%	0%	100%
02SF040	100	0%	0%	0%	0%	0%	0%	0%	80%	0%	20%	100%
02SF041	100	0%	0%	0%	0%	0%	0%	0%	92%	0%	8%	100%
02SF042	30	27%	13%	3%	7%	10%	0%	0%	37%	0%	3%	100%

DISCUSSION AND CONCLUSIONS

Sites Representative of Sensitive Soils Affected by Past Timber Harvest

Soil monitoring data from undisturbed forest is compared with data from primary skid trails and closed roads associated with past timber harvest areas. This comparison is in compliance with direction from the National Forest Management Act to evaluate "effects of each management activity to the end that it will not produce substantial and permanent impairment of the productivity of the land" (Section 6 (g) (3) (C), NFMA 1976). Helena National Forest Plan monitoring requirement F-3 measures compliance with NFMA direction: Productivity changes in sensitive soils are indicated, "When changes of baseline levels of the soil's chemical and physical properties exceed 20%" (USDA Forest Service 1986, page IV/15).

There is less than 20% change in average soil bulk density values on primary skid trails compared to adjacent undisturbed forest. *Average soil bulk density values indicate compaction on all primary skid trails sampled is in compliance with Forest Plan monitoring requirement F-3 (Table 7).*

Average soil bulk density increases more than 20% on all closed roads compared to adjacent undisturbed forest. *Average soil bulk density values indicate compaction on all sampled closed roads is not in compliance with Forest Plan monitoring requirement F-3 (Table 7).*

Table 7. Evaluation of Compliance with Forest Plan Monitoring Element F-3: "When Changes of Baseline Levels of the Soil's Chemical and Physical Properties Exceed 20 Percent" in Past Timber Harvest Areas, Clancy-Unionville Project Area 2002.

Soil Parameter Evaluated	Skid Trails Less Than 20% Change (Number of Samples)	Skid Trails Greater Than 20% Change (Number of Samples)	Closed Roads Less Than 20% Change (Number of Samples)	Closed Roads Greater Than 20% Change (Number of Samples)
Soil Bulk Density	3	0	0	2 (adverse)
Infiltration Rate	1	1 (adverse)	0	3 (adverse)
Organic Matter Content	2	2 (beneficial)	2	1 (adverse)

This level of increase in soil bulk density on closed roads has adverse effects on soil productivity. The magnitude of increase in bulk density needed to limit plant root growth varies by soil texture. Soils sampled on the closed roads, and in much of the Clancy-Unionville project area, have sandy loam or loam textures. With sandier soil textures, bulk density needs to exceed 1.5 to 1.7 grams per cubic centimeter before plant root growth is limited (Daddow and Warrington 1983; page 9). This level of increase in soil bulk density is recorded on the sampled closed roads. Thus, there is an adverse effect on soil productivity as plant root growth is limited in compacted soils on closed roads.

There is less than 20% change in average soil infiltration rate on one primary skid trail sample site compared to adjacent undisturbed forest. On one other skid trail sampling site, average soil infiltration rate decreases more than 20% compared to adjacent undisturbed forest. *Thus, average soil infiltration rates indicate one primary skid trail sampled is in compliance with Forest Plan monitoring requirement F-3 (Table 7), and one sampled skid trail is not in compliance.*

Average soil infiltration rates decrease more than 20% on closed roads compared to undisturbed forest. *Thus, soil infiltration rates indicate all sampled closed roads are not in compliance with Forest Plan monitoring requirement F-3 (Table 7).*

There is less than 20% change in average soil organic matter content values for 2 sampling sites on primary skid trails, compared to undisturbed forest. *Thus, these 2 sites on primary skid trails are in compliance with Forest Plan monitoring requirement F-3 (Table 7).*

On the other 2 skid trail sampling sites, average soil organic matter content increased more than 20% compared to undisturbed forest. On these same two sites, depth of the plant root mat extends below the depth of the "A" horizon (Table 6, plots 02SF002 and 02SF003). As suggested by findings of other researchers (Liechty et al. 2002), an increase in grasses, forbs and shrubs following tree harvest has allowed a more vigorous root mat compared to undisturbed forest, that has led to increased soil organic matter. An increase in soil organic matter content is a beneficial effect, because organic matter enhances soil productivity. *Technically, these 2 skid trail sites exceed the guideline to limit changes in soil properties to less than 20%. However, these 2 skid trail sites meet the intent of the Forest Plan monitoring requirement (and NFMA) to "ensure that management practices do not adversely affect soil productivity".*

In summary soil productivity has been adversely affected on closed roads used to access past timber harvest areas that have not had any type of previous reclamation, as measured by Forest Plan monitoring requirement F-3. There are at least two possible options to address this situation:

1. These closed roads can be managed as part of the permanent transportation system for the National Forest. In this case, soils in the road prism would be managed for transportation uses, and not productivity.
2. These closed roads can be rehabilitated to improve soil conditions, and restore productivity in the long-term. Rehabilitation measures might include slope recontouring, or some type of soil ripping, harrowing, disking, etc. to break up the compacted layer and increase infiltration. Soil mulching, with seeding or planting, could provide protective soil cover and increased organic material.

