MINIMUM SNOW DEPTH REQUIREMENTS FOR OSVs:

STATUS REPORT & SUGGESTED BEST MANAGEMENT PRACTICES

Prepared by Trails Work Consulting

For the American Council of Snowmobile Associations

November 2020

ACSA equals ACCESS

AMERICAN COUNCIL OF SNOWMOBILE ASSOCIATIONS

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ACKNOWLEDGEMENTS AND DISCLAIMER

These best management practices were developed by the American Council of Snowmobile Associations (ACSA) with funding provided by the Recreational Trails Program (RTP) administered by the U.S. Department of Transportation – Federal Highway Administration (FHWA).

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BACKGROUND

Photo 1: U.S. Forest Service officer patrolling OSV area

The U.S.D.A. Forest Service issued amended Subpart C, the Over-Snow Vehicle (OSV) portion of its Travel Management Rule (TMR), effective January 2015. Subpart C allows for a system of roads, trails and areas on National Forest lands to be designated for motorized OSV use. Once roads, trails and areas are designated for use under Subpart C, all other OSV use is prohibited if not in accordance with the prescribed OSV use designations. The OSV Travel Rule applies to all National Forest System lands *where snowfall is adequate* for OSV use to be allowed.

The responsible Forest Service official may incorporate previous administrative decisions regarding OSV use, made under other authorities, in designating roads, trail and areas for OSV use under Subpart C. ***If deemed appropriate, permitted OSV use may also be designated by Class of Vehicle (width, type) and by Time of Year (season start and ending dates).***

<u>**Of note, *Snow Depth* is not listed in Subpart C as a designation criterion**</u> – meaning the TMR does not set, suggest or require using 'minimum snow depths' as a condition of OSV operation upon designated roads, trails and areas. Rather, the perspective of 'snow depth' is addressed in the TMR only as "*where snowfall is adequate*."

ISSUE: MIMIMUM SNOW DEPTH RULES ARE BEING APPLIED IN SOME JURIDCITIONS

Despite Subpart C ***no***t stipulating minimum Snow Depth as an appropriate TMR designation standard, several national forests have implemented, or are currently considering, Minimum Snow Depth stipulations in their local OSV travel plan decisions. This is problematic since snow is a live substance subject to on-going metamorphosis which causes continual transformation and shrinkage of snow particles within the snowpack across a landscape. Consequently, it must be recognized that, in respect to 'snow depth' as a TMR 'minimum standard' across an entire landscape versus only measured localities, snow itself is ever-changing, can vary from hour to hour and day to day within a locality or landscape, can be generally inconsistent within single sight-lines, and is continually transformed by wind and other uncontrollable weather conditions. As a result, OSV / snowmobiling access can be adversely obstructed by irrational and unsubstantiated snow depth limitations.

The question of 'W*hat is adequate snow depth?*' for snowmobile operation has generated wide ranging opinions and discussion, with verifiable facts as well as unsupported supposition in this conversation that include:

<u>Facts:</u>

- A snowmobile ***is*** an over-the-snow vehicle designed to ***only*** be operated over snow-covered terrain.
- A snowmobile does not steer or maneuver properly when not operated on snow.
- Operating a snowmobile on asphalt, concrete, gravel or frozen dirt where this is inadequate snow cover will not damage the hardened surface, but can potentially damage the snowmobile.
- Operating a snowmobile on bare ground, unfrozen dirt, or vegetation where this is inadequate snow cover may potentially cause resource damage as well as potentially damage the snowmobile.
- Most experienced snowmobilers generally agree that you can damage a snowmobile and/or the land (resources) if a snowmobile is operated on less than 4 to 6 inches of snow.
- The vast majority of snowmobile trails are located over a non-vegetated or hard surfaced route since they are typically located on existing roads or trails which have an asphalt, gravel or frozen dirt surface that is free of vegetation. Consequently, these trail routes typically are not adversely damaged by snowmobile traffic – with or without snow cover.

Unsupported Supposition:

- The Winter Wildlands Alliance (WWA), a human-powered snowsports organization with a long history of working to restrict or eliminate OSV access, advocates for a minimum of 12-inches of snow being required before allowing snowmobile use on trails and for a minimum of 18-inches being required before allowing snowmobile use off-trails. WWA has boldly pushed this agenda by publishing a biased and unsupported document titled *Snowmobile Best Management Practices for Forest Service Travel Planning* (https://winterwildlands.org/wp-content/uploads/2015/06/BMP-Final.pdf) in its attempt to make it appear this is official guidance for national forests and Forest Service travel planning – which it is not.

SUMMARY OF EXISTING MINIMUM SNOW DEPTH RULES

Table 1: Minimum Snow Depth Research Summary – Web research conducted by Trails Work Consulting between December 2019 and July 2020 identified existing rules and regulations pertaining to 'minimum snow depth' required before snowmobiles (OSVs) are allowed to be operated in various jurisdictions across the United States. This list is by no means intended to be all encompassing or include absolutely every circumstance or locality where a 'minimum snow depth' rule is in place – yet is deemed to portray an accurate representation of the range of current practices in use across the United States, particularly on U.S.D.A. Forest Service lands.

Entity or Jurisdiction	Minimum Snow Depth (inches)	Comments
GENERAL PUBLIC PERSPECTIVE		
Hardcoresledder.com forum, etc.	4 to 6	General agreement by snowmobile riders that you can damage your sled or the land if you're riding on less snow
STATE / LOCAL GOVERNMENT REQUIREMENTS		
St. Louis County – Missouri	2	For snowmobile use
New York	3	State law – amount required to open trails
Massachusetts	4	State law – hard packed snow required to open trails
Cook County – Illinois	4	For snowmobile use
Montana State Parks	4	Recommended minimum cover over vegetation to operate
Connecticut State Forests	6	For snowmobile use
Mt. Spokane State Park – WA	12 to 18	For snowmobile use
Minnesota DNR	12	To start trail packing and grooming
California State Parks policy for grooming:		To start grooming trails, which are generally located over non-vegetated existing roads & OHV trails
Most National Forests (NF)	12	
Eldorado, Stanislaus & Inyo NFs	18	
Sequoia NF	24	
U.S.D.A. FOREST SERVICE REQUIREMENTS		
Vast majority of National Forest (NF) units across the Snowbelt	None / Silent	Forest websites, maps, special orders, notices and press releases are generally silent regarding snow depth; generally allowed ***as conditions permit*** with no minimum depth stated
Fish Lake NF – Utah	Adequate Snow	Adequate Snow definition: Sufficient depth, density, and continuity of snow to prevent direct disturbance of ground cover when using an over-snow vehicle to travel cross-country. This definition recognizes that adequate snow conditions can be provided by a variety of conditions depending on factors such as current snow conditions, time of year, local climate, aspect, elevation, and vegetation types
Uinta-Wasatch-Cache NF – Utah Logan & Ogden Ranger Districts	Adequate Depth	Manages winter over-snow vehicle travel and winter recreation when there is an adequate depth of snow present on the ground to protect vegetative resources. When there is inadequate snow depth present, the Wasatch-Cache National Forest District Travel Plans apply and the use of over-snow vehicles is not permitted off designated Travel Plan routes

Entity or Jurisdiction	Minimum Snow Depth (inches)	Comments
Superior NF – Minnesota	4	It is prohibited to possess or use a motor vehicle off National Forest System roads, except snowmobiles when snow depth on the ground is four (4) inches or more.
Uncompahgre NF – Colorado	6	Cross-country travel by over-snow vehicles is permitted over at least 6 inches of snow
Ottawa NF – Michigan UP	6	For cross-country riding
Bighorn NF – Wyoming	6	For off-road over-snow travel
Fremont-Winema NF – Oregon	6	Roads are closed to wheeled vehicles & become trails
Wallowa-Whitman NF – Oregon	12	Certain motorcycle & ATV trails become snowmobile trails
Medicine Bow NF – Wyoming	12	Before OSVs are allowed off designated routes
Routt NF – Colorado	12	Before OSVs are allowed off designated routes
Wallowa-Whitman NF, Hells Canyon NRA – Oregon	12	On designated routes
	24	Off-trail to protect subnivean creatures
California: USFS/SHPO Programmatic Agreement	12	Pertains to Historic Properties within designated areas: On-Site Historic Property Protection Measures – requires at least 12” of compacted snow or ice on sites
Tahoe NF – California	6	On designated trails with underlying roads
	12	Off-trail / cross country travel in designated open areas
	12 to 18	To groom trails
Lassen NF – California	6	On designated snow trails overlying roads & trails
	12	On designated snow trails not overlying roads & trails
	12	For cross-country riding in designated open areas
Plumas NF – California	6	On OSV trails with underlying roads & trails
	12	For cross-country riding in designated open areas
	12 to 18	For trail grooming to occur
Stanislaus NF - California	12	On designated OSV trails & in designated cross-country OSV use areas
	24	Cross-country travel in the Stanislaus Meadow and Highland Lakes areas
Eldorado NF – California	6	On OSV trails regardless of underlying surface
	12	For cross-country riding in designated open areas
	12	For trail grooming to occur
NATIONAL PARK SERVICE REQUIREMENTS		
Rocky Mountain NP – Colorado	24	On-trail route through park

