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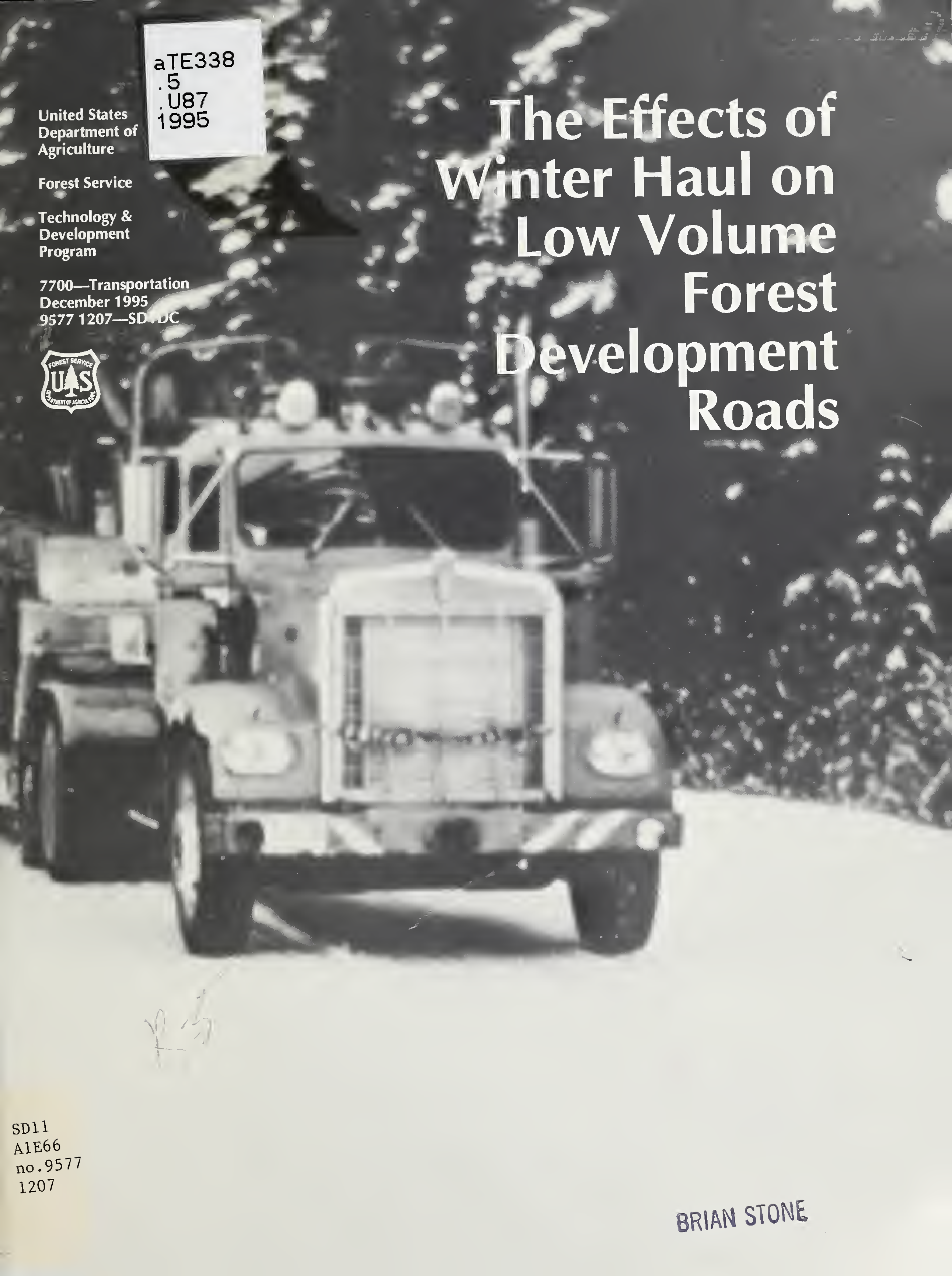
The Effects of Winter Haul on Low Volume Forest Development Roads



The Effects of Winter Haul on Low Volume Forest Development Roads

Palmer Utterback —*Transportation Engineer*
Willamette National Forest
and
Thomas L. Moore—*P.E.*
Project Leader, Engineering Technology
San Dimas Technology & Development Center

with Annotated Bibliography by
Maureen A. Kestler and Rosa Affleck
U.S. Army Cold Region Research and Engineering Laboratory (CRREL)
72 Lyme Road, Hanover, NH 03755

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INTRODUCTION

Purpose

The purpose of this report is to describe the effects that winter hauling of commercial forest products and transportation of heavy equipment have on Forest Service roads; compile a list of related publications; and discuss possible solutions to on-the-ground problems associated with winter haul activities.

Scope

A Forest Service agency-wide questionnaire (survey) was distributed to engineers in the field to obtain input on the effects of winter haul on gravel native surfaced and asphalt surfaced roads. The survey was used to help identify key concerns, impacts, and questions. The survey results are included, and methods to reduce impacts are discussed.

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) contributed an annotated bibliography to this report. The bibliography consists of separate summaries of papers, reports, manuals, and articles that relate to various aspects of winter and springtime use of pavements. Also, a more comprehensive list of references is included. All publications are indexed and on file at the USDA Forest Service, San Dimas Technology and Development Center.

Project Description

Forest Service roads are used as winter haul routes on many national forests and winter haul is expected to continue in the future. It is well documented that roads are often adversely impacted by winter haul activities. This project studied and evaluated the effects of using Forest Service roads as winter haul routes. Solutions to these problems, submitted by various field units, are documented in this report.

The performance of a road structure is effected by several factors such as wheel loads from heavy trucks on thaw-weakened pavements, freeze-thaw cycling, frost heave, thermal cracking, snow removal, and spring runoff. Many research papers, manuals, design guides, technological applications, and reports have been written on the effects of heavy truck traffic on roads during the winter and spring seasons. A comprehensive list of reference of current and past research related to the effects of winter/spring road use is included in this report.

RESULTS OF QUESTIONNAIRE

The questionnaire (figure 1) was sent to field units in all Regions of the Forest Service (figure 2). The goal of the survey was to help determine the future trend of winter haul, identify problems experienced in the field, and prioritize concerns related to winter haul activities on forest development roads. Possible solutions for preventing or mitigating the adverse effects of winter/spring road use were also solicited.

Winter/Spring Road Use Trend and Reasons Cited

Thirty-one responses to the questionnaire were received. The number of responses per Region are presented in Table 1. Of the 31 respondents, 10 indicated that heavy road use during winter/spring was likely to increase, 5 said heavy road use would stay the about the same, and 6 said use would decrease due to declining timber programs. Ten respondents did not indicate a trend.

Several reasons for continuing winter/spring timber haul were given. Maintaining timber inventory during the winter for the mills was the most frequent response; however, summer wildlife restrictions are becoming more prevalent and as a result haul must be accomplished during the winter/spring season. For example, timber operations are restricted to winter months in some areas of Region 1 to protect the Grizzly Bear from harassment during the spring, summer and fall seasons. Regions 1, 2, 3, 5 and 6 reported other reasons for summer wildlife restrictions such as big game summer range and calving season, Northern Goshawk restrictions, and Spotted Owl nesting season. Region 9 reported that some logging activities occur during the winter months when the ground is frozen to prevent soil damage from yarding. The extended drought recently experienced in many Regions has resulted in more stringent summer and fall fire restrictions which force hauling operations to late fall, winter, and early spring months. Other reasons reported for winter/spring haul include

PLEASE ANSWER THE FOLLOWING QUESTIONS

1. Give location where below information applies (Or respond by DG).

2. Are your forest development roads adversely effected (in terms of cost, accelerated road damage, or maintenance) by heavy road use during the winter or early spring months? (If the answer is NO skip all of the below questions and please send in the questionnaire).

3. Please indicate your climatic that effect winter/spring road use and road deterioration.
    - A. Prolonged period of freezing (greater than 3 ft depth) with cyclic freeze/thaw in spring.
    - B. Moderate freeze/thaw (less than 3 ft depth) with considerable winter moisture.
    - C. Minor freeze/thaw, may cycle during winter, moderate moisture.
    - D. Other, describe climatic conditions during winter/spring road use.

4. Describe any adverse effects (short or long term) of winter/spring road use and what times of year are most critical.

5. What maintenance, monitoring, policy, or road rules are required (or you would like to see established) as a result of winter/spring road use? (Describe any ideas you may have.)

6. What cost factors need to be considered to account for the effects of winter/spring road use?

7. Please indicate type of winter/spring road use.
    - A. Timber Haul, log trucks.
    - B. Other, Describe type of use.

8. What are the reasons for winter/spring road use and will future use increase, decrease, or remain the same?

9. Are there any areas related to the effects of winter haul that are not well defined and need more study? If so please describe.

RETURN TO: **Palmer Utterback**
Willamette National Forest
P.O. Box 10607,
Eugene OR, 97401
Phone (503) 465-1766 or DG:R06F18A

Figure 1—Winter Haul Questionnaire.

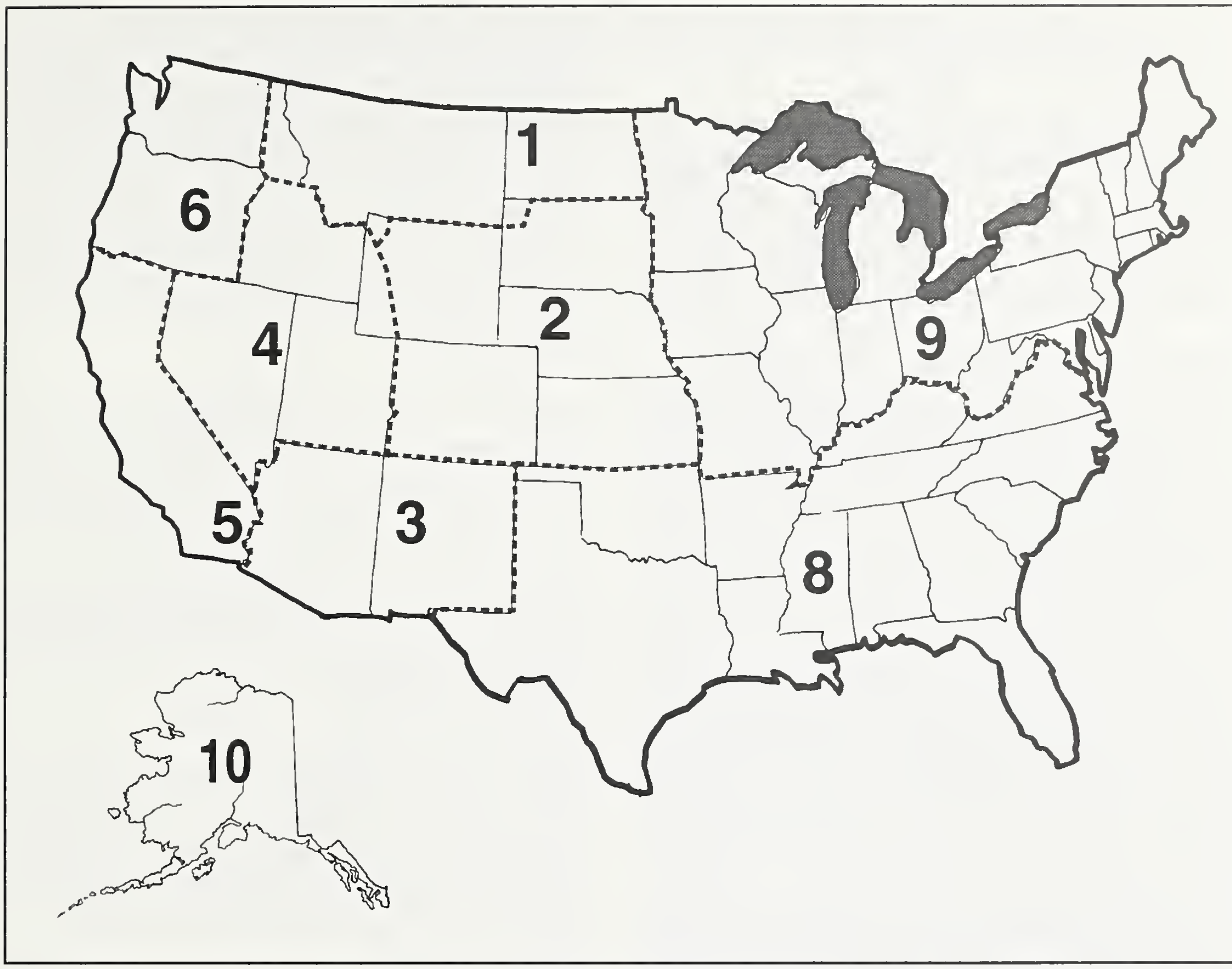


Figure 2—USDA Forest Service Regions.

requiring snow cover for protection of sensitive plants, access to private lands, and winter cattle operations.

Table1—Number of responses.

REGIONS	RESPONSES
1 — Northern	4
2 — Rocky Mountain	5
3 — Southwestern	5
4 — Intermountain	3
5 — Pacific Southwest	3
6 — Pacific Northwest	4
8 — Southern	1
9 — Eastern	5
10 — Alaska	1
TOTAL RESPONSES	31

Critical Time Period

All forests reporting a moderate to severe freeze depth indicated that the spring thawing period is the critical time of year for incurring road damage. Several forests also indicated that freeze-thaw cycling occurs during winter months and results in damage to the road structure when heavy haul is allowed.

Climate Conditions

Three climate conditions were identified by the responding forests and are listed below.

I. Prolonged period of freezing with depth greater than 3 feet (1 meter) and spring freeze/thaw cycling.

II. Moderate to minor period of freezing with freeze/thaw cycling possible during winter.

III. Predominately wet conditions with occasional freeze/thaw.

Nine responses indicated climate condition I, 18 climate condition II, and 4 climate condition III. Since the majority of the responses indicated climate conditions I and II, this report focuses on areas with freezing conditions as opposed to predominately wet conditions.

Reported Effects of Winter Haul Activities

Tables 2, 3, and 4 present the effects of winter/spring road use categorized by the above climatic conditions. The break-up of asphalt surface during spring, severe potholes, alligator cracking, and early failure of chip seals are the most commonly reported adverse effects for asphalt paved roads.

For aggregate surfaced roads, the most common (12 forests) effect was aggregate loss from either plowing snow or repeatedly blading wheeltrack ruts out of the road surface. Other common problems included formation of wheeltrack ruts which channel spring runoff off the road causing erosion and a loss of fines; pumping of subgrade materials through surfacing materials; subgrade damage from using the road when saturated conditions exist; waterbars and drainage dips destroyed by deep ruts.

