Impacts of Fuel Treatment Methods on Soils and Management Recommendations for Future Fuel Treatments in Yellowstone National Park:

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Introduction

Yellowstone National Park is located primarily in the northwest corner of Wyoming, with portions extending into southwestern Montana and southeastern Idaho. It lies within Wyoming's Teton and Park counties, Montana's Park and Gallatin counties, and Idaho's Fremont county. The gateway communities of West Yellowstone, Gardiner, Cooke City, and Silver Gate, Montana and Cody and Jackson Wyoming are adjacent to the park (Yellowstone National Park, 2002, doc. 38). The following geographic data were taken from that report.

The Park is 2,221,772 acres (3,472 square miles) in size, and occupies a large mountainous plateau in the northern Rocky Mountains. Elevations range from 5,200 feet to over 11,000 feet with an average of 8,000 feet above sea level. It is characterized by several broad, forested volcanic plateaus surrounded by the Absaroka Mountain Range on the East, the Gallatin

Mountain Range on the north, and the Red Mountains on the south. Lakes such as Yellowstone, Shoshone, Lewis, and Heart are prominent features as are the Yellowstone, Snake, Lewis, Madison, Gibbon, Firehole, Gardner, and Lamar rivers.

There are two major climatic types within Yellowstone National Park. The "valley" type is common to large valleys and central plateaus and is similar to that of the Great Plains with peak precipitation falling as rain in May and June. The "mountain" type occurs along the Continental Divide and at higher elevations throughout the park. The mountain climate is characterized by precipitation falling predominantly during the winter months as snow. Vegetation varies from high alpine meadows, lodgepole pine and spruce/fir forests, to grasslands in broad valleys.

Resources include the world's largest and most active geothermal areas. These areas were among the principal reasons for the Park's establishment. Approximately 120 thermal areas in 9 major basins have been identified. These areas include geysers, hot springs, mud pots, and fumaroles. There are a diverse community of wildlife and unique opportunities to view remarkable and relatively rare species such as the bison, gray wolf, and black and grizzly bears.

The Park has a long association with free-burning fire and its present forests have grown up in the wake of large fires (ibid). Not all fires were natural; some were human induced and were associated with historic Native American fire practices, mining, logging, and general settlement of the area. The historic record demonstrates the capability of the region to support large, occasional fires. The evidence supports the premise that fire in some form has had a continual presence in the park. It is not possible to determine the full character of the presettlement fire regime, though the settlement era produced an unusually intense period of burning. The 20th century record indicates a period of intense burning followed by a period of fire exclusion. Organized fire suppression in the park began about 1929, which reduced the frequency and size of fires. Large fires have burned at average intervals of 25-60 years on the low elevation grasslands of the northern range, at intervals of 250-400 years in the conifer forests and less frequently in the alpine areas.

In 1992, after the extensive 1988 fires, a park-wide fire management plan was prepared (Yellowstone National Park, 2002, doc. 38). It identified two management zones; a prescribed natural fire zone and a suppression zone. In 2002 a fire management plan was developed (ibid) to address fuel management issues in the suppression zone. The wildland-urban interface (WUI) treatment areas discussed in this assessment all occur in that zone. Since its completion, projects have been completed, including some utilizing heavy equipment.

Changing climate and vegetation response is an increasingly stronger determinant of wildfires intensity, frequency, and size. Predicted lower snowpack, earlier snowmelt, increased water stress, and lower streamflow will cause insect infestations, longer summer drought, lower carbon uptake, and more intense wildfires (Running, 2009, doc. 28).

This research project (Yellowstone National Park, 2010, doc. 39) was initiated to support fire and fuels management by allowing fuel treatment methods to be based on the best available science. Cost-effective fuel treatments often require the use of heavy equipment (feller bunchers, forwarders, or skidders) when forest density is high. In recent years, there has been disagreement among staff regarding the best way to protect soil resources during these activities. In some cases, projects have only been implemented after stripping all the topsoil from heavy equipment travel routes and replacing it when the project is complete. In other cases, projects were significantly delayed while the appropriate mitigations are debated. In the absence of a solid understanding of the science, it is not clear whether limiting heavy equipment use is necessary or whether stripping topsoil is an effective soil mitigation measure on fuel treatment sites. It does not appear that the current literature addresses the effects of heavy equipment conducting fuel treatments on stripped soils.

Project objectives include answering the following questions:

1. What is the status of current literature describing effects of heavy equipment use and soil stripping on those soil types present in the Wildland Urban Interface areas of Yellowstone National Park (YNP)? A synthesis of relevant literature will be performed in which the current body of literature would be reviewed, an annotated bibliography would be prepared, and knowledge gaps will be identified.
2. What is the best way for managers to proceed when conducting fuel projects utilizing heavy equipment? The literature synthesis will be utilized to draft Management Recommendations that address impacts of heavy equipment and soil stripping on soil types found in YNP WUI areas. The research design and sampling methods will outline an approach to future data collection on YNP sites that have already been impacted or to utilize upcoming fuel treatment areas to study additional management recommendations.