THE FALLACY OF MINIMUM SNOW DEPTH RULES

- **If there is 12” of snow and you groom it, the snow depth then becomes significantly less than the ‘12-inch minimum.’ So, you are then out of compliance with the rule and can’t groom again until snow accumulates back to 12”. Plus, no one can ride on the groomed trail since it now consequently has less than the required 12” of snow.**
- **A snowmobiler rides off-trail where there is 12” of snow – but once a snowmobile passes there is no longer 12” of snow depth left in its path – so the next rider over that same path is in violation of the 12-inch rule since snow depth is less than 12”.**

AN UNNECESSARY CREATION OF AN IRRATIONAL ENFORCEMENT NIGHTMARE

OSV TRAVEL GUIDANCE FOUND IN USDA FOREST SERVICE MANUALS

At least two Forest Service manuals contain guidance related to suggested BMPs for OSV travel management in watersheds. This guidance is targeted at very specific circumstances related to water quality and watersheds. Unfortunately, this guidance has been misinterpreted and consequently improperly applied at larger scales during some local Forest planning processes. These manuals, and examples of misapplication to OSV travel planning, include:

1. **Forest Service Watershed Conservation Practices Handbook (2006)** (https://www.fs.fed.us/cgi-bin/Directives/get_dirs/fsh?2509.25) Two sections in this Handbook relate to '12-inches of snow cover' discussions:

CHAPTER 10 – MANAGEMENT MEASURES AND DESIGN CRITERIA

12 – Riparian Areas and Wetlands (page 7)
Vegetation next to water bodies plays a major role in sustaining the long-term integrity of aquatic systems. Values provided include shade, bank stability, fish cover, woody debris input, storage and release of sediment, surface-ground water interactions, and habitat for terrestrial and aquatic plants and animals. Riparian zones and wetlands must be managed with care to protect these values.

12.4 – Management Measure: Maintain long-term ground cover, soil structure, water budgets, and flow patterns of wetlands to sustain their ecological function. (page 13)

Wetlands control runoff and water quality, recharge ground water, and provide abundant and diverse biota. Natural patterns and processes must be protected. Executive Order 11990 directs that impacts to wetlands should be avoided, minimized or mitigated where practicable. The Corps of Engineers protects wetlands under Section 404 regulations, which may permit wetland impacts if mitigation measures are applied to replace wetland values in-kind. Design Criteria pertinent to OSV travel includes:

1. Design Criteria
   a. Keep ground vehicles out of wetlands unless protected by at least 1 foot of packed snow or 2 inches of frozen soil. Do not disrupt water supply or drainage patterns into wetlands.
   b. Keep roads and trails out of wetlands unless there is no other practicable alternative. If roads or trails must enter wetlands, use bridges or raised prisms with diffuse drainage to sustain flow patterns. Set crossing bottoms at natural levels of channel beds and wet meadow surfaces. Avoid actions that may dewater or reduce water budgets in wetlands.

Important Application Considerations

- This specific design criterion is directed only at **Riparian Areas and Wetlands** (and not entire watersheds) – thus, it should not be used as justification to apply a forest-wide 12-inch minimum snow depth.
- This design criterion is specifically directed at '**ground vehicles**' – which does not include over-snow vehicles (OSVs). An OSV has a PSI of 1.0 or less (snowmobile = 0.5 or less, tracked ATV = 0.55, tracked UTV = 0.6 to 0.9). Comparatively, ground vehicles (wheeled vehicles) have a PSI ranging from 2.0 to 4.0 for an ATV or UTV while a 4WD and other vehicles typically have a PSI of 30 or greater. Consequently, it is inappropriate to use this criterion to justify a forest-wide (or smaller scale) 12-inch minimum snow depth rule since OSVs are not ground vehicles.

14 – Soil Quality (page 24)
Soil quality determines vegetation growth capability in all terrestrial ecosystems. Soil depth, structure, organic matter, and nutrients are critical to sustaining this potential. Management measures and design criteria to protect soil quality apply to all actions that may impact these soil qualities.

14.1– Management Measure: Manage land treatments to limit the sum of severely burned soil and detrimentally compacted, eroded, and displaced soil to no more than 15% of any activity area. (pages 24 and 25)

Severe burns kill soil biota, alter soil structure, consume litter and humus, and remove organic matter and nutrients. Severe fires occur when humus and large fuels are dry and heavy fuels near the ground conduct much heat into the soil. Recovery takes years.

Soil compaction is caused by the weight of vehicles and animals on the ground. It increases soil density and reduces large pores so that water absorption and root growth are impaired. Clay and loam soils compact more than sandy soils. Soils compact more when soil moisture exceeds the plastic limit. Detrimental compaction may occur with few passes in moist soils but may take many passes in dry soils. Ground cover, deep snow, and frozen soil reduce compaction. Severe compaction can extend to two feet in roads, major skid trails, and log decks; tree growth may be greatly reduced and recovery may take decades.

The 15% limit applies to all natural and human disturbances that may impact soil structure, organic matter, and nutrients in areas allocated for vegetation production (R2 FSH 2509.18). Where excessive soil impacts already exist from prior activity, the emphasis should be on preventing any additional detrimental impacts and on reclamation where practicable. As defined in the National Soil Handbook (FSH 2509.18) soil quality standards are intended for areas where management prescriptions are being applied, such as timber harvest areas and range allotments. They are not intended to apply to administrative sites or other areas with dedicated uses such as the permanent transportation system, well pads or ski areas, for example. Design Criteria pertinent to OSV travel includes:

1. Design Criteria
   d. Allow dispersed winter motorized recreation when snow depths are sufficient to protect soils. Specify a minimum unpacked snow depth of 12 inches unless a site-specific analysis shows a different snow depth is adequate to protect soils. Allow use of snowcats or grooming machines when unpacked snow depths equal or exceed 18 inches. Evaluate special use permit conditions on a site-specific basis.

Important Application Consideration:

- This specific design criterion is directed only at **watersheds with 'severely burned soil and detrimentally compacted, eroded and displaced soil**.' Consequently, its use must be contained accordingly and should not be used as justification to apply a 12- or 18-inch minimum snow depth outside severely impacted areas or forest-wide.

2. **National Best Management Practices for Water Quality Management on National Forest System Lands, Volume 1: National Core BMP Technical Guide (2012)**
   (https://www.fs.fed.us/naturalresources/watershed/pubs/FS_National_Core_BMPs_April2012.pdf)
   - These BMP's do not establish any specific numerical minimum snow depth for OSV use:

Rec-7. Over-Snow Vehicle Use (page 96)

Objective: Avoid, minimize, or mitigate adverse effects to soil, water quality, and riparian resources from over-snow vehicle use.

Practices: Develop site-specific BMP prescriptions for the following practices, as appropriate or when required, using State BMPs, Forest Service regional guidance, land management plan direction, BMP monitoring information, and professional judgement.
(5 bullet points follow; the one which is pertinent to snow depth is listed below)

- Allow over-snow vehicle use cross-country or on trails when snow depths are sufficient to protect the underlying vegetative cover and soil or trail surface.
  - Specify the minimum snow depth for each type or class of over-snow vehicle to protect underlying resources as part of any restrictions or prohibitions on over-snow use.
  - Specify season of use to be at times when the snowpack is expected to be of suitable depth.

- Specify over-snow vehicle class suitable for the expected snowpack and terrain or trail conditions.

Important Application Considerations:

- The 2015 OSV Rule does not include 'snow depth' as a designation criterion; consequently, it supersedes this 2012 publication which suggests that minimum snow depth be considered for each type or class of OSVs.
- State BMPs generally advocate that 3 to 6 inches (see Table 1) of snow can be adequate to begin OSV use or trail packing operations (if a State has any stipulation at all regarding minimum snow depth).
- Nothing in this Guide tiers to either science-based or monitoring-based reasons to establish specific snow depth, or how 'sufficient' snow depth should be defined.