Region 9 forests reported subgrade failures are occurring two to three years after winter road use, even though haul is only allowed when the road is frozen and is prohibited during spring thaw. It is suspected that snow plowing these roads drives frost deeper into the subgrade due to loss of snow insulation. The result may be increased frost heave, transverse temperature cracking, culvert heave in low fills, and prolonged subgrade saturation for snow plowed roads compared to roads not plowed. Freezing water in culverts was another concern because it creates a dam and water overflows onto the road.

Maintenance Cost Factors

Several maintenance cost factors resulting from winter/spring road use were commonly identified. The cost to replace aggregate surfacing material lost during winter haul operations was identified by almost every responding forest. Other costs identified included snow plowing, repair of damaged culverts caused from snow plowing operations, blading wheeltrack ruts out of the road surface, reconstruction to repair subgrade damage, reconstruct waterbars, dips and leadoff ditches, and the cost of spot rocking for added structure. For asphalt surfaced roads pothole patching, road structure repair, crack sealing, and an accelerated need for seal coating were reported.

Culvert associated costs included repair or replacement of damaged inlets, road repair where culvert heave cracked pavement, repair to culverts that displaced due to frost heave action, and steaming to thaw out pipes.

The cost of law enforcement for haul restrictions was also cited as a significant cost maintaining winter haul operations.

Road Use Restrictions

Eight of the 31 responding forests indicated no adverse effects to roads. Five of the forests claiming no adverse effects either prohibit or restrict road use during critical thaw periods. The other three forests indicated no heavy use.

Various methods for determining when road restrictions should be applied were reported; they included having a written policy or a list of road use rules which provide guidelines for monitoring road damage and stopping timber haul when necessary. Some of the guidelines given to restrict winter timber haul in order to protect the road structure investment included:

- Close all roads during spring break-up
- Permit haul on frozen roads only
- Stop haul when rut depth is greater than 2" (50 mm).
- Leave 4" (100 mm) snow pack on road, stop haul when snow pack breaks up
- Haul is allowed only in the morning when road is still frozen
- Prohibit road use when saturated conditions exist
- Purchaser pays triple surface replacement rate for winter hauling.

Table 2—Reported effects of winter haul for Climate Condition I.

Region	Forest	State	Effects
1	Kootenia	MT	Gravel loss, loss of fines, wheel track ruts, damaged culvert inlets.
1	Kootenia	MT	No effects. Haul restricted during critical period. Thermister monitoring program used to determine critical thaw period.
2	Medicine Bow	WY	Winter logging opens road to early spring recreation traffic when road is saturated. Heavy use stops before spring breakup, but subsequent recreation traffic causes damage.
2	White River, Holy Cross	CO	Ground saturation in spring, wheel track rutting, loss of fines. Damage reduced by restricting haul during critical thaw period.
6	Malheur	OR	Asphalt potholes, pumping and mixing subgrade into base material. Sign damage. Thermisters used to restrict haul during critical thaw period.
9	Regional Perspective	MN, WI, MI	Loss of road material from snow plowing. Aggregate pushed into subgrade, rutting, latent effects of removing snow cover and driving frost deeped into subgrade during winter increasing spring thaw damage.
9	Nicolet	WI	Subgrade failure, deep rutting, contamination of surfacing, loss of surfacing from snowplowing, culvert damage.
9	Superior	MN	Frost is driven deeper when snow cover is plowed off, deep rutting, rocks pushed up by frost, culvert heave up in road, culverts freeze and plug causing fill washout, snow blocks ditches, water runoff on road sur face, aggregate loss from snow plowing.
9	Hiawatha	MN	No effects, Road Rules prohibit haul during critical periods.
9	White Mtn	MA	No effects, all roads closed during critical thaw period.
10	Regional Response		No effects reported

Table 3—Reported effects of winter haul for Climate Condition II.

Region	Forest	State	Effects
1	Regional perspective	ID, MT	Gravel loss, culvert heave in low fills, culvert damage from plow.
1	Deerlodge	MT	No effects. Haul restricted or prohibited during critical thaw period.
2	White River	CO	Latent subgrade failures that show up in 2 to 3 years, roads not designed for all weather use, haul restricted during critical that but subsequent recreation and hunting use damage road.
2	Gunnison	CO	Gravel loss, wheel track ruts, pavement breakup during spring.
2	San Juan	NM	Gravel loss, subgrade damage, pumping of subgrade thru surface materials.
3	Gila	NM	Deep wheel track ruts, waterbar and dips fail due to ruts, water channeled on road surface, big mud holes in road.
3	Santa Fe	NM	Aggregate loss, saturated subgrade, rutting.
3	Prescott	AZ	Deep rutting, distruction of waterbars, water channeled on road.
3	Apache-Sitgraves	AZ, NM	Surfacing loss, wheel track ruts, accelerated spring runoff.
3	Lincoln	NM	No effects reported
4	Sawtooth	ID	Road is damaged when used in a thawed state.
4	Targhee	ID	No effects, no heavy use during winter/spring.
4	Payette	ID	No effects reported
5	Eldorado	CA	Subgrade saturation, wheeltrack ruts, subgrade contamination, distress cracking, loss of chip seals, pavement failure before design life.
5	Shasta-Trinity	CA	Breaking up of asphalt pavement surface and chip seals.
5	Sierra	CA	Rutting, increased sediment yield.

Table 4—Reported effects of winter haul for Climate Condition III.

Region	Forest	State	Effects
6	Siskiyou	OR	Saturated subgrades, potholes, wheel track ruts.
6	Mt.Baker Snoqualmie	WA	No effects, annual cut less than 5 mmbf.
6	Mt. Hood	OR	No effects, road rule restrictions enforced, reduced harvest.
8	Regional		No effects reported.

Some forests reported using various road distress types to trigger road management action. For example, when minor potholes, washboarding, alligator cracking, wheeltrack ruts, or muddy ditch water begin to occur, a decision is made to do maintenance, stop use, or strengthen the road. Such guidelines and measures have been incorporated as provisions in the timber sale contract on some forests. The road condition is monitored, and restrictions, when warranted, are enforced during the administration of the contract. The appendix includes road maintenance policies, federal orders, and Road Use Permits generated and used by several national forests to determine triggers and enforce decisions for road maintenance activities.

Thermistor strings are currently being used in Regions 1, 4 and 6 to monitor asphalt pavement and road structure temperatures at various depths. Temperatures above freezing indicate when the road is beginning to thaw. When thawing is detected, timber haul is restricted to prevent major damage to the thaw-weakened road structure.

While thermistors help detect when to impose restrictions, they only indirectly help determine when pavement strengths have recovered. The Kootenai National Forest in Northern Montana is using the Road Rater deflection testing device in conjunction with thermistors to determine when pavement strengths have recovered enough to allow traffic to resume. Deflections are measured four times a year. First a baseline deflection is measured in August when strength is good. Then the other three measurements are taken two months after spring breakup and compared to baseline. Timber haul is resumed when deflections indicate the road structure has recovered sufficient strength. The Malheur and Ochoco National Forests in central Oregon are using the Benkleman Beam to measure deflections to determine road structure recovery. Another popular device is the Falling Weight Deflectometer (FWD) —see Figure 3.

Figure 3—Falling Weight Deflectometer used to assess pavement strength recovery.

The Superior and Hiawatha National Forests in Region 9 report that the County Commissioner imposes road restrictions that the Forest Service matches. If heavy truck traffic is restricted on county roads, then the same restrictions apply to this traffic on forest development roads.

ADVERSE EFFECTS OF WINTER HAUL ON DRY-WEATHER ROADS

Increased industry and summer wildlife restrictions are pressuring some forests to allow winter-spring haul on roads designed for only dry-weather use. When these roads were initially designed it was assumed they would simply be closed and haul prohibited during the critical winter-spring period. Allowing unrestricted haul during periods when the subgrade is saturated results in a cumulative deterioration of the road structure with increasing maintenance and reconstruction costs. For example, the San Juan NF in Region 2 identifies four stages in the deterioration of an aggregate surfaced road. Figure 4 shows repair costs significantly increase as damage progresses to failure in the subgrade (stage 4). Figure 5 shows deterioration progresses from shallow ruts in the aggregate surface (stage 2) to failure in the subgrade (stage 4).From the adverse effects reported in the questionnaire, the failure stages and cost trend indicated in Figures 4 and 5 are typical for most responding forests.

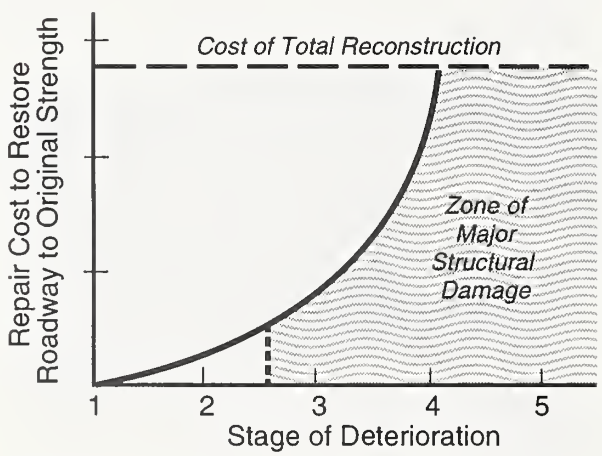


Figure 4—Generalized graphic of road deterioration stage versus repair costs.

Road deterioration can be categorized into investment damage to the roadway, and damage to resources outside the roadway. Figures 4 and 5 indicate conceptually that investment and potential resource damage and repair costs rise sharply as the road structure progresses from stage 3 to stage 4 deterioration. Due to low maintenance funding and resource concerns, the risks, costs, benefits, and mitigation alternatives of using dry weather roads for winter haul should be strongly considered when the decision to allow winter haul is made. Dry weather roads lack the structural support required for wet weather conditions. Significant cost savings and reduced resource impacts can be realized by focusing efforts on making management decisions and technical advancements which prevent progression from stage 3 to stage 4 deterioration while allowing winter haul.

ADVERSE EFFECTS OF WINTER HAUL RELATED TO SNOW PLOWING

Region 9 is concerned about latent damage occurring to the road structure when snow is removed to allow winter logging. The region also expressed concern about how to account for the latent road damage in terms of collection of maintenance deposits along winter haul routes. Even though timber haul is restricted to periods when the road structure is frozen and traffic related damage is at a minimum, it is perceived that road damage occurs later in the season and is related to opening roads to winter harvest activities.

The detrimental effects of frost action is, in part, related to the depth of frost penetration. Other factors include frost susceptible soils, the number of sub-freezing days, and the amount of moisture. Frost penetration under snow cover is less than under bare ground; therefore snow plowing a road surface may increase the depth of frost penetration. Figure 6 indicates a trend of increasing frost penetration as snow is removed from the road surface. Greater frost penetration on snow plowed roads with frost susceptible subgrades could increase frost-related damage and prolong the period of reduced subgrade support of thaw-weakened pavements.

Frost related damage that may be increased by snow plowing can be categorized into non-traffic and traffic related causes. Non-traffic damage that could be affected by greater frost-penetration includes:

- Boulder heave
- Culvert heave in low fills
- Distortion of pavement associated with non-uniform heave of subgrade

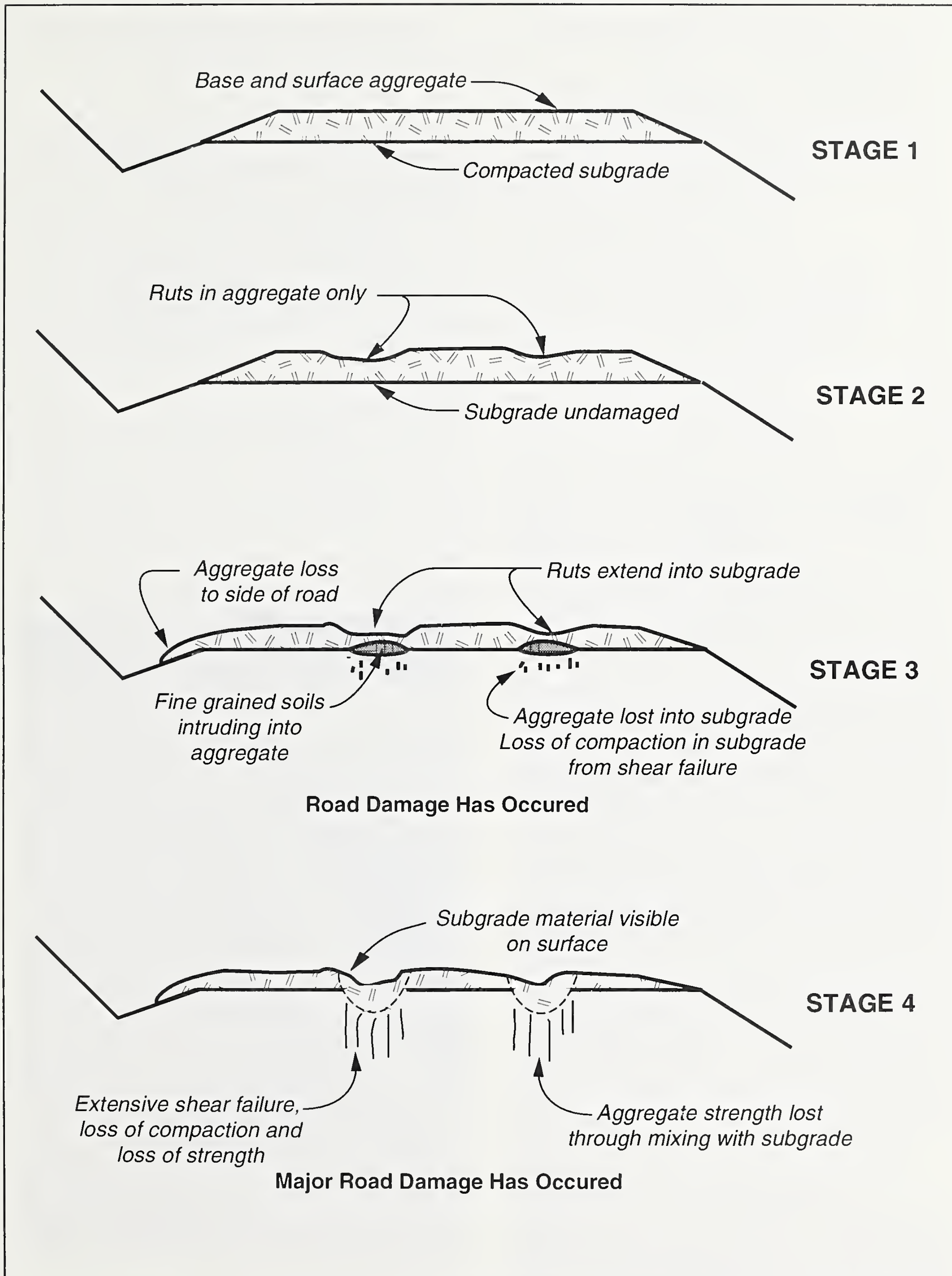


Figure 5—Typical stages of deterioration for aggregate surface roads.

