Wisconsin's Forestry 2016 Soil Disturbance Study on State and County Lands




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Acknowledgements

We would like to thank and recognize the county and state foresters and administrators for all their help during multiple phases of this study, who generously:

- Provided maps and information on selected timber sales
- Met us on site to go over study details
- Answered our questions, whether they were specific to a site or on general information
- Provided thoughtful feedback and discussion on the interpreted data (BMP Advisory Committee)

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Box 7921
Madison, WI 53707
PUB-FR-705-2017

Printed on Recycled Paper

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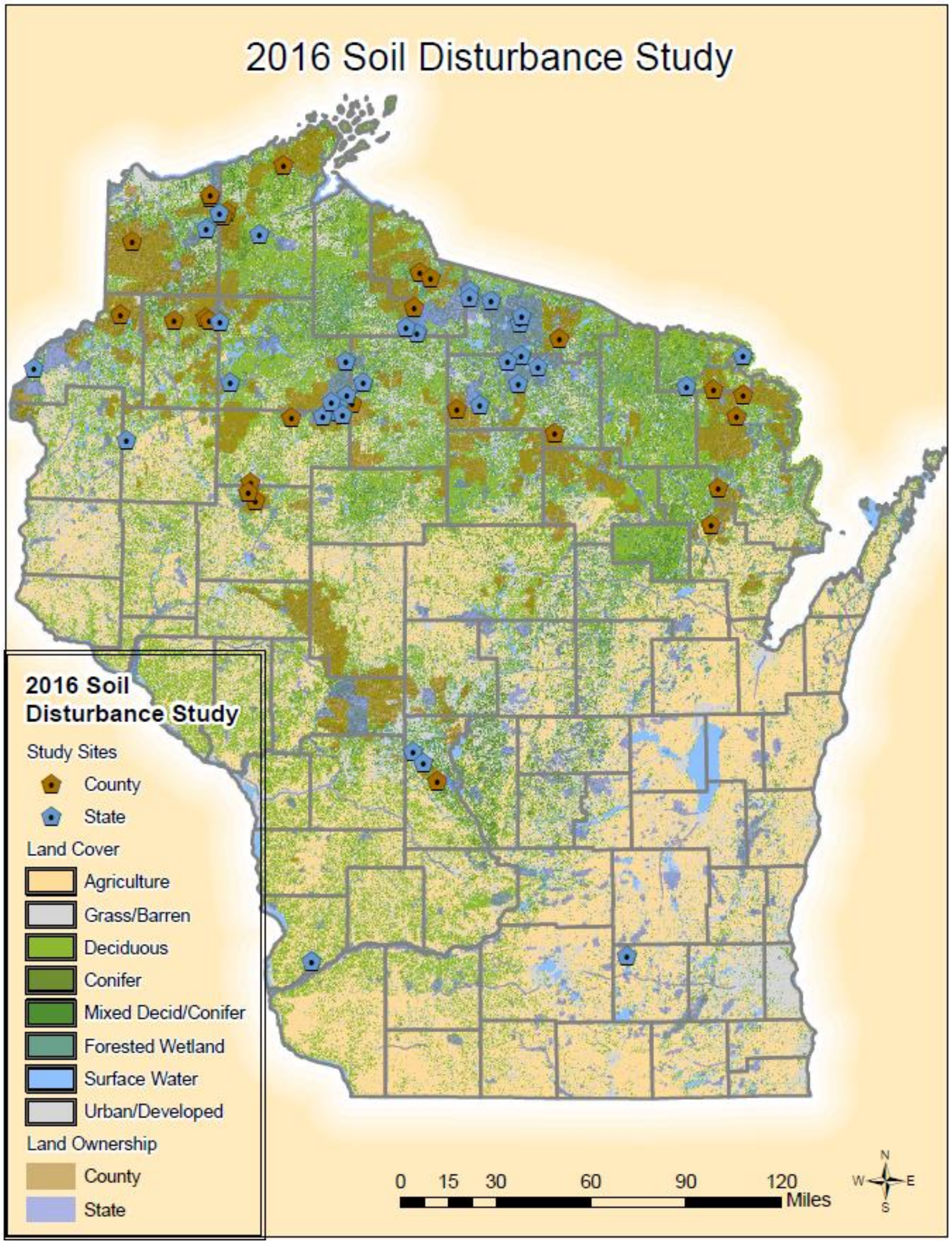

Figure 1. Sites monitored for the 2016 Soil Disturbance Study. Blue dots represent sites owned by the state and brown dots represent sites owned by the county. Lands shaded in blue are under state ownership while lands shaded in brown are under county ownership. *Note: Some dots are grouped closely together, making the total number of sites difficult to determine on this map. Disclaimer:* The Department has made reasonable efforts to provide you with accurate information, but cannot exclude the possibility of errors or omissions in sources or of changes in actual conditions. The Department makes no warranties of any kind, either the express or implied. Changes may be periodically made to the information herein.*

History and Introduction

The 2016 Soil Disturbance Study was the result of state and county forest certification audits. The auditory review of forestry practices on lands owned by the state occurred in 2004. After the audit was completed, the Wisconsin Department of Natural Resources (DNR) received a Corrective Action Request (CAR) from the Forest Stewardship Council (FSC) and an Opportunities for Improvement (OFI) citation from the Sustainable Forestry Initiative (SFI). During the auditory review, after visiting a site with significant soil disturbance, SFI and FSC auditors found that the Department did not have written guidelines regarding what level of soil disturbance that would be considered "acceptable" during forest management activities. The county forestry program also received a CAR and OFI from FSC and SFI (respectively) for similar reasons during 2005/2006. Both the state and county agencies were tasked with developing "written and preferably quantitative guidelines for defining the limits of acceptable rutting on roads and trails".

To comply, DNR and County Forestry staff mutually sought to obtain guidance which balanced both science and practicality. The Wisconsin Professional Loggers Association and Timber Producers Association worked with the two agencies to draft a policy for rutting that would eventually be used in State Land Timber Sale contracts in May 2006. This policy went through three drafts and a public comment period from June 2005 to March 2006; the final guidelines were incorporated in May 2006. The guidelines for excessive rutting are shown in Table 1 below.

Infrastructure	Soil disturbance is excessive if:
Roads, Landings, Skid Trails and General Harvest Area	A gully or rut is 6 inches deep or more and is resulting in channelized flow to a wetland, stream or lake
Roads, Landings and Primary Skid Trails	In an RMZ or wetland, a gully or rut is 6 inches deep or more and is 100 feet long or more. In an upland area (outside of RMZ), a gully or rut is 10 inches deep or more and is 66 feet long or more.
Secondary Skid Trails and General Harvest Area	A gully or rut is 6 inches deep or more and is 100 feet long or more.

Table 1. Excessive rutting guidelines on state and county lands are divided into Infrastructure type.

A timber sale involving an excessive soil disturbance requires special attention from a sale administrator who must evaluate the effect of the soil disturbance, halt current harvesting operations, and develop repair or mitigation recommendations. Classifying a soil disturbance as "excessive" does not mandate closing a timber sale or forest road; however, appropriate actions shall be taken, to minimize any further disturbances. Although the request to develop the above table was straightforward, its development was surprisingly time-consuming and complex. The task was difficult because the policy had to align three key elements: scientific knowledge, practical aspects of implementation, and the ability of forest administrators to regulate.

Goals of the Soil Disturbance Policy

- Minimize inadvertent soil disturbances during timber harvests and potential adverse impacts to soil productivity, water quality, fish and wildlife habitat, and other natural resources.
- Protect public investment in state and county forests.
- Maintain existing roads and related structures to intended design standards.
- Combine professional level expertise and operator experience in the formation of on-the-ground decisions.
- Provide a protocol for identifying and responding to maintenance needs.

Foci of the Policy

- Avoid and minimize soil disturbances.
- Recognize some soil disturbance is inevitable.
- If soil disturbance does occur, mitigate or repair to the extent possible.
- In some instances "doing nothing" is preferable to mitigation, if mitigation will exacerbate the situation.
- Not to mandate decisions, but guide timber sale administrators and contractors in management decisions, considering on-the-ground-conditions, availability of equipment and other resources.

It is important to note that these goals and foci are consistent with protocol used in both the Wisconsin Forest Management Guidelines and Wisconsin's Forestry Best Management Practices (BMPs) for Water Quality Field Manual. While these guidelines apply to timber sales on state lands and to projects on the state forest road system, they do not apply to intentional soil disturbances, such as mechanical site preparation or firebreak construction. They are also not applicable to soil disturbances caused by recreational users on designated recreational trails. Within addition to the developed policy, management expectations remain in place when the Department oversees a timber sale; all steps and precautions, including implementation of BMPs, will be taken to avoid and minimize soil disturbances during the sale. If a timber sale involves soil disturbances below the excessive threshold, the contractor will evaluate the disturbance and determine what actions, if any, are needed to repair or mitigate the effects of the soil disturbance.

If a timber sale involves soil disturbances that exceed the excessive threshold, then the contractor is required to contact the timber sale administrator (or vice versa) and together they will evaluate the disturbance and determine what actions, if any, are needed to repair or mitigate the effects. The timber sale administrator must meet on-site with the timber sale contractor and equipment operators. The administrator and contractor should consider management goals and objectives, weather, site conditions, availability of equipment and other factors when evaluating repair and mitigation options. Prior to closing a sale, the timber sale administrator should ensure that any soil disturbances are properly addressed.

The Soil Disturbance Study (SDS) was developed to monitor the success of the policy. This study was first performed in 2006 on state lands only; in 2011 and 2016 it was conducted for both state and county lands. The results are summarized in this report, which is the first published report released by the Department. The report focuses heavily on collected data, methodology, and analyses from the 2016 study. The results for the remaining two years (2006 and 2011) were summarized into PowerPoints and presented to various interested groups over the past years. The study provided valuable monitoring on soil disturbances subject to the developed rutting policy; it also offered an opportunity to gather similar types of data on soil disturbances which can influence stand health and productivity, which are reflected in the goals and objectives of the SDS.

With the broad objective of *collecting information on soil disturbances to determine whether forestry practices on state and county lands are protecting soil resources,* the questions emerge: are the appropriate people adhering to the rutting policy? Does the policy provide timber sale administrators, contractors, and loggers with clear direction and expectations in dealing with soil disturbance? The study will hopefully quantify and describe the effects of soil disturbances on natural drainage patterns and soil erosion. A specific goal in 2016 was to examine how the continued push for summer harvesting interrelates the language of timber sale contracts with the overarching rutting policy and soil disturbance expectations.

Many other studies have been conducted that have very similar goals to the 2016 SDS. To maximize efficiency, this study incorporated many of the previous studies' field protocols. One of those studies is the Wisconsin State Forests Continuous Forest Inventory (WisCFI) which, in turn, was adapted from the USDA Forest Service Forest Inventory and Analysis. To demonstrate the similarity between study goals, and to emphasize overall importance of monitoring the physical properties of soil and its susceptible to human activity, part of the introduction from WisCFI is noted below:

> "The soil resource is a primary component of all terrestrial ecosystems, and any environmental stressor that alters the natural function of the soil has the potential to influence the vitality, species composition, and hydrology of forest ecosystems. Specifically, soils data are collected on [Phase 3] plots to assess:
>
> - The potential for erosion of nutrient-rich top soils and forest floors.
> - Factors relating to the storage and cycling of nutrients and water.
> - The availability of nutrients and water to plants (dependent upon soil structure and texture).
>
> Nutrient and water availability to forest vegetation is dependent on the physical capacity of roots to grow and access nutrients, water, and oxygen from the soil. In addition to playing an important role in plant nutrition, the physical properties of the soil largely determine forest hydrology, particularly with regards to surface and ground water flow. Human activities that result in the destruction of soil aggregates, loss of pore space (compaction), and erosion may increase rates of surface runoff and alter historic patterns of stream flow. In some areas, these changes may result in flooding and/or dewatered streams and can reflect on both the health of aquatic ecosystems and the management and conservation of associated forest and agricultural areas."