Overall, soil productivity has not been adversely affected within past timber harvest units, and especially on primary skid trails, in the Clancy-Unionville project area. This conclusion is based on the soil condition monitoring that demonstrates compliance with Forest Plan monitoring requirement F-3.

The past harvest units sampled represent the sites likely to have the greatest magnitude of residual soil impacts from previous management activities within Clancy-Unionville project. This is because these sites have sensitive soil types, the areas within harvest units likely to have the greatest magnitude of soil impacts were sampled (i.e. on primary skid trails), the sites were harvested by the most impactive harvest method (i.e. clear cutting), and timber removal occurred prior to consistent, effective application of BMPs for protection of soil and water resources (i.e. prior to 1988). Yet, soil monitoring data from these harvest units demonstrates that soil productivity has not been significantly or permanently impaired within the harvest units (note this conclusion does not apply to the closed roads used to access these units; refer to discussion of closed roads in a previous paragraph).

Based on compliance with Forest Plan monitoring requirement F-3 in these sites with greatest magnitude of soil impacts, it is predicted that other past harvest units not sampled will also be in compliance with the Forest Plan. Further, it is reasonable to expect that soil conditions following proposed harvest will also be in compliance with the Forest Plan, since application and effectiveness of BMPs has improved protection of soil resources with forestry practices over the past 10-15 years.

In conclusion, data from past harvest skid trails suggests that effects of proposed timber harvest, combined with effects of past timber harvest, will not have a cumulatively adverse effect on soil productivity within the Clancy-Unionville project area. This conclusion does not apply to roads, which the 2002 monitoring data demonstrates have an adverse effect on soil productivity.

Sites Representative of Forest Soils in Areas Proposed for Timber Harvest

Beyond providing baseline soil information to compare pre-management soil conditions with post-management conditions, soil data gives a glimpse into past fire disturbance in the project area. These sites have no record of past management activities, such as timber harvest or prescribed burning, but field evidence demonstrates these sites have a history of natural disturbance processes.

For the sampled forest soils, 6 of the 12 sites had charcoal (Table 2). The charcoal was typically located at the soil surface, beneath the existing layer of surface litter and duff. One site, however, had charcoal mixed in the top 5 centimeters of soil.

The presence and position of charcoal documents these sites have a history of fire disturbance that at least consumed the surface organic material, and likely removed overstory vegetation as well. These sites have subsequently recovered the surface litter layer, along with regrowth of a mature forest.

The site with charcoal mixed in the topsoil strongly suggests the site experienced soil deposition from substantial erosion up-slope, following fire disturbance. Again this site has recovered the surface litter layer, along with regrowth of a mature forest. Also erosion has subsided to negligible levels, and soils have stabilized as the area recovered.

Sites Representative of Rangeland Soils in Areas Proposed for Prescribed Burning

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 Clancy-Unionville project area. Thus, there is no well-defined benchmark for determining changes in soil condition associated with past livestock grazing in the project area.

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).

The evaluation of 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 2-4 centimeters on the 4-rangeland sites. The depth of "common" roots (i.e. 10-100 very fine or fine size roots within an area of one square decimeter) ranged from 11-17 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.

On 3 of the monitoring plots (i.e. plots 02SF024 and 02SF025), the root mat almost entirely filled the "A" horizon, by occupying 88 to 96 percent of the volume of topsoil. On the one remaining rangeland site, the root mat extended slightly deeper than the "A" horizon, occupying 110 percent of the volume of topsoil. Based on professional judgment, the depth and abundance of roots appears to be adequate in vigor compared to what is expected in healthy native grasslands (National Research Council 1994, page 120).

The monitoring data for ground cover showed that bare ground ranged from 6-20 percent of the area monitored on the 4-rangeland sites. Only one plot had bare ground on greater than 15 percent of the area. Based on professional judgment and recent scientific research, the amount of bare ground (i.e. greater than 15%) appears to be slightly higher on this one plot compared to what is desired in healthy native grasslands (Naeth et al. 1991, page 11). For the remaining three sites, the amount of soil cover appears adequate to protect soil from erosion, which is desired in healthy native grasslands (National Research Council 1994, page 120).

Overall, the soil monitoring data demonstrates changes in plant rooting depth and soil cover do not exceed 20%, compared to what is expected in healthy native grasslands (National Research Council 1994, page 120). *Thus, soil conditions on the 4-rangeland sites are in compliance with Forest Plan monitoring requirement F-3.*

Cumulative soil effects of decreased plant root vigor and soil cover might occur, if grazing resumes too soon after prescribed burning. This is especially applicable to the rangeland site with ground cover already close to the threshold of exceeding 20%. To avoid these soil cumulative effects, grazing can be deferred following prescribed burning, until these conditions are present:

- Plant roots fill at least 80 percent of the "A" horizon, and;
- At least 80 percent ground cover is present on the burned units.

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