Deliverables include:

1. An annotated bibliography of relevant literature and identification of knowledge gaps will be assembled related to soil disturbances. Copies of those research papers will be given to the park in hardcopy or electronic format for future reference and to facilitate an understanding of the science.
2. A written document describing Management Recommendations for heavy equipment use during fuel treatments on soil types commonly found in WUI, with references to the literature provided to guide YNP in designing future mitigations for fuel treatments based on soil type.
3. A written document describing a research design if current literature is inadequate, and a monitoring design with sampling methods to allow YNP staff to adequately monitor soil impacts of the specified mechanical fuel treatment methods in the future when necessary.
4. A map (and spatial data layer) will be provided showing where this information is applicable.
5. A presentation will be provided to park fire and resource managers to present and discuss findings. If appropriate, the study will be submitted to *Yellowstone Science* for publication.

Methods

The following methods were used to address the management questions.

- Relevant, applicable scientific literature was reviewed.
- Current practices of soil protection used in other Federal agencies (primarily the U. S. Forest Service) were researched and summarized.
- Potential study areas were defined using existing spatial data.
- An example soils study on sensitivity to disturbance was completed.
- A study design for a future study to apply literature results (if necessary) and a monitoring protocol were outlined

- Draft management recommendations were developed specifically for Yellowstone National Park's objectives.

Client/Research contacts were as follows:

1. A field/office trip to Yellowstone National Park to define and clarify objectives with management (May 24, 2010 for office; Aug 4, 2010 for field)
2. Two field/office trips to a relevant Forest Service office to research current soil protection guidelines, relevant science behind the guidelines, and current statistical sampling methods (Feb 2010 and May 18, 2010).
3. Derivation (with the assistance of Yellowstone Park Fire Ecologist, Spatial Analysis Center, and other staff) of a study area to more specifically define spatial parameters of interest (July 2010).
4. A final field/office trip to present deliverables and orally present the results (scheduled for November, 2010 by agreement with staff).

The August field trip was made with Roy Renkin and Joe Regula with additional meetings including Eleanor Clark. We reviewed rehabilitated fire lines just outside the Northeast entrance, the Northeast entrance treatments, and the Canyon treatments. The initial May meeting included Ann Rodman, Tonja Opperman, and Roy Renkin. The Yellowstone National Park Spatial Analysis Center provided fire-related data, and www.nature.nps.gov provided background spatial data.

Results

Study Area Definition and Characterization

The study area consists of 346 polygons, extracted from spatial data provided by the Spatial Analysis Center, Yellowstone National Park (version of 080510). These polygons were identified as forested and needing vegetative treatment. They are concentrated around developed areas, for a total of 8,431 acres (Table 1). There are a total of 61 different projects, of which 23 are near backcountry cabins. There are 19 major project areas, lumping backcountry project areas (Table 1). These were developed based on an environmental assessment completed in 2002 by Yellowstone National Park (Yellowstone National Park, 2002, doc. 38), and reflect the objective of reducing fuels near these areas to limit fire behavior. They are still in draft form as of 08052010.

Table 1. Proposed Fuel Treatment Projects

Area Name	Acres
Backcountry	353
Bechler	63
Canyon	651

East Entrance	449
Fishing Bridge	153
Grant	1,799
Lake	260
Lewis Lake	351
Madison	544
Mammoth	494
Norris	119
Norris Geyser Basin	50
North Entrance	25
Old Faithful	1,647
Roosevelt	1,275
South Entrance	83
Stephens Creek	4
West Entrance	75
West Thumb	37
Total	8,431

The following map shows the location of all areas (Figure 1). Total treated areas since the environmental assessment was completed are indicated on the map with a total of 308 acres. A sample of these treated areas was reviewed below.