The goals between the SDS and the WisCFI are similar and the soil data collected by these types of studies are a great way to monitor a vital, easily damaged, and often marginalized variable of forest health.

Defining "rut" and "gully"

Before describing the methodology used for this study, some definitions for commonplace terms must be established. For example, each person who has worked in the forest management and silviculture field is likely familiar with ruts. However, it is doubtful that the criteria is the same between individuals due to their independent experiences. Establishing quantitative measurements to define rutting is important for the consistency of this study.

A **rut** is an elongated depression caused by the dragging of logs, or from the movement of wheeled or tracked harvesting machinery and equipment. Erosion from water runoff can exacerbate existing ruts, increasing their length and/or depth. In this study, a measurable rut is one that, at some point, becomes greater than six inches in depth and is greater than five feet from depression start to depression end. The only ruts measured were those found on infrastructure types such as; roads, landings, primary skid trails (PST), and on all transects.

Gullies were another soil disturbance feature noted during the study (Figure 2). A **gully** is an erosion channel that cuts into the soil, forming a concentration of preferential water flow. Gullies were measured if they meet the same quantitative values and infrastructure types as ruts (described above).

Figure 2. Gully on a forest road system. Lack of water control structures, led to channelized run-off forming gullies that have active erosion.

Figure 3. Displaced sediment from the gullies on the forest road shown in figure 2. This sediment will make it more challenging for the road to re-vegetate and become stable.

Number of Sites and Acres Monitored

In this study, 60 sites were monitored for soil disturbances including rutting, gullies, compaction, infrastructure and bare soil. Twenty-seven of the sites were located on land under the stewardship of Wisconsin County Forests and 33 were located on state land and under the stewardship of the Department of Natural Resources. While the sites ranged across the state in longitude, from Lake Michigan to St. Croix/Mississippi Rivers, they were clustered in the northern part of the state where forests more often merge with county and state land (Figure 1).

While many of the analyses will differentiate between findings on state and county lands, no further deviation (into different state forests or county forests) will be made for two reasons. First, when subgroups are analyzed, the amount of data decreases which can decrease the significance of the finding. This is especially true for this study where even the largest subgroup had only nine sites (which occurred on the Northern Highlands/American Legion State Forests). The nine sites that were included in this study, on the property, were not enough to represent the 81 sites that met criteria for being included during the time of this study. To further emphasize the point, it must also be taken into account that each individual property may have dozens or even hundreds of sales that have been conducted since the last time this study was done in 2011.

Secondly, if subgroups were analyzed individually, it would be very easy to connect the occurrence of soil disturbance (or lack thereof), to a specific team of foresters and land managers; each county and state property is managed by a unique and different team. It could be misleading to portray individual forestry teams as successful or unsuccessful based on a very small and statistically insignificant group of sales monitored for this study for each property.

During this study, 4083 acres were monitored and split between state and county. 2,288 acres were under state ownership, and the remaining 1,795 acres were under county ownership (Figure 4). Approximately 500 more acres were monitored on state lands than on county lands; however, when the number of sites is taken into account (33 state sites vs 27 county sites), the average number of acres monitored per site is almost identical at 69 acres for the state sites and 66 acres for the county sites(*Note: averages and percentages are rounded to the nearest whole number)*.It must also be noted that acreage for state timber sales were much larger on average – 124 acres on state lands vs. 91 acres on county lands. Therefore, only 56 percent of acres from each state sale were included in the study while 72 percent of acres from each county sale were included in the study.

The main reason portions of the sale were not included in the study was because sale had not been completely harvested. During the study, it was found that state sales were more likely to be only partially harvested compared to those in counties, leading to a discrepancy between total sale acres and total acres monitored between the two landowners. The largest number of acres monitored for any one sale was 190 acres on state lands and 177 acres on county lands. The largest sale for state lands was 589 acres, whereas the largest sale on county lands was 177 acres.

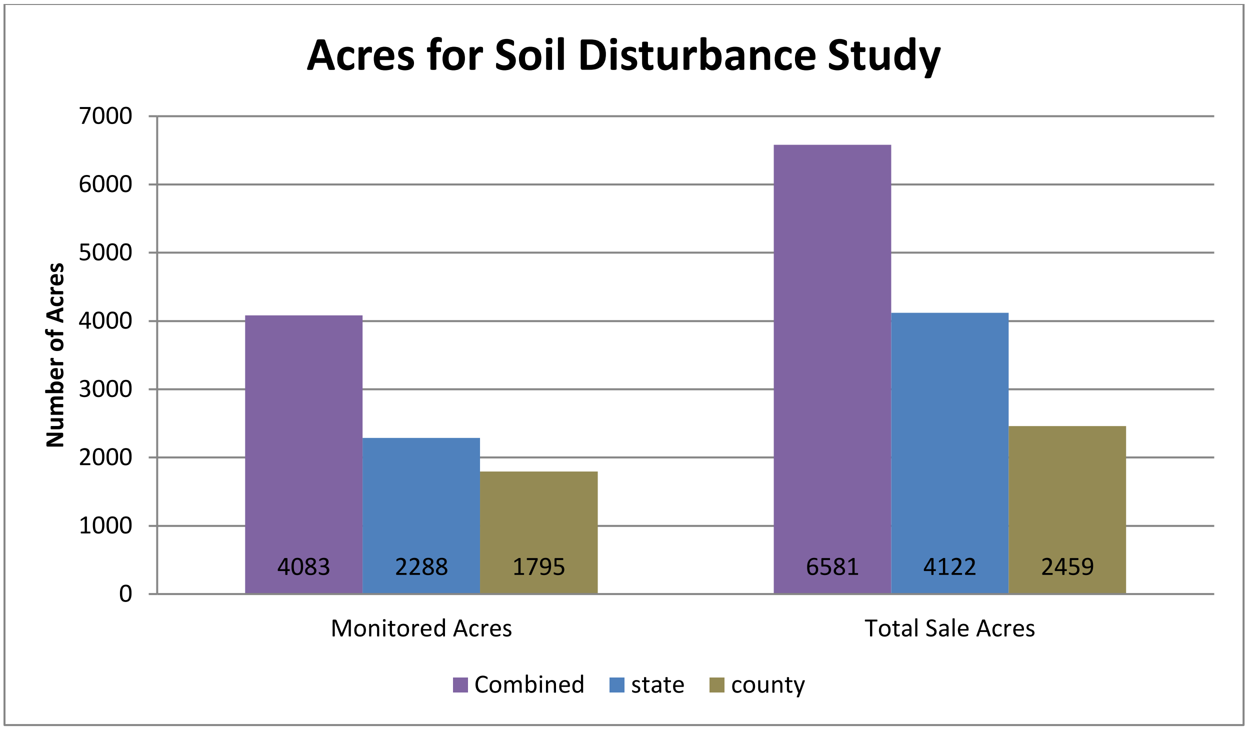

Figure 4. The number of acres monitored for the Soil Disturbance Study on state and county lands.

Selection Criteria and Methodology

Site Selection

Although site selection for this study was rather straightforward on paper, actual implementation was difficult. The goal was to monitor 30 sites on both state and county (60 total sites) that had recent activity. However, determining what comprised "recent activity" portion proved complicated as there are no reliable, updated master lists of active sales for either county or state lands. Fortunately, the Wisconsin Forest Inventory Reporting System (WisFIRS) can sort sales on status by "completed", "incomplete" and "active". "Active" means that the forester in charge of the sale has entered data into the system to verify that the sale been successfully bid upon but the final payment had not been received. Unfortunately, "active" in the WisFIRS system does not actually indicate any on-the-ground harvest activity undertaken by the logger(s). Thus "active" status may be given to a sale prior to harvest. For example, the timber may be sold in the summer but be subject to winter restrictions, creating a gap in the time the actual start of the harvest. Harvests could also be partially harvested due to a number of reasons such as unfavorable weather – this caused loggers to stop harvesting until favorable weather conditions resumed. Many of the monitored sales fell into this category. Lastly, "active" could refer to post-harvest, where the loggers have completed the harvest but monetary conclusion (i.e. closing the contract) had not yet occurred.

Obviously, the forester in charge of the sale would have a much better idea if the site was truly active; however the time needed to contact the number of foresters involved in addition to accounting for the time gaps between preparing/selecting sites was beyond the means of this study. Therefore, the WisFIRS "active" list system was used for the SDS. After the sites were selected, state and county foresters were contacted to see if any recent harvesting had occurred on the sites that were originally selected by the WisFIRS system.

Transects

To meet the objective goals of this study, multiple data locations were sampled and timber sale infrastructure measured. The WisCFI developed an efficient way to measure many of the desired data based on using transects. This study used a transect method to take multiple data points based on the number of monitored acres (Table 2). Transects were randomized as much as possible and distributed throughout the sale. True randomization done with a computer, before the site was visited, was impeded because knowledge of which parts of sales might have been partially or completely harvested prior to inspection was not always available. Another consideration was that truly random models may clump points together, leading transects to intersect or parallel closely, possibly replicating a previously completed transect. Many of the harvests included more than one type of harvest (such as clearcutting and selective) which could reflect a forest tree species shift. By being able to choose where to start transects, non-harvest areas were avoided and the complexity of each harvest site was much more likely to be captured.

Table 2. Minimum number of transects to establish.						
Size of Sale (acres)	≤ 25	26 – 50	51 – 100	101 – 150	151 – 200	> 200
Number of Transects	2	3	4	6	8	10

Table 2. The minimum number of transects established based on the monitored acreage of the timber sales.

Four data collection points were taken on each transect, each 300 feet long. The data collection points were spaced 100 feet apart. Data was measured at the beginning point, at 100 feet, at 200 feet, and at the end of the transect. The distance between the points was estimated by pacing out 33 steps (one step was roughly three feet). The data collected at the beginning and end of each transect varied than data taken at the 100 and 200 feet intervals (the middle two points). Several variables were measured at the beginning and end points including: soil compaction, bare soil, slope, infrastructure type and soil typing. In addition, GPS coordinates were taken for accurate relocation. Data from the middle two data points included only two variables: soil compaction and infrastructure type. In the results section, the difference in data collection will become important, when the sample size becomes different based on the data collected at each of these points. There was a total of 225 transects completed, which included 900 data collection points along those transects.

Soil Compaction

Soil compaction was measured with a soil compaction tester (penetrometer) that could measure soil resistance, in pounds per square inch (psi), between 0 psi and in excess of 300 psi. Each data collection point on the transect had up to five compaction readings taken, completed in a five feet radius circle from a center reading. It was not always possible or necessary to perform five compaction readings at each data collection point. Since the data points were recorded as an average of the readings, there were no more points needed if three results were the same. It was not always possible to take a measurement due to a variety of forest conditions, such as excessively rocky soil. These conditions would hinder the compaction tester to reach a depth of nine inches – the depth which all measurements were ideally taken. There were classes of compactions which all readings were sorted into: 0-100, 100-200, 200-300, and 300+. The individual tests (up to five) were grouped into these compaction classes, as well as the final recording (averaged from the five) for the transect data point.

Figure 5. The ground surface of this primary skid trail is covered with an abundance of slash (wood waste). Slash significantly reduces the compaction impact from multiple equipment passes.