CURRENT 'MINIMUM INCH' SNOW DEPTH RULES LACK SCIENTIFIC SUBSTANTIATION

The 'minimum inch' snow depth rules currently used to regulate snowmobile travel and trail grooming on national forest units – which go beyond 'as conditions permit' 'adequate snow/depth' or '4 to 6 inches' – generally lack substantiation by research-based snow science. These 'minimum inch' rules are primarily driven by unsupported anecdotal local agency staff and/or advocacy group perspectives versus being tiered to science-based research conclusions. Minimum snow depth regulations in California – particularly as they relate to trail grooming – are even more obtuse, with local anecdotal perspectives further (inappropriately) influenced by '12-inch minimum snow cover' rules dictated by historic property protection agreements – which have been incorrectly applied to all lands versus to only officially designated historic properties within specifically defined historic district boundaries. Misapplication of design criteria from the Forest Service Watershed Conservation Practices Handbook has also played a role in several national forests proposing 12-inch to 18-inch minimum snow depth rules related to OSV use and OSV trail grooming.

Agencies and trail managers must recognize that snow science data does exist and that it should be consulted when prescriptive snow depth rules are contemplated by agency staff and/or advocacy groups. While snow science exists largely in the context of 'hard surface runways and snow roads' research, this body of science is applicable to OSV trails – because snow trails are in essence snow roads. Consequently, this information should be used to help determine best management practices for OSV travel, particularly if inch-based minimum snow depth rules are (inappropriately) being considered in a local TMR designation process. This body of snow science has been built over several decades, and while primarily related to Antarctic travel on snow roads, it represents the pertinent best available science for any regulatory considerations related to OSV use policies.

Most importantly, this body of snow mechanics science relates directly to the management of snowmobile (OSV) trail grooming practices and emphasizes the importance of beginning to manipulate (groom) the snowpack early in the season before snowfall accumulations become too deep. So not allowing grooming to begin until 12 to 24 inches of snow has accumulated has been soundly proven to be detrimental to overall trail grooming success. Additionally, while 'snowmobile riding' and 'trail grooming' have been viewed to be different (and consequently treated differently) in flawed planning processes, they in reality have similar, lower, minimum-depth thresholds as to when riding or grooming can/should be allowed to occur.

SYNOPSIS OF SNOW MECHANICS SCIENCE PROGRESS RELATED TO SNOW ROADS (TRAILS)

Numerous research studies and construction projects have been undertaken over the years to develop hard surface roads and runways in deep snow and in extreme cold environments. Methods to move redeposit, restructure, and compact deep snow packs have been tried in all sorts of environments in an attempt to increase the strength of snow layers. These studies have resulted in a good understanding of how difficult it is to mechanically manipulate snow packs to develop hard surfaces and to form a "pavement" made entirely and supported by, underlying snow, especially in extreme cold. This research has also resulted in an indication of which crystal and pack properties need to be manipulated to help promote bonding, which is necessary to develop strength in roads and trails. There are several phenomena that drive the bonding process within a snow layer. Temperature gradients over a thickness of snow will drive vapor transport and deposits to form bonds. A second driving force for bonding is the surface energy of the individual crystals.[1]

Over the past fifty years, snow mechanics research has made possible the construction of snow roads and runways in deep snow areas. Extensive field and laboratory studies have greatly advanced the understanding of snow mechanics, specifically the effects of environmental conditions and snow characteristics on the behavior of snow under stress and the changes in snow properties with time. This knowledge has enabled researchers to develop methods for maximum improvement of the load-bearing capacity of snow pavements. Studies by the U.S. Army Corp of Engineers Cold Regions Research and Engineering Laboratory [CRREL] (Wouri 1960 and 1963) have shown that by milling or disaggregating snow and then compacting it, the metamorphism of snow is greatly enhanced. Studies made by CRREL in the 1960s (Abele and Wouri 1962, Abele 1963, and Wouri 1963) and further work in the 1970s indicate that a mixture of mechanically milled snow, having grain sizes of one to several millimeters in diameter, and compacted to a density of 0.55 g/cc (34 lb/ft3), hardens to approximately one-half its ultimate strength, or roughly 690 kPa (100 psi) (unconfined strength) in two to three days. The resulting surfaces, if thick enough, can support heavy-wheeled aircraft as well as other vehicles.[2]

An excellent overview of the progress of snow mechanics science studies over the years can be found in a report by Gunars Abele.[3] Highlights from this report include:

- **History of Snow Compaction:** The advantages of a compacted snow trail for improved winter mobility were recognized by animals long before man had the need to compact snow for either his personal or his business endeavors. It has been frequently observed that a herd of animals, during migration over terrains covered with deep snow, travel in a single line. Animal trails, produced by repeated traffic by deer or other animals during winter, represent the most basic method for improving the traffic ability of a snow surface: compaction. The same procedure for traveling over snow has been practiced by man, first on foot, then on snowshoes, later with dogs or horses and sleds, and eventually with motorized vehicles.
- It has been observed that merely disturbing or mixing the original snow layer caused it to harden significantly within a few days.
- The snow structure is subject to changes due to time, temperature, wind and solar radiation. Any mechanical disturbance of the snow (disaggregation, compaction etc.) causes radical changes in the snow structure. The structural change that occurs naturally after the deposition of snow and that can be greatly accelerated by mechanical disturbance is an irreversible time- and temperature-dependent process called metamorphism, referred to in the literature as sintering or age-hardening (Bader 1962, Mellor 1964, 1975, Ramseier and Keeler 1966).
- **Grain Size:** The size of snow crystals varies greatly, depending on the atmospheric conditions during precipitation, wind, temperature during the subsequent metamorphism, overburden pressure and age. After deposition, during the process of metamorphism, gradual grain growth occurs, primarily as a result of sublimation, and intergranular bonds form by sublimation and diffusion. Therefore, older snow has coarser grains than fresh snow. The subsequent grain growth and bond formation are greatly accelerated by the disaggregation and the resulting densification.
- **Effect of Time and Temperature:** The strength of snow generally increases with an increase in density, with time, and with a decrease in temperature. The rate of the strength increase decreases with a decrease in temperature (Ramseierand Sander 1965). That is, the lower the temperature, the slower the rate of strength increase (age-hardening). However, the snow at the lower temperature will ultimately reach a higher strength than that of the snow that has been age-hardened at the higher temperature.
- **Importance of Incremental Compaction:** If snow compaction equipment is available during the initial snowfall season, incremental compaction of each snowfall is preferable to disaggregation and compaction of a thick snow layer all at once. Compaction of thin layers produces a snow pavement with a more uniform

[1] Development of a Hard Surface Runway at the South Pole, Antarctica; Alger, Russ and Blaisdell; National Science Foundation Office of Polar Programs, 2000.
[2] Evaluation of a New Snow Paver at McMurdo Station, Antarctica; Sally A. Shoop, Russ Alger, Joel Kunnari and Wendy L. Wieder; US Army Corps of Engineers, Engineer Research and Development Center; 2013.
[3] Snow Roads and Runways; Abele, G.; CRREL Monograph 90-3, 1990.
https://pdfs.semanticscholar.org/8aa1/171b72ae62eacecf55a09e508172f5fa65b9.pdf

strength profile. If this procedure can be continued throughout the winter season, no disaggregation or processing is required.
  - It is also beneficial to pre-compact deep, soft snow prior to disaggregation. Any leveling activity automatically results also in compaction. Low-ground-pressure, wide-track vehicles are especially suitable for pre-compaction.
  - 6" of snow is generally enough to begin snow compaction with a roller or a pan.
- **Disaggregation:** Since the effects of compaction alone are usually too limited in depth to provide a sufficiently thick snow pavement, some method of disaggregation (depth processing) may be required if the snow thickness exceeds 30 cm (11.8 inches).

More recent work by Shoop, Alger, Kunnari and Wieder (2013)[4] has further affirmed that:

- Not all snow is new or fresh. Under traffic and with time, snow changes to a coarse mixture (sometimes called corn or sugar snow) which does not bond together.
- Vehicle traffic rapidly deteriorates this type of surface to cause large bumps or moguls. Action of tires and tracks also helps to accelerate the formation of large, non-active crystals on the snow pavement. So, in order to cause this type of snow to bond and form a hard, durable surface, it must be finely milled to a powdery material to promote bonding and hardening.
- Most recent studies at the Keweenaw Research Center (KRC) have shown that a mixture of finely milled snow and a percentage (50% or less) of larger crystals can bond together to form a snow pavement matrix. In simple terms, this process is similar to crushing washed gravel to a consistency that resembles road gravel. This is a mix of the original gravel particles, and smaller particles from sand size, to silt and clay sized particles. These types of mixes work well for soil roads, and even better for snow since the strong bonds created in the mix increase the strength considerably (Alger 2003).
- Through this research, it became evident that strong snow roads and runways could be developed, but the mechanical development of these pavements was difficult and costly.
- Strength values for the top 15 cm (5.9 inches) of the snow is a critical layer for vehicle traffic.
- During trafficking, areas with slight surface roughness caused the vehicle to bounce resulting in progressively worse rutting, reaching up to 16 inches (40.6 cm) in the worst areas. Effects from turning are evidently much less than the damage caused by vehicle bounce where the high vertical load immediately crushes the snow bonds, allowing progressive damage with each pass.