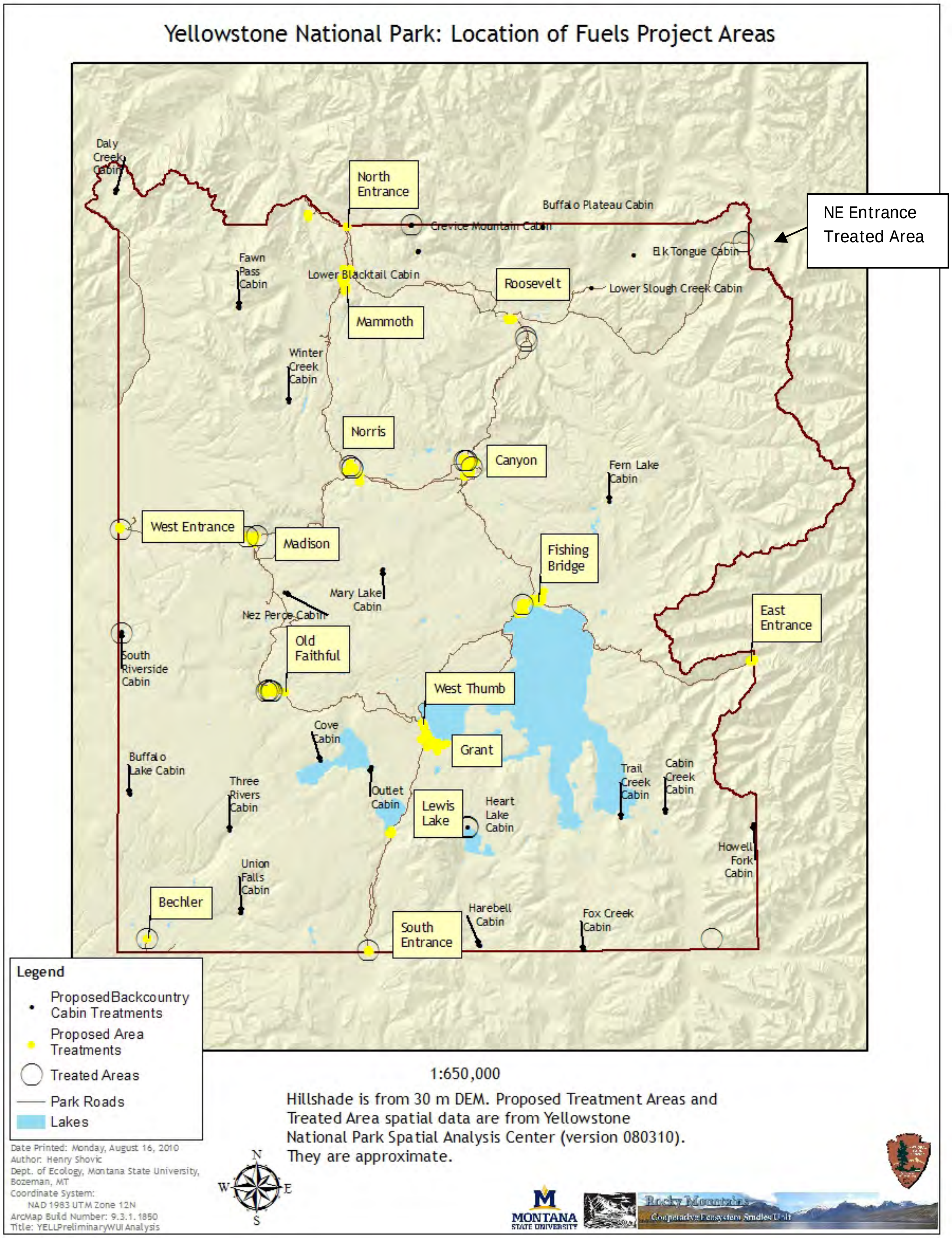

Figure 1. Location of Fuels Projects

Field Review to Verify Data and Clarify Objectives

On August 4, we reviewed an area treated in 2001 near the Northeast Entrance developed area (Figure 2). Soils are medium textured and formed in andesitic glacial till. Slopes are from 0 to 15%. Park staff indicated the treatment was completed using a standard logging contract, using ground-based machinery (dispersed skidding using a rubber tired skidder). GPS points 64 – 67 are on the main access road built to treat the area. The main access road has revegetated (as shown on the imagery and on Figure 3), primarily with forbs and grass. Park staff indicated some reclamation of the main road was completed.

Soil disturbance was significant at points on the main logging road. Though the 2' and 3' cuts were partially reduced, the road bed was still evident in terms of subsoil exposure and profile disturbance. Figure 4 shows the kinds of remaining disturbance. The area around and west of point 68, which was part of the dispersed skidding area had moderate disturbance, but was still quite visible (Figure 5). There was a buried water pipe and an old wagon at point 69 (Figure 6).

Though the area has revegetated, permanent changes have been made to the soils on the main access road. Reclamation has reduced the intensity of these changes and the soils are relatively resilient, but the significant sub-surface soil exposure is visually apparent and will likely permanently change the character of the vegetation. The dispersed logging area also has some disturbance. However, previous disturbance is probable, based on ground evidence and the proximity to a developed area. This confounds estimating the effects of dispersed logging.

We also reviewed a treated area around the Canyon developed area. Other than small burn piles and stumps, we saw no soil disturbance. According to Park staff this area was thinned and hand-piled with some horse-based skidding.