Soil Texture

Using the soil core, soil texture was determined into two layers below ground surface, from the 0-4 inch layer and the 4-8 inch layer. The soil samples were classified as either sand, clay, silt, or as organic matter. However, as with the compaction tester, sometimes there were times the soil proved too difficult for sampling. The reason soil classifications were simplified into basic categories was to increase efficiency. Soil texture was differentiated based solely on soil texture and not soil color. If the soil ranged from damp to saturated and formed a self-supporting ribbon at least one inch long when handled, it was a clay. If it had a smooth texture but did not form a complete ribbon, it was classified as silt. Whereas, sand had a coarse texture and did not form any sort of ribbon when handled. Organic soils contained poorly decomposed detritus, which were very dark to black in color and develops under low oxygen conditions. Only one soil texture reading was taken at the beginning and end of each transect for a total of 450 data points.

Figure 6. Sand contains larger particles than clay and silt. Individual particles can be seen in this picture without the aid of magnification. Compared with other soil types, sand possesses a very unique color distinction (orange/tan), as seen here.

Bare Soil and Slope

Bare soil was estimated as a percentage of cover within 24-foot diameter circles. Slope was averaged over the same area, again as a percentage. However, slope was put into categories, called classes, and were based from USDA-NRCS Web Soil Survey (Class A: “0-3”, Class B: “3-8”, Class C: “8-15”, and Class D: “15-25”) (Note a percent slope differs from degrees and gradient. For example, a landscape that has 100% slope would be a gradient of 1:1 (1 foot vertical for 1 foot horizontal) and be considered at 45 degrees). Both of these data types were taken only at the beginning and end of each transect, which made 450 total data points.

Infrastructure

Infrastructure was measured independently from transects. As explained in the introduction, there are five infrastructure types: general harvest areas, secondary skid trails, primary skid trails, forest roads, and landings. **General harvest areas (GHAs)** are areas where equipment did not transport (either haul or skid) wood during the harvest. **Secondary skid trails (SSTs)**, are areas within the harvest that were used by equipment for one or two discrete passes. **Primary skid trails (PSTs)** are paths used by equipment during three or more passes. **Roads**, like PSTs, are used for multiple passes of equipment, but differentiate from PSTs by being more developed – they can support vehicle traffic meant for on-road use, such as semi-trailers and trucks. Roads are usually maintained during the sale and removed of all debris such as stumps and large boulders. **Landings** are any area of the sale used to deck wood before it is picked up and loaded on a vehicle to be taken off site (usually by a semi-trailer). There are two types of landings: the first is the tradition landing, where an area is cleared of debris and can be used for loading vehicles to turn around (usually at the end of a forest road within the sale). The second type is simply decking wood along the side of a road (forest road or public road), where the logs will be loaded onto a transport vehicle without ever going to a true landing. Decking wood is becoming more common, especially during sales that have public roads immediately adjacent to the sale area.

Every PST, landing, and road was traveled and its length was estimated by pacing them off. Due to continual improvements of aerial photos available online, some of the roads were easily recognizable and secondarily measured through satellite imagery. PSTs and landings were always paced off for measurement. For all landings, roads, and PSTs, the area removed from production was estimated as a percentage and recorded. Only forest roads and landings which were located within or immediately adjacent to the sale were included in the calculations. Public roads, regardless of their location, were not included in this study.

Figure 7. A forest road that has been blocked to keep traffic out by an earthen berm. The harvest on this forest road system was seasonally restricted (winter). Barriers are the best way to stop soil disturbance that could occur if sensitive sites are exposed to traffic after the harvest is completed.

Ruts and Gullies

Separate protocol was used for measuring ruts and gullies during the Soil Disturbance Study. First, it was determined which ruts/gullies would be measured. Each had to be over 5 feet long and over 6 inches deep, at some point, to be included. They had to be either located on designated infrastructure (primary skid trails, landings and roads), or bisect transects. Ruts/gullies that did not meet either the magnitude (five feet long by six inches deep) or infrastructure requirement were not included in numeric data and analysis. However, they were recorded in the supplemental questions as a rutting observation and if it would have met the definition of excessive rutting. Many variables pertaining to ruts and gullies were used in this study (See Appendix B), including:

- Designation (rut or gulley)
- Type of infrastructure (road, landing, primary skid trail, secondary skid trail, general harvesting area)
- Location (upland, wetland or riparian management zone)
- Orientation to slope (up/down to the slope, parallel to the slope, flat ground)
- Presence of active erosion (yes or no)
- Incidents of altered drainage (yes or no)
- Cause of soil disruption (use of harvesting equipment, ATV, or other)
- Age of rut/gully (1 week, 1 month, 3 months, or greater than 3 months)

The length and depth of ruts/gullies were also recorded using several measurements. The total length was measured from the beginning of the depression to the end. A second way ruts/gullies were measured for length is where the depth was greater than six inches (see example in Figure 8: purple mark). Likewise, the third and final length measurement, if present, was where ruts and gullies length was in excess of 10 inches deep. These length recordings are not exclusive – so a section of a rut/gully that is greater than 10 inches will be measured three times (total length, 6”+, and 10”+). The deepest section of each rut/gully was also measured using two different methods. First, the section was measured from the bottom of the rut to the original ground surface (the same way the depth is recorded for determining rut/gully definitions and rut/gully lengths). Secondly, the rut/gully was measured from the bottom of the rut/gully to the highest point of soil. This highest point was usually higher than the original ground surface, especially in ruts where tires or tracks have pushed soil to the side, resulting in a mounding phenomenon.

Interestingly, in gullies, the maximum depth measurements and maximum depth to highest point of soil measurement were almost always the same: as gullies remove soil to a different location whereas rutting compacts and horizontally displaces soil. Pairs of ruts were measured separately, as two individual ruts. If individual lug marks from tires or track tread were seen, the lesser of the two measurements was used for determining depth.

Figure 8. Purple lines represent the distance where the rut is over 6” deep to the original ground surface (represented in blue). The red line represents the maximum depth to the top of the soil. Green lines outline soil which was pushed out of the ruts and is above the original ground surface.

Results

Compaction

A total of 900 collected data points were measured for soil compaction with a soil compaction tester, which takes ground pressure readings in pounds per square inch (PSI). The number of recorded data points taken on transects breaks down as follows: 650 readings in General Harvest Areas (GHAs), 221 readings on Secondary Skid Trails (SSTs), 22 readings on Primary Skid Trails (PSTs), five readings on roads, and only two readings on landings (one on each landing type). It is no surprise that infrastructure categories heavily correlate to the ground PSI. Infrastructure categories that undergo high use (roads, landings, and PSTs) and receive multiple passes of equipment were much more likely to have a higher ground PSI reading than categories that received little to no equipment passes (GHA and SSTs).

- Ninety-seven percent of the GHA fell into the first two compaction categories of 0-100 psi and 100-200 psi (Figure 9). No GHA readings of over 300 psi were observed in the study.
- Like GHAs, SSTs are generally considered to belong in a low impact category; and, as in the GHA data, the majority of PSI readings fell into the lower two compaction categories (73%). Almost all the readings in the higher two categories were in the 200-300 psi category, leaving only 1% of all readings from SST's being classified at 300+ psi.
- PSTs receive three or more passes of equipment which is reflected in the soil compaction readings found during this study. The majority of PST readings were in the top two compaction categories (64%). Almost a quarter (23%) of all readings taken on PSTs were in the highest category of 300+ psi.
- Roads are even more compacted; 80% of all readings from roads were in the top two categories and, of these, 60% were in the highest category of 300+ psi.
- Landings are a little unique because of their two different landing styles (described in the methods section). The distinction between the two landings was reflected in the compaction readings; the landing type which only had ground contact with decked wood received readings the 100-200 psi category and the landing type where equipment operated received the highest compaction reading at 300+ psi.

The number of readings in each infrastructure category was not only unequal but dramatically different. This is the result of transects being random. The likelihood of readings being taken on less common infrastructure types (some categories only made up 1%-5% of the total monitored area) were very slim. In addition, if a similar non-harvested forest type was immediately adjacent, background readings were often taken just outside the sale boundary. Those readings varied from 0 psi to above 200 psi. As expected, some other factors besides infrastructure can cause a variation between soil compaction readings; soil type is one of those factors.

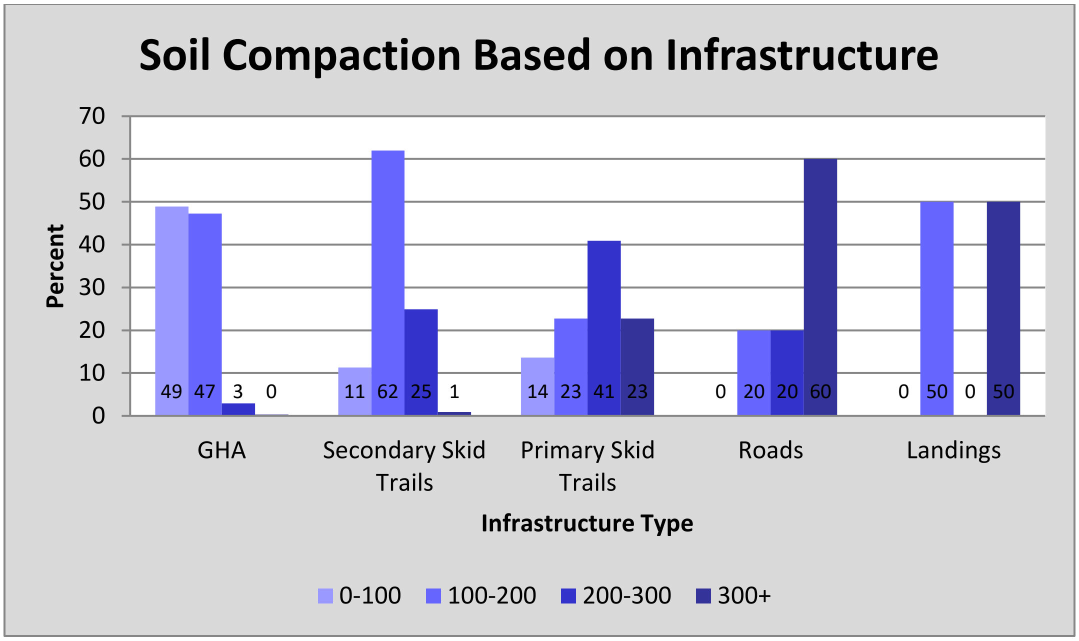

Figure 9. Soil compaction readings based on the different infrastructure categories. Infrastructure type is strongly correlated to the soil compaction (displayed in PSI).

Figure 10. Primary skid trail going through a general harvest area. Compaction levels were much higher for the primary skid trail than areas immediately adjacent to it.

Soil types definitely affected the compaction measured along transects during this study. As described in the methods section, there were only four different categories – of sand, silt, clay, or organic matter. Soil type was determined at the beginning and end points of each transect. Since there was not an equal number of transect points collected for each soil type, results are best expressed as a percentage. Because soils types were taken at 0-4 inches and 4-8 inches, there could theoretically be many groups of soil types for each compaction reading. For the purpose of this study, however, four soil categories is sufficient. For simplicity, the results will show soil types as a singular class, rather than two homogenous measurements.

The study identified 282 sand samples, 50 silt samples, 47 clay samples, and three organic matter samples. Sandy soil types demonstrated the most compaction compared to the other soil types: 13% of sandy soil samples fell into the two highest compaction categories (200-300 psi and 300+ psi, Figure 11). Only two percent of silt samples and four percent of clay samples measured in the two highest categories; none measured in the highest category of 300+ psi. The three samples of organic matter measured in the lowest compaction category (0-100 psi). Twenty-eight percent of sand samples fell into the lowest compaction category (0-100psi), followed almost linearly by silt at 46%, clay at 64%, and organic matter at 100%.