EXPERT OPINION ON 'MINIMUM SNOW DEPTH' REQUIREMENTS FOR OSV TRAVEL

The foremost expert opinion issued to-date regarding proper application of 'minimum snow depth' requirements for OSV travel on roads, trails and other routes has come from Russ Alger, Director of the Institute of Snow Research at KRC. Mr. Alger is a leading international snow science expert who has been involved with research regarding the travel of vehicles over snow for over 40 years. His key comments related to minimum snow depth requirements for OSV travel on roads, trails and other routes on the Plumas National Forest in California – which proposed requiring six inches of snow before snowmobile travel can occur on designated routes (trails), and 12 to 18 inches for off-trail use or trail grooming – are summarized below and also included in their entirety in Appendix 1.

> ***"When snowmobiles and groomers make snow 'denser' or more 'compact,' they are by definition decreasing the thickness of the snow while either increasing or holding constant the protective qualities of the snow. Accordingly, it is not appropriate to regulate on the basis of snow depth, when the meaningful metric is the protective quality of the snow, which is far more dependent on density than on depth."***
> ***Russ Alger, Director of the Institute of Snow Research – Keweenaw Research Center***

[4] Evaluation of a New Snow Paver at McMurdo Station, Antarctica; Sally A. Shoop, Russ Alger, Joel Kunnari and Wendy L. Wieder; US Army Corps of Engineers, Engineer Research and Development Center; 2013.

- Snow on regular travel routes is compacted by the weight of snowmobiles and groomers and so is denser and more protective of the ground than un-compacted snow.
- The development of standards for over-snow travel, namely snowmobiles and groomers in this case, is complicated by the fact that terrain and snow-cover are extremely variable. Snow is a complicated material that changes constantly from the time it starts to develop high in the atmosphere, through all of the time it is on the ground and until it finally melts or sublimes. For this reason, the author (Mr. Alger) believes it is difficult to look at standards that are depicted solely by snow depth.
- Snow depth can vary considerably across even small areas within a snow event. This is even more evident at higher elevation and in areas where mountain ranges can affect the flow of the weather.
- It is obvious that properties of snow are quite variable depending on weather, location, time, and so on. The effect of light vehicle traffic moving over the snow as well as the support or flotation afforded by the pack are therefore also quite variable and difficult to quantify.
- Compacting snow and increasing the potential for soil freezing is a great way to minimize damage to soil.
- The snow on the trail will be compacted in layers so it will become denser as the season goes along. Loose snow will support a few passages of snowmobiles, and will also form into a stiffer trail with every subsequent passage. In most cases, snowmobiles will follow paths of previous sleds magnifying this result.
- As snow ages, even in the first hours on the ground, the crystal structure can change quite rapidly. This change in structure and properties is magnified dependent upon certain weather conditions such as temperature gradients, ground temperature, solar load, rain, depth, etc. In general, snow densifies with time and at depth.
- While qualitative judgments using the skills of Forest Service personnel are preferable to inflexible empirical measurements, should the Forest insist on an empirical measurement, it should base it on sample of snow water equivalent (SWE) taken from compacted trails, not snow depth. Having only snow depth without other qualifying parameters such as density, crystal structure, ice layering, bonding, etc., makes the specification much harder to justify. Moreover, if there is a layer of ice at the bottom of the trail sample, that should be noted because the ice has extra protective qualities.

"In conjunction with all of the natural properties of snow mentioned already, the passage of both snowmobiles, various other over-snow vehicles, and groomers change the bulk properties of the snow pack. Vehicle weight, tracks, and tires tend to increase the density of the trafficked snow layer. This densification makes the snow layer considerably stronger and works to 'armor' the underlying terrain. This is the essence of grooming practices, but even the weight of snowmobiles can cause this effect."
Russ Alger, Director of the Institute of Snow Research – Keweenaw Research Center

EARLY SEASON TRAIL GROOMING IS CRITICAL TO PROPER SNOW TRAIL BUILDING

Grooming/compacting/de-aerating snow early in the season is critical to help begin building trail base and preserving snowpack – so that OSV trails stay smoother and last longer through the winter season. The excerpt below from *Guidelines for Snowmobile Trail Groomer Operator Training: A Resource Guide for Trail Grooming Managers and Equipment Operators* provides important points about Early Season Trail Preparation (see Chapter 3, page 55; International Association of Snowmobile Administrators (IASA), 2005. http://www.snowmobileinfo.org/snowmobile-access-docs/Guidelines-for-Snowmobile-Trail-Groomer-Operator-Training.pdf):

Given the importance of early season compaction, there is fallacy in policies which delay / do not allow snowmobile trail grooming to begin until there is 12, 18 or 24 inches of snow accumulated on the trail surface. Such 'minimum snow depth' policies are ill-conceived with negative consequences that include:

Early Season Trail Preparation
The first snowfalls that are processed on the trail often create the base for the remainder of the winter. An early solid, smooth base of snow will help keep the trail smoother throughout the rest of the winter. Early winter snowfalls can contain more free water and can compact well. Therefore, vigorous smoothing and heavy compaction is often important for early snows. **Newly fallen snow layers should ideally be cut to 6 inches (15 centimeters) or less before compacting to ensure full compaction throughout the layer.** Thick layers of newly fallen snow typically do not compact well.

In areas prone to wetness, such as low swampy crossings, it is advantageous to keep the snow thickness to a minimum in the early part of the winter. This allows the underlying soil to freeze and become stable. This frozen layer of earth will also help to keep the trail solid later into the spring season. Since snow is an excellent insulator, these areas should be kept thin so the ground remains frozen. Banked snow can be pulled onto these areas later in the season if bare spots occur.

IASA Guidelines for Snowmobile Trail Groomer Operator Training, page 55

- Six (6) inches of snow or less is ideal / preferred to initiate trail grooming since it helps facilitate full compaction throughout the snow layer. Therefore, delaying the start of trail grooming until there is two, three or four times that depth ultimately leads to rougher snowmobile trails where subsequent grooming repetitions do not last due to poor or inconsistent compaction at the bottom of the trail's snow layers.
- Not allowing grooming to start before there is 12, 18 or 24 inches of snow accumulated on the ground insulates the ground, preventing the underlying soil from freezing and becoming stable (i.e., armoring it). Consequently, unfrozen soil beneath a snow trail's base can cause snow to melt from the bottom up, which in turn causes unstable trail conditions throughout the winter season as well as earlier trail melt-out toward end of winter.
- Not allowing the compaction of early snowfall, which typically has more free water content, decreases opportunity for firm trail compaction, from the ground up, as the trail base is set at the beginning of winter.
- Not allowing the compaction of early snowfall – while waiting to reach a dictated 12-, 18- or 24-inch depth threshold – results in inconsistent density within snow layers as ungroomed snowpack accumulates. Unpacked early snow layers can vary in density due to snow's potentially wide-ranging water content related to varying weather conditions during each cumulative snow event, the effects of wind distribution, freeze-thaw cycles, and metamorphosis which naturally occurs within fallen snow. Earlier grooming would provide mixing of snow particles to improve bonding.
- Requiring that trail grooming not start until 12, 18 or 24 inches of snow has accumulated on the ground can result in early snow layers being too thick to process and compact properly. Consequently, poor or inconsistent compaction will persist at the bottom of the trail's snow base throughout the entire winter season – meaning poor quality trails which are consistently rough for OSV riders.

IMPACT STUDIES GENERALLY FAIL TO DOCUMENT ADVERSE EFFECTS FROM OSV USE

Unfortunately, attempts to close or limit OSV use all too often allude to unsubstantiated published articles or special interest groups' misinformation – all which are inappropriate to use if OSV travel planning is to be done properly without undue bias.

There is a fairly significant body of peer reviewed scientific research available regarding potential impacts from snowmobile use – which is what should be used when considering management policies for snowmobiles and other OSVs. SnowmobileInfo.org hosts a 'Library of Research Studies Related to Snowmobiling Impacts' at http://www.snowmobileinfo.org/research-studies-related-to-snowmobiling-impacts.aspx. This library is based upon *Research Studies Related to Snowmobile Impacts* (http://www.snowmobileinfo.org/snowmobile-access-docs/Research-Studies-Related-to-Snowmobiling-Impacts.pdf) which was developed by the American Council of Snowmobile Associations with financial support from the Federal Highway Administration – Recreational Trails Program. This *Research Studies* publication provides abstracts, summaries, and web links for over 190 impact studies related to snowmobiling, and approximately 150 of them can be downloaded in their entirety from the on-line library. Generally, this body of science fails to document significant adverse effects from OSV use that cannot be either totally mitigated or at least managed at acceptable levels.