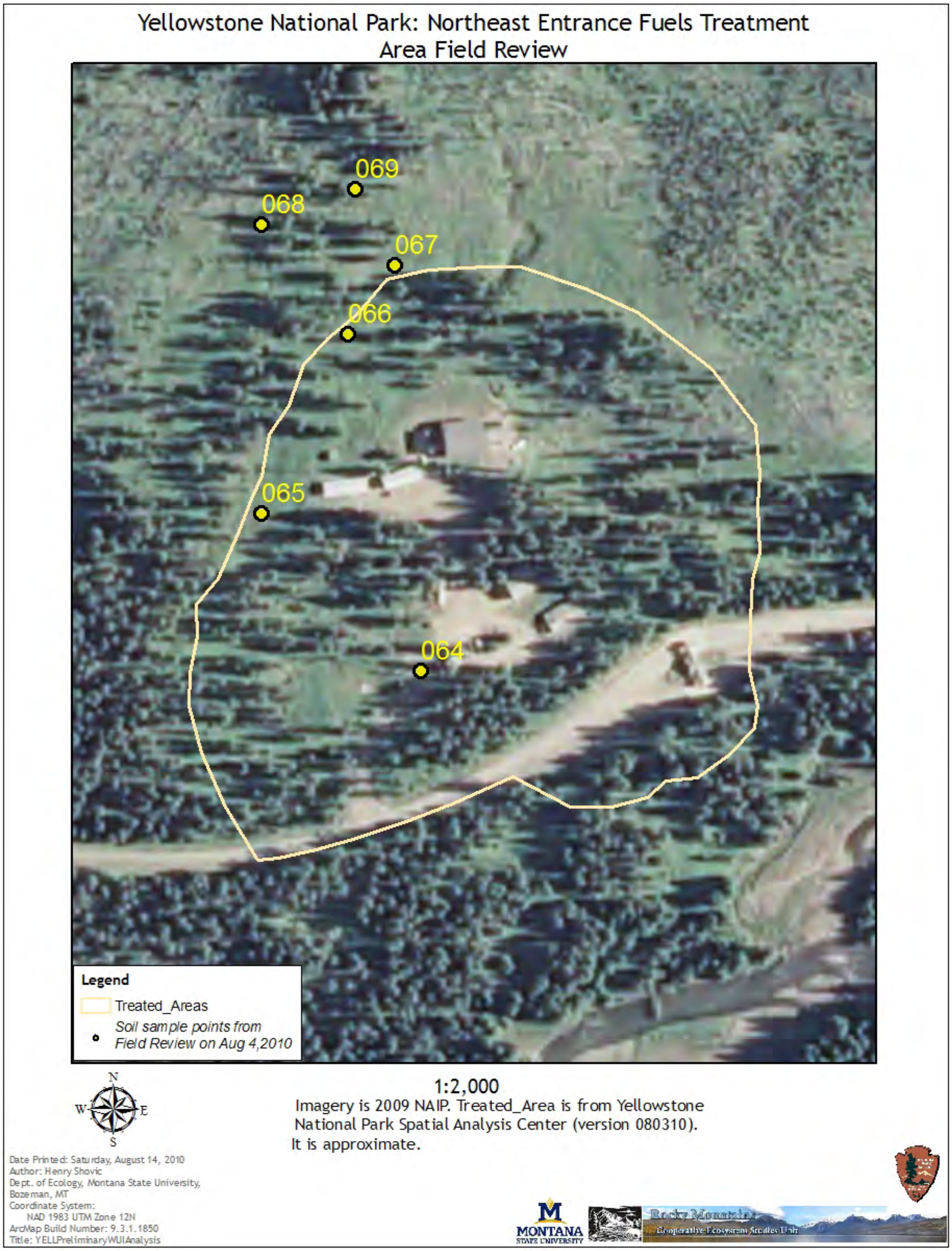

Figure 2. Map of Northeast Entrance Field Review

Figure 3. Main access road revegetation

Figure 4. Soil disturbance in main access road area


Figure 5. Treated area


Figure 6. Water pipe in treated area

Example Soil Sensitivity Analysis

To illustrate a way to evaluate the sensitivity of proposed treatment areas, soil type and slope were used to estimate a “sensitivity” index. Higher values of the index indicate areas are more sensitive to soil-disturbing treatments. Since the research evaluation indicated soil texture influences sensitivity to management, the soil survey (Rodman, Shovic, and Thoma, 1996) was used to determine soil texture for each area. Slope is also a factor in mechanical treatment impacts, so was added as another factor (Table 2). The index is additive, with higher numbers indicating higher sensitivity.

Table 2: Soil Sensitivity Rating Factors

Soil texture	Factor	Slope	Factor
Medium to moderately fine	1	0 – 10%	1
Moderately-coarse	4	10-30%	2
Coarse	4	30+%	3

A large (36 x 48 inch) map is included in the electronic package, which shows all the ratings with their weighted average sensitivities. Figure 7 shows an example for the Grant Village Proposed Treatment Area. The green areas have medium-textured soils and the reddish-yellow areas have moderately-coarse soils. A small area in the lower right has a very high sensitivity due to slope. This area should be carefully considered before treatment. This analysis can guide managers in planning mitigations and prioritizing treatment areas.