- Non-uniform re-consolidation of heaved subgrade soils
- Increased pavement shrinkage cracking caused by exposing surface to sub-freezing ambient temperatures

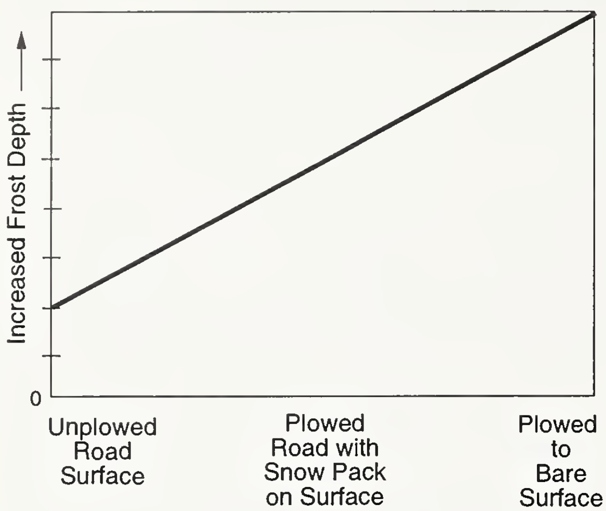


Figure 6—Frost depth increases with removal of snow insulation.

During thaw periods severe loss of subgrade and unbound base strength is typical. Snow plowing roads for timber haul may increase frost penetration which may increase the duration of the following subgrade weakening phenomenon:

- Loss of compaction of the subgrade which occurs when melting ice leaves soil in a weakened unconsolidated condition.
- Frost melts mostly from the surface down. Plowed road surfaces absorbs heat and melting is accelerated. Soil directly below road structure becomes saturated with a resulting loss of strength. Rutting or pavement distress cracks form from normal traffic wheel loads.
- Drainage of saturated subgrade soils becomes restricted by frozen under layers. The frozen under layers prolongs the time road structure is in a thaw weakened state.
- Plowing of the traveled width and allowing the shoulders to remain snow covered results in the "bathtub" effect. This occurs when the subgrade under the plowed area becomes saturated and drainage cannot occur due to the still frozen and impermeable road shoulders.

When the subgrade is saturated a severe loss of strength may occur in frost susceptible soils. Roads in a thaw-weakened state, for example, are especially vulnerable to damage from even small magnitude traffic loads. For aggregate roads, damage occurs in the form of subgrade failure and deep ruts shown in Figure 5 as a Stage 4 failure. In asphalt pavements, subgrade failure is indicated by severe alligator cracking and potholes shown in Figure 7. These distress factors are visible sometimes much later than when the actual damage occured. The amount of latent damage in asphalt pavements is something that is difficult to determine. Figure 8 is an example of damage that has occured and is not yet visible from the surface. Snow plowing opens roads to general public use. Even though logging traffic may be restricted during thaw periods, other forms of light and heavy traffic may not.

Figure 7—Typical alligator cracking resulting from heavy haul during weak pavement conditions.

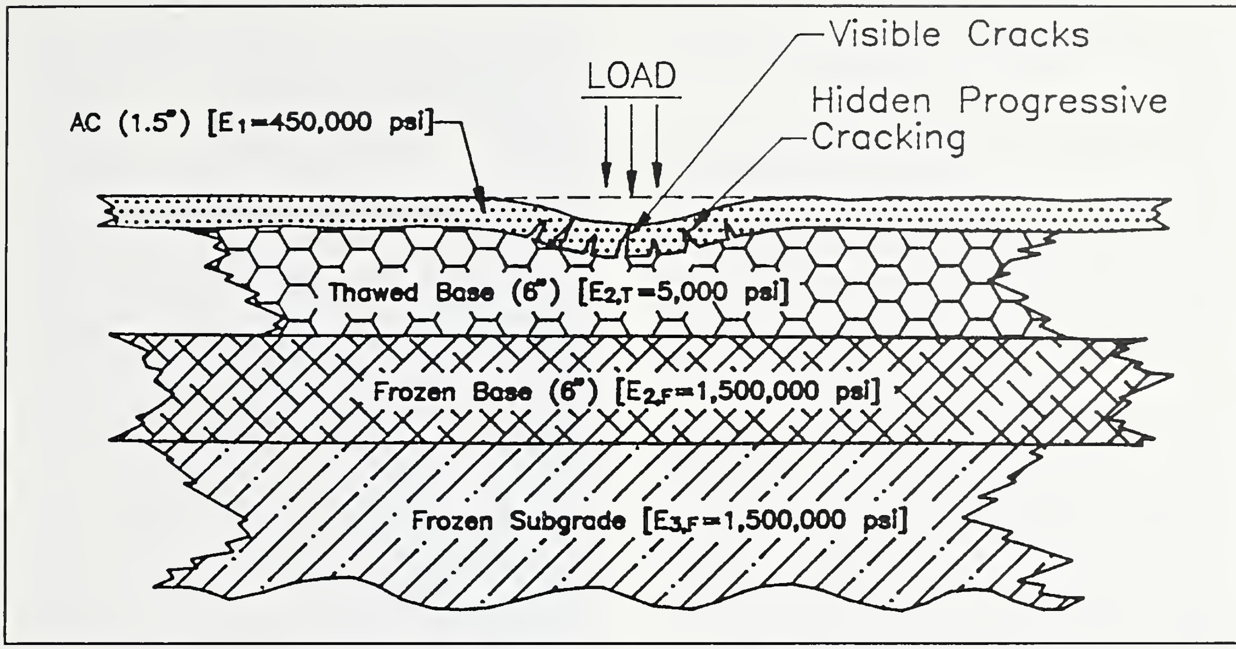


Figure 8—Hidden damage due to progressive cracking upward from bottom of asphalt mat.

Though not related to frost penetration, temperature or thermal shrinkage, cracks caused by extreme cold temperatures could also be increased when snow insulation is removed by snow plowing for winter haul.

There are numerous road maintenance related effects in addition to the temporary structural effects caused by snow plowing asphalt and aggregate surfaced roads. Some of these include:

- Loss of aggregate on aggregate sufaced roads
- Storage of snow removed from the road surface
- Narrowing of the roadway
- Finding and plowing existing turnouts.

METHODS TO REDUCE OR MITIGATE DAMAGE TO ROAD STRUCTURE

The questionnaire results indicated five possibilities to reduce accelerated road structure deterioration caused by commercial use during critical thaw periods. They are listed and discussed below.

1. Modify (strengthen) existing road structure for all season use.
2. Prohibit road use during winter.
3. Apply seasonal load restrictions.
4. Monitor pavement temperatures and moisture content during thaw weakening periods.
5. Use Variable Tire Pressures (VTP)

Modify (Strengthen) Existing Road Structure For All Season Use

It is possible to reconstruct an existing road structure, initially designed for dry-weather haul, to an all-season standard. However, in many instances, extensive reconstruction is required. Examples of typical modifications needed to the road structure to extend the hauling season include: removal of outsloping, widening of the template to accommodate taper, realignment to improve sight distance, culvert replacement, additional surfacing and base material, additional clearing, and signing. Budget constraints may make these modifications impractical for most forests.

Prohibit Road Use During Winter

Some forests are able to prohibit road use by seasonally closing roads to all heavy traffic during winter and wet-weather months. These forests typically have reasonably long spring, summer, and fall haul seasons. Prohibiting haul during the seasons when roads are most vulnerable to damage is the most cost effective method of preserving the road structure. However, due to summer wildlife restrictions, extension of fire seasons, and the demand for timber, some forests are unable to simply prohibit commercial use on a strictly seasonal basis. These forests would like to maximize use of roads susceptible to thaw weakening while minimizing damage to the road structure and adjacent resources.

Apply Seasonal Load Restrictions

Only a few forests mentioned using load restrictions during the critical thaw period. Instituting and enforcing spring load restrictions is an effective method of reducing road structure damage. This approach is commonly used by state Departments of Transportation such as Montana, Idaho and Washington on secondary and county roads. However, it requires using scales to weigh trucks and personnel for enforcement. A study designed to determine the magnitude of a load restriction would also be necessary. The following cost factors should be considered when determining if load restrictions are cost effective: the volume of timber hauled per truck under load restriction; associated haul costs of load restricted operation; and enforcement costs.

Monitor Pavement Temperature and Moisture Content to Manage Heavy Haul During Thaw Weakening Periods

Monitoring pavement and subgrade temperatures is an effective approach for determining when to curtail hauling operations. However, the question of when to resume haul has been more difficult to address and is not readily apparent by monitoring temperatures alone. The road subgrade and base is often in a saturated condition immediately following thawing. To allow for adequate drainage, an arbitrary time period is usually adopted that will ensure effective drainage. This time period is often either overstated or understated depending upon the drainage characteristics of the subgrade material. Recent technological breakthroughs (currently under study) have resulted in development of inexpensive equipment for assessing when the subgrade is sufficiently drained. Time Domain Reflectometry (TDR) technology (figures 9 and 10) and Radio Frequency (RF) probes (figure 11) can be placed at strategic depths indicating whether the particular location is saturated. There is a good potential that this technology will effectively be used by field personnel to provide information on when to allow continuation of heavy haul traffic during spring thaw periods.

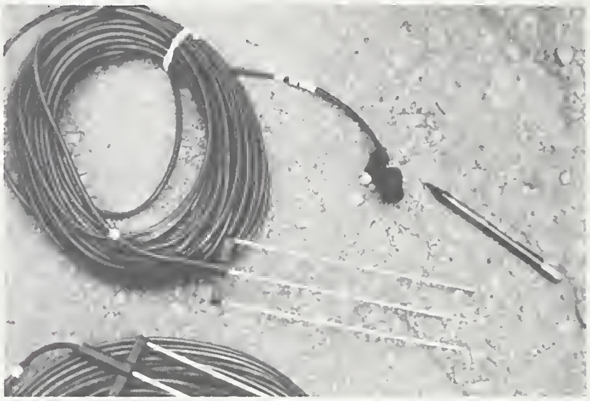


Figure 9—Time Domain Reflectometry (TDR) probe.

Figure 10—TDR reading device.

As of this date, TDRs that are buried in the subgrade cost approximately $90 each. A portable digital reader to operate in conjunction with the TDR, costs about $8000 and can be moved from site to site. Radio Frequency technology is cheaper but not as refined as the TDRs; however, it is still an effective method of determining subgrade moisture conditions. Less sophisticated and inexpensive reading devices are currently being developed. In the future, RF reading devices will be as simple as a modification of inexpensive volt meters and a homemade TDR probe that can be fabricated for

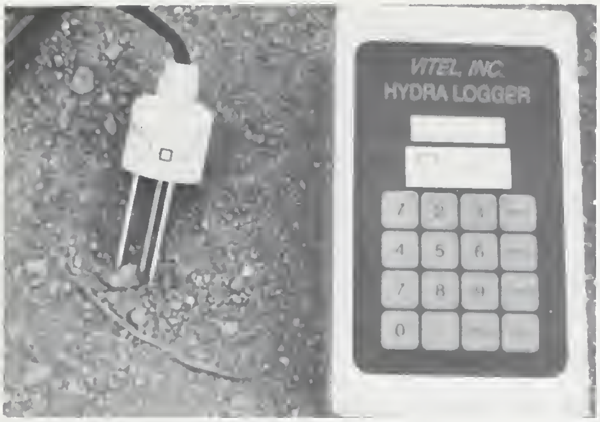


Figure 11—Radio Frequency (RF) probe and reader.

about $60 per device. An example of an inexpensive RF probe that effectively monitors road structure moisture content is included in the appendix.

Use Variable Tire Pressures (VTP)

Use of reduced tire pressures in lieu of, or in combination with, load restrictions may mitigate some of the costs, road structure damage and adverse resource impacts associated with winter/spring timber haul. Alberta-Pacific Ltd. located in Alberta, Canada requires that all log trucks using the company-owned transportation system be equipped with on-board Central Tire Inflation (CTI) systems for the purpose of protecting road structures. A study conducted by the Intermountain Research Station on the Willamette National Forest in western Oregon determined that in addition to protecting road structures, significant (up to 84 percent) reductions in traffic generated sediment were achieved be reducing the inflation in logging truck tires. The benefits of VTP technology is becoming well known and documented. Many studies and tests have demonstrated a dramatic reduction in damage to aggregate surfaced roads using reduced tire pressures (55 psi or 379 kPa) as compared with typical highway tire pressures (100 psi or 690 kPa).

A recent study performed by the U.S. Army Cold Region Research and Engineering Laboratory (CRREL) indicates that damage caused by using high tire pressures on heavy haul vehicles can be reduced 5-8 times when using reduced tire pressures on thin asphalt pavement.

SHARING COSTS OF WINTER HAUL

Opening roads for winter use by snow plowing leaves the roads more vulnerable to damage than roads left undisturbed under snow cover. How to equitably proportion a cost for commercial maintenance collection rates is a difficult question. However, focusing on the effects of snow plowing and increased frost penetration as it relates to the above discussion may be a good starting point. Some possible solutions are presented below:

- Share in the cost of temperature crack repair when snow insulation is removed
- Share in the cost to repair culvert displaced by frost heave on snow plowed roads
- Share in the cost of repairing differential settlement from frost heave on snow plowed roads
- Share in the cost of monitoring subgrade
- Share in the cost of surface replacement for gravel and native surfaced roads.

SUMMARY AND CONCLUSIONS

Fifteen of the 31 responses indicated that the future trend of haul during winter would either increase or remain the same. While winter haul is the lesser part of the overall timber program, a continuing trend of winter timber activities is indicated. With continuing application of summer environmental restrictions and the desire for sustained timber inventories at mills, the effects of winter haul on forest development roads is likely to be a significant concern in the future.

The amount and degree of damage resulting from increased winter haul depends upon a variety of factors. Some of these include winter traffic levels and loads, climatic condition, available maintenance funding, ensuring adequate surface drainage, timely blade maintenance, existing pavement structure, traffic management restrictions, and snow plowing operations. Numerous techniques and methods currently exist, used either singly or in combination, to reduce the adverse effects cause by increased winter haul activities. These techniques include use of VTP technology, applying load restrictions during thaw weakened periods, prohibiting use during winter and early spring months, reconstruction of the road template to accommodate increased levels of winter haul, and monitoring pavement temperatures and moisture content of the subgrade using inexpensive TDR and RF technology.

Finally, increased winter haul should involve sharing the additional costs between the resources that require winter access. Financial schemes should be pursued that provide for adequate protection of the road surface and adjacent resources when increased levels of winter haul are proposed. A Road Management Objectives (RMO) document should be available for each road facility which describes how the road is to be operated and maintained. This documentation is the "cornerstone" for documenting decisions made through the environmental analysis process and should be changed after evaluation of alternative techniques for operating and maintaining the road facility with the increased levels of winter haul.

RECOMMENDATIONS

Field units should compare historic levels of winter haul activities on individual road systems with recent levels of activity to determine whether winter haul has substantially increased over time. If significant changes have occurred, the changed condition should be reviewed with the RMO and Access Travel Management (ATM) Plan and an assessment made whether the changed haul patterns are still in conformance with management's intent. In many instances it may be that particular road systems need to be managed differently (such as imposing road restrictions, using VTP technology, etc.) or the road may need to be reconstructed if management decides to accommodate increased winter haul levels. Either way, it is evident from the information received from field units, and documented in this report, that much of the Forest Services' transportation system is being expected to operate at service levels above what was originally anticipated when the road was initially designed and constructed.

Increased levels of winter haul should result in review of existing road maintenance rates to quantify the additional costs associated with hauling timber products outside the normal haul season. The information presented in this report can serve as guidance in determining possible factors that may need to be considered. The importance of reassessing the impacts of increased levels of winter haul can not be over-emphasized especially as maintenance funds continue to decline.

FUTURE STUDY

Several areas of concern, including questions, and need for more information were identified by the survey. The following is a list of possible topics for further investigation related to the effects of winter hauling. Information would be used to further support the Forest Service position for collection of maintenance deposits along winter haul routes.

Study the effects of low tire pressures on thaw-weakened pavements and aggregate roads. Test pavement deflections with low tire pressures; use data to establish criteria for using low tire pressures as an alternative to applying load restrictions during critical thaw period. Study the effects of simultaneously reducing log truck loads and lowering tire pressure.

Investigate "tunnel effect" of deep snow along road surface where water is channeled on road surface and washes away fines.

Study the accidents on snow plowed roads during winter/spring which were the result of not sanding for icy conditions.

Investigate the latent effects caused by the removal of snow insulation when a road is plowed for winter logging use.

Study the amount of frost penetration caused by snow plowing and snowmobile use and its effect on later spring break up and increased road damage.

Investigate culvert heave and the resulting cracks on pavement surfaces; also investigate culvert heave-up into road surface in low fills.

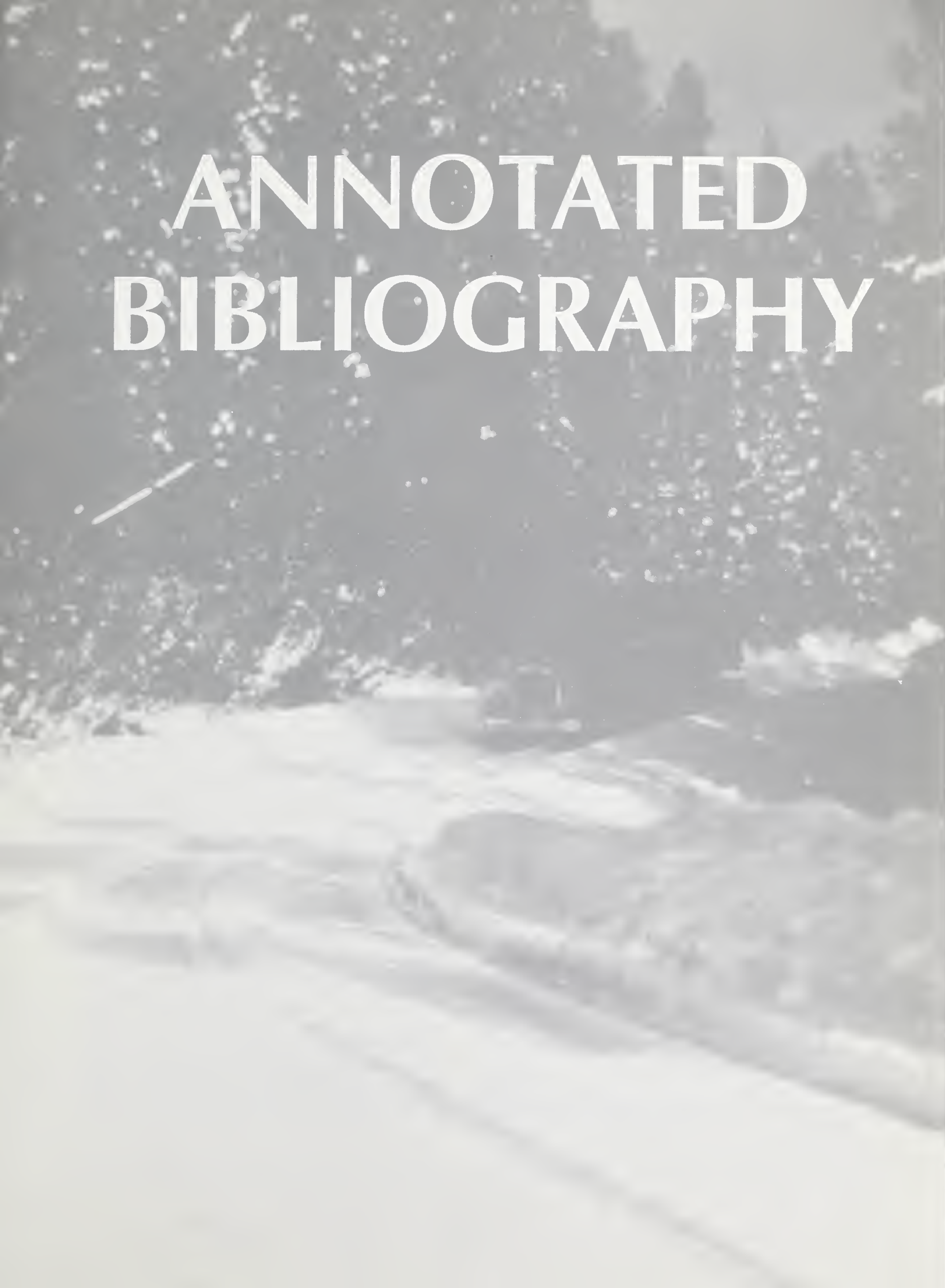
Study frozen culverts plugging with ice during spring which causes water to wash out fills.

What are the effects of, and cost effective alternatives to using dry weather roads for winter/ spring haul routes. When roads were originally designed they were not winter haul routes; now, due to summer wildlife restrictions these roads will be used for winter haul. Conduct a study of using saturated roads with under designed thickness. Land managers need to understand the long term economic consequences of using roads for uses other than originally designed.

Continuation of the study of moisture in subgrades effecting overall pavement strength.

Additional information is needed to help communicate winter haul issues to road managers and non-technical personnel involved in winter haul decisions.

ANNOTATED BIBLIOGRAPHY



ANNOTATED BIBLIOGRAPHY

Description

The following bibliography consists of separate summaries of selected papers, reports, manuals and articles that relate to various aspects of winter/spring use of pavements. Topics discussed include:

- Winter maintenance
- Detection systems for monitoring winter pavement conditions
- Environmental effects of deicing agents
- Increase in bearing capacity with frozen conditions
- Minimizing frost penetration and resulting detrimental effects of frost action
- Loss in pavement strength during spring thaw (and wet seasons)
- Load restrictions—several authors have developed criteria for estimating when appropriate magnitude for these load reductions.

This annotated bibliography includes only a representative sampling; a more comprehensive list, including additional papers on similar topics, is included in Appendix F. (Multiple papers on the same topic by the same author are generally not included in the list. Individual bibliographies within the listed papers often cite such additional references.) Papers discussing related topics of a more technical nature than would probably be applicable for Forest Service timber hauling purposes, e.g., pavement temperature and moisture models are also provided in the Appendix.

Bibliography

Alkire, B. D. and C. Keller (1991) *Shallow Refraction Surveys on a Low Volume Road For Determining P-Wave Velocity of Seasonal Thawing Soils*, Transportation Research Record 1291, volume 2.

Methods of determining when to impose load restrictions are generally subjective, however, incorrect timing can result in substantial economic losses. This paper discusses the use of shallow refraction techniques to determine P-Wave velocity as an indicator of degree of thaw, and the correlations between P-Wave velocity and Clegg impact testing device values.

Both types of field tests were conducted on a low volume aggregate-surfaced road south of Houghton, Michigan. Results indicate that P-Wave velocities can be used to monitor roadway condition through spring breakup. P-Wave direct arrival velocity decreases as the soil undergoes thawing, then increases following thaw. Both P-Wave velocity and Clegg Impact Valves reach a minimum value well after the day when the corresponding freezing degree day curve attains its maximum value. Finally, Alkire and Keller provide simple equations which relate P-Wave velocity to the number of days since the beginning of thaw and to the modulus of elasticity.

Baichtal, J.F., *Monitoring Subgrade Frost Penetration Using Constant Data Loggers with Thermistor Installations*, Engineering Field Notes, USDA Forest Service, Washington DC Vol. 22, 1990.

The OmniData Easy Logger works will as a multichannel data recorder when used in conjunction with the Forest Service Subsurface temperature probe. The Umpqua Forest operated two of these units from October 1989 through April 1990. Data acquisition was interrupted only by operator error. Once unit worked flawlessly even when it was half-submerged in water. Once the Easy Logger's operation is mastered, the unit is user friendly. It is important to set aside one OmniData E-Prom Data Storage Pack as a master copy of the Easy Logger setups. If an operator accidentally removes the unit's memory, the master E-Prom Data Storage Pack can be installed and the system quickly brought back into operation. As an alternative to hand-programming the individual units and other Forests' units, the Umpqua National Forest's master E-Prom could be used to download the setups into other units. The setup can be cloned from one of the Umpqua's Easy Loggers to other Forests' master E-Prom Data Storage Packs.

There are other applications for the thermistor string/Easy Logger marriage. Since the thermistor string assembly is completely watertight, it can be modified for use in water temperature studies, using the Easy Logger to record the data. Soil temperature studies could also benefit from this technology. Besides temperature probes, one could also attach the Easy Logger to other instruments such as rain gauges, slope movement indicators, strain gauges, and so forth. As long as the probe generates either a voltage or resistance fluctuation and a sensor conversion function can be determined, the Easy Logger should be able to handle it. An example of such an application is to have, at one site, a subsurface thermistor installation, a rain gauge, and soil moisture sensors. As long as there are no more than 12 sensors at one site, the OmniData Easy Logger can be programmed to monitor the various sensors.

Barcomb, Joe (1989*) Use of Thermistors for Spring Road Management,* Transportation Research Board 1252.

A study was conducted in the Kootenai National Forest, northwestern Montana, in which thermistors were used for determining when to restrict timber hauling. Approximately 70 thermistor strings were installed in paved Forest Service and county roads. Subsurface temperatures were initially recorded weekly or biweekly, then increased to daily as thaw became imminent. Hauling restrictions were imposed at the start of, or shortly after the start of thaw (defined as 31.7° F). This method has provided the Kootenai NF with a quantitative method for placing hauling restrictions.

Barcomb, Joe (1995), *Prolonging Haul Over Frozen Roads,* Volume 2, Sixth International Conference on Low-Volume Roads, TRB, National Research Council 1995, pp. 207-210.

The Kootenai National Forest in northwestern Montana covered a winter haul road with a five-centimeter deep blanket of sawdust to prevent thawing. The haul season was extended from mid-February to the end of March.

Berg, Richard, L. (1994) *Large Aircraft Winter Operations at Small Airports: A Progress Report.*

This progress report discusses the feasibility of allowing larger than design aircraft at small airports during frozen conditions. While the USDA Forest Service is neither concerned with heavy aircraft nor airports, the concept of pavements providing appreciably increased bearing capacity (therefore little or no pavement damage) is applicable to non-surfaced, aggregate surfaced, and double bituminous surfaced treated roads that are not necessarily designed to survive heavy and repeated load applications, but can support them during frozen conditions. This simply opens up certain otherwise non-accessible timber stands for winter hauling operations.

The study discussed in this progress report originated in 1992 when the Federal Aviation Association (FAA) received a request from airport officials at a small airport in North Dakota to allow heavy aircraft to operate at Sloulin Field International Airport during winter months. The purpose of the ensuing study was to collect quantitative data to enable decisions to be made regarding when larger aircraft can be allowed to use the airport.

Three sites (runway, taxiway, and parking apron) were instrumented with thermistors to monitor subsurface temperatures, electrical resistivity gauges to monitor frozen/non frozen conditions, and time domain reflectometry probes to measure soil moisture content. Groundwater wells were installed at each of the sites. Additionally, pavement stiffness was monitored at 45 test points by conducting monthly Falling Weight Deflectometer (FWD) tests. Based upon data from the 1992-1993 winter, it appeared that heavier aircraft could have used the runway from mid December 1992 through early March 1993. However, heavy aircraft could cause significant damage to the pavement during the spring. Additional monitoring and the development of a computer program to indicate pavement bearing capacity are planned.

Berg, Richard L., Vincent Janoo, and L. David Minsk (1994) *Design, Evaluation and Winter Maintenance of Pavements.*

This paper, divided into two sections, discusses pavement design and evaluation methods recommended by the U.S. Army Corps of Engineers (COE) for seasonal frost areas and current wintertime pavement maintenance practices in the United States.

Highway pavements in areas of the United States experiencing seasonal freezing and thawing often exhibit only one half the maintenance-free life span of those pavements in non seasonal-frost areas. The primary goal of the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) is to develop pavement designs which minimize initial cost plus pavement related maintenance costs during the life cycle of a pavement. The authors believe that mechanistic design methods may contribute toward this goal.

COE empirical design procedures for pavements in areas of seasonal frost have evolved from the 1940's. They provide satisfactory pavement performance by minimizing differential frost heave, providing adequate strength during spring thaw, and minimizing cracking due to low temperatures. Pavement layer thickness is determined by design air freezing index, frost susceptibility of the subgrade, and quality of the subbase and base material. While effective, this method is sometimes considered too conservative.

Mechanistic design procedures utilize layered elastic theory for estimating stresses and strains at critical positions within the pavement structure and may provide an important tool in minimizing life cycle costs. These procedures have been in existence for more than twenty years, but are currently gaining more rapid acceptance in the U.S.

Such procedures have the advantage of allowing the designer or evaluator to consider different loading conditions as well as different seasons. While most mechanistic design procedures simply subdivide the calendar year into shorter time increments (such as months), CRREL proposes to divide the year into seasons determined by pavement support capabilities. This is extremely important because support capabilities of certain thawed subgrades differ significantly from those of identical subgrades which are simply saturated, but did not undergo freezing and thawing.

Thermal cracking is also briefly discussed. Low temperature transverse cracking has been reported in areas where the air freezing index is as low as 8665 hours, and severe thermal cracking in areas where the freezing index is equal to or greater than 13,330 hours. Thermal cracking occurs when the temperature induced tensile stress in the asphalt concrete (AC) exceeds the tensile strength. Water can then enter through the cracks into the pavement and subgrade, reduce the bearing capacity, and accelerate pavement failure. During the winter, deicing agents can enter the cracks and cause localized thawing. Additionally, winter water access may result in greater differential heave, therefore more cracking. Figures and guidelines are provided for selecting asphalt for minimizing low temperature cracking.

Section 2 discusses decentralization of authority and the wide diversity of climate and techniques related to maintenance in the United States. Salt remains the most commonly used ice control agent. However, the quantity continues to decrease as a result of environmental concerns and new techniques. Calcium magnesium acetate has proven to be an environmentally acceptable yet effective method for ice control. However, because of high cost, its use remains limited.

The Strategic Highway Research Program, a 6-year $150 million program which was recently completed, included a research program in snow and ice control. One primary product was the design of an improved ice cutting edge. Other significant products include a handbook for evaluating ice control chemicals; criteria for the selection, installation, and use of road weather information systems; a design guide for snow fences for control of blowing snow; a local area

high-accuracy weather forecast computer program; and preliminary recommendations for anti-icing treatments for minimizing bonding of ice or compacted snow to pavements.

DeJean, K. et. al, Ochoco National Forest, Region 6, *Policy For Managing Log Haul on Paved Roads Under Freeze/Thaw Conditions for Deschutes, Malheur, and Ochoco National Forests*, March 5 1991, (Unpublished).

The Forest Service worked together with the timber industry and developed a list of recommendations to optimize log haul during freeze/thaw conditions while protecting resource and road structure investments. The agreement sets guidelines for using thermisters to monitor thaw in road structure and the Benklemen Beam to measure deflections on pavement surface. The guidelines are used as a basis for identifying when the pavement is in a thaw weakened state and when to restrict log haul.

Departments of the Army and the Air Force (1985) *Pavement Design for Seasonal Frost Conditions*, Army TM 5-818-2, Air Force AFM 88-6, Chap. 4.

This manual provides a comprehensive description of criteria and procedures for design and construction of pavements and materials subject to seasonal frost action. Topics covered include design procedures, base course requirements, use of stabilized soils in frost areas, definitions of frost-related terms, and methods for controlling differential frost heave at culvert. Additionally, appendices provide guidance for minimizing low temperature cracking and using insulating materials in pavements.

Eaton, R. A., R. H. Joubert and E. A. Wright (1981, revised 1985) *Pothole Primer, A Public Administrator's Guide to Understanding and Managing the Pothole Problem*, Special Report 81-21, U.S. Army Cold Regions Research and Engineering Laboratory.

The *Pothole Primer* is a practical, non-technical guide prepared to assist officials and non-engineering administrators of cities, towns and military facilities in New England understand and manage their pothole problems in asphalt pavements. Factors contributing toward the increase in pothole occurrence are categorized; and financing, traffic growth, safety, weather, and drainage are all discussed separately. The primer reviews the developmental process of a pothole, recommends and identifies a preventative maintenance program, and carefully outlines pothole patching procedures. Additionally, the appendix provides a description of materials and equipment necessary for patching.

Giesa, S. (1994) *European Level of Service for Winter Maintenance with Regard to Safety and Environment.*

This paper discusses the use of deicing salt in Europe, effects on traffic safety, influences of deicing salt on the environment, and maintaining standardized effective winter service throughout all of Europe.

The author indicates that deicing salts are more effective when the time between ice formation and salt application (preferably wet salt) is minimized. This can be achieved by ice prediction equipment in combination with meteorological stations. Environmental concerns were addressed in a long term study commissioned by the Highway Administration of Hessen. The study showed that salt damage to roadside plants was primarily attributed to salt mist whirled up by passing vehicles while damage due to salt contamination of the soil was limited and localized.

Hanek, Gordon L., *Thaw Weakening of Low Volume Asphalt Pavements*, Proceedings of The 40th Annual Road Builders Clinic, Moscow, ID., March 1989.

Describes the thaw weakening effect on pavement structures and the use of thermistors with Benkelman Beam deflections to evaluate the relationship between thaw depth and loss of strength.

Ishitani, M., K. Himeno, A. Kasahara (1992) ***Seasonal Variations in Bearing Capacity of Asphalt Pavements,*** **Transportation Research Board Paper No. 92039.**

This paper discusses seasonal variations in pavement layer moduli and bearing capacity. The authors point out that, during freezing conditions, asphalt concrete (AC) exhibits a substantial increase in modulus and decrease in tensile strain (at the bottom of the AC). Consequently, loads heavier than typically permissible can be safely supported.

The authors also observed an appreciable increase in base course modulus during frozen conditions followed by a decrease in base course modulus during spring thaw to values well below pre-frozen condition values. Subgrade modulus also increased under frozen conditions but, in contrast to base course modulus, simply returned to modulus values similar to those prior to spring frozen conditions.

Kestler, Maureen A. (1983) ***Culvert Problems in the White Mountain National Forest,*** **(Unpublished), White Mountain National Forest.**

This in-house engineering report discusses culvert washouts and differential heaving of several culverts on Burnt Knoll Road and Gardiner Brook Road in the Saco District of the White Mountain National Forest. These two culvert washouts were believed to have been initiated by a preferential path of seepage along a discontinuity which, in turn, was probably created by frost action (differential vertical displacement at the interface between native material and culvert backfill). Simple tests on subgrade material from Burnt Knoll and Gardiner Brook showed the subgrade material was highly frost susceptible. Differential frost heaving often occurs because non frost susceptible backfill material is typically specified immediately adjacent to culverts. One solution is provided by simply backfilling (to an appropriate depth) around the culvert with native material. Installing insulation panels during construction can provide an alternate solution.

Additionally, the report discusses a variety of other cold-induced culvert problems and presents preventative or controlling measures collected via communications and publications.

Kestler, Maureen A. and Richard L. Berg (1995) ***Case Study of an Insulated Pavement in Jackman, Maine.*** **Transportation Research Board Paper No. 951039, Washington, D.C.**

Traditionally, detrimental effects of frost action are reduced by excavation and removal of large quantities of frost-susceptible material and replacement with a thick layer of non-frost-susceptible material. However, incorporating an insulating layer within the pavement structure can often provide a cost-effective alternative for protecting the subgrade from frost penetration. The latter method was utilized during the 1986 reconstruction of a 2.5-inch thick bituminous surfaced runway pavement in Jackman, Maine. Although this paper discusses incorporation of insulation panels in a runway pavement, this method could provide a cost effective alternate method for reconstruction of segments of low volume timber-access roads which exhibit serious distresses as a result of frost action—particularly when haul distances for aggregate borrow and/or associated cost are excessive.

Even though the paper discusses the seemingly poor performance of this particular runway pavement, it emphasizes the excellent performance exhibited by several adjacent insulated pavement test sections for which construction controls and specifications were more closely observed.

Kestler, Maureen A., Richard L. Berg, Craig Schrader, and Greg Johnson (1995) ***Spring Thaw at the Minnesota Road Research Project Pavement Testing Facility,*** **International Symposium on Unbound Aggregates in Roads (UNBAR 4), Nottingham, England.**

The Minnesota Road Research Project consisted of 40 pavement test cells each measuring 150 meters (500-ft). The cells were designed for several different service lives, and are composed of a variety of thickness and materials. An intensive monitoring program was undertaken by the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory and Minnesota Department of Transportation in March and April 1994 to assess variations in pavement strength through spring thaw. Observations were conducted on 14 test cells for 6-weeks. This paper discusses observations on one test cell. A multivariate statistical analysis was conducted, correlations among various parameters were determined, and simple indices for estimating pavement layer moduli from HWD data were developed.

A well defined loss in pavement stiffness was observed during spring thaw. Although conventional and dynamic back calculations were conducted, partial basin area—a simple parameter to determine—proved to be an excellent indicator of pavement stiffness. Center sensor deflections were extremely sensitive to pavement surface temperature; however, deflections measured by sensors 5, 6, and 7 were all (in themselves) good indicators of changes in pavement stiffness.

Lu, Jian John, David Junge, and David Esch (1995) *Evaluation of Winter Vehicle Traction with Different Types of Tires.* Transportation Research Board Paper No. 950772, Washington, D.C.

Studded tires have been used for many years for safety reasons to increase vehicle traction. However, researchers in the United States, Japan, Sweden, Germany, and France have confirmed that their use causes accelerated pavement wear, airborne dust, and environmental noise. Because of these detrimental effects, Canadian Provinces, and some countries have actually banned studded tires.

Traction performance tests were conducted with several types of tires by the Alaska Department of Transportation and Public Facilities and the University of Alaska. Tires tested included the Blizzak tire (recently developed to improve winter vehicle traction and minimize pavement wear), two types of studded tires, and two types of all-season tires. Vehicle types included full size rear-wheel-drive sedans, full size half-ton pickups, and compact front wheel drive cars. Tests were conducted on pavement surfaces covered with both old and freshly packed snow, old surface ice, and fresh glare ice.

The authors discuss tests conducted and provide several tables summarizing tire performance for 25 mph stopping distances, maximum cornering speeds, hill climbing ability, starting traction, and times to reach 25 mph for each test category. The Blizzaks were superior to all-season tires under all conditions. Blizzak performance was equal to that of studded tires in all categories on snowpacked surfaces, and only slightly inferior in two categories on icy surfaces. The authors conclude that Blizzaks may be used during the winter season to replace studded tires in Alaska.

Mac Inness, W. A., (1994), *Weather Detection Systems for Winter Maintenance,* Workshop A5 for CEEC's and NIS on Winter Road Maintenance.

The climate of Scotland's Highland Region—the country's most northerly region—ranges from the temperate coast to the central Highlands where temperatures reach -20° C. Historically, winter road maintenance activities had been determined from daily weather forecasts which included anticipated road conditions for the following 24 hours. Since a 5-year analysis of weather forecasts showed that 11 percent of the forecasts were incorrect, 35 percent were correct, and 54 percent were marginal, a decision was made to investigate ice detection systems. Trial test results using ice detection systems were extremely positive, and a program of ice sensor installation was implemented throughout the region.

Sensors located at the edge of the road record air temperature, wind speed, wind direction, precipitation, dew point temperature, road surface temperature, and road surface condition. The information is transmitted to the Divisional Master Station and input into a forecast model to predict road surface temperatures. Both short range and 5-day forecasts are transmitted to Road Managers who make decisions to place crews on alert for salting or plowing activities.

Managers can also directly interrogate the system to monitor current conditions. The system is supplemented by weather radar systems.

Mahoney, Joe P., Jo Lary, Jay Sharma, and Newton Jackson (19) *Investigation of Seasonal Load Restrictions in Washington State,* Transportation Research Record 1043.

Slightly less than one half of the states impose seasonal load restrictions. Such restrictions are generally based upon experience, and occasionally on deflection data. The authors of this paper conducted field studies and subsequent data analyses to determine whether load restriction criteria in the State of Washington were adequate and how the criteria effected freight and timber hauling companies. Specifically, the authors observed variation in base and subgrade modulus, moisture content, frost depth, and pavement deflection, then attempted to develop procedures for using easily obtainable data to predict when load restrictions should be applied.

The study showed the falling weight deflectometer was an excellent device for collecting data necessary for evaluating structural support of pavement. It also showed that, during the spring thaw event, the base course cannot drain due to underlying frozen material or low permeability subgrade. For these particular test sections, the base coarse actually experienced greater variation in modulus than did the subgrade. The authors determined that 60 percent load reductions during spring thaw resulted in "acceptable" damage. Finally, although site specific deflection data were determined to be the best criterion to use for imposing load restrictions, a low cost air-temperature-based criterion was developed. Field and analytical procedures showed that the critical period is pending when the thawing index approaches 30° F days, and pavements will be in the midst of the critical period at a thawing index of 50° F days.

Mc Bane, J., and Hanek, G., *Determining the Critical Thaw-Weakened Periods in Asphalt Pavement Structures,* Engineering Field Notes, USDA Forest Service, Washington, D.C. Vol. 18, 1986.

These results were obtained from one season of monitoring asphalt and soil temperatures as indicators of pavement structural strength during the spring thaw period. They suggest that Forest Service Road Managers now have a tool they can use to address past problems with seasonal load restrictions. By monitoring average soil temperature changes through the late winter and early spring, Road Managers can make a reasonable prediction of the expected onset of pavement weakening. Road users now have the opportunity to remove equipment from the field and to plan their spring activities. The beginning of spring thaw can be accurately and objectively confirmed by the occurrence of temperatures above the freezing point of local soil moisture measured at the base of the asphalt mat. In areas of non-plastic soils, the recovery of pavement strength can be determined indirectly by monitoring the depth of thaw. When thawing progresses to approximately 4 feet below the base of the asphalt mat, vehicle load restrictions can be removed. Finally, this method can be used to evaluate the effects of short-term weather fluctuations on pavement load-carrying capacity. Implementing this inexpensive system could result in large decreases in annual maintenance costs and extended road serviceability. The system's installation cost per site in 1984 was approximately $240.00, including all parts, equipment, and labor. Although sites were selected for instrument string installation for this study based on a combination of criteria (including exposed/sheltered locations within given road segments, soil types, and elevation extremes), a practical monitoring system need only include sites anticipated to enter the spring thaw-weakened state early (exposed sites) and late (sheltered sites) within given road management segments. The actual instrument density would depend on the length and number of road segments selected.

Minnesota Department of Transportation—New Technology Research Committee (1993) *Road Weather Information System,* Task Force Report.

Many European countries utilize a network of weather data gathering systems for providing decision making information for improving the efficiency and effectiveness of snow and ice control while reducing costs. This is known as Road Weather Information System (RWIS).

In 1992 the New Technology Research Committee established an RWIS task force in Minnesota. Their report provides a thorough outline of the committee's recommendations, findings, analysis, and conclusions for nine primary objectives. Objectives included such activities as developing recommendations for the acquisition of appropriate tailored weather support, developing a plan for statewide siting of RWIS sensor stations, developing communications guidelines, and implementing a plan to tie together information gathering and dissemination.