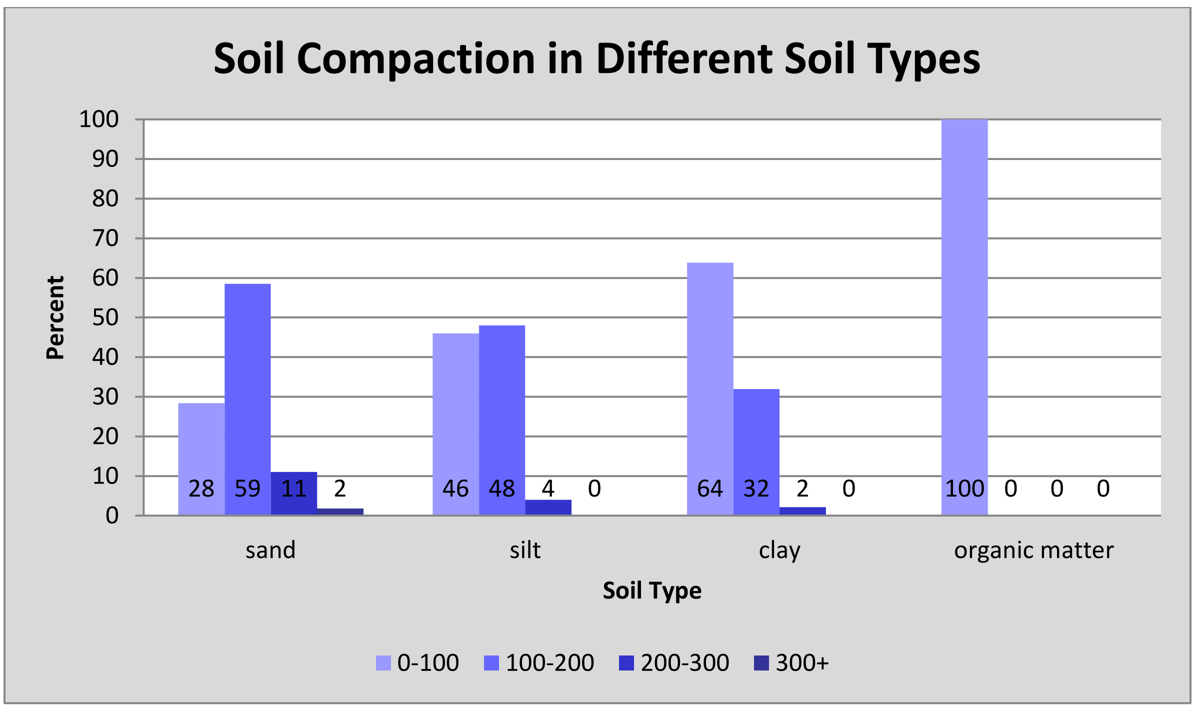

Figure 11. Soil compaction in different soil types. Soil types are grouped into four categories: sand, silt, clay, and organic matter. Only samples that contained the same soil type at both 0-4" depth as the 4-8" depth were shown and were analyzed.

To ensure that the analyses captured true compaction differences in soil types and not just co-variable interactions, soil types were examined while holding infrastructure (which is already known to have a correlation with soil compaction) constant. In other words, the study aimed to verify that sand, the most compacted soil type, is displaying compaction because of its composition (i.e. physical soil properties) and not because the samples contained a larger proportion of Primary Skid Trails, Roads or Landings and a smaller proportion of General Harvest Areas and Secondary Skid Trails. Since only three samples of organic matter soil type were taken, this part focuses more on sand, silt and clay. There is an approximate 10% decrease in the percentage of GHA taken in sand soil types when compared to silt and clay (Table 3). However, the percentage of SSTs taken in sand increased almost nine percent when compared to silt and clay. In this study, Roads and Landings contained only in sand soil type, but each as a fraction of a percent. Primary Skid Trails contained the highest percentage of clay soil types at 4.3%, compared to the percentage of sand (2.5%) and silt (2%).

Examining only one infrastructure category at a time might lead to mixed conclusions. For example, sand soil type had the lowest amount of GHA (the lowest compaction infrastructure type) which could explain why sand was more compacted than the other soil types such as silt and clay. However, clay soil type had less (76.6%) of its data points in GHA than silt did (80.0%) even though clay was less compacted. So by only looking at the GHA infrastructure category, the order of compaction should have gone as follows (from most compacted to least compacted) sand, clay and silt. This is not the actual order presented in the prior section of sand, silt, and lastly clay. Likewise, when only PSTs are examined separately, again the order varies from the true results. Clay would be expected to be the most highly compacted soil type – because clay has the largest percentage of PSTs when compared to sand and silt soil types. This is contrary of the actual results, presented earlier (Figure 11), where clay has the lowest compaction rate, other than organic matter.

The data becomes much clearer when infrastructure categories are grouped into low or high compaction groups. As before, GHAs and SSTs are considered low compaction infrastructure types whereas PSTs, roads, and landings are considered high compaction infrastructure types. When infrastructure categories were grouped into low or high, very little difference between soil type total percentages was observed. For example 96.9% (69.9% in GHA and 27% in SST) of sand was in the low compaction group, which is almost identical to the 98% of silt and 95.7% of clay in the low compaction infrastructure group. Likewise, 3.3% of sand was observed in the high compaction group, along with 2% of silt and 4.3% of clay. These small variations between total percentages of soil types in both the high and low compactions groups made explaining large differences of soil compaction between the types difficult to account for using uneven infrastructure categories as the only criterion. Therefore, soil types certainly appear to play a prominent role in the soil compaction measured in the study.

Table 3.	sand	silt	clay	organic matter
General Harvest Areas	69.9%	80.0%	76.6%	100.0%
Second Skid Trails	27.0%	18.0%	19.1%	0.0%
Primary Skid Trails	2.5%	2.0%	4.3%	0.0%
Roads	0.4%	0.0%	0.0%	0.0%
Landings	0.4%	0.0%	0.0%	0.0%

Table 3. The percentage of infrastructure categories within each soil type.

The degree of slope is another variable which may influence compaction levels within the soil. Slope was recorded at 450 data points, at the beginning and end of each transect (Figure 12). Slope *Class A* ("0-3%") contained 355 data points, *Class B* ("3-8%") contained 77 data points, *Class C* ("8-15%") contained 14 data points, and *Class D* ("15-25%") contained just four points. *No data points were recorded with a slope greater than 25%*. Percentages of compaction category 0-100 psi increased from *Class A* (35%) all the way to *Classes C* and *D* (both at 50%). Inversely, the percentage of compaction in the 100-200psi category decreased as slope increased, from 54% in *Class A* to 25% in *Class D* (Figure 12). No clear pattern of either increasing or decreasing percentages was observed in either compaction classes 200-300 psi and 300+ psi.

As previously noted, it was helpful to analyze data by grouping compaction categories of 0-100 psi and 100-200 psi into a "low" group and 200-300 psi and 300+ psi into a "high" group. Slope *Class D* will not be a focus of further analysis because of its small number of data points. Eighty-nine percent of data points in slope *Class A* fell into the "low" soil compaction group, which was similar to the 93% of data points in slope *Class B* and 86% of data points in slope *Class C*. Nine percent of data points in slope *Class A* fell into the "high" compaction group, as did 8% for slope *Class B*, and 7% for slope *Class C*. (Note percentages may not equal 100% in total due to rounding and because some points were "too rocky" to sample). Although the first two compaction groups (0-100 psi and 100-200 psi) displayed trends, overall slope does not appear to have a strong influence on compaction, especially when compaction groups are divided into "low" and "high" categories.

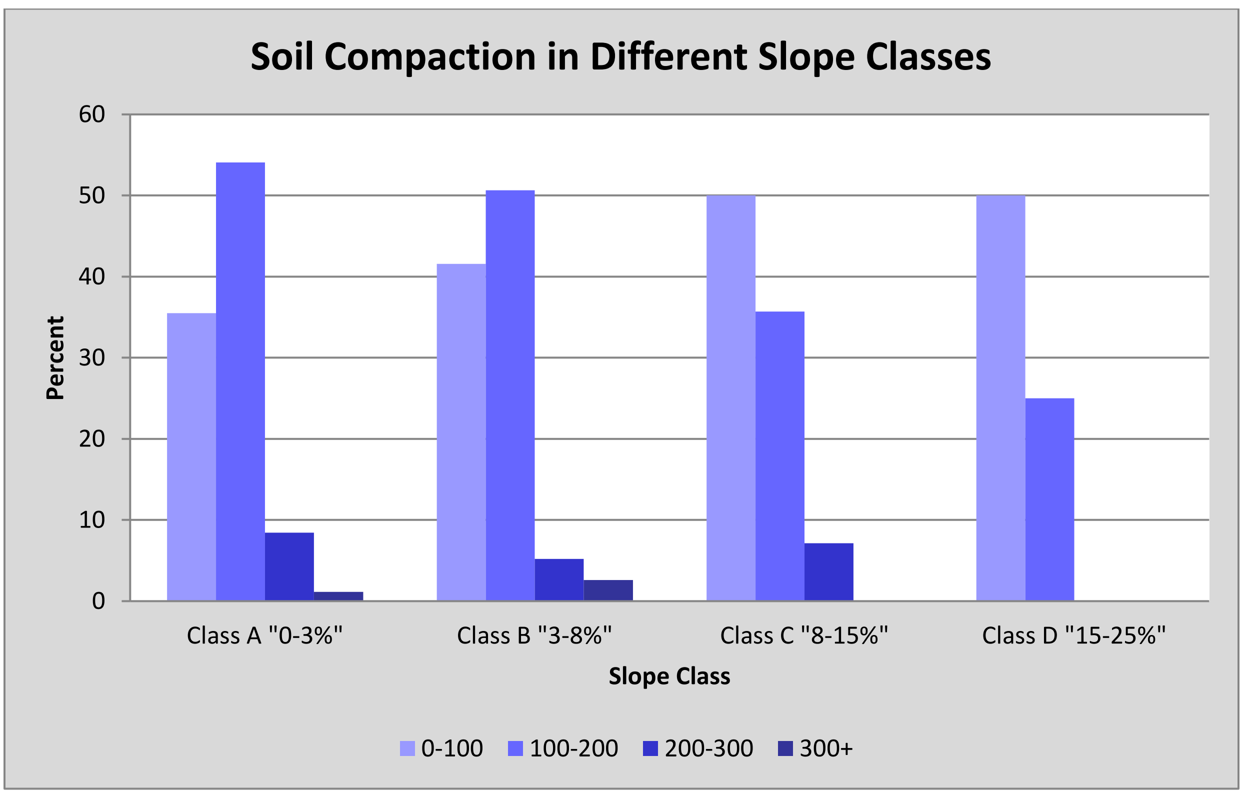

Figure 12. Soil Compaction within different slope classes.

It is apparent from this study that slope does not greatly affect soil compaction when infrastructure is held constant. If this were the case, the expectation would be for infrastructure to reinforce the minor compaction differences, which were initially observed in the slope classes. For example, slope *Class A* had the highest amount of compaction (9%) in the "high" group, which could be caused from a higher prevalence of infrastructure that leads to high compaction rates – like PSTs, roads, and landings. *Class A* did contain a higher percentage of roads and landings (still less than 1% combined, Table 4) than *Class B* and *Class C* but this marginal increase does not account for the significantly smaller number of PSTs when compared to *Class C* (7.1%) vs. *Class A* (2.5%). Conversely, even though *Class C* had the lowest percentage of GHA, it still contains the highest amount of the compaction 0-100 psi group (50%, Figure 12). These findings are the opposite of what would have been expected if infrastructure was correlated to slope. It is clear that slope is not a primary variable in determining compaction like infrastructure and soil types.