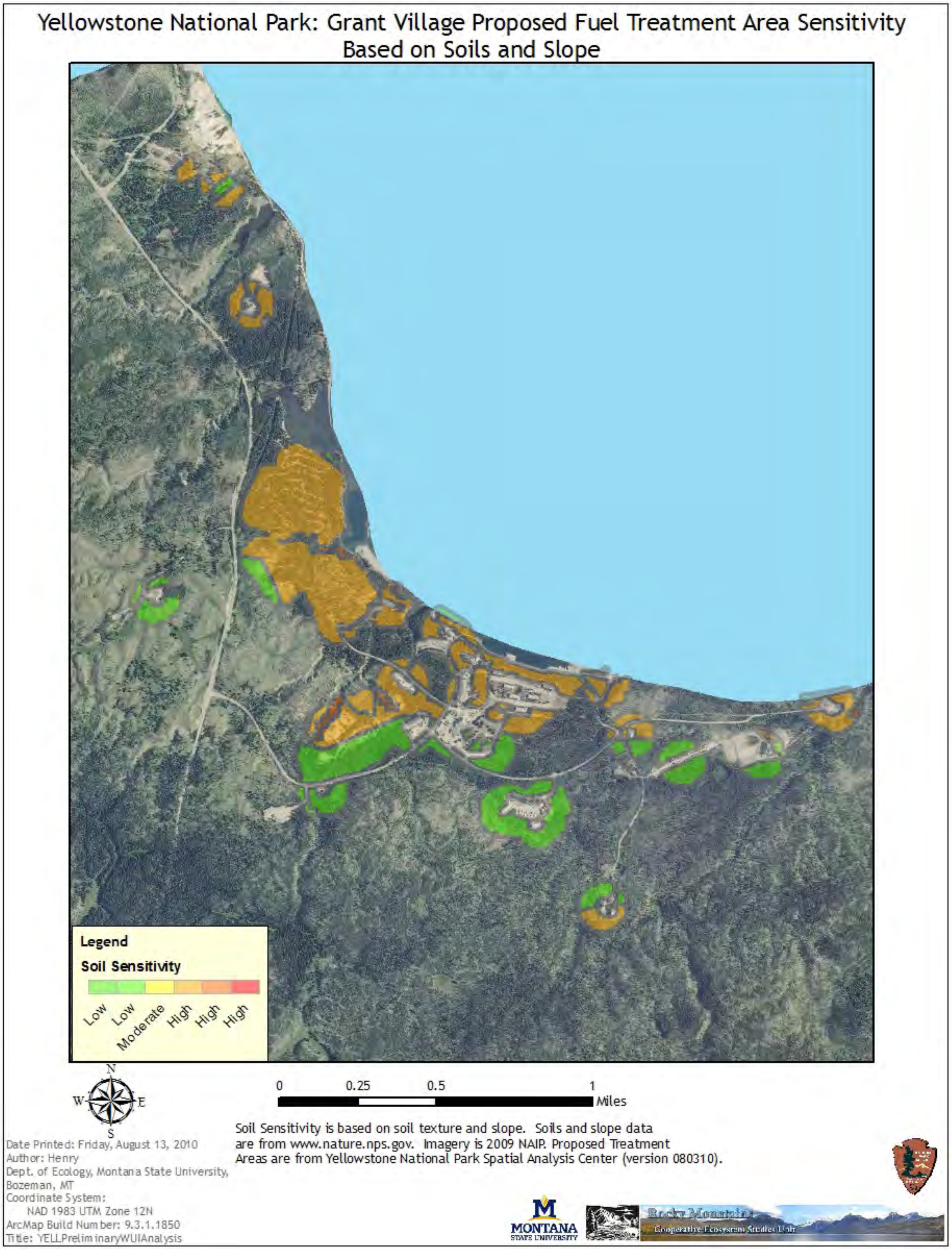

Figure 7. Example Soil Sensitivity - Grant Village

Summary of Literature and Management Options

The following summary was developed from 39 references gathered for this study. Annotated cited literature is included in the Appendix.

Mechanical treatment methods have been proposed to address the fire hazards described above. These generally include using ground-contact machinery to cut, haul, and dispose of standing and ground vegetation. Ground impacts of mechanical treatment can be severe (Page-Dumroese et. al, *in* Elliot, et al, ed., 2010, doc. 4). Direct impacts can include soil compaction, displacement, smearing (surface sealing), degradation of soil properties by heating, and removal by erosion. Effects of these changes include loss of productivity, long term changes in vegetation, increased erosion, sedimentation, or increased invasion by non-native or weedy species. There has been discussion on the kinds of likely ecosystem impacts and the best way to either restore the landscapes after treatment or to protect them during the process. Two general approaches are reviewed below: 1) restoring the affected landscapes after treatment using techniques used in Yellowstone National Park for construction projects, and 2) soil protection during treatment, using U. S. Forest Service methods.

The concepts of surface soil replacement used in “restoration” vs. “reclamation” are different. Reclamation practices may have objectives more related to preventing erosion and creating a reasonable vegetation cover, “Restoration” implies a more holistic approach (Holl, et al, 2003, doc. 8), involving restoring vegetation and landscapes to pre-disturbance levels. National Park Service policy relates more to the restorative approach, while most “reclamation” texts emphasize the importance of “more is better”. However, both approaches place importance on surface soil replacement and potential impacts of changing that part of the ecosystem.

The National Park Service has been charged with the protection of its natural resources. In the event of natural resource damage, policies require assessment and restoration, including soils and vegetation (Environmental Quality Division, 2003, doc. 5). In terms of restoration of vegetation cover, Glacier, Denali, and Yellowstone National Parks have used techniques including surface soil replacement, recontouring, and native plant revegetation in their construction and reclamation activities (Majerus, 2000, doc. 11) (Densmore, Vander Meer, and Dunkle, 2000, doc. 2).

The concept of preservation and re-spreading of surface soil as an ecological restoration technique is well known throughout the reclamation industry and scientific world (Munshower, 1994, doc. 15). In particular, successful alpine or high elevation restoration depends heavily on the re-use of its limited soil resource (Mackyk, 2000, doc. 10). On arid landscapes, reclamation success is related to reclaimed surface soil depth (Bowen, et al, 2005, doc. 1). Both environments are common in National Parks.