Information presented by this scientific research is an important tool to help assist trail providers in negotiations for new or continued access. Whether old or new, these studies have relevance to present day discussions about snowmobiling access. While not every study applies to every local situation, many can be credibly extrapolated for use where local situations are similar to a particular study's setting.

All abstracts in these documents are presented as direct cites from study authors. Information is organized alphabetically by impact topic, and then listed from the most recent to the oldest studies with key findings highlighted. Important perspectives can be gained by following the progression of knowledge forward in time, from old to new, as impact topics gain perspective with new research that either dispels myths or better defines real impacts.

This Library of Research represents the 'best available information' about snowmobiling impacts; consequently, public land and trail managers should use it to help make the best-informed decisions about snowmobiling access. A synopsis of key impact studies, by topic, includes:

Impacts to Vegetation, Soil and Snow Compaction

Everything recreationists do has some effect on the environment. When a hiker steps on a flower, he or she affects the environment. When land is paved over for a bicycle path, it affects the environment. Many of the foot paths man has used for centuries still exist and are clearly visible throughout the world. There is no trail without some level of impact.

It's a fact however that a snowmobile and rider exert dramatically less pressure on the earth's surface than other recreational activities (i.e., just one-tenth the pressure of a hiker and one-sixteenth the pressure of a horseback rider). Table 2 below shows the average pounds of pressure per square inch exerted on the earth's surface by various recreation travel modes (all vehicle weights include an estimated weight of 210 pounds for one person and his/her gear):

Table 2: Pressure Exerted by Various Recreation Travel Modes

Recreation Travel Mode	Pounds of Pressure exerted per square inch
4-Wheel Drive Vehicle	30
Horse	8
Man (hiking)	5
ATV	1.5
Snowmobile	0.5

Moreover, a snowmobile's one-half pound of pressure is further reduced by an intervening blanket of snow. Given adequate snowfall and responsible operation, all evidence of snowmobile operation generally disappears when the season changes and snow melts.

General conclusions from studies or planning processes across the Snowbelt include:

- A U.S. Department of the Interior environmental impact statement concluded: "A major distinction is warranted between snowmobiles and other types of off-road vehicles. Snowmobiles operated on an adequate snow cover have little effect on soils – and hence cause less severe indirect impacts on air and water quality, and on soil-dependent biotic communities, than other ORVs do." It further stated that, "Where snowmobiles are used exclusively over snow on roads and trails, the impact on vegetation is indeed virtually nil."

- A University of Wisconsin study found that snowmobile traffic had no effect on grain yield of winter wheat, alfalfa, red clover plots, or grass legume. Species of turf grass showed slightly reduced yields at first harvest, but were not negatively affected in subsequent harvests.
- Research undertaken by the University of Maine concluded that "compaction by snowmobiling does not alter the grain weight yields of alfalfa in Maine."
- A Utah Water Resource Laboratory study found that snow compaction, caused by snowmobile tracks, does not damage wheat crops. Instead, the compaction increases the yield and eliminates snow mold. Erosion is also reduced.
- There is no evidence that snow compaction caused by snowmobiling, ski-touring, or snowshoeing has a significant impact on the population of small burrowing animals. Since these recreations take place over a minuscule portion of the total land area, the ecosystems of burrowing animals tend to be overwhelmingly affected by natural forces such as wind-induced compaction, early and late snowfalls, temperature fluctuations resulting in thaws and freezes, etc.

Specific studies related to vegetation, soil, and snow compaction include:

1. **Effects of Winter Recreation on Vegetation**. (1999) Effects of Winter Recreation on Wildlife of the Greater Yellowstone Area: A Literature Review and Assessment. Olliff, T., Legg, K. & Kaeding, B. Greater Yellowstone Coordinating Committee, Yellowstone National Park. pp. 119-121. http://www.nps.gov/yell/parkmgmt/upload/wildlifewint.pdf
    - Adverse effects to vegetation are the result of cumulative factors. The impact of snowmobile activities on the physical environment varies with winter severity, the depth of snow accumulation, the intensity of snowmobile traffic, and the susceptibility of the organism to injury (Wanek 1973). Activities occurring on roadbeds and (most likely) trails are probably having little effect on vegetation as the areas are already compacted or disturbed. Effects of snowmobile activities on off-trail vegetation should be assessed at a landscape level.
2. **Snowmobile Impact on Old Field and Marsh Vegetation in Nova Scotia, Canada**: An Experimental Study. Keddy, P.A., Spavold, A.J., & Keddy, C.J. Department of Biology – Dalhousie University, Halifax, Nova Scotia. (1979) Environmental Management, Vol. 3, No. 5, 409-415.
    - The first pass by a snowmobile caused the greatest increase in snow compaction – roughly 75% of that observed after five sequential passes. Snowmobile treatment resulted in highly significant increases in snow retention in spring. Frequency was more important than intensity in this regard.
    - Marsh vegetation showed no significant effects of snowmobile treatment.
3. **Effects of snowmobile traffic on bluegrass**. Foresman, C.L., Ryerson, D.K., Walejko, R.N., Pendleton, J.W., & Paulson, W.H. (1976) Journal of EnvironmentalQuality5(2): 129-130. http://nohvcclibrary.forestry.uga.edu/SCANNED%20FILES/W-0002-effect%20of%20snowmobile%20bluegrass.pdf
    - Early growth was slower but late summer yields were the same. No soil compaction was detected in the treated plots.
4. **Effects of Snowmobile Traffic on Non-Forest Vegetation and Grasses**. (1974) Proceedings of the 1973 snowmobile and Off the Road Vehicle Research Symposium., Michigan State University. East Lansing, MI
    - The results revealed that: where snow cover exceeded 3 inches in depth there were no detrimental effects on grass or vegetation stands, their vigor, or yield; high-grade grasses recover naturally from heavy snowmobile traffic; and snowmobile traffic caused no stand reductions, but did cause a slower recovery in early spring.
5. **Snowmobile Impact on Three Alpine Tundra Plant Communities.** Greller, A.M., Goldstein, M., & Marcus, L. (1974) Environmental Conservation, Volume 1, No.2, 101-110
    - General conclusions included: 1) In communities that are snow-free in winter, damage by snowmobiles was severe to lichens, Selaginella, and to relatively prominent, rigid cushion-plants. Part of the damage in the present study may have been due to the manual removal of rocks, necessary for the operation of snowmobiles in snow-free areas. 2) Kobresia, present in isolated tussocks in a cushion-plant community absorbed the major portion of snowmobile impact. 3) Snowmobile travel in uniform, closed Kobresia meadows inflicted much less damage to most plants than did similar travel on a sparsely vegetated community. 4) Plants best able to survive the heaviest snowmobile impact were those with small stature and little woodiness, or with buds well-protected at or below the soil surface. 5) Snowmobile traffic

should be carefully restricted to snow-covered areas. It should be noted that the snowmobile damage to vegetation on Niwot Ridge was probably of greater severity than would be expected from undirected recreational travel. Recreational drivers would be expected to avoid snow-free areas whenever possible, thus reducing, considerably, the impact on vegetation. Also, it is unlikely that large numbers of stones would be removed by random travel on those snow-free areas.

6. **Effect of snow compaction on frost penetration and soil temperature under natural conditions in central Maine.** Wentworth, D. S. (1972).
   - Compaction of the snow cover had little effect on average soil temperature under the different treatment areas.
7. **Effects of snowmobile traffic on several forage species and winter wheat.** Ryerson, D. K., Schlough, D. A., Foresman, C. L., Tenpas, G. H., & Pendelton, J. W. (1977). Agronomy, 69(Sept.-Oct.), 769-772. http://nohvcclibrary.forestry.uga.edu/SCANNED%20FILES/W-0031.pdf
   - Attempted to identify conditions under which OSV use would cause plant damage; this was not accomplished because each winter had unique and unpredictable characteristics. Six common species were studied for 3 years. 4 species showed no detrimental effects; winter wheat yields were not reduced below the check (control) areas; 1 species was significantly reduced during one year but unaffected during the next year. Concluded that trail use (rather than open uncontrolled use) would be most appropriate in crop vegetation environs.
8. **A continuing study of the ecological impact of snowmobiling in Northern Minnesota.** Wanek, W., & Schumacher, L. H. (1975) The Center for Environmental Studies, Bemidji State University, Bemidji, MN.
   - Five years of research have shown conclusively that snowmobiles have an impact on the physical environment and plant communities of northern Minnesota. The impact may vary from year to year due to differing temperature extremes and snowfall. The extent of plant injury often depends on the intensity of snowmobile traffic and the susceptibility of each species to physical or cold temperature damage. The environment beneath the snow compacted by snowmobiles is substantially colder than that under natural snow cover. This can cause damage to herbs and perennials. Many woody plants are particularly vulnerable to physical damage by snowmobiles. The damage to plant communities reported during this study should not be considered maximal. In all cases snowmobile traffic began after six inches of snow had accumulated – a condition which is usually not met during normal snowmobiling activity.
9. **The ecological impact of snowmobiling in Northern Minnesota.** Wanek, W. (1973) The Center for Environmental Studies – Bemidji State College, Bemidji, Minnesota.
   - Snowmobiles have an impact on the physical environment and biota of northern Minnesota. The impact varies with the severity of the winter, the depth of snow accumulation, the intensity of snowmobile traffic, and the susceptibility of the organism to injury, caused by cold temperatures or physical contact. Temperatures beneath the snow compacted by snowmobiles are considerably colder than those under undisturbed snow cover. The growth of early spring flowers is retarded, and reproductive success is reduced where snowmobiles travel. Many herbs with massive underground storage organs (alfalfa included) are winterkilled in the modified environment under snowmobile tracks. Woody plants are particularly vulnerable to physical damage by snowmobiles. Snowmobile traffic can be beneficial by reducing the stature of woody vegetation in area where it needs to be controlled. However, traffic is unwise in places where forest regeneration is being encouraged, or where the esthetic or economic value of fragile communities necessitates their preservation.

<u>Impacts to Water Quality (including Snowpack and Snowmelt)</u>

Winter recreation could affect aquatic organisms mainly by indirect impacts due to water pollution. Some believe two-stroke snowmobile engines can deposit contaminants on snow, leading to ground and surface water quality degradation, which subsequently may impact aquatic life. Information gained from the following research studies rebuff s those claims:

1. **Snowmobile Trail Chemistry Study.** Perry, M.J., (2010) VHB Pioneer, North Ferrisburgh, VT and Vermont Association of Snow Travelers, Inc. http://www.vtvast.org/VAST/Forms/Other-Resources.html
   - This study evaluated the impact of snowmobile traffic on the chemical composition of snowpack, soil, and runoff in the proximity of heavily traveled snowmobile trails in Vermont.

- Snowmelt and runoff chemistry monitoring indicated no detectable levels of volatile organic compounds (VOCs) or total petroleum hydrocarbons in surface waters that are located immediately downgradient of the snowmobile trails that were evaluated. Snowmelt samples that were taken immediately following the end of the snowmobile season did not differ in comparison with runoff samples that were taken at the beginning of the snowmobile season, which are considered representative of background water quality conditions. These data indicate that snowmobile usage during the 2009/2010 season did not have any impact on the surface water quality in the vicinity of heavily used snowmobile trails.
- Snowpack chemistry monitoring indicated that there were no detectable levels of VOCs or total petroleum hydrocarbons in background or on-trail snow sampling stations, with the exception of one chemical compound detected in an on-trail sample taken at Station B2, which is the most heavily used station in the study. 1,2,4-Trimethylbenzene was detected at a concentration of 1.3 ug/L; no regulatory standards apply to snow, but for comparison this concentration is below the drinking water standard of 5.0 ug/L. Snowmobile usage has no significant impact on the chemistry of snowpack located on snowmobile trails, but may cause trace levels of volatile organic compounds within the snow, and these levels are likely to be low concentrations that meet regulatory water quality standards.
- Soil chemistry monitoring indicated that there were no detectable levels of VOCs or total petroleum hydrocarbons in background or on-trail soil sampling stations, with the exception of one chemical compound detected in an on-trail sample taken at Station C1. Toluene was detected at a concentration of 24.4ug/Kg, which is far below the EPA Soil Screening Guidance Level of 12,000 ug/Kg. At six on-trail soil sampling stations, soil chemistry monitoring also indicated detectable levels of polycyclic aromatic hydrocarbons, which most likely were present due to historic railroad use along the Lamoille Valley Rail Trail (LVRT), other historic activities, and possible natural sources such as forest fires, and tree leaves and needles. All PAH levels in tested soil were below the EPA Soil Screening Guidance Levels with the exception of one exceedance at station A4 on the LVRT, which is most likely the result of the historic railroad use and the highway adjacent to this location. These data indicate that snowmobile usage does not have any significant impact on volatile organic compounds within soil in the vicinity of the heavily used snowmobile trails that were evaluated. Trail usage by snowmobiles and other motorized vehicles may result in low levels of VOCs and PAHs in soil, that are far below applicable regulatory levels and environmental screening levels.

2. **Effects of Snowmobile Emissions on the Chemistry of Snowmelt Runoff in Yellowstone National Park**. Arnold, J.L., & Koel, T.M. (2006) Yellowstone National Park, Center for Resources – Fisheries and Aquatic Sciences Section. http://www.nps.gov/yell/parkmgmt/upload/snwmbil_snwmlt_rpt.pdf
   - All in situ water quality measurements were within acceptable limits. The concentrations of all VOCs detected each year were considerably below the U.S. Environmental Protection Agency's water quality criteria and guidelines for VOCs targeted in this study. During the course of the study, VOC concentrations of snowmelt runoff in Yellowstone National Park were below levels that would adversely impact aquatic systems.
3. **Impacts of Two-Stroke Engines on Aquatic Resources.** (1999) Effects of Winter Recreation on Wildlife of the Greater Yellowstone Area: A Literature Review and Assessment. Olliff, T., Legg, K. & Kaeding, B. Greater Yellowstone Coordinating Committee, Yellowstone National Park. pp. 145-149. http://www.nps.gov/yell/parkmgmt/upload/wildlifewint.pdf
   - In situations where snowmobiling occurs over open water (which is rare), obvious impacts will include direct discharge into aquatic habitats. Appreciable contamination from emissions from backcountry snowmobiling probably occurs less frequently.
4. **Effects of Snowmobile Use on Snowpack Chemistry in Yellowstone National Park,** 1998.Ingersoll, G.P. (1999) U.S. Department of the Interior –U.S. Geological Survey, Water-Resources Investigations Report 99-4148, prepared in cooperation with the National Park Service
   - Snowpack samples representing most of the winter precipitation were collected at about the time of maximum annual snow accumulation at a variety of locations in and near the park to observe the effects of a range of snowmobile traffic levels. Concentrations of organic and inorganic compounds in snow samples from pairs of sites located directly in and off snow-packed roadways used by snowmobiles were compared. Concentrations of ammonium were up to three times higher for the in-road snow compared to off-road snow for each pair of sites. Thus, concentrations decreased rapidly with distance

from roadways. In addition, concentrations of ammonium, nitrate, sulfate, benzene, and toluene in snow were positively correlated with snowmobile use.

- Although clear patterns have emerged to establish ammonium and sulfate as reliable indicators of snowmobile emissions in nearby snowpack, particularly along the corridor from West Yellowstone to Old Faithful, nitrate concentrations are not much influenced by these local effects. Snowpack concentrations of nitrate were relatively unaffected by snowmobile traffic.
- Siting off-road sampling sites 50 m from snowmobile routes seems adequate to eliminate contamination from snowmobiles and allow observation of regional effects. Comparisons between chemistries at the West Yellowstone sites 50 and 1,000 m off-road show similar values for all major ions and also are similar to background levels elsewhere in the Rocky Mountain region; therefore, contamination from snowmobiles is less likely 50 m from highway corridors, especially when compared to in-road chemistry. Furthermore, two sites 50 m off-road and a third site1,000 m off-road around Old Faithful also had good agreement between major-ion concentrations and also were unaffected by snowmobile traffic, as shown by the in-road snow chemistry.
- Hydrocarbon levels in the snowpack near snowmobile use were elevated relative to background snowpack chemistry in the study but were lower, in general, than concentrations at hundreds of locations nationwide representing a full spectrum of watershed settings ranging from subalpine to urban (Dennehy and others, 1998). Detectable concentrations of VOC's in Yellowstone ranged from 12.2 to 973 ng/L. VOC concentrations detected in urban storm water in the United States have been found to range from 200 to 10,000 ng/L, with more concentrated levels observed less frequently (Lopez and Bender, 1998; Lopez and Dionne, 1998). In a variety of urbanized, forested, and agricultural settings in New Jersey (Reiser and O'Brien, 1998), median concentrations of seven streams detected for benzene(60 ng/L), MTBE (420 ng/L), toluene (60 ng/L), ando-xylene (10 ng/L) were markedly higher than concentrations in snowmelt runoff at Yellowstone except for except for toluene.
- Toluene concentrations in snowmelt runoff in Yellowstone (less than 25 to 252 ng/L) further indicate the potential sensitivity to contamination of snow and surface-water samples. Even at Loch Vale, the backcountry site in Colorado several kilometers from the nearest roadway, toluene concentrations were similar to those detected in the snow packed roadway at Sylvan Lake(108 ng/L).Additionally, toluene concentrations in the snow packed roadway at Old Faithful also were very similar to the concentration in snow 1 km off the highway. In some cases, there was a more clearly observable pattern, such as with comparisons between in-road and off-road sites at West Yellowstone and at the site 8 km east of West Yellowstone (West Yellowstone, 8 km east). The Tower Falls site, several kilometers from snowmobile traffic, had a low concentration (89.3 ng/L) similar to that detected in both the original (91.5 ng/L) and replicate (III ng/L) snow samples at Loch Vale, Colorado. Oddly, the snowmelt runoff grab sample from the area near Tower Falls contained the highest concentration of toluene (252 ng/L). Clearly, more investigation is needed to determine whether these anomalously high values for toluene (relative to benzene, MTBE, and xylenes) in snowmelt runoff are due to the sampling methodology, other sources of contamination, analytical techniques, or ambient conditions. In spite of these uncertainties, the toluene snow chemistry positively correlates with other hydrocarbon and major-ion concentrations.
- Drinking-water standards for benzene (5,000 ng/L), toluene (1,000,000 ng/L), and xylenes (10,000,000 ng/L) published by the U.S. Environmental Protection Agency (1996) far exceed any levels detected in either snow or snowmelt runoff at Yellowstone in this study. Even the highest detections of benzene in snow (167 ng/L at in-road site 8 km east of West Yellowstone) or snowmelt (less than 10 ng/L at all sites), or toluene in snow (726 ng/L at in-road site 8 km east of West Yellowstone) or snowmelt (252 ng/L near Tower Falls) at Yellowstone are far less than the established standards for water consumed by humans (less than 4 percent and less than 1 percent, respectively).
- These results indicate that snowmobile use along the routes originating at the South and East Entrances (lower volume of traffic compared to West Entrance), and not including the immediate area (within 1 km) surrounding Old Faithful, may not be substantially affecting atmospheric deposition of ammonium, sulfate, and hydrocarbons related to gasoline combustion.
- Preliminary analyses of snowmelt-runoff chemistry from five of the snow-sampling sites indicate that elevated emission levels in snow along highway corridors generally are dispersed into surrounding watersheds at concentrations below levels likely to threaten human or ecosystem health.

Impacts to Subnivean (under-the-snow) Mammals

Adaptations to snowpack are an important component of the ecology of small mammals in temperate climates. Some small mammals, such as chipmunks, hibernate and have limited interaction with the snowpack environment. However, shrews and voles stay active throughout the winter, and much of their activity occurs in the subnivean space under the snowpack. Other species (deer mouse for example) undergo bouts of inactivity between activity. These subnivean mammals are dependent on the subnivean space between the basal layer of snow and the ground for shelter, foraging, and travel. Past research suggests that subnivean space may be formed in one of two ways: mechanically or thermally. The relative importance of each of these mechanisms in forming biologically useful subnivean space varies by region and type of snow. Subnivean space forms mechanically when the weight of the snowpack is supported by vegetation, woody debris, or complex rocky environments.

1. **Winter Recreation Effects on the Subnivean Environment of Five Sierra Nevada Meadows.** Wildlife Resource Consultants, (2004) U.S. Forest Service, Lake Tahoe Basin Management Unit.
    - This study investigated the distribution of subnivean space or the effects of winter recreation on subnivean space in maritime snowpack conditions found in the Sierra Nevada Mountains in California.
    - Vegetation structure appears to be an important factor in creating subnivean space. Subnivean space was high in the vegetation communities with woody shrubs, likely due to the influence of stems that are less compressible than in herbaceous vegetation communities. However, subnivean mammal use was not noted in pits dug in the riparian shrub or silver sage community types. Because no mammal use was noted in the shrub communities, and because the sample size in these communities was small and was not proportionately distributed among recreational use categories, the shrub communities were excluded from the analysis of recreational effects.
    - Wet meadows, with their additional herbaceous density and height, may provide more subnivean space compared to dry meadows.
    - Pits dug in shallower snow had substantially more subnivean space than pits dug in deeper snow, and the height of the space was greater in the shallower pits. This suggests that the depth of snow, which is affected by elevation, strongly influences the development and maintenance of subnivean space.
    - More pits dug in shallow snow were in the 'no recreational use' category than in other recreational use categories. Given that low snow depth and wet meadow vegetation are correlated with high subnivean space, some of the difference in the amount of subnivean space development between recreational use categories is likely due to these factors.
    - This study's results suggest that snowmobiles and cross-country skiing may affect the amount of subnivean space, but both snow depth and vegetation are also strong influences. While recreational use did appear to affect snowpack density, it could not cause the same adverse effects reported in other study locations such as destruction of depth hoar, since this snow type did not occur in the study areas.
    - The distribution of subnivean space correlates with snow depth, vegetation type, and woody debris.
    - Recreation use did not appear to affect niveal burrows. The actions of the subniveal animals themselves appear to create subnivean space.
    - It was not possible to perform a multifactorial analysis in this study because the importance of snow depth and vegetation type on the formation of subnivean space was not understood.
    - This study strongly suggests that wet meadows at low elevations with low snow depth probably have the most subnivean space. This study's findings were not as conclusive regarding the effects of recreational use on subnivean space. But there is some suggestion that winter recreation may impact subnivean space at low elevations. Winter recreation probably has the greatest effect at low snow depths. Further research is needed to produce data that can be tested for statistical significance, with controlled variables, and even distribution of snow pits among the recreational use categories, snow depth, and vegetation types.
2. **Effects of Winter Recreation on Subnivean Fauna.** (1999) Effects of Winter Recreation on Wildlife of the Greater Yellowstone Area: A Literature Review and Assessment. Olliff, T., Legg, K. & Kaeding, B. Greater Yellowstone Coordinating Committee, Yellowstone National Park. pp. 97-99. http://www.nps.gov/yell/parkmgmt/upload/wildlifewint.pdf

- Skiers may do more damage to the snowpack than snowmobilers because narrow skis cut deeper into the snowpack and because skis have a greater foot load (amount of weight per surface area) in comparison to a snowmobile track.
- For both ski tracks and snowmobile tracks, multiple passes over the same track will have more impact than a single pass

BEST MANAGEMENT PRACTICE RECOMMENDATIONS
Related To
MINIMUM SNOW DEPTH REQUIREMENTS FOR OSVs

1. **Avoid Generalized Numerical Snow Depth Standards:** Jurisdictions should resist establishing inflexible numerical snow depth measurements in order to provide the best adaptive management protocols for OSV travel management across a landscape. The development of numerical standards for OSV use is complicated by the fact that terrain and snow-cover are often extremely variable across the landscape. And snow is a complex material that changes constantly from the time it starts to develop high in the atmosphere, through all of the time it is on the ground, until it finally melts. Since snow is ever-changing and continually transformed by metamorphosis, wind, and other uncontrollable weather conditions, it can only be expected to be uniformly measured at a specific locality – and that measurement will be valid for only that particular, tiny point in time. Consequently, any measured snow depth will rarely be consistent when applied to an entire landscape versus the locality where the measurement was performed since snow depth is always subject to being smaller or larger in a different location – which could be within sight distance of the snow measurement location – as well as be different an hour, hours, or a day later depending upon atmospheric conditions at that location.

   Furthermore, once a 'minimum depth' threshold is compacted by either trail grooming or being driven over by an OSV, snow depth falls back below the minimum depth threshold – prohibiting use – until enough new snowfall is deposited over the groomed or tracked path – illustrating the fallacy of such arbitrary standards.

   In the end, numerical snow depth standards only invite needless inappropriate challenges to OSV use by those wishing to restrict their use in properly designated motorized use zones – rather than truly providing for meaningful resource protection or appropriate best practice for winter trails management. Consequently, OSV management is best served by the straightforward guiding principle of 'where snowfall is adequate.'

2. **Do Not Exceed Six Inches of Snow Depth If an Ill-Advised Minimum Snow Depth Restriction Is Considered:** While numerical minimum snow depths are firmly not recommended and strongly advised against as a best management practice, any ill-advised minimum snow depth restrictions which are established related to being able to start trail compaction / grooming should not exceed six (6) inches of uncompacted snow depth. The first snowfalls that are processed on a trail create the base for the remainder of the winter. An early solid, smooth base of snow will help keep the trail smoother throughout the rest of the winter. Consequently, vigorous smoothing and heavy compaction is important for early snows and should be done to the greatest extent possible, depending up equipment and budget availability. Trail compaction with a packer bar, roller or drag pan should begin early in the season, as soon as adequate snow begins to accumulate, so that snow layers no more than 6 inches in depth are consistently packed from the ground up. Newly fallen snow layers should ideally be cut to 6 inches or less before compacting to ensure full compaction throughout the layer. Early snow which is allowed to accumulate to thick deep layers, as well as thick layers of newly fallen snow during the season, typically do not compact well.