Ring, George W. III (1973) *Seasonal Strength of Pavements*, Proceedings of the Symposium on Frost Action on Roads, Norwegian Road Research Laboratory.

Although written many years ago, this paper presents a thorough overview of factors contributing to reduction in load bearing capacity during spring thaw as well as recommendations for minimizing seasonal variations in pavement strength.

The author observed 2 percent variations in moisture resulting in 50-100 percent reductions in California Bearing Ratio. The methods described for minimizing seasonal strength changes included insulation of the subgrade, chemical additives to reduce frost susceptibility, removal of frost susceptible material and replacement with non frost susceptible material, and implementation of drainage methods. The author emphasizes the importance of drainage. The first three methods described above may be ineffective unless there is adequate drainage provided to minimize moisture movement into the frost zone and to drain excess water from above the frozen layer. Drainage methods considered effective include:

1. Drain open-graded layers.
2. Drain water trapped in ledge cuts.
3. Provide deep side ditches to help lower water table.
4. Drain seepage layer.
5. Provide drainage for seepage layers under hill side fills.
6. Provide underdrains in shaded areas where frost penetration is deeper.
7. Drain low points of subbase materials.
8. Raise the pavement grade in areas with a high water table.
9. Provide underdrains in wet cuts unless in silt or clay. If silt or clay, undercut and backfill.

Road Transport Research (1988), *Heavy Trucks, Climate, and Pavement Damage*, Organization for Economic Co-operation and Development.

This study was commissioned by the Organization for Economic Co-operation and Development Steering Committee for Road Transport Research. The report serves as a compendium of international pavement technologies and current research knowledge on separate and combined effects of vehicle loading and climatic factors.

While the entire report is an overview of research on pavement distress due to the effects of vehicles and climate, separate chapters focus on effects of heavy vehicle loads on fatigue life, climatic factors influencing pavement behavior and their role in pavement deterioration (frost/thaw, rutting, and thermal cracking), economic and policy considerations, and future research to limit economic consequences of combined action of heavy vehicle traffic and climate on pavements.

The report covers a variety of concerns and issues which, when properly addressed, may lower road maintenance costs. For instance, frost penetration beneath a pavement clear of snow may be substantial, yet it may be almost non-existent beneath roadside snowbanks due to the insulating effect of snow. Consequently, uneven frost penetration and resulting frost heave may initiate longitudinal cracking along or near the centerline of narrow low volume roads. Cracks enable water to enter the pavement structure thereby accelerating pavement deterioration. Simply plowing the pavement shoulders beyond the edge of the asphalt concrete (AC) results in more uniform frost penetration beneath the AC and therefore more uniform frost heave. This, in turn, may minimize or completely eliminate longitudinal centerline cracking.

Sections concentrating on climatic effects discuss how seasonal weather variations alter material properties and therefore change material behavior and pavement system response to loading. These climatic factors which influence pavement behavior, (temperature, frost, water, sun) are all separately discussed.

Rutherford, Mary, *Evaluation of Variables Affecting Flexible Pavement Thawing for Timing Spring Load Restrictions,* Transportation Research Record 1286.

Primary road facilities generally do not exhibit thaw weakening since they are designed to support a high volume of traffic and level of service throughout the year. However, it is not always economically feasible to design secondary roads in seasonal frost areas for adequate protection against frost penetration and subsequent thaw weakening. Consequently, vehicle or axle loads are frequently restricted during part of the spring thaw period to reduce ensuing damage.

The author states that field studies in Alaska, Minnesota, and Washington, and previous analytical studies of hypothetical pavements, have shown that flexible pavements were susceptible to damage when thawing reached the bottom of the base course layer. Both studies indicated that the time required for thawing of the base was short and that thawing occurs before the air temperature warms to 32° F. The length of thaw is variable and is a function of several other variables. The author emphasizes that the end of thaw does not necessarily warrant removal of load restrictions because additional time may be required for recovery of stiffness of the unbound layer.

A finite element analysis of four pavement cross sections which represented typical roads "presently" being restricted was conducted to simulate pavement freezing and thawing. The purpose was to evaluate when thawing occurs and gather information for timing spring load restrictions. Areas addressed include the start of pavement thawing, time for thawing to reach the base/subgrade interface, time for a small amount (4-in.) of subgrade thawing to occur, and time for complete thaw. The paper discusses methods of selection of variables used, thermal analyses conducted, and sensitivity analyses performed.

Thermal analysis results indicate that the relation between pavement surface temperature and air temperature is primarily a function of date, and thawing begins well before air temperature reaches 32° F. A figure is provided which shows the minimum air temperature which can initiate pavement thawing for a given date. Additionally, thaw reached the top of the subgrade in 1 to 4 days for thin pavements and 4 to 9 days for thick pavement. The author also notes that the greatest variation in results occurred for variations in density and moisture content of the subgrade.

Several useful tables and graphs are shown which can be used as an aid in determining when pavement thawing will begin. Additionally several simple regression equations are provided which enable the duration of thawing to be estimated. In combination, the graphs and equations can serve as an aid in timing springtime load restrictions.

Rutherford, Mary (1989) *Pavement Response and Load Restrictions on Spring Thaw Weakened Pavements,* 68th Annual Transportation Research Board Meeting, Washington, DC

In response to the existence of only limited guidelines for selecting the time to impose spring load restrictions and the magnitude of load restrictions, thirty two hypothetical pavement sections were modeled and analyzed using ELSYM5, a layered linear elastic program developed at the University of California, Berkeley. Analyses were conducted at three different times during thawing to determine when and for how long various pavement structures remain in a weakened condition.

Simulations showed that some thin pavements required load reductions during base thawing. For two-inch AC pavements, asphalt tensile strain (which leads to cracking) was the critical parameter at the end of thawing. For four-inch AC pavements, vertical subgrade strain (which leads to rutting) was generally the critical parameter. This did not occur until some subgrade thawing occurred.

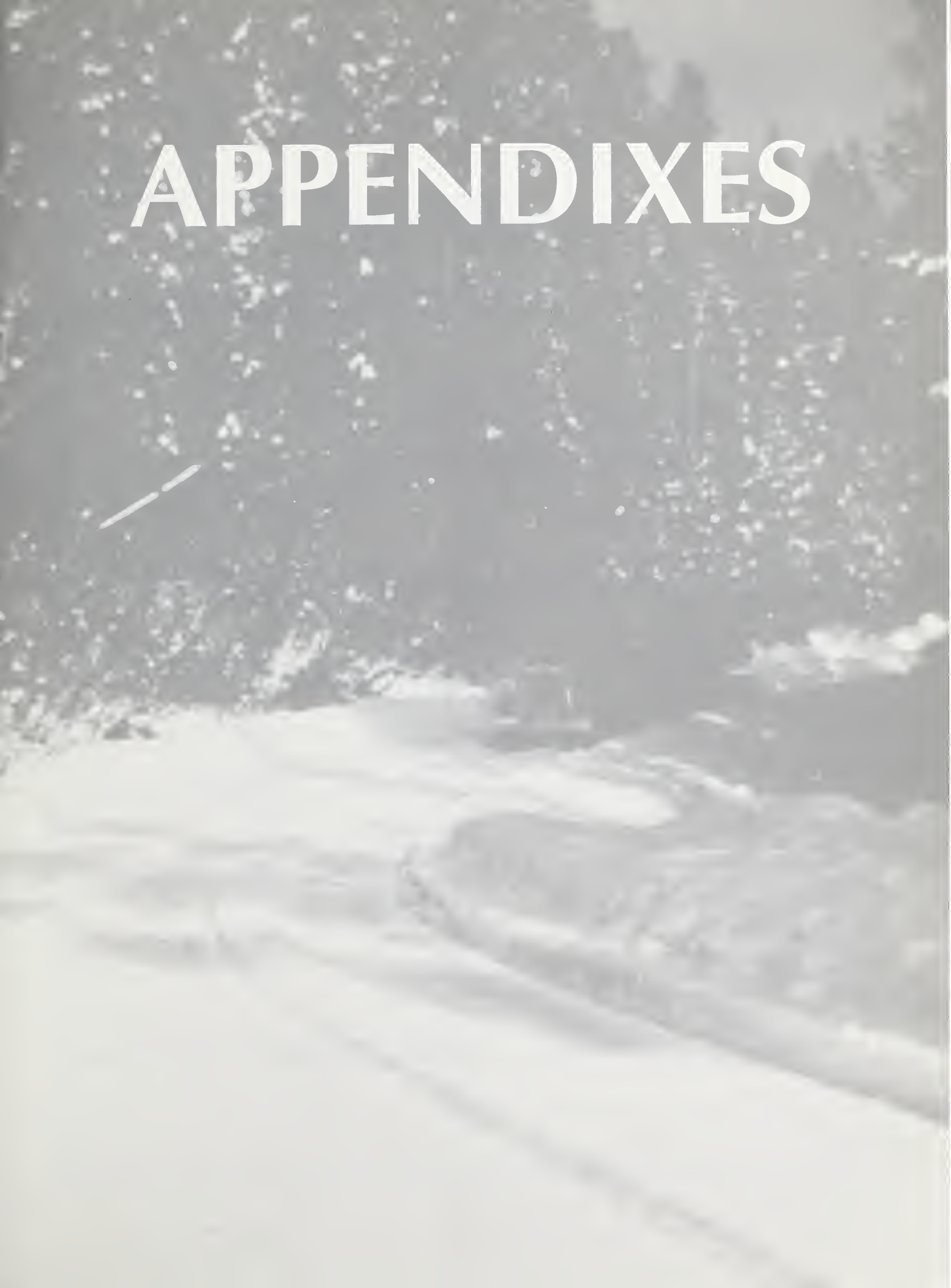
White, T. D. and B. J. Coree (1990) *Threshold Pavement Thickness to Survive Spring Thaw*, Third International Conference on Bearing Capacity of Roads and Airfields, July, Trondheim, Norway.

Primary variables assessed in the AASHO Road Tests comprised wheel configuration, load, pavement layer thickness and total pavement thickness. Artificial scales were created to enable application of climatic effects and different subgrades to other sites. Because the majority of failures occurred during spring, traffic was weighted in attempt to account for thaw weakening. However rigorous analyses assessing seasonal variations in pavement strength were not included in the AASHO Road Test.

The authors revisited the AASHO Road Test data for the purpose of developing probabilistic relations among pavement performance and spring thaw. Three performance patterns were observed and categorized for probabilistic analysis: pavements which do not exhibit weakening during spring thaw; pavements which fail during the first thaw event; and an intermediate category that includes pavements in which cracking may or may not occur following the first thaw, but would crack with the onset of winter and fail the following spring.

A probabilistic analysis showed a significant correlation between total pavement thickness and probability of survival, and can be used to evaluate load limitations during spring thaw. Probability plots are provided which show long term pavement survival as a function of a given load reduction. Additionally, the effect of load on single or tandem axles can be evaluated in response to given load limitations.

APPENDIXES



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ORDER
FOREST DEVELOPMENT ROADS
MT. BAKER-SNOQUALMIE NATIONAL FOREST

Pursuant to Title 36 CFR 261.50 (b), the roads described below, all within the Mt. Baker-Snoqualmie National Forest, are closed, when posted, to all vehicles, except those listed as exempt, and the following act is prohibited:

(1) Using any motor vehicles. 36 CFR 261.54 (a)

Pursuant to 36 CFR 261.50 (e), the following are exempt from this order:

(1) Two-axle vehicles with passenger loads only.

(2) Any Federal, State, or local officer, or member of an organized rescue or fire fighting force in the performance of an official duty.

Mt. Baker Ranger District

Road Name & Number	Junction	Termini
Sauk Mtn Road #1030	State Highway 20	End
Diobsud Creek Road #1050	State Highway 20	End
Bacon Creek Road #1060	State Highway 20	End
Baker Lake Road #11	Sandy Creek Bridge	End
East Bank Road #1106	Forest Highway 25	End
Loomis-Nooksack Road #12	Forest Highway 25	End
Jackman Thunder Road #14	State Highway 20	End
Illabot Road #16	State Highway 530	End
Finney-Cumberland Road #17	County Road	County Road
Segelson Road #18	Road #17	M.P. 12
East Church Road #3040	State Highway 542	End
Razor Hone Road #3070	State Highway 542	End
Anderson Creek Road #3071	State Highway 542	End
White Salmon Road #3075	State Highway 542	End
Canyon Creek Road #31	State Highway 542	End
Hannegan Road #32	State Highway 542	End
Wells Creek Road #33	State Highway 542	End
Dead Horse Road #37	Road 39	End
Middle Fork Nooksack Road #38	County Road	End
Glacier Creek Road #39	State Highway 542	End

This closure is due to freeze and thaw actions which are damaging to the roadway when subjected to heavy loads.

Closure will be posted at the discretion of the District Ranger.

This order supersedes Order No. 84-06-05-08

Done at Mountlake Terrace, Washington, this 12th day of April, 1993.

Walter S. Weaver

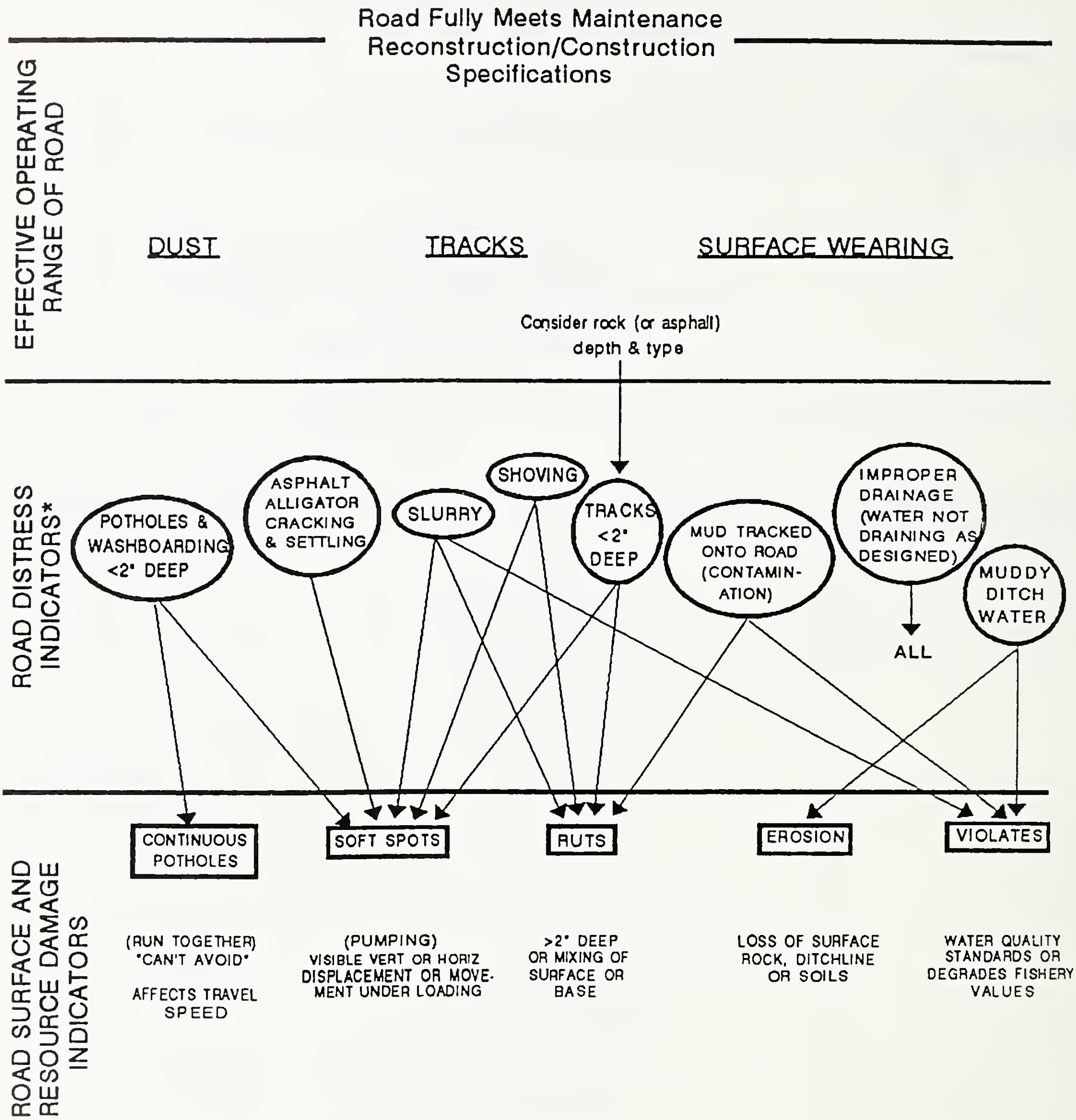
WALTER S. WEAVER
Acting Forest Supervisor
Mt. Baker-Snoqualmie National Forest

Violation of these prohibitions is punishable by a fine of not more than $5,000.00 or imprisonment for not more than six months or both. Title 16 USC, Section 551.

Order No. 06-05-01-93-003

APPENDIX B

GRAPHIC REPRESENTATION OF ROAD DISTRESS FACTORS



* Indicators identify the need to (1) do maintenance, (2) stop use, or (3) strengthen the road surface to avoid damage. Depths shown are for rock; divide by 4 for asphalt.

ROAD FACILITY DAMAGE

ROAD TYPE	MAINT BY	DAMAGE IS	CONTRACT ACTION
All Paved Roads	FS	Rutting, flexure cracking, or chuckhole is damage. Failures requiring minor patching should be considered routine maintenance.	(PREVENT DAMAGE) Closely monitor weather, haul, and areas of low strength pavement to prevent damage from occurring. Advise Purchaser that haul will be restricted during freeze-thaw or near saturated conditions to prevent pavement damage.
Major Aggregate Rds (Arterials, Collectors, major locals, mixed use, serve large area, long)	FS	Rutting or pumping that contaminates the aggregate is damage. Chuckholes, washboards, or other affects that make the road unsafe for other traffic is damage. If it can be corrected by routine maintenance it is not damage. Spot surfacing is routine maintenance. The road template should not be significantly affected other than minor rutting, chuckholes, etc.	(REPAIR SURFACE) If damage is occurring stop haul and have the Purchaser correct it. Allow haul to continue if he agrees to repair future damage and this is acceptable. If the FS is performing excessive maintenance* to prevent damage the Purchaser may be given the option of assuming the maintenance or stopping haul.
Major Aggregate Rds (same as above)	Purch	(Same as above)	(See above) Also ensure that repair to damaged surfacing is done in kind (a repair with 3" rock should be finished off with a fine crushed rock on Major Aggregate Roads). Purchaser and Forest Service shall come to a common understanding of what maintenance is to be performed in advance of haul operations.
Minor Aggregate Rds (short, dead end, single user, serves small area, work road)	Purch	If the road template cannot be restored or if drainage is impaired damage has occurred. Chuckholes, washboards, or rutting that causes contamination of rock is acceptable unless timber or administrative traffic cannot safely use the the road.	(REPAIR TEMPLATE) If damage is occurring stop haul and have Purchaser correct it. Allow haul to continue if he agrees to repair future damage and this is acceptable. Aggregate lost due to damage should only be replaced if it is needed to prevent erosion or to support an upcoming use as defined in the RMO's.
Native Surface Roads	Purch	Damage has occurred if the road template cannot be restored or if drainage is impaired or if the road cannot be safely used.	(See above) Purchaser may place rock to support haul if acceptable.

* "Excessive Maintenance" may mean blading more than 1 time per mmbf or spot surfacing more than 20 cy per mile. These quantities may vary for differing weather, haul and road conditions. Make this decision in consultation with the Road Monitor.

APPENDIX D

POLICY FOR MANAGING LOG HAUL ON PAVED ROADS
UNDER FREEZE/THAW CONDITIONS
FOR
DESCHUTES, MALHEUR, AND OCHOCO NATIONAL FORESTS

OCTOBER 17, 1990

Prepared by:

Kelsey DeJean, Team Leader
Geotechnical Engineer
Ochoco NF

Chuck Tietz
Regional Network Manager
Region 6

Don Witte
Purchaser Representative
Snow Mountain Pine Ltd

Greer Kelly
Purchaser Representative
DAW Forest Products

Bill Case
Timber Management Contracting Officer
Ochoco NF

Bob Slimp
Timber Sale Officer
Malheur NF

Larry Chitwood
Engineering Geologist
Deschutes NF

Glenda Wilson
Forest Engineer
Ochoco NF

Charlie Yriarte
Road System Manager
Malheur NF

Jerry Arsena
Ass't District Ranger-Operations
Ochoco NF

Additional input was contributed by:

Tom Moore
Assistant Forest Engineer
Ochoco NF

Jim Powell
Lead Timber Sale Officer
Ochoco NF

PURPOSE

Forest Service and Industry will cooperate to provide uniform and consistent guidelines to optimize log haul during freeze/thaw conditions on paved roads while protecting resource and road structure investments.

CURRENT SITUATION AND PROBLEM DEFINITION

Studies by numerous public agencies have conclusively shown that thawing of frozen bases and subgrades seriously weakens their ability to provide support for pavements. If hauling continues during this time, subsequent pavement damage can be up to 350 times as severe as that during normal use.

Freeze/thaw weakening occurs in all road materials that are not free draining, which includes almost all of our subgrade soils and most of our base materials (especially old "used" base materials). Thawing generally occurs faster on the running surface of roads. This traps the thawed water between the frozen shoulders causing a "bathtub" effect. The subgrade and base strength returns when the water has had a chance to drain away.

Several eastside Oregon Forests (Ochoco, Umatilla, Deschutes, and Fremont National Forests) are using thermistors to determine when road subgrade thaw-weakening occurs and subsequently to shut off log haul on their paved roads. The Fremont N.F., however, is using deflection testing, measured with a Benkleman Beam, to determine strength recovery and subsequently when log haul can resume.

Due to a lack of consistent approach, some confusion has developed between Forest Service officials (sale administrators and engineers) as well as Industry as to when, and if, road damage is actually occurring. One concern is that thermistors alone only monitor temperature and not the presence of moisture, which makes the thawing condition most detrimental. Another is very short notices of shutdowns for operators causing problems with their operations. Therefore, we need to develop a simple, yet dependable, method that will enable us to determine and communicate if the potential for excessive road damage is present. This policy should also provide a means to refine current technology, including correlation of deflection, temperature and moisture content.

Identifying initial thaw is straight forward, but identifying strength recovery is not as clear. A variety of methods and tools are used to predict initial thaw and strength recovery. They are discussed in the next section.

EXISTING TECHNOLOGY

TEMPERATURE

Thermistor strings have been successfully utilized since 1984 in Montana and have been used on these three Forests since 1986. They have been thoroughly tested in the lab for their dependability to predict temperatures accurately in different conditions and materials. This same lab testing has shown that thawing occurs at 31.7°F.

MOISTURE

A moisture probe can be used to give an approximate indication of amount of moisture in the subgrade or base material. Another method of detecting excess moisture is to drive a spike in the pavement structure and visually observe the presence of free moisture. Soil moisture cells can also be used but they have some limitations; i.e., they work only in fine grained cohesive soils, must be calibrated to get actual readings, and have a tendency to be short lived. Other methods, such as soil tension (suction), may be used in the future to measure the effects of the presence of moisture, but the current technology is not complete at this time.

DEFLECTION

There are several methods for determining pavement deflections. The Benkleman Beam is used in conjunction with an 18 kip axle load to measure deflection at a given point. Temperature of the pavement must be measured for a correction back to 70°F. This is a reasonably simple and accurate process for determining deflections. Other methods are available but require expensive equipment which is not normally available.

RECOMMENDATIONS

1. **Pavements shall be protected from damage due to freeze/thaw conditions but need to be available for use when damage is not expected to occur.**

- The pavements which are referred to are those asphalt surfaced roads for which the road management objectives (RMO's) stipulate an asphalt pavement. There will be little risk taken on these roads with regard to damage.

- Roads which are currently asphalt surfaced for dust abatement and surface stabilization where the primary intent of the RMO's is an aggregate surface will be protected also, but more risk may be taken.

- This policy should be implemented through the Forest Roads Rules document.

- Alternative methods to optimize haul will be considered such as: load restrictions, loaded trucks in outside lane, etc.

2. **Industry and the Forest Service will work together to optimize haul and operations time.**

- Both parties should maintain good communications about site conditions.

- Thermistors will be used to more accurately predict the thaw period.

- The Forest Service will attempt to provide a warning of impending thaw conditions 3 to 4 days before possible shutdown and notify purchasers 48 hours before operational shutdown (see Exhibit 1). Purchasers Representatives will be encouraged to take thermistor readings to aid in monitoring and predictions.

- Deflection measurement by Benklemen Beam or equivalent method normally will be used to determine strength recovery so haul can resume. Purchasers are encouraged to provide assistance in taking deflection tests.

- Forest Service and Industry should provide training to all parties involved.

- A joint meeting will be scheduled annually to critique past efforts and identify necessary improvements.

3. **Thermistors should be installed on all pavements where freeze/thaw protection is necessary.**

- Install thermistors to cover the temperature extremes; i.e., locate coldest and warmest locations. If there is a substantial difference in elevations, distance between the extremes, or change in aspect then install a thermistor at a reasonable midpoint. It may be good to install one near major intersections or at the junction of different pavement structures.

- Location of thermistors should be marked and an identification number assigned to each site. A consistent method should be used between Forests. Share the locations with involved District and Industry people.

4. **Thermistors will be monitored as directed by Exhibit 1 (see attached).**

- Monitoring can be done by anyone with a thermistor reader. Results will be recorded on a data form (see attached Exhibit 2) and submitted to the Forest Road Manager.

- When temperatures are above 31.7°F and if questions arise in interpreting readings, contact the Forest Geotechnical Engineer.

5. **Deflection testing should be completed on all pavements to determine normal deflections as reference.**

- Strength recovery following thawing will be considered adequate when the total deflection is 0.055 inches or less using temperature corrected value.

- If the baseline data under normal conditions exceeds 0.050 inches the road use will be reviewed on a case by case basis.

- Deflection testing frequency will follow Exhibit 1. A minimum of 3 readings per site spaced 100ft apart should be taken. Use the numerical average of the 3 readings to determine the deflection value.

EXHIBIT 1

Summary of Monitoring Activities
For Paved Roads Under Freeze/Thaw Conditions

	***********************GROUND CONDITION************************				
	NORMAL	FROZEN	INITIAL THAW 1/	CRITICAL THAW 2/	POST THAW 3/
Activity	Deflection testing for data base information	Temperature readings	Temperature readings and/ or visual observations	Temperature readings. Moisture readings if available	Temperature readings. Moisture readings if available. Deflection testing.
Frequency of Activity	As necessary	On active haul routes once every two weeks; as convenient on other routes	2 to 3 times a week on active haul routes; as convenient on other routes	Daily on active routes; as convenient on other routes	Once a week unless more often is needed on haul routes; as convenient on other routes
*Responsibility	Forest Service	Forest Service	Forest Service	Forest Service	Forest Service
Communications			Provide warning 3 to 4 days before possible shut down 4/ 5/	Notify Purchaser Rep when shutdown may occur in 48 hours 4/ 5/	Notify Purchaser Rep when startup is approved 6/

1/ When melting conditions appear on road surface.
2/ When the top two thermistors are equal to or above 30°F.
3/ When deflections are decreasing and reflect strength recovery.
4/ These warning times may not be possible under extreme weather conditions, therefore Purchasers & Operators must keep close attention to thawing weather conditions and plan to halt operations accordingly. Allowance to remove loggin equipment can be agreed to if vehicle axle loadings are kept to standard legal limits and pavement damage is not imminent.
5/ SHUTDOWN: Haul will be suspended when thawing occurs in the base or when it occurs at the top of the subgrade if there is a free-draining base. Thaw temperature is defined as 31.7°F in base and subgrade.
6/ STARTUP: Haul may resume when strength has adequately recovered or when deflections measure 0.055 inch or less by the Benkleman Beam or equivalent method.

*NOTE: Purchasers are encouraged to participate in all aspects of monitoring.

EXHIBIT 2

Thermistor Data Form

Road________________ Name________________________

Forest________________ Date________________________

SITE #	1	2	3	4	5	6	7	8	9	10
Milepost										
1-Mat										
2										
3										
4										
5										
6										
7										
8										
9										
Air										
Time										
MC @	/	/	/	/	/	/	/	/	/	/
inch	/	/	/	/	/	/	/	/	/	/

How Moisture Content (MC) measured____

____

Road Condition____

____

Weather____

____

Remarks____

____

VITEL inc.

Hydra Logger

Data Collection • Satellite • SCADA Systems

Features

- *Hydra* Soil Moisture Probe Data Aquisition and Storage
- Direct Download of Collected Data to PCs
- No Maintenance or Calibration Requirements
- Lightweight, Portable, and Environmentally Hardened
- Convenient and Accurate

Hydra Logger with *Hydra* Soil Moisture Probe

Description

The *Hydra* Logger is a handheld field unit used to accurately acquire, log, and display data obtained by the *Hydra* Soil Moisture Probe.

The Logger is designed to provide its user with flexibility and convenience. The Logger converts raw Probe voltages directly into soil moisture, salinity, and temperature readings without requiring any further processing or calibration. This data can then be logged for later use freeing the user from manual record keeping. The user is prompted for a station ID number, and the recorded value is automatically given a date and time stamp.

Adding further convenience is the Logger's ability to download data to a PC for archiving, graphical presentation, and report generation. Software is provided to make downloading simple and provides the user with the ability to customize data to specific needs.

The *Hydra* Logger is both small in size and lightweight resulting in easy portability. An additional benefit is that there are no maintenance requirements. The unit is made of durable ABS plastic and is rain and shock resistant. A membrane sealed keypad creates a dustproof enclosure for the unit giving further protection against field conditions. The unit is powered by standard AA batteries which typically provide 3,500 measurements.

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5493 Kendall Street, S.E. • Boise, ID 83706 • USA • (208) 322-2717 • FAX (208) 322-2718

Specifications

POWER		
Batteries	6 standard AA batteries	
Battery Life	3,500 measurements (typical)	
Low Power Warning	displayed during measurement	
Backup	separate battery retains logged values	
TEMPERATURE		
Operating	+22°F to +122°F	-5°C to +50°C
Storage	-40°F to +149°F	-40°C to +65°C
DATA LOGGING		
User Station ID	Integer from 0 to 32,000	
Logged Data Memory	approx. 450 measurements	
Interface	RS-232 serial cable to PC	
Download Time	maximum 60 seconds	
MEASUREMENT TIME	5 seconds	
ACCURACY	full inherent *Hydra* Probe accuracy	
Calibration Requirements	none	
ENVIRONMENTAL HARDENING		
Water	rain/splash resistant	
Dust	dust proof	
Shock	shock resistant	
DISPLAY	LCD, 16 characters	
SIZE		
Dimensions	3" x 4.8" x 8"	7.5cm x 12cm x 20cm
Weight	1 lb., 9 oz.	700g
MATERIALS	ABS plastic	

How to Order

HYDLOG	*Hydra* Logger with download software for IBM PC compatibles, serial download cable for linking PC to Logger during data downloading, and User's manual.
HYDLOG-MAN	Additional *Hydra* Logger User's manual.

VITEL inc.

Hydra Soil Moisture Probe

Data Collection • Satellite • SCADA Systems

Features

- Simultaneous Soil Moisture, Salinity, and Temperature Measurement
- Easy Integration with Most Data Acquisition Systems
- No Calibration Requirements
- Employs No Nuclear Materials
- Compact, Rugged No-Maintenance Design

Hydra **Soil Moisture Probe**

Description

The *Hydra* Probe performs high frequency electrical measurements of the capacitive and conductive properties of soil. These properties are then directly related to the soil's moisture and salinity content while a thermistor determines soil temperature. This versatility makes the probe an ideal tool in applications for agriculture, hydrology, meteorology, geophysics, and civil engineering.

A small, precisely defined sensing area allows accurate measurements in regions where there are strong soil moisture gradients, such as near the soil surface. Response time is immediate to changing soil moisture conditions, and no calibration is required. Additionally, the probe can be used in all soil types.

The *Hydra* Probe can be operated in conjunction with the *Hydra* Logger, a portable field unit with direct down-loading capability, or a number of other data acquisition units offering further versatility.

The probe is equipped with a connecting cable to attach the sensor to the data unit of choice. This cable can be up to 100 feet in length allowing one data collection point to cover a large study area.

A rugged, zero-maintenance design makes this unit ideal for use in remote and environmentally hostile conditions. The probe maintains accurate and reliable readings under both below freezing and extremely hot soil conditions.

The Probe employs no nuclear materials and is constructed of stainless steel and PVC; all internal electrical components are "potted" to exclude moisture. This durable construction makes it possible for the unit to remain in the field for many years, maintenance free.

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Specifications

POWER	During Measurement	7-30 volts DC, 40 mA (maximum)	
	Standby	none	
DATA OUTPUT		four 0-5 volt analog signals	
WARMUP TIME		3.0 seconds	
TEMPERATURE	Operating	+14°F to +149°F	-10°C to +65°C
	Field/Storage	-40°F to +158°F	-40°C to +70°C
ACCURACY			
SOIL MOISTURE	No Soil Specific Calibration	±0.03 (fraction water by volume)	
	Soil Specific Calibration	±0.005	
SALINITY	No Soil Specific Calibration	±20%	
	Soil Specific Calibration	±2%	
TEMPERATURE	Standard	±1°F	±0.6C (typical)
SIZE	Length	approx. 4"	10cm
	Diameter	approx. 1.6"	4cm
	Weight	approx. 7 oz.	200g (without cable)
MATERIALS	Body	stainless steel & PVC	
	Cable	direct burial, 7 wire, 18 gauge.	

How to Order

HYD-10-L	*Hydra* Probe with 10 foot cable - *Hydra* Logger connector attached.
HYD-10	*Hydra* Probe with 10 foot bare wire cable - for use with general data collection platforms.
HYD-XX-L	*Hydra* Probe with XX foot cable - *Hydra* Logger connector attached (min. 3 ft., max. 100 ft.).
HYD-XX	*Hydra* Probe with XX foot bare wire cable - for use with general data collection platforms (min. 3 ft., max. 100 ft.).
HYD-JIG	Jig for easing probe installation in very hard soils.
HYD-MAN	Additional User's Manual. One User's Manual is included with all initial Probe orders. Manuals contain IBM PC compatible software to convert raw probe voltages into soil moisture, salinity, and temperature readings.

VITEL inc.

HEADQUARTERS
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FAX: (703) 968-7581

NORTHWEST REGIONAL OFFICE
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Boise, ID 83706, USA
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FAX: (208) 322-2718

WARRANTY Vitel, Inc. warrants its products for one year from date of delivery.

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APPENDIX F

Spring Thaw Literature Searched

	AUTHORS	TITLE	DATE	REPORT/SOURCE
S1	Alkire, B.D., & Keller, C.	Shallow Refraction Surveys on a Low-Volume Road for Determining P-Wave Velocity of Seasonal Thawing Soils	1991	TRR 1291 Vol. 2
S2	Atkins, R.T.	Determination of Frost Penetration by Soil Resistivity Measurements	Jul-79	CRREL
S3	Barcomb, J.	Use of Thermistors for Spring Road Management	1989	TRB 1252
S4	Berg, R.L.	Design of Civil Airfield Pavements for Seasonal Frost and Permafrost Conditions	Oct. 74	CRREL
S5	Bhandari, A., Harral, C., Holland, E. & Faiz, A.	Technical Options for Road Maintenance in Developing Countries and the Economic Consequences		TRR 1128
S6	Bonnard, D. & Recordon, E.	Road Foundations: Problems of Bearing Capacity and Frost Resistance	May 76	CRREL TL 524
S7	Chandra, D., Lytton, R.L., & Yang, W.	Effects of Temperature and Moisture on Low-Volume Roads	Dec. 88	Texas Transportation Institute
S8	Connor, B.,	Alaska's Experiences with Non-Destructive Testing		
S9	Dysli, M.	Swiss Philosophy and Developments Concerning the Loss of Bearing Capacity during Thaw	Jun. 82	Intn'l Symp. on Bearing Cap. of Roads & Airfields
S10	Dysli, M. & Pfister, R.	Test of Bearing Capacity during Thaw	Jun. 82	Frost I Jord Nr. 24
S11	Eaton, R.	Pot Hole Repair Primer		CRREL
S12	Eaton, R.A.	Comparison of the Performance of All-Bituminous Concrete and Reduced Subgrade Strength Highway Pavement Test Sections Under Freezing Conditions	Dec. 75	CRREL TR 270
S13	Eaton, R.A., & Payne, J.O. Jr.	Full-Depth and Granular Base Course Design for Frost Areas	Jan. 82	CRREL
S14	Esch, D.C. & McHattie, R.L.	Prediction of Roadway Strength from Soils Properties	1983	TRR 918 /State of Alaska DOTPT
S15	Flaate, K.	Norwegian Practice in Cold Regions Engineering	May 81	
S16	Gatto, L.W.	Soil Erodibility and Runoff Erosivity Due to Soil Freezing and Thawing		USA CRREL
S17	Hanna, A.N.	A New Material for Pavement Subbases in Frost Areas		
S18	Hardcastle, J.H., Lottman, R.P., & Buu, T.	Fatigue-Based Criteria for Seasonal Load Limit Selection	1983	TRR 918

S19	Hauck, C.	Water Susceptibility of Base Gravel Materials	Jul. 90	3rd Intn'l Conf on bearing Cap. of Roads &Airfields
S20	Hinshaw, R.F., & Northrup, J.L.	Predicting Subgrade Moisture under Aggregate Surfacing	1991	TRR 1291 Vol. 2
S21	Ishibashi, I., Irwin, L.H., & Lee, W.	Resilient Behavior of Base and Subgrade Materials	Aug. 84	Cornell Univ.
S22	Ishitani, M., Himeno, K., & Kasahara, A.	Seasonal Variations in Bearing Capacity of Asphalt Pavements	Jan. 92	TRB
S23	Janoo, V., Berg, R., & Bigl, S.	The use of The Falling Weight Deflectometer (FWD) to Characterize Seasonal Variation in Pavement Response		
S24	Janoo, V.C., Berg, R.L.	Thaw Weakening of Pavement Structures in Seasonal Frost Areas		
S25	Janoo. V.	Use of Soft Grade Asphalts in Airfields and Highway Pavements in Cold Regions	May-90	DOT/FAA/RD-90/12
S26	Johnson, T.C., Berg, R.L., Carey, K.L., & Kaplar, C.W.	Roadway Design in Seasonal Frost Areas	Mar. 75	CRREL Technical Report 259
S27	Jones, C.	Solar Radiation Effects on Frost Action in Soils	1983	TRR 918
S28	Kasahara, A., Himeno, K., & Igarashi, M.	Seasonal Variations in Bearing Capacity of Asphalt Pavements		
S29	Kestler, M.	Culvert Problems in the White Mountain National Forest	1983	In-house Engrg Report, WMNF
S30	Kestler, M., Bigl, S. & Berg, R.	Statistical Significance of Freeze-Thaw Related Factors on Cumulative Damage to Flexible Pavements		In preparation
S31	Kestler, M.A. & Berg, R.L.	Case Study of an Insulated Pavement in Jackman, Maine	Jan. 95	TRB
S32	Kestler,M. & Berg R.	Asphalt Concrete Pavements Subjected to Traffic During Thawing	Oct. 91	Unpublished Report
S33	Kestler,M. & Berg R.	The Effects of Seasonal Variations in Temperature and Moisture Conditions on Pavement Strength at Lebanon Airport's Taxiway Bravo, Lebanon, NH	Sept. 92	Unpublished Report
S34	Kubo, H.	Frost Heave Preventing Measures in Road Pavements		
S35	Kubo, H., & Sugawara, T.	The Influence of Frost Action on the Bearing Capacity of Flexible Pavements	Jun. 82	
S36	Kubo, H., & Takeichi, K.	Seasonal Nondestructive Evaluation of Frost-Heave Prevention Layers in Asphalt Pavements		TRR 1362
S37	Kurt, C.E.	Rating Bridges on Low-Volume Roads	1987	TRB/TRR 1128

S38	Leonard, L.	Highway Load Restriction Determination	May 82	State of Alaska DOTPF
S39	Linell, K.A.	Frost Action and Permafrost		
S40	Madden, D.A.	Seasonal Variation for Structural Strength Value: Final Report	Jun. 87	Maine DOT
S41	Madden, D.A., Rand, D.W., & Dunphy, W. J. Jr.	Correlation of Frost Depth, Thaw Periods and Pavement Deflection to Spring Load Restrictions	Jun. 90	State of ME DOT TR # 89-7
S42	Mahoney, J.P.	The Evaluation of Frost Related Effects on Pavements: Summary Report	Sep. 85	WA STC
S43	Mahoney, J.P., Lary, J.A., Sharma, J., & Jackson, N.	Investigation of Seasonal Load Restrictions in Washington State		TRR 1043
S44	Mahoney, J.P., Rutherford, M.S., & Hicks, R.G.	Guidelines for Spring Highway Use Restrictions. Summary Report	Jun. 86	State of WA DOT
S45	Molenaar, A.A., & Van Gurp, C.A.	Seasonal Variations in Deterioration	Oct. 90	Highway Research
S46	Newcomb, D.E., Bubushait, A.A., Mahoney, J.P., & Sharma, J.	State-of-the-Art on Pavement Overlay Design Procedures	Dec. 83	State of WA DOT
S47	Nordal, R.S., & Hansen, E.K.	The Vormsund Test Road	Jul. 87	
S48	Orbom, B.	The Effect of Spring Thaw Subgrade Conditions on the Load-Carrying Capacity of Flexible Airfield Pavements in Cold Regions	1975	Stockholm, Sweden
S49	Potter, J.C., Rollings, R. S. & Barker, W.R.	Corps of Engineers Low-Volume Road Design	1987	TRB/TRR 1128
S50	Ring, G. W. III	Seasonal Strength of Pavements	1974	OECD / Road Research
S51	Roy, M., Crispin, J., Konrad, J., & Larose, G.	A Field Study of Two Road Sections During a Freeze-Thaw Cycle	Jan. 92	TRB
S52	Rutherford, M.	Evaluation of Variables Affecting Flexible Pavement Thawing for Timing Spring Load Restrictions	1990	TRR1286
S53	Rutherford, M. S.	Pavement Response and Load Restrictions on Spring Thaw-Weakened Flexible Pavements	Jan. 89	TRB
S54	Rutherford, M.S., Barcomb, Alfelor, et al.	Design, Management, and Operation of Pavements	1989	TRB/TRR 1252
S55	Rwebangira, T., Rutherford, M.S., Mahoney, J.P. & Hicks, R.G.	Development of Spring Load Restrictions for Local Roads	1987	TRB/TRR 1128

S56	Saarelainen, S., Kivikoski, H., & Takala, J.	Consideration of Frost Heave in the Design of Road Embankment		
S57	Sage, J. D., & D'Andrea, R.	Long Term Mitigation of Frost Deterioration of Existing Roadways	Mar. 88	NSF
S58	Scherocman, J.A., Proctor, J.J., & Morris, W.J.	Prevention Of Moisture Damage in Asphalt Concrete Pavement		13th Annual Cnf. of Canadian Technical Asphalt Association
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