Yellowstone National Park has long been successful in landscape restoration using these techniques (Eleanor Clark, personal communication), and has a standardized policy for any construction activities that disturb the soil that includes recontouring, surface soil replacement, and revegetation (Landscape Architect Department, 1997, doc. 9). Most examples relate to linear features such as road construction, pipeline or power burial corridors, or small construction sites. Examples abound of areas where no special techniques were used, with attendant poor revegetation (Roy Renkin, personal communication).

However, there are also impacts related to active restoration techniques. Re-spread surface soil or subsurface layers may be compacted, strength and resistance to root penetration increased, aeration reduced, and soil structure may be destroyed, changing the ecological system over the long run (Torbert and Burger, 2000, doc. 35). Surface soils may be too shallow to be effectively stock-piled (Mackyk, 2000, doc. 10), or may be too mixed during disturbance for effective use (Ruebke, 2007, doc. 27).

The U. S. Forest Service has dealt with soil impacts over its land management history and its research and management responses appear to be useful to provide an alternative to restoration for National Park Service projects. Over the last 30 years there has been increased recognition of machine effects on soils. Harvest monitoring in the 80's and early 90's indicated high disturbance levels (Shovic and Birkeland, 1992, doc. 33), effects on nutrient levels (Mann, et al, 1988, doc. 12) and potential decreases in productivity (Dyck and Mees, 1990, doc. 3). This prompted the start of studies to evaluate the potential linkages between soil disturbance and long-term productivity (Page-Dumroese, et al, ed, 2010, doc. 22). The concept of soil disturbance standards was introduced as a way to begin quantitative comparison and evaluation as well as provide management with documentable compliance (USDA Forest Service, 1999, doc. 36). According to this policy, if soil disturbance is kept below the designated, measurable standard, no measureable change in productivity will occur, this meeting the objective of non-impairment.

Management practices that limit disturbance based on quantitative monitoring were introduced on a National Forest level, eg. on the Gallatin National Forest (Shovic, 2008, doc. 32). The rise of litigation in the 2000's relating to soil disturbance, the quantitative standards, and measurement of compliance prompted additional research (Page-Dumroese, et. al, ed, 2010, doc. 22). This litigation has primarily been directed at the processes of analysis, rather than the effects of management on soils. This research has resulted in solid statistical methods of disturbance measurement (see below). Clarity of the linkage between soil disturbance and long term productivity is improving (Geist, et al, 2008, doc. 6; Page-Dumroese, 2010, research update presentation, doc. 17; Powers, et al, 2005, doc. 24). Results are mixed, but it is clear there are long term effects of soil disturbance on both soil properties and vegetation (Page-Dumroese et. al, *in* Elliot, et al, ed., 2010, doc. 4). In particular, different soils respond differently to a given disturbance. On coarse-textured soils productivity may be decreased with disturbance (Page-Dumroese, Jurgensen, and Terry, 2010, doc. 18), there may be no discernable effect on higher-fertility, non-moisture limited sites (Miller, et al, 1996, doc. 13). Furthermore, soil texture affects both the disturbance from a given impact, and the long-term vegetative response ((Page-Dumroese, et al, 2006, doc. 21). Clayey soils appear to have a greater sensitivity to machine effects (Powers, et al, 2005, doc. 24).

The above research does not directly address the existing standards made policy in 1999 (USDA Forest Service, 1999, doc. 36) though it generally supports the linkages between soil disturbance and productivity. The use of existing quantitative standards limiting maximum disturbance will probably continue until more research results are available.

The application of those existing soil quality standards with attendant changes in harvest methods have resulted in improvement in disturbance levels. In fact, average disturbance (using the existing standards) for the last decade in the Northern Region (Montana and Idaho) now appears to be within quality limits (Reeves and Page-Dumroese, draft research report, 2010, doc. 25) With continuing improvement in harvest methods and application, it appears that in some cases soil management practices are now relatively effective in preventing productivity losses.

Note that there are limitations in applying these results. The quality standards are still in the process of verification. Only above-ground productivity is measured (though soil properties are included). Therefore, meeting the standards does not necessarily equate to ecological preservation, so it would probably be best to use the most conservative methods available if the goal is to maintain or restore ecological integrity.

There are a number of mitigative methods that appear to successfully prevent long-term disturbance. These are as follows:

- Limiting disturbed area – Designating skid trails concentrates machine disturbance on a limited area. Most soil compaction occurs in the first few passes (Han, et al, 2006, doc. 7; Williamson and Neilsen, 2000, doc. 37), so restricting machinery to these trails, in combination with other methods (such as directional felling) can be effective if designed to meet standards.
- Limiting machine contact – Limiting ground contact is an effective way of reducing disturbance. Using an adequate slash-mat (Han, et al, 2006, doc. 7) can minimize impacts, especially with modern harvesting machinery.
- Limiting treatment conditions – Soil moisture levels affect their potential for compaction and other kinds of disturbances (Williamson and Neilsen, 2000, doc. 37). Machine use only when the soils are dry may be effective, when used with other area-limiting methods.
- Limiting treatment on sensitive soils – It appears that there is no "one size fits all" set of standards for all soils. Some soils are more sensitive to disturbance then others (Page-Dumroese, 2010, research update presentation, doc. 17). Those could be flagged for special mitigative measures or considered for exclusion.
- Limiting treatment season - One of the most effective methods is to employ over-snow treatments. This can not only limit soil disturbance, but also prevents damage to the understory vegetation (Page-Dumroese, et al, 2006, doc. 21; Philipek, 1985, doc. 23).
- Certain kinds of machines tend to have higher impacts. For example, skyline harvesting systems generally have far lower impacts than do ground-based ones (Shovic and Birkeland, 1992, doc. 33). Also, the U. S. Forest Service has volumes of harvest operator specifications. Using these will also help prevent disturbance, when used with qualified administrators. Further evaluation of machine types and sale administration are beyond the scope of the present project.