Table 4.	Class A "0-3%"	Class B "3-8%"	Class C "8-15%"	Class D "15-25%"
GHA	71.8	76.6	64.3	100.0
Second Skid Trail	24.8	23.4	28.6	0.0
Primary Skid Trail	2.5	0.0	7.1	0.0
Road	0.6	0.0	0.0	0.0
Landing	0.3	0.0	0.0	0.0

Table 4. Slope classes for different infrastructure categories.

Infrastructure

Infrastructure is vital to the completion of any timber sale as it provides the main route for harvesting equipment, which inevitably leads to some compaction. However, issues regarding infrastructure may prevent timber production in affected areas, increase the amount of bare soil, which may lead to an increase in erosion. Designing and building infrastructure that allows efficient movement of wood from harvest areas while minimizing long term economic loss and ecological degradation is critical for success. In this study, it was determined which infrastructure types have more potential for negative impact on harvesting – PSTs, landings, and roads. These three infrastructure types were all examined for the presence of ruts/gullies; their total surface areas were recorded along with the percentage of surface area which was removed from future timber production. The area devoted to these three infrastructure types, on all monitored harvest areas, was 41.7 acres for state lands and 34.8 acres for county lands (Figure 13). While this may seem like a fairly large number, this only equates to less than two percent (1.82% - state lands, 1.94% - county lands) of the total sale area. Newly created Infrastructure was less common on state and county land than were existing infrastructure, but there were much larger differences between new and existing infrastructure on state lands (16.2 acres vs. 25.5 acres) compared to county lands (16.5 acres vs 18.3 acres respectively). In terms of area, roads were also the most abundant infrastructure type present, for both state lands (28.6 acres) and county lands (22.7 acres). Primary skid trails made up of less than half of area of roads, 9.8 acres of state lands and 9.3 acres of county lands. Compared to PSTs, landings constituted about one third of the acres monitored in this study (3.3 - state acres, 2.8 - county acres).

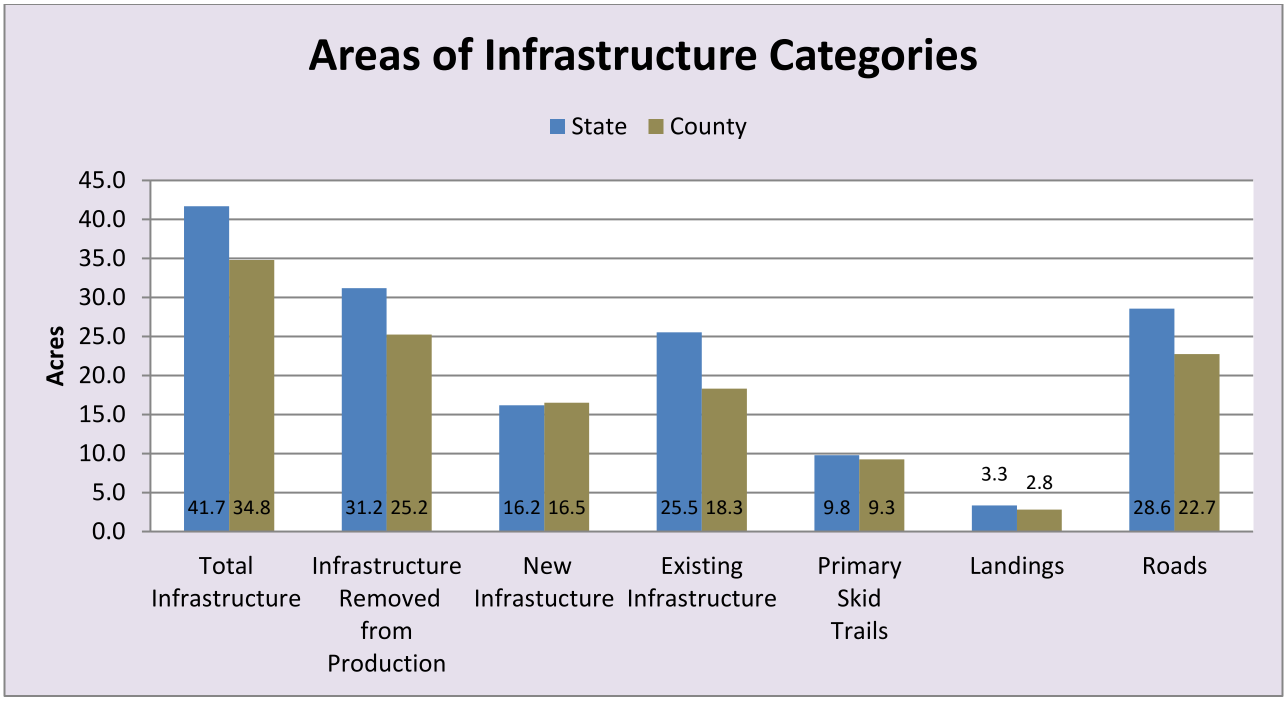

Figure 13. Amount of acres devoted to three types of infrastructure: PSTs, landings, and roads.

Infrastructure conditions caused 75% of the total infrastructure area to be removed from future timber production on state lands and 73% on county lands (Figure 14). However, these values are only averages because there were large differences in the amount of infrastructure removed from production when different categories such infrastructure age (new and existing) and infrastructure type (PSTs, landings and roads) were examined. New infrastructure had only 46% of its area removed from production for state lands and 42% for county lands, whereas existing infrastructure had a much higher percentage of its area removed from production for both landowners (93% - state land, 100% - county land). PSTs had the lowest amount of production area removed for both landowners, but PSTs on county lands had half the amount removed compared to state lands, 16% versus 35%. Landings had approximately half of its area removed (53% - state lands, 40% - county lands) and almost all of roads were removed from production (91% - state lands, 99% - county lands).

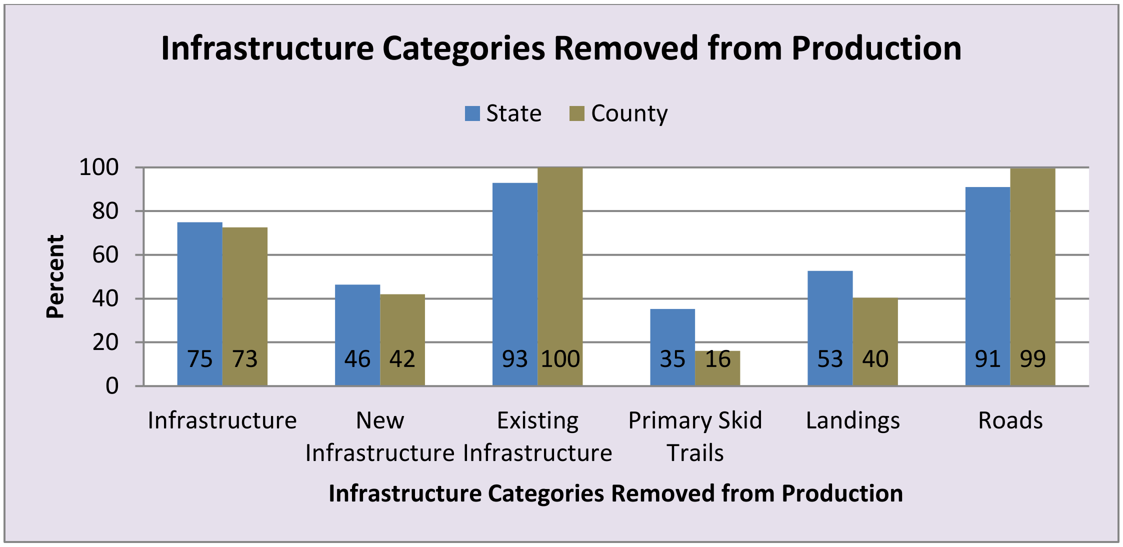

Figure 14. The area, expressed as a percent, removed from production for each infrastructure category.

The study showed that the quantity of infrastructure recorded did not correlate to the total acreages for each infrastructure category (Figure 15.). For example, even though new infrastructure had less acres than existing infrastructure, the number of new infrastructures recorded was over twice the amount of existing for each landowner (116 new vs 57 existing for state lands, 141 new vs 38 existing for county lands). PSTs, landings and roads all had similar quantities recorded with the 69 PSTs for county lands (the greatest number), and 47 roads for county lands (the least number). Any infrastructure that altered drainage or that had active erosion was also noted although very few were observed.

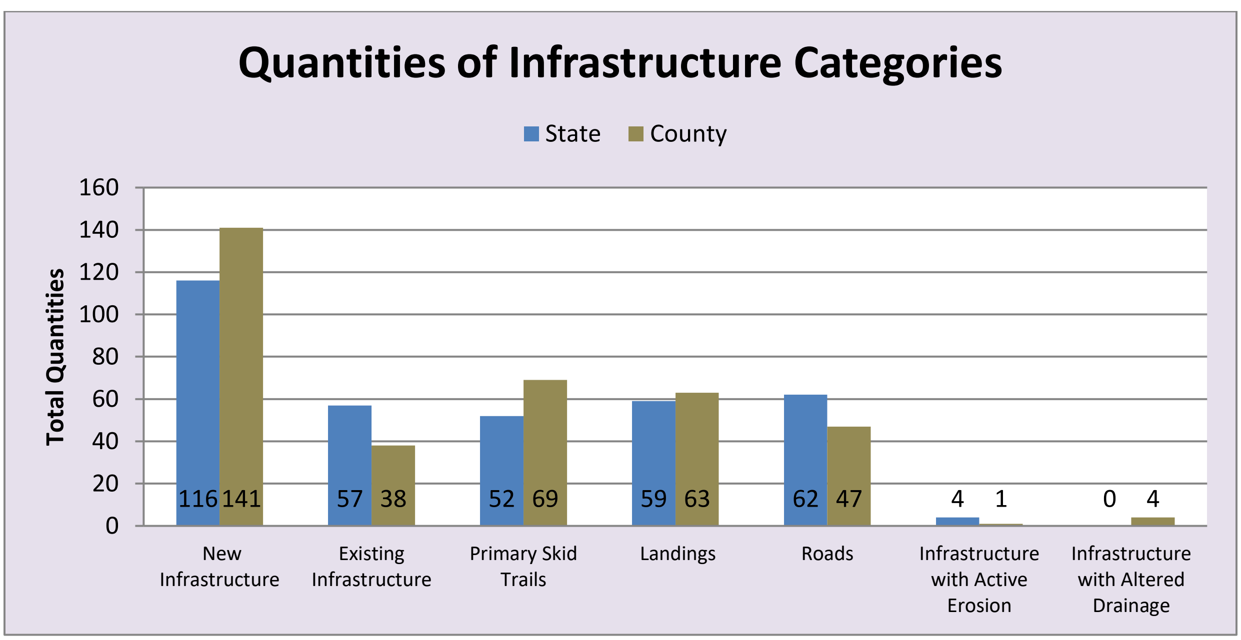

Figure 15. Infrastructure numbers recorded during the SDS.

Ruts and Gullies

There were not many ruts or gullies encountered in the 2016 Soil Disturbance Study. Less than one-half of county sites (13 of 27 sites) and less than one-third of state sites (10 of 33 sites) contained ruts or gullies that were either recorded or observed (Figure 16). (*Note: observed ruts or gullies still had to meet the criteria described earlier in the methods section).* Of the few sites that displayed rutting or gullies, many contained ruts or gullies which were both recorded and observed. Of the ruts/gullies that were recorded in the data and not just observed in the supplemental questions, state sales did not include many sites where there was more than one rut or gully recorded. Only 12 ruts/gullies were recorded over 10 sites. The presence of multiple ruts or gullies were more common in county sales: there were 31 recorded ruts/gullies throughout 13 sites. Overall, there were more recorded ruts/gullies in every category on county land (Table 5). The total length of ruts on state land was 649 feet while there were 1,668 feet on county land. While these numbers may sound large, it is important to keep in mind the large scope of this study; often single roads or primary skid trails were longer than the total length of ruts/gullies recorded for either land owners. This can best be understood by examining the percentage of infrastructure that was rutted or contained gullies (Table 5), which was less than two percent for either the state or the county. Ruts and gullies were most commonly found on PSTs for both state and county sites (7 and 19 respectively, Table 6). There were not any recorded ruts or gullies on landing infrastructure on either state or county land.

Table 5.	State	County
Recorded Ruts/Gullies	12	31
Length of Ruts/Gullies	649 ft	1668 ft
Length of Ruts/Gullies 6"+	364 ft	978 ft
Length of Ruts/Gullies 10"+	132 ft	212 ft
Percent of Infrastructure containing Ruts/Gullies	0.55%	1.49%

Table 5. The total number of recorded ruts and gullies found during the SDS. The total length is broken up into the different measurement classes.

Table 6.	State	County
General Harvest Areas	0	2
Secondary Skid Trails	2	2
Primary Skid Trails	7	19
Roads	3	8
Landings	0	0

Table 6. Infrastructure category for recorded ruts and gullies.

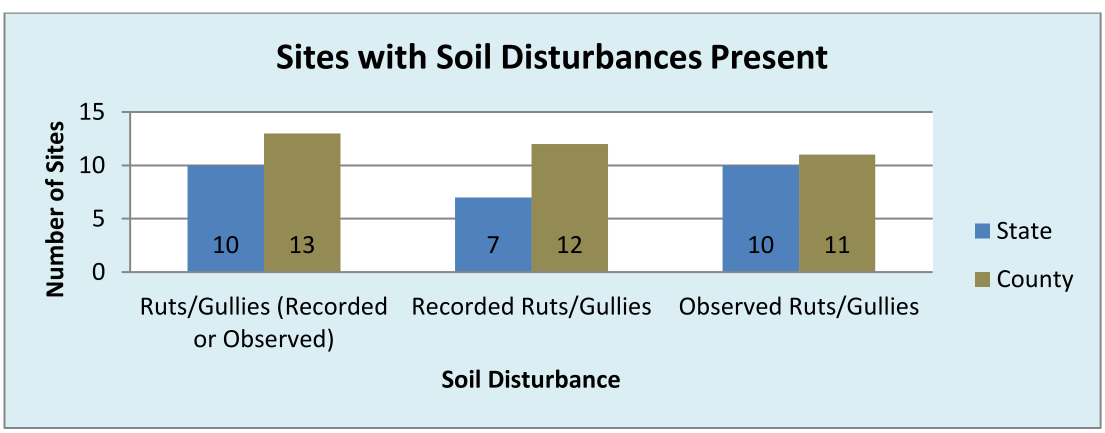

Figure 16. The number of sites that had the presence of ruts/gullies either recorded or measured.

The location of ruts/gullies was concentrated on upland areas for state sites (8 of 12) and on wetland areas for county sites (19 of 31, Figure 17.) No ruts or gullies were recorded in a Riparian Management Zone (RMZ) on either state or county lands. For the orientation of ruts/gullies, state and county properties were equivalent in number of rut/gullies that went up or down an incline, at seven each. There were many more ruts/gullies on county lands with a flat orientation; neither county nor state sites contained ruts/gullies that traversed across slopes. In both the state and county sites, ruts and gullies were more likely to be caused by harvesting and associated equipment rather than post-harvest use by ATV's or other vehicles (Figure 18). The age of ruts/gullies varied between county and state properties; state sites had more ruts/gullies that were older than three months (a total of eight) as opposed to three which were less than one week old. County sites contained ruts that were split between the oldest category and most recent category with 13 recorded ruts/gullies less than one week old and 14 ruts/gullies older than three months. Neither state nor county sites had many soil disturbances in the middle two age classes (one and three months old).

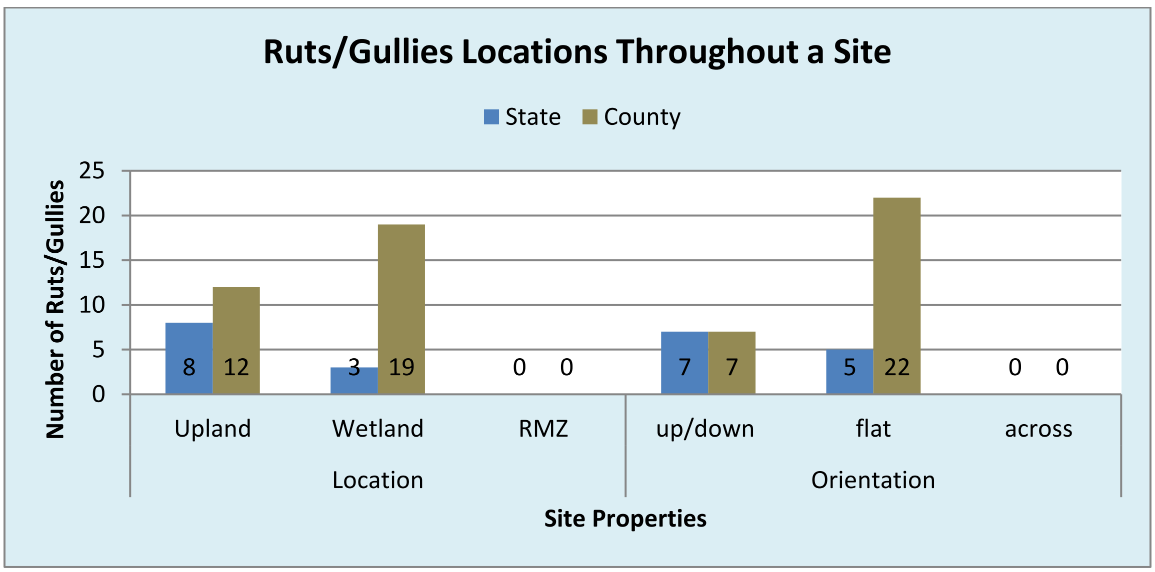

Figure 17. The location and orientation of ruts/gullies that were recorded during the SDS.

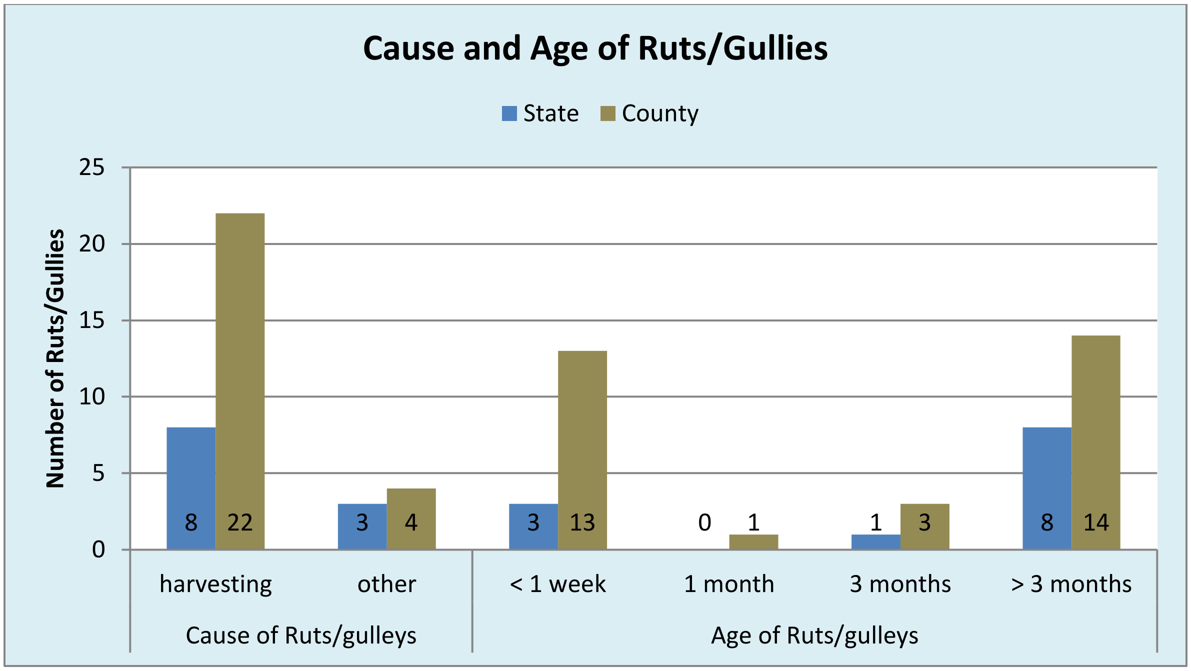

Figure 18. The age and cause of soil disturbance during the 2016 study.

Figure 19. Very recent rutting observed in an upland environment on a primary skid trail. Although ruts are not very deep, tracked equipment caused large amount of top soil to be displaced, especially around bends in the trail.

Figure 20. Older ruts in a wetland environment, which were located throughout the general harvest area. Soil disturbances were common on site because of the soil's inability to bear equipment weight when freezing had not occurred.

No soil disturbance, in this study, met the definition of "excessive" adopted by the state and county. Some soil disturbances were noteworthy; the longest rut on a state site was 200 feet long while the longest on a county property was 360 feet long. Gullies were significantly shorter at both state and county sites, less than one third the length of the longest rut (Table 7). The greatest depth to the original soil horizon, for ruts was similar on both state (18 inches) and county (21 inches) sales. A gully (Figure 21) with a depth of 36 inches was found on state property; the deepest gully on county property only measured 12 inches. No excessive ruts were recorded and the number of ruts/gullies that either altered drainage patterns or led to active erosion were also minimal (Table 8). Only eight total gullies had active erosions – five on state lands and three on county lands. Fewer ruts displayed active erosion – three on county lands and one on state lands. There were eight ruts on county properties that altered drainage but none on state property. Only one gully altered drainage on state property with only two on county lands.

Table 7.	State	County
Greatest Length of Single Rut	200 ft	360 ft
Greatest Length of Single Gully	60 ft	90 ft
Greatest Depth of Single Rut	18"	21"
Greatest Depth of Single Gully	36"	12"
Number of Excessive Ruts Recorded	0	0

Table 7. Information on ruts and gullies recorded during the Soil Disturbance Study.

Table 8.	State	County
Active Erosion on Ruts	1	3
Active Erosion on Gullies	5	3
Altered Drainage on Ruts	0	8
Altered Drainage on Gullies	1	2

Table 8. Ruts and gullies that had either active erosion or altered drainage.

Figure 21. The deepest gully found during the study. It was discovered on state property in the driftless area. The location of the road is at the bottom of two slopes. Since there was no drainage structures present to control the water magnitude or velocity, the water naturally concentrated in this area, and created this deep gully which engulfed almost the entire width of this forest road.

Discussion, Limitations, and Bias

One of the primary ways to judge success on any new guideline is to compare data from before the guideline was introduced to data both shortly and significantly past the original guideline establishment. Unfortunately, the only data the Department has available is from the 2006, 2011, and now the 2016 Soil Disturbance Studies. All of these studies were conducted after the guideline was introduced. However, some of the sales monitored on state lands during 2006 were actually harvested before the guidelines were established. The focus will be on the changes documented on infrastructure, soil compaction, and rutting between the three study years. As was stated in the introduction, all three of these harvest variables can play an essential role in determining the forest health and future forest productivity.

Compaction

In 2006, 51 transects were taken over 11 sites on state land for soil compaction. In 2011, 151 transects were taken over 34 sites on state land for soil compaction. This is compared with the 60 sites where 225 transects were measured in 2016. Overall, 2016 observed much less compaction than both 2006 and 2011 for every infrastructure type and compaction category. There could be many reasons for these collective phenomena including the possibility of:

- More winter harvests in 2016
- Soil moisture content
- Continual advancement of harvesting equipment

Data was not collected on the season of harvest during any study years, because many sales are completed over the course of more than one season and seasonality can vary from year to year and location to location – based on the ground thawing conditions (this is the most important data with regards to timber harvesting, not an actual date). Soil moisture content could conceivably influence soil compaction, where the higher the moisture, the less compaction would be expected. With rainfall varying similar to seasonal (both in location and in quantity), it would be very difficult to accurately describe soil moisture content on each site from precipitation data. However, it is noted that much of Wisconsin experienced drier conditions during 2006 and 2011 as compared to 2016. Lastly, harvesting equipment is continuing to change – new low-impact harvesters and forwarders are constantly being released. While it would be possible to gather data on machinery used, it isn't often very practicable. Many harvesting crews use multiple pieces of varying equipment. Without being able to determine exactly where each piece of different equipment went and how many passes were made, it can only be speculated that changing equipment may have an impact on compaction.

Figure 22. Undisturbed water course after winter time, frozen ground harvest.

Infrastructure

Even though data was taken the same way for each study, there is not much surviving Infrastructure data available from the prior two studies. There is infrastructure data available from 2006, however, it doesn't go into much detail. Compared to the 2016 data, the 2006 data has much more infrastructure (4% - 2006, <2% - 2016) but has a lower rate taken out of production (50% - 2006, 75% - 2016). There are several reasons that this report shows a decrease in infrastructure but a higher percentage of infrastructure removed from production, including limitations of the study itself. Gathering data on infrastructure relies greatly on two factors: the time between when the harvest took place and when it was monitored, and the season of the original harvest. Each growing season reduces the visibility of any infrastructure that is not actively maintained. With the exception of some roads, most are not maintained. The more time that passes from when the sale was harvested, the more likely infrastructure was missed during its monitoring. Again, there is no clear way to compare the ages of the sales in 2006 to those in 2016 but if 2016 saw longer times between the harvest and monitoring; it could explain the decrease of infrastructure.

Winter harvests conducted when soils are frozen tend to protect soil from erosion, compaction and rutting. However, collecting meaningful data from sales harvested during winter can be challenging as there is very little evidence left behind to indicate where equipment has been. Heavily used infrastructure categories such as roads and some primary skid trails can still be easy to identify, but secondary skid trails can be impossible to distinguish. If 2016 had more winter harvests, it could explain both findings (less infrastructure and a higher percentage removed from production) because the little remaining infrastructure still visible during the study was removed from production.

Another reason 2016 could have contained less infrastructure is because of a change in harvesting techniques, either from one or several other factors including newer equipment, increased awareness to soil disturbance, or out of economic practicability. Although newer pieces of equipment have doubtlessly been used during the past ten years, it was not specifically recorded during the monitoring. In general, it was observed that metal-tracked equipment caused more soil disturbance than rubber-tired equipment. This was especially true when the tracked equipment made turns in soft or semi-soft soil. The soil disturbance from tracked equipment didn't necessarily cause deeper ruts but displaced more soil on the ground surface. Another observation was landings were placed outside of sale areas instead of within the sale boundary. This also could have caused a decrease in measured infrastructure based on this study's methodology rather than an actual decrease in landing infrastructure because landings outside the sale boundary were not recorded while those inside the sale were recorded.

Figure 23. Logs piled for a short time alongside a forest road. The soil compaction under this log pile is usually less than the traditional type of landing.

Figure 24. Traditional type landing includes a large turn-a-round build into the forest road system.

Ruts and Gullies

The most direct comparable data from the 2006 and 2011 studies to the 2016 study is regarding ruts and gullies. In 2006, ruts or gullies were observed on 20 out of 30 sites on state lands; two met the definition of excessive. In 2011, ruts or gullies were found in 17 out of 31 sales on county lands and 11 out of 34 sales on state lands. There were no excessive ruts or gullies detected in 2011. In 2016, only 10 state sites contained ruts or gullies; only 13 county sites contained ruts or gullies. Neither county or state sites containing ruts or gullies that met the excessive definition. There was a significant and obvious numeric decrease in the number of ruts and gullies observed in 2006, 2011, and 2016. The most likely explanation for this trend is the implementation of soil disturbance guidelines and application of the excessive rutting definition. The threat of losing certified wood designation under FSC and SFI has motivated both county and state foresters to administer/enforce soil disturbance guidelines and excessive rutting definition. For economic reasons, Loggers may be equally motivated to avoid causing excessive ruts since the forest sale administrator might shut them down and mandate repair.

One of the by-products of enforcing based on a definition is that forestry activities may be focused more on avoiding the “excessive” definition rather than the focus of minimizing/ceasing soil disturbance. However, with the decreasing number of sites that contained ruts or gullies, not just stopping excessive ruts that were initially found in 2006, data does not support this pitfall. Rather, the definition seems to have fulfilled its intended purpose to encourage sustainable forestry practices. However, one general observation was that state and county foresters were leery of the word “excessive”. There was more concern that their individual sales might meet the definition of excessive than if the sale they administered contained soil disturbances in the first place. Some sites that contained the most observed ruts (but not recorded) never met the definition of excessive soil disturbance (long continuous disturbance of a certain depth), but contained many numerous, short and separate ruts.

One of the ways soil disturbances from ruts can be minimized is by referring to the excessive rutting definition and imposing seasonal restrictions directly on the timber sale contracts. While all timber sales sold on county and state lands have to abide by the soil disturbance guidelines, some sales add extra precautions like adding seasonal restrictions and rutting language directly under the special site considerations. Timber sale contracts generally include much information such as sale maps, estimated wood volumes, instructions for bids, minimum bid value, acres, silvicultural prescriptions, and an abundance of candid language. One of areas most unique to a specific harvest is usually listed under the special site considerations section. Much of the important and most pertinent information about the site is found here, which may consist of only a paragraph or a few bullet points within a much longer document. This section may be considered a highlight of the most important information about the sale that the successful bidder should know. Finding generic soil disturbance or seasonal restrictions in this section may seem repetitive; however, it may play a vital role in keeping soil disturbance on the forefront of all operations. For the 2016 study, this relevant language was recorded when it was observed in this section (Figure 25). It is important to note that seasonal restrictions referred to in this document pertain only to soil conditions (i.e. frozen or dry ground) and do not include other seasonal restrictions that do not refer to soil condition (i.e. pest or disease restrictions to minimize spread as in oak wilt restrictions). Not every sale monitored for the 2016 study had their sale contracts available but of the sales that did, state lands had 64.5% of sites seasonally restricted compared to county lands which had 59.1% of sites seasonally restricted. Rutting language was much less common in both state and county contracts at 12.9% and 22.7% respectively.

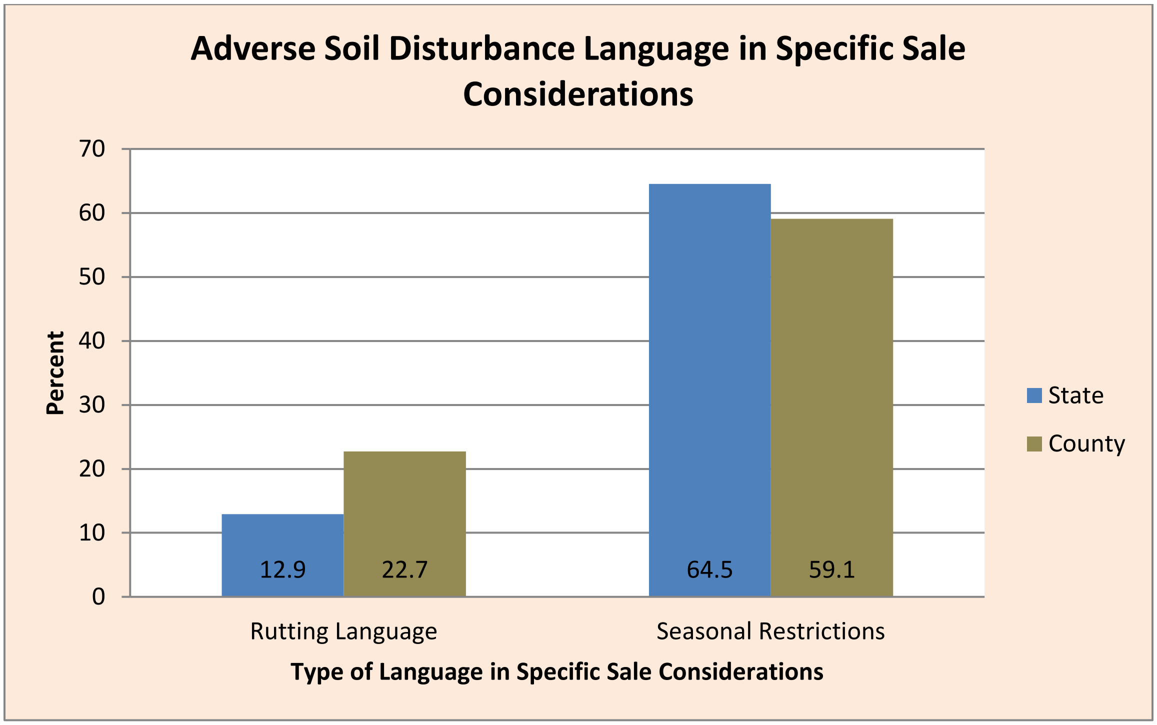

Figure 25. Timber sale contracts that contained rutting and/or seasonal restrictions within the section of special site considerations. (*Note: only ruts were used in all seasonal and rutting language calculations – sites that contained only gullies were not included. Also, rutting language and seasonal restrictions are not mutually exclusive; in fact, almost all the sales that contained rutting language contained seasonal restrictions.)*

Seasonal restrictions are often used to minimize the number of soil disturbance that may be caused by any silviculture activity. Interestingly, most of the rutting, even though none of it was excessive, was found on sales that were already listed under seasonal restrictions. Nearly 86% of the ruts on state lands occurred on sales with seasonal restrictions, which was close to the county level of 81.8% (Figure 26). On the other end of the spectrum, only 14.3% of the ruts on state lands and 18.2% of the ruts on county land had contracts with rutting language in the special harvest considerations. This could indicate that county and state programs did excellent jobs seasonally restricting sites that were prone to rutting but did not put the rutting language in as an additional reminder. By adding the rutting language to more sites, the state and county could possibly see a benefit in reduced rutting. The data shows a majority of rutting still happens under seasonal restrictions (frozen or dry soil) for both county and state lands – indicating that the harvest timeline is not staying completely within the seasonal restriction. If the harvest was staying within the seasonal restriction, the expectation would be to find minimal disturbance on seasonally restricted sites. This also means selecting more sales to become seasonally restricted, would probably not see any significant decrease in the presence of ruts found on either state or county land. This is because most ruts were found on sales that were already seasonally restricted. These values would indicate that field foresters for the county and state are very good at determining which sales may be prone to rutting and they appropriately add seasonal restrictions to minimize the chance of soil disturbance from occurring. However, field foresters might see less rutting under seasonal restrictions by considering some additional options:

- Seasonal restrictions are explained more clearly to loggers before the start of the harvest
- Provide more "check ins" with the loggers on site to verify working that conditions meet the written requirement of the seasonal restrictions.
- Immediate action taken when rutting is occurring on seasonally restricted sales