3. **Recognize the Armoring Benefits from Early Season Snowmobile Compaction:** Snow compaction from snowmobile traffic helps to armor soil and underlying vegetation. Consequently, OSV use should be allowed to begin early in the season, just as soon as adequate snow cover (generally 4 to 6 inches) begins to accumulate. A snowmobile's track and weight tend to increase the density of the trafficked snow layer. This densification makes the snow layer considerably stronger and works to 'armor' the underlying terrain. This is the essence of trail grooming practices, but even the weight of snowmobiles or other tracked OSVs being operated prior to grooming can cause this effect and is a particularly important, beneficial contribution to best management practices early in the winter season related to OSV use.

4. **Twelve-Inch Minimum Rule Only Appropriate in One Limited Circumstance:** OSV operation should not be allowed in *watersheds with 'severely burned soil and detrimentally compacted, eroded and displaced soil*' unless there is a minimum of 12-inches of snow cover. Outside this situation, any area-wide 12-inch minimum snow cover rule is generally considered unnecessarily restrictive and detrimental to proper OSV management.

APPENDIX 1: Snow Depth Comments from Russ Alger – Keweenaw Research Center

Michigan Technological University
Keweenaw Research Center

1885

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COMMENTS ON SNOW DEPTH FROM RUSS ALGER – DIRECTOR, INSTITUTE OF SNOW RESEARCH at KRC

February 28, 2019

Ms. Katherine Carpenter
Forest Environmental Coordinator
Plumas National Forest
159 Lawrence Street
Quincy, CA 95971

Re: Over-snow Vehicle Routes and Area Designation

Dear Ms. Carpenter:

I am Russ Alger, the Director of the Institute of Snow Research at the Keweenaw Research Center of Michigan Technological University (MTU). This letter is my written comment to Plumas National Forest on the Forest's proposal for over-snow vehicle route and area designation. Thank you for extending the comment deadline to March 1, 2019.

My comments are designed to be read together with the detailed comment letter submitted on January 23, 2019 by the International Snowmobile Manufacturers' Association (ISMA) and the American Council of Snowmobile Associations (ACS) through their attorney James Lister of Birch Horton Bittner & Cherot. The purpose of my comments is to provide my expert opinion in support of the ISMA/ACSA comments, which I have considered.

The Institute of Snow Research at the Keweenaw Research Center (KRC) a Research Institute of Michigan Technological University, I have been involved in research regarding the travel of vehicles over snow for over 40 years. A good part of this research has revolved around snowmobiling including mobility and trail construction. Over the years, a large amount of expertise in this area has been developed and KRC has become subject experts in over snow transport.

I hold a Masters in Civil Engineering from MTU. My CV including list of publications is attached to these comments. My writings include many publications regarding snowmobile travel. I have particular expertise in the field of "snow pavement," which is the design of a thin hard compacted layer of snow that can support considerable weight. Please see "Development and Construction of a Hard Surface Runway at the South Pole", R.G. Alger and G.L. Blaisdell, *US Army Cold Regions Research and Engineering Laboratory*, June 2000,

My work focuses on the importance of snow compaction to over-snow travel over roads, trails, and other routes (e.g. runways). My comments will focus on the Forest's proposal to require six inches of snow before snowmobile travel can occur on designated routes (trails). Snow on regular travel routes is compacted by the weight of -snowmobiles and groomers and so is denser and more protective of the ground than un-compacted snow.

The development of standards for over-snow travel, namely snowmobiles and groomers in this case, is complicated by the fact that terrain and snow-cover are extremely variable. Snow is a

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complicated material that changes constantly from the time it starts to develop high in the atmosphere, through all of the time it is on the ground and until it finally melts or sublimes. For this reason, the author believes it is difficult to look at standards that are depicted solely by snow depth.

First, snow depth can vary considerably across even small areas within a snow event. This is even more evident at higher elevation and in areas where mountain ranges can affect the flow of the weather.

Snow characteristics such as snow density also vary widely dependent on atmospheric conditions such as temperature above the ground and at the surface, wind conditions above and at the ground, solar load, snow age, ground temperature, etc. Coupled with density is free moisture content in the snow. This is liquid water that is present within the pack and amongst the crystal structure. Temperature affects the formation of the snow and drives the free water, and thus density. Essentially, "cold snow" is dry, and "warm snow" is wet. Also, in general, dry snow is much less dense than wet snow. Crystal structure as snow is formed in the air also drives the density on the ground.

As snow ages, even in the first hours on the ground, the crystal structure can change quite rapidly. This change in structure and properties is magnified dependent upon certain weather conditions such as temperature gradients, ground temperature, solar load, rain, depth, etc. In general, snow densifies with time and at depth. This will be explained further in the following paragraphs. Ice from frozen rain and melt layers tend to add strength to the overall snow pack also.

From the information given above, it is obvious that properties of snow are quite variable depending on weather, location, time, and so on. The effect of light vehicle traffic moving over the snow as well as the support or flotation afforded by the pack are therefore also quite variable and difficult to quantify.

In conjunction with all of the natural properties of snow mentioned already, the passage of both snowmobiles, various other over-snow vehicles, and groomers change the bulk properties of the snow pack. Vehicle weight, tracks, and tires tend to increase the density of the trafficked snow layer. This densification makes the snow layer considerably stronger and works to "armor" the underlying terrain. This is the essence of grooming practices, but even the weight of snowmobiles can cause this effect. In general, wet warm snow compacts much better than dry snow. Once snow is densified, even by weight of snow above a lower layer, it tends to bond to itself. This bonding actually causes a snow mass that is similar to a "snow pavement" and in fact can become ice when the density reaches about 0.6 g/cc. These hard layers are perfect for protecting the underlying soil. Furthermore, if the underlying terrain (soil) can freeze, the protection is much better. Snow is a great insulator when it isn't compacted, but the densified layer does not have the insulating ability like "fluffy" snow. Therefore, compacting the snow and increasing the potential for soil freezing is a great way to minimize damage to the soil.

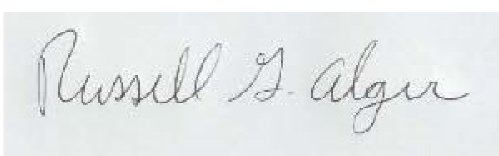
As explained in the discussion above, when snowmobiles and groomers make snow "denser" or more "compact," they are by definition decreasing the thickness of the snow while either increasing or holding constant the protective qualities of the snow. Accordingly, it is not appropriate to regulate on the basis of snow depth, when the meaningful metric is the protective quality of the snow, which is far more dependent on density than on depth.

Snow density is frequently measured by taking snow water equivalent (SWE) samples (tube stuck in snow). SWE could rise all the way to approximately 0.9 if this measurement was taken in clear ice (for each inch of ice depth in the sample tube, there is about 0.9 inch of water in the tube when sample is melted). When SWE measurements are made, it is preferable to record snow depth at the time of measurement. This allows for the direct calculation of average density in the pack and gives a better indication of what the pack should be able to support. While qualitative judgments using the skills of Forest Service personnel are preferable to inflexible empirical measurements, should the Forest insist on an empirical measurement, it should base it on sample of SWE taken from compacted trails, not snow depth. Having only snow depth without other qualifying parameters such as density, crystal structure, ice layering, bonding, etc., makes the specification much harder to justify. Moreover, if there is a layer of ice at the bottom of the trail sample, that should be noted because the ice has extra protective qualities.

ISMA and ACS in the comments filed by their attorney have developed analyses that look at the various amounts of compaction and how this affects the depth on the trail or off-trail terrain. These calculations are supported by the previous explanations of snow properties. In essence, snow will compact to various degrees dependent on the properties described. I would tend to concentrate on compaction ratios in the range of 4:1 down to 2:1. This should be a good coverage for the snows that would be seen in these areas. The snow on the trail will be compacted in layers so it will become more **d**ense as the season goes along. Loose snow will support a few passages of snowmobiles, and will also form into a stiffer trail with every subsequent passage. In most cases, snowmobiles will follow paths of previous sleds magnifying this result.

The point should also be made that most riders police themselves when it comes to riding in areas that don't have enough snow. Snowmobiles are expensive not only to purchase, but to repair. The vast majority of owners will not risk the potential of causing expensive damage caused by hitting rocks, logs, stumps, etc., while riding in areas where there isn't enough snow to guard against a catastrophic hit.

Sincerely,



Russ Alger
Director – Institute of Snow Research
KRC/MTU