Research Design to Monitor Soil Disturbance

The effects of ground-based machinery have been monitored in the U. S. Forest Service at least since the late 1980's (Shovic and Birkeland, 1992, doc. 33; Shovic, 2005, doc. 31). Though these examples included statistical measurements, there was a wide diversity in methods of measurement and reporting throughout the Northern Region and indeed throughout the country (Page-Dumroese, ed, et. al, 2010, page 121, doc. 22). These early attempts at quantification employed slow and laborious methods of measuring soil properties (particularly compaction) so more-rapid visual methods were correlated with those results to allow more timely monitoring programs (Shovic and Birkeland, 1992, doc. 33).

This early work was limited to the National Forest level (e.g. Shovic, 2005, doc. 31), but beginning in 2002, Regional and National levels began efforts to improve and standardize methods of measuring soil disturbance (Page-Dumroese, ed, et. al, 2010, page 123, doc. 22). Significant changes were made, including developing rapid visual methods for estimating disturbance, statistically-based sampling designs, and scientifically-based interpretations. These methods have been incorporated into the planning process (Northern Region, 2009, doc. 16).

Morphological (visual) methods of measuring soil disturbance have been developed with contributions from private industry (Scott, 2007, doc. 29), research organizations, and land management Agencies (Page-Dumroese, ed, et. al, 2010, doc. 22). Visual methods are widely used throughout the world and the U. S. as indicators of soil quality (ibid, page 61; Page-Dumroese, et. al, 2009, doc. 20, page 4). Measured disturbance types include compaction, displacement, erosion, puddling or smearing, and burn effects.

The statistical methods (Page-Dumroese, ed, et. al, 2010, doc. 22, page 109) were developed in concert with the standardized visual indicators. They were designed to be relatively straight-forward, applicable in the field, and to have a defined level of reliability. During the planning and execution process, they should be applied both before and after a mechanical treatment, and to a representative number of activity units. In the U. S. Forest Service, guidelines have been developed to determine the extent and intensity of the sampling design (Northern Region, 2009, doc. 16). Pre-treatment sampling is used to determine the nature of existing problems and to design mitigations. Its extent depends on the estimated level of previous disturbance, the variability of soils on site, and the proposed treatments. If there is no apparent previous disturbance, there may be no need for a statistical pretest. The post-treatment sampling intensity and extent is dependent on the site variability, and the number of activity areas having potential disturbance. Such parameters as described above, sample size, and other measurements may be modified to fit management objectives and environmental conditions since they differ between agencies, but they should all be considered in the research design, with consideration for statistical reliability.

The monitoring methods themselves are spelled out in detail in a technical guide titled "Forest Soil Disturbance Monitoring Protocol: Vol I" (Page-Dumroese, et. al, 2009a, doc. 19). Briefly, the protocol includes the following:

- Define the monitoring objective (preactivity, postactivity, short-term monitoring, long term monitoring, etc)
- Gather necessary background information- soil survey, maps, photos, etc., and determine if the site should be stratified.
- Decide on confidence levels, transect design, and indicators needed.
- Describe site management, slope, and other landscape parameters.
- Begin monitoring
- Summarize results

The background and basis for this protocol is described in "Forest Soil Disturbance Monitoring Protocol, Vol II" (Page-Dumroese, et. al, 2009b, doc. 20). The method is based on a stratified random sample using proportions, using either randomized transects, systematic grid points with a random direction, or a single random multi-vector transect (Figure 8).

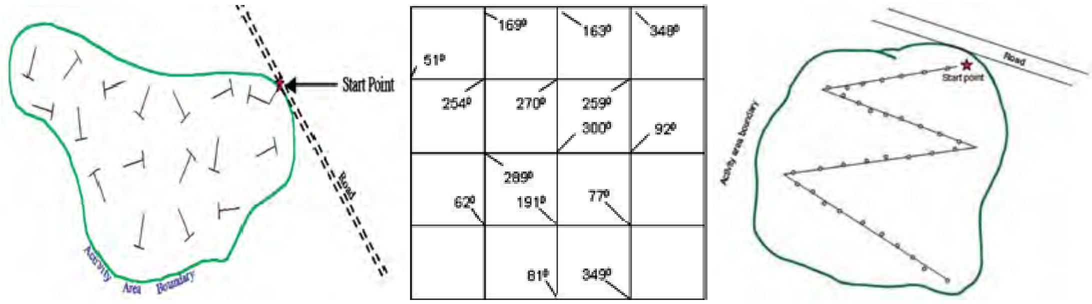

Figure 8. Sampling schemes

The statistical results used for this method are automatically calculated if using the spreadsheet form described above. Equipment needed includes the standard electronic data collection form, a portable data recorder (that can accept the standardized electronic data collection form), with some method of point location on the ground. The scientific background for the concepts of soil productivity, soil quality, and their relationship to these protocols is discussed at length in "Scientific background for soil monitoring on National Forests and Rangelands" considered to be volume III of this set (Page-Dumroese, et. al, ed, 2010, doc. 22).

The scientist responsible for this research design should be qualified in statistics, soil science, and forest management. Specific qualifications used in the U. S. Forest Service are spelled out in policy documents (Northern Region, 2009, doc. 16), and include specific soil science qualifications. Field crews should be under his/her supervision and control. All personnel should be trained in these techniques to maintain quality control. All these methods are quite dependent on judgments made by the sample taker, and training is important to quality control (Miller, et. al., 2010, doc. 14).

Conclusions

From the above analysis it appears there is high potential for continuing mechanical fuels treatments in Yellowstone National Park. The provided data indicate only a small portion of the proposed treatments have been completed, and a large future program is probable based on current plans. Climate change will probably also increase these kinds of programs. Also, based on field review there is some basis for concern about ecosystem impacts of the treatments. This is underscored by the literature. The standard restorative specifications appear to have a place in restoring disturbed areas, but they also have impacts, and may not be appropriate for entire treatment area. A great deal of work has been done on limiting productivity impacts in the Forest Service, and even though not all questions have been answered, there appears to be some well-defined mitigative measures that are research-based and practical to implement. A combination of restorative and preventative techniques may be the best combination to meet National Park Service objectives.

Management Recommendations

Recommendations for future treatment area planning include:

- Use soils expertise in the planning phases of treatments to identify potential problem areas, familiarize Park staff with mitigations designed to minimize disturbance, and integrate these protocols modified by Park objectives and conditions.

- Complete pretreatment monitoring, to prevent confusion between treatment effects and previous conditions on sites.
- Define the construction part of the treatment. There are generally two parts to treatment projects, as illustrated by the field review above. The main haul trail is actually a "road" leading to a landing, and the skidding (cutting and moving wood to the landing) is more of a dispersed impact. Because of significant disturbance in the "road", standard construction restoration techniques (including surface soil removal, recontouring, and replacement) should be considered for those parts of the projects.
- In skidding areas, define mitigations that are designed to keep soil disturbance below minimums established by Park objectives and scientific literature. From the literature it appears that disturbance in skidding areas could be kept low by using mitigative techniques. These appear to meet current standards as defined in the U. S. Forest Service.
- In terms of particular mitigations, oversnow impacts are likely to be the lowest. Since National Park Service objectives are somewhat different from the Forest Service, this mitigation may be more likely to prevent any significant disturbance to the ecosystem. Since the Park's climate is conducive to a long snow/frozen ground season, this may also be the most cost effective solution.
- Apply post-treatment monitoring to sites using qualified crews under supervision of a qualified individual. The monitoring techniques described above are statistically rigorous and the research design has been tested.
- Use results to show the effectiveness of those mitigations and improve areas that have excessive disturbance.

Recommendations for Future Work

- It appears that soils/landscape analysis could benefit future planning by helping to define sensitive areas. There appears to be some work that could be done on prioritizing fuel treatment areas in an interdisciplinary or multi-disciplinary setting. The enclosed map can start this process by relating soils, slope, and WUI together to rate sensitivity of mapped areas. However, a more formal way of rating has been developed and applied in two projects: Canyonlands National Park trail management, and watershed improvements in Afghanistan (Shovic, 2009, doc. 30; Shovic, et al, 2009, doc. 34). It is a relatively-straightforward decision support system using industry-standard software that could be applied to the selection and prioritization of the many proposed WUI areas in Yellowstone National Park.

- The literature shows the importance and potential impacts of surface soil replacement in the general sense. However, its practical use in the field has not been described in National Parks. Scientific analysis and publication of the large amount of scattered data that pertains to Yellowstone National Park's long-running and successful revegetation/restoration program would be very helpful in advancing the state of restoration efforts in other Parks.

Spatial Data and Maps Included with This Report

Potential_Treatment_Areas: obtained from Yellowstone National Park Spatial Analysis Center, version of 08/03/2010. This was further modified by a definition query including only forested land.

Treated_Areas: obtained from Yellowstone National Park Spatial Analysis Center, version of 08/03/2010.

IntSoilTreatmentWUISlope: intersection of soils, slope classes, and “Potential_Treatment_Areas (subset by forest) for sensitivity calculations.

Printable Adobe Acrobat document (pdf) of the potential treatment areas and soil sensitivity (36 x48 inches).

Appendix: Annotated Cited Literature

Note that citations include the document number. Electronic versions of these documents have been provided to Yellowstone National Park. Their file names use these numbers as indices.

1. Bowen, C. K., G. E. Schuman, R. A. Olson, and L. J. Ingram. 2005. Influence of topsoil depth on plant and soil attributes of 24-year old reclaimed mined lands. Arid Land Research and Management, 19:267-284, 2005: Most vegetation and soil properties improved with increasing topsoil depth; arid lands; long term study.
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