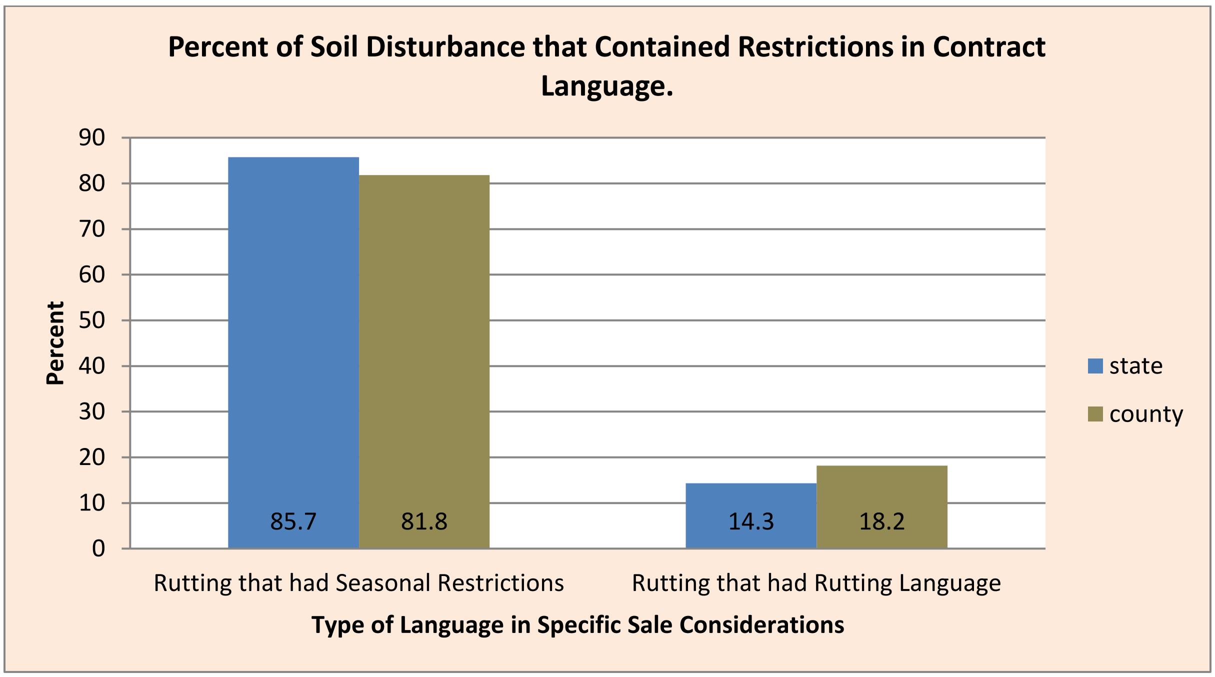

Figure 26. The percentage of rutting within a sale which had either a seasonal restriction or rutting language in the special harvest considerations.

Figure 27. Many small ruts were observed on this site. Most the sale was completed during frozen conditions where no soil disturbance was observed. The remaining small portion of this sale was harvested during the summer season, resulting in small ruts along the primary skid trail through a wetland environment. The use of well place slash saved this primary skid trail from becoming a pair of long and continuous ruts.

Conclusions and Recommendations

The frequency and severity of soil disturbances have lessened since 2006 when guidelines were first established on excessive rutting and adopted into the timber sale handbook used by both county and state foresters. The percent of compaction and infrastructure was at its lowest rates during the 2016 study in comparison to past studies conducted in 2006 and 2011. Infrastructure types (general harvest areas, secondary skid trails, primary skid trails, landings and roads) played a vital role in the level of compaction measured in 2016, which was similar to measurements from past years. Soil type also played a role in the level of compaction, with sand being the most compacted followed by silt, clay and organic matter. While these findings are quantifiable, the study fails to provide specific information on why the quantitative data is undergoing certain trends such as the positive trend of less soil disturbance, compaction, and infrastructure. It is difficult to determine if the established excessive rutting guidelines caused the decrease in soil disturbance or if they are only acting in tandem with other factors such as better sale administration, newer equipment, continuing BMP training for loggers and foresters, more winter harvests, different silvicultural practices, and a new 2010 updated BMP manual. All these factors could, at least in part, be reason for decreases in soil disturbance. The lack of certainty on the role of these other factors makes it is very difficult for the Department provide specific recommendations for county and state foresters/administrators to further reduce soil disturbance impacts. Except, the current system of allowing the forester in charge of the sale to use professional judgment on soil disturbance and working closely with the logger appears to be working, especially since there are clear guidelines in place for the kinds of disturbances that are not acceptable.

If this type of study were to be completed again, some changes might be considered to answer site specific questions. This information would be beneficial, especially to new county and state foresters who may be less experienced or uncomfortable determining if a timber harvest operation should continue. The more concrete and specific results a study can deliver, the better a forester can fall back on state wide recommendations, and hopefully alleviate some of the problems that often surround either stopping a current timber harvest or imposing seasonal restrictions. A future study could achieve this is by changing up the methodology. Instead of the standard practice of finding random “active” sales for both state and county, sites could be selected using specific variables that could play roles in future recommendations. An example of this would be to select a few sales that are started and completed during winter, when ground is frozen, compare information from these sales to harvests conducted during summer months. This could help answer specific questions on winter harvest soil disturbance vs summer harvest soil disturbance. It would also be very beneficial to monitor a winter harvest for infrastructure use when it is actively being harvested and then later re-monitor the same harvest in the summer. This would help determine the amount of infrastructure that is either down played (winter primary skid trails may appear to be lesser secondary skid trails in the summer months) or missed all together. Another recommendation would be to keep monitoring sites not synonymous with an entire sale. This works well in some cases where the sales are smaller, completed by one crew (similar equipment and harvesting technique), silviculture prescription is the same (all selective harvest or all a clear-cut), and competed within one season. Some of the larger sales contain multiple compartments that, in reality, have no similar variables for study purposes, other than they are all “one sale" on a map. These could either by avoided by a future study, or be treated as separate sites according to their characteristics. This study had challenges describing the success or problems of a sale to a specific group of variables, because the sales themselves were made of dissimilar components.

Overall, the findings of this study were positive – soil disturbance of all types are on the decrease in Wisconsin. This study successfully quantifies the decrease in soil disturbances from 2006 to 2016, which met its intended goal – tracking soil disturbance after the establishing guidelines. However, the reasons for the decrease in soil disturbance are difficult to identify. If the cause(s) for the soil disturbances decrease needs to be described, changes in this study's methodology should be considered. This would allow for the study to bring forth more specific sale and site recommendations to state and county foresters, in order to help aid them in minimizing soil disturbance on two of Wisconsin's largest public forests. The decrease in soil disturbances does show the professionalism both county and state forestry staff, along with the loggers and other contractors exhibit while working on timber sales in Wisconsin – no sales were found to have excessive ruts present. This is a large testament to their work.

Appendix A: References

Wisconsin State Forests Continuous Forest Inventory Volume 2: Field Data Collection Procedures for Phase 3 Indicators. *Wisconsin Department of Natural Resources. Division of Forestry*. October 2007.

Wisconsin's Forestry Best Management Practices for Water Quality: Field Manual for loggers, landowners and land managers. *Wisconsin Department of Natural Resources. Division of Forestry*. 2010.

USDA Forest Service Forest Inventory and Analysis (FIA) Northern Region (NRS) field guide, version 5.0. *Forest Service. U.S. Department of Agriculture*. October 2010.

Timber Sale Handbook # 2461. *Wisconsin Department of Natural Resources. Division of Forestry.*

Appendix B: Monitoring Worksheet

Soil Disturbance Monitoring Worksheet

ID:__________________ Date: ____________ Time to Complete: ________

Background Information

Property:	TSA:
County:	Sale #:
Township: Range:	Section:
Harvest Status: Active Suspended	Complete
Harvest Starting Date (m/yr):	Harvest Finish Date (m/yr):
Acres Harvested:	Total Sale Acres:
Type of Harvest: Thinning Clear-cut	Salvage Other:
Logging Equipment: Dragged Carried	Rubber-tired Tracked
Species Harvested:	
Slope Range:	Soil Type:
Soil Texture:	Soil Drainage:

Roads, Landings & Skid Trails

Infrastructure	Length (ft)	Width (ft)	New or Existing?	Removed from Production?	Percent Removed	Active Erosion?	Altered Drainage?
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
Rd Land P Skid				Y N		Y N	Y N
		Total Area:		% of Sale:			

RD=Road Land=Landing P Skid=Primary Skid Trail

Table 1. Minimum number of transects to establish.						
Size of Sale (acres)	≤ 25	26 –	51 –	101 – 150	151 – 200	> 200
Number of Transects	2	3	4	6	8	10

	Survey Pt	Infrastructure	Latitude (dec degrees)	Longitude (dec degrees)	% Slope	% Bare Soil	Soil Texture (0-4")	Soil Texture (4-8")	Soil Resistance
Randomly Distributed Harvest Area Transects	T_1A	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	$T_1$100	Rd Lnd P Skd S Skd GHA							
	$T_1$200	Rd Lnd P Skd S Skd GHA							
	T_1B	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	T_2A	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	$T_2$100	Rd Lnd P Skd S Skd GHA							
	$T_2$200	Rd Lnd P Skd S Skd GHA							
	T_2B	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	T_3A	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	$T_3$100	Rd Lnd P Skd S Skd GHA							
	$T_3$200	Rd Lnd P Skd S Skd GHA							
	T_3B	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	T_4A	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	$T_4$100	Rd Lnd P Skd S Skd GHA							
	$T_4$200	Rd Lnd P Skd S Skd GHA							
	T_4B	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	T_5A	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	$T_5$100	Rd Lnd P Skd S Skd GHA							
	$T_5$200	Rd Lnd P Skd S Skd GHA							
	T_5B	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	T_6A	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	$T_6$100	Rd Lnd P Skd S Skd GHA							
	$T_6$200	Rd Lnd P Skd S Skd GHA							
	T_6B	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	T_7A	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	$T_7$100	Rd Lnd P Skd S Skd GHA							
	$T_7$200	Rd Lnd P Skd S Skd GHA							
	T_7B	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	T_8A	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	$T_8$100	Rd Lnd P Skd S Skd GHA							
	$T_8$200	Rd Lnd P Skd S Skd GHA							
	T_8B	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	T_9A	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	$T_9$100	Rd Lnd P Skd S Skd GHA							
	$T_9$200	Rd Lnd P Skd S Skd GHA							
	T_9B	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	T_{10}A	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	
	T_{10}100	Rd Lnd P Skd S Skd GHA							
	T_{10}200	Rd Lnd P Skd S Skd GHA							
	T_{10}B	Rd Lnd P Skd S Skd GHA					OM C SL SD	OM C SL SD	

OM=Organic matter C=Clay (forms1"+ ribbon) SL=Silt loam (feels smooth, but will not form ribbon) SD=Sandy (feels gritty)

Rd = Road Lnd = Landing P Skd = Primary Skid Trail (3+ equipment passes)
S Skid = Secondary Skid Trail (1-2 equipment passes) GHA = General Harvest Area

Were Ruts or gullies observed, but not recorded? Yes No

Did it appear to meet the criteria of excessive rutting? Yes No

Disturbance	Infrastructure	Notes	Total L	L = 6"+ to orginal soil horizon	L = 10"+ to orginal soil horizon	Max. D	Max. D to top	Location	Orientation to slope	Active Erosion?	Altered Drainage?	Cause	Age
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +
R G	Rd Land P Skid S Skid GHA							UL WL RMZ	U/D AC FT	Y N	Y N	H ATV O	1W 1M 3M +

R=Rut G=Gully RD=Road Land=Landing P Skid=Primary Skid Trail S Skid = Secondary Skid Trail GHA=General Harvest Area

UL=Upland WL=Wetland RMZ=Riparian Management Zone U/D=Up/Down AC=Across FT=Flat

H=Harvesting Equipment ATV=ATVs and other OHVs O=Other cause

1W=Less than 1 week 1M=Less than 1 month 3M=Less than 3 months +=More than 3 months