Supplemental Appendices to Independent Review Panel Report

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Appendix A

Relationship of Vegetation Management Workshop Independent Review Panel Findings and Recommendations to "Lake Tahoe Fuels and Vegetation Management Review" (2002); USFS Lake Tahoe Basin Management Unit

This appendix provides a detailed table comparing findings and recommendations of the independent review panel to findings and recommendations from a 2002 review of the U.S. Forest Service Lake Tahoe Basin Management Unit (LTBMU) fuels management program. (A copy of the complete 2002 LTBMU fuels management program review is available at http://www.fs.fed.us/r5/ltbmu/fuels-review/summary.html.)

Information in the table below clearly identifies a high degree of similarity between the two sets of findings and recommendations; albeit the two reviews occurred six years apart. Such a parallel suggests the Lake Tahoe Basin Community (agency, stakeholder, and science community representatives, and elected officials) have made limited progress to address the challenges facing vegetation management projects in the Basin. There are at least three reasons that would potentially explain the limited progress: 1) the recommendations are flawed; 2) a response was attempted but it was unsuccessful; or 3) no response was attempted. The panel strongly encourages agency and stakeholder representatives to critically evaluate all of the panel's recommendations. Relevant individuals should determine if an action response is appropriate, and if so, employ the means to ensure all implementations are successful. Follow-through is as important as the decision to initiate a response, since during times of fiscal constraint continued opportunities to assess our problems without commensurate demonstration of progress will soon evaporate.

Table A1. Comparison of findings and recommendations from the vegetation management workshop independent review panel (Panel) and the 2002 review of the U.S. Forest Service Lake Tahoe Basin Management Unit fuels management program (LTBMU).

Panel Finding or Recommendation	LTBMU Review Finding or Recommendation
Panel Finding & Recommendation 3.1.1: Multiple but separate regulatory processes are cumbersome to navigate in a timely manner. Agencies should develop procedures and protocols that are consistent within, and between agencies.	The regulatory structure and environmental oversight is more intensive around Lake Tahoe than in most other wildland areas and makes accomplishment of hazardous fuels reduction and forest health projects difficult. There is a lack of a common vision regarding fuels management between the Forest Service and some regulators. The single purpose focus of regulatory agencies often impedes the ability to conduct fuel hazard reduction treatments. There is a perception that an adversarial environment for program accomplishment exists between some regulators and implementers at the ground level. The LTBMU deals with four different air quality regulatory agencies that have different reporting requirements and approaches to issuing permits for prescribed burning. A unified approach to regulation of water quality would assist in program development. Sometimes, LTBMU receives conflicting or different regulatory reviews and acceptable project mitigations from different regulatory agencies.
Panel Recommendation 3.1.2: Implementing agencies and land managers should develop a protocol for periodic (7-10 year) review, verification, and update of quantitative thresholds and policy relevance.	The LTBMU should seek to involve scientists in problem solving and in resolving interagency disagreements over methodologies for assessing environmental impacts of fuel treatments.
Panel Recommendation 3.1.3: Current efforts to improve coordination and collaboration between regulatory and action agencies should continue. Streamlining of the permitting process by developing a clear step by step process and projected timeline would benefit both the action and the regulatory agencies.	Integrate permit process into National Environmental Planning Act (NEPA) process to streamline project implementation. Seek a means to combine NEPA and California Environmental Quality Act (CEQA) analysis to streamline planning and development of interagency projects that do not stop at jurisdictional boundaries. Enhance partnerships for implementation with regulatory agencies. Rapidly develop approaches that reduce erosion and fuel accumulations through cooperative and compatible efforts. Use a consistent, interagency group to meet monthly to expedite projects and solve problems that threaten to slow the process.
Panel Recommendation 3.1.4: Use of interagency MOU's should continue and be expanded to more strongly facilitate cooperative interaction among agencies, particularly on the issue of available burn days.	Revisit or establish memorandums of understanding (MOU's) with all regulatory agencies to establish operating norms for project planning and permits. The MOU with the Lahontan Regional Water Quality Board should be updated as soon as possible to reflect the current needs and situation. Pursue establishment of a unified approach to regulation of air quality in the Lake Tahoe Basin.

Table A1 Continued.

Panel Finding or Recommendation	**LTBMU Review Finding or Recommendation**
Panel Recommendation 3.1.5: Implement a concurrent and comparative disturbance risk assessment strategy that simultaneously weighs the relative importance and immediacy of environmental, health and public safety strategies, and dollar costs/benefits. A zero discharge concept to regulating fuel management practices is not in keeping with the natural disturbance driven ecosystem, and an alternative approach should be developed which will tolerate a level of sediment and nutrient discharge similar to historical levels associated with fire driven terrestrial and aquatic ecosystems.	Work with the research consortium conducting the TMDL research to incorporate the outputs from fuel hazard reduction activities in addition to the currently funded forest background levels.
Panel Recommendation 3.2.1: The opportunity for cost sharing among the public and private sector beneficiaries of Basin wide management strategies should be more strongly pursued.	The pooling of resources and cooperative projects between local government, local fire departments, NDF, the state of California and the Forest Service should be explored as a method of improving efficiency. Actively seek to develop interagency projects and to involve other agencies throughout development and implementation of projects. Coordinate these with compatible grants on private lands
Panel Recommendation 3.2.3: An advanced strategic planning process should be developed to identify specific project objectives and investigative protocol necessary to answer key management questions. Such advanced planning would help to avert timeline/funding/implementation disconnects.	Use a consistent, interagency group to meet monthly to expedite projects and solve problems that threaten to slow the process.
Panel Finding & Recommendation 3.2.4: Outreach education has generated acceptance of treatment strategies such as prescribed burning. The Nevada and California Cooperative Extension Services have effectively facilitated outreach education, not only within the community but with agencies and research institutions as well. These efforts should continue and be expanded where appropriate.	Define stakeholders and work to gain their support through active public involvement from the earliest stages of project development. Hold personal scoping meetings with the local neighborhood leaders early in fuels project development. This should be defined in an interagency communication strategy concerning projects to reduce fire hazard. Develop a plan to work effectively with interest groups and homeowner groups to bring them into the process as advocates for a fuels program at both the conceptual and project level. Use monitoring of fuels, urban lots and vegetation management projects as a communication vehicle with regulators and public.

Table A1 Continued.

Panel Finding or Recommendation	LTBMU Review Finding or Recommendation
<u>Panel Recommendation 3.3.4:</u> Regulatory agencies need to clearly identify specific areas of concern and articulate respective key management questions. This is an essential step in guiding the development and design of successful monitoring and/or research programs that generate data and information directly applicable to agency needs. Existing protocols should be evaluated as to their unique applicability to Sierran ecosystems. Appropriate monitoring activities should then be compiled for each key management activity and adopted as the standard protocol among agencies and contractors in the Tahoe Basin. A publication on "Standard Methods for Ecological Measurement and Monitoring in the Lake Tahoe Basin" should be developed and used.	The LTBMU should seek to involve scientists in problem solving and in resolving interagency disagreements over methodologies for assessing environmental impacts of fuel treatments.
<u>Panel Finding 3.3.6:</u> Operational costs in the Basin are typically much higher than outside the Basin.	Operators may be reluctant to bid on work on the LTBMU because of high costs and delays due to permits that are not required in other areas.
<u>Panel Recommendation 3.3.6:</u> Carefully evaluate Basin-specific requirements to determine necessity. Guarantee a long-term program, and coordinate/ consolidate operations on small-scale units and ownerships. Look at project management and assessment in the context of a larger temporal and spatial perspective.	Actively seek to develop new markets for excess fuels to reduce treatment costs including: explore development of cogeneration plants in the local area to utilize material from the Basin; small, multipurpose timber sales; and Christmas tree and firewood sales.
<u>Panel Recommendation 3.3.7:</u> Optimize the use of limited resources by conducting a Basin-wide analysis of: a) costs and expected benefits of various treatments (e.g., mechanical, hand and/or fire) under various spatial and temporal scenarios, and the need for roads or other access; b) expected environmental costs of treatments; and c) simulated resulting behavior and costs associated with wildfire.	Develop a comparative cost study of treatments to improve the cost efficiency of treatments. Subdivide by urban lots, wildland urban interface (WUI) and general forest. Compare costs between agencies and treatment types.
<u>Panel Recommendation 3.4.1:</u> Management agencies should work more directly with scientists during project planning to develop a scientific foundation for the assessment of project impacts in the context of cumulative and landscape scale impacts associated with sensitive area management strategies.	Conduct quantitative monitoring of effectiveness and environmental effects of fuel hazard reduction activities. Reestablish a point of contact for researchers working in the basin. Work with the research consortium conducting the TMDL research to incorporate the outputs from fuel hazard reduction activities in addition to the currently funded forest background levels.

Appendix B

The Fuel Management Interface: WEPP FuME

For Further Information Contact Dr. William Elliot (welliot@fs.fed.us; 208 883-2338)

Available online at http://forest.moscowfsl.wsu.edu/fswepp/

Scientists at the USDA Forest Service Rocky Mountain Research Station have developed an online interface to aid in preparing environmental impact plans to support fuel treatment projects. Soil erosion occurring in the aftermath of a wildfire, prescribed fire, or mechanical treatment can be a substantial source of environmental impact. The idea behind this interface is that there are essentially three sources of sediment in a forested watershed: 1) Sediment from the forest (undisturbed and wildfire conditions); 2) Sediment from forest management activities (thinning and prescribed fire); and 3) Sediment from the road network. The documentation that describes the assumptions behind the interface also is available online. This appendix describes how one would go about applying the interface to a project in the Lake Tahoe Basin.

On the input page, users can specify a climate typical of every 2.5 mile grid cell around Lake Tahoe. Soil options include sandy loam, typical of the granitic soils around the lake, and silt loam, representative of the volcanic soils around the lake.

The interface evaluates a single hillslope, typical of a fuel treatment area. The user enters the length and steepness of the project area, and the width of any undisturbed buffer at the bottom of the hill. For larger projects, more than one hillslope will need to be analyzed. The user also enters a road density (miles of road per square mile of watershed).

To address fire frequency, the user enters the historical fire return interval for wildfire. In the lower elevations of the Tahoe Basin, this was believed to be about 20 years, or less. The user also indicates the frequency of treatment. The workshop indicated this was likely to be 10 to 20 years.

Once the input screen is completed, the user clicks the run button, and the interface carries out nine different disturbance scenarios for the hillslope (undisturbed forest, low, medium and high intensity wildfire; low, normal, and high intensity prescribed fire; and moderate and low intensity thinning). It also carries out three runs for road segments, no traffic, low traffic, and high traffic with gravel, noting both the amount of sediment that may be delivered at a stream crossing, and the amount of sediment that may cross a buffer of the width that was specified on the input page.

The results of these runs are all converted to common watershed analysis units of tons of sediment per square mile (Figure A1). They are presented in a table showing how much sediment would be generated the year of a disturbance in the case of fire or management, or every year in the case of an undisturbed forest or roads. For the disturbed scenarios, the amount of sediment delivered during the treatment is divided by the frequency of disturbance to give an “average” annual delivery from the hillslope to the stream system.

This annual watershed sediment delivery will vary with the runoff. In average and dry years, very little sediment will move, but in years with above average runoff, detached sediment will be gradually routed through the stream system. For the conditions specified in this example, there is no erosion predicted from an undisturbed forest, nor following the thinning operation. This is not unusual in a snowmelt dominated climate, where snow melt rates are slow compared to the intensities of rain experienced in other forests.

On the output screen, Table 1 is followed with a one-page narrative describing how to interpret the table and calculate a true background erosion rate. One of the sources of erosion that is discussed is road erosion. In this example, as is often the case, the erosion from the road could well exceed the erosion from the fuel treatments. Since roads are now a part of our existing landscape, the narrative suggests that the watershed manager may wish to include road erosion as part of the current background levels.

After the narrative, alternative erosion rates are given that can be substituted into Table 1 if desired, with the erosion from moderate or low intensity wildfires that may occur. In this case, if the fuel treatment reduced the wildfire severity from high, as shown in Figure B1, to moderate, the predicted erosion would drop by about 80 percent, offsetting any erosion that may have resulted from the treatment. If the prescribed fire proved to be hotter than anticipated, the final table shows that the erosion rate from the prescribed fire would increase by 150 percent. Other scenarios can also be pursued by comparing the predictions in the first table (Figure 1) and the additional information in the final table.

Figure B1. Output form WEPP FuME for the Tahoe, CA climate, 400-ft long slope with a steepness of 35 percent and a 50-ft buffer.

Source of sediment	Sediment delivery in year of disturbance (ton mi^{-2})	Return period of disturbance (y)	"Average" annual hillslope sedimentation (ton mi^{-2} y^{-1})
Undisturbed forest		1	0
Wildfire	3616	20	180.8
Prescribed fire	64	10	6.4
Thinning	0	10	0.0
Low access roads	1.5 to 8.2	1	1.5 to 8.2
High access roads	6.2 to 12.4	1	6.2 to 12.4

If the above erosion rates are compared to information provided as background readings at the workshop, the values are reasonable for wildfire, prescribed fire, and roads.

This web site is an interface to the Water Erosion Prediction Project (WEPP) model, which was developed during the 1990s by the USDA Agriculture Research Service, with collaboration from the USDA Forest Service. Interfaces are also available for the WEPP model in Windows and to run with Arc GIS 9.x.

Additional information about applying and interpreting WEPP FuME or the other online or standalone interfaces can be obtained from the online documentation, or by contacting Dr. William (Bill) Elliot.

Appendix C
Mechanical Treatment
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The TRPA Code for SEZs states that innovative technology vehicles considered for use should be able to be operated to

- Minimize soil compaction
- Minimize disruption of soil surface
- Minimize damage to vegetation

These are in fact good criteria for any area whether riparian, steep or otherwise, and provide a good basis for a simplified functional analysis of mechanical treatment alternatives. Traffic – from vehicles, trees, logs and/or people – compacts soil, displaces soil and damages vegetation to a lesser or greater degree, so tradeoffs occur when conducting fire hazard reduction operations. From the array of case studies presented at the Workshop, however, it seems that a number of systems can be used without creating substantial impacts, if methods are used properly and under the right conditions.

Important aspects to consider include:

- Compaction occurs when compressive stress (pressure, psi) > soil strength (psi)
    - The first pass causes the most compaction
- Soil displacement (parallel to soil surface) occurs when shear stress exceeds the shear strength of the soil.
- On flat ground, compressive stresses and therefore compaction can be major concerns. Plowing from ground-lead loads could displace soil. Shear from dragged loads will almost certainly disturb duff and litter. Mineral soil is unlikely to be displaced by dragging loads or vehicles if the vehicles or loads do not present compaction risks.
- On steep terrain, as on flat ground, the main issues with dragging loads are plowing (if groundlead or highlead) and sweeping of the organic surface layer. Both compaction and soil disturbance potential under dragging loads diminish somewhat as slope increases if the loads are pulled uphill. The risk of shear displacement by vehicles increases with slope.

Numerous studies have evaluated the effects of forestry vehicles on soils, and several of these are included in the list of references. Many such studies would have been more useful if they had documented more of the important parameters such as weight and tire pressure of the vehicle, or moisture content or initial strength measurements of the soils. Without this information, interpreting the results is difficult.

The effects of a particular system are not related to the name, e.g., CTL, Hand Pile and Burn, Tong Tosser or Whole Tree, but with how each element of the system interacts with the soil and vegetation. For example, forwarders used with CTL systems come in a variety of configurations with varying loaded weights and payload capacities, numbers of tires (or tracks) and nominal ground pressures (Table C1). If a “CTL system” is specified, exactly which forwarder or forwarders are acceptable, and why?

Table C1. Specifications for example forwarders. Some of these are no longer manufactured, but the ranges of values help illustrate the point.

Mfr	Model	Loaded Wt, lb	Payload, lb	Tires (option[1])	Loaded Nominal[2] Ground Pressure, psi
Fabtek	240	34000	12000		
Cat	554	48000	22000	8	
Rottne	Rapid	50000	26000	6 (A)	
Rottne	Rapid	50000	26000	6 (B)	
Rottne	Rapid	52000	26000	8 (A)	
Rottne	Rapid	52000	26000	8 (B)	
Cat	574	66000	31000	8	
Rottne	SMV Rapid	67000	35000	6 (A)	
Rottne	SMV Rapid	67000	35000	6 (B)	
Ardco	CLF	69000	30000	6	6.1
Timbco	TF815-C	73000	32000	8	14.5
Timbco	TF815-C	73000	32000	8 (w/tracks)	10.3
Rottne	SMV Rapid	74000	35000	8 (A)	
Rottne	SMV Rapid	74000	35000	8 (B)	
Timbco	TF820-C	88000	40000	8	14.4
Timbco	TF820-C	88000	40000	16 (A)	14.1
Timbco	TF820-C	88000	40000	16 (B)	9.1
Timbco	TF820-C	88000	40000	16 (C)	8.3

[1] Letters refer to different tire options for the same vehicle.
[2] As specified by the manufacturer. Actual ground pressure depends on operating conditions.

I. Soil-Vehicle/Load Interactions

Because soil compaction and disruption/disturbance, and vegetation damage are mechanical impacts of mechanical treatments, a simplified basic understanding of how traffic interacts physically with soil (and vegetation) gives insight for selecting acceptable elements of complete operating systems. This is much simpler than, say, predicting the effects of prescribed burning or wildfire on nutrient transport. An earlier report associated with the Tahoe Basin (Poff, 2006) began with a good overview of some of the effects of equipment on soils, but unfortunately did not synthesize that information into its recommendations for equipment. The following is provided in an attempt to close that gap.

A. Compressive Strength of Soils

Consider a soil particle in an army of soil particles, shoulder to shoulder in each layer and layer upon layer. The army's objectives are to resist getting squeezed closer to other particles (compaction) or separated from their neighbors (let's call this displacement or disruption). The army doesn't have eyes or ears, but does have nerves so any given particle can feel other particles or things pushing in. The strength of the army depends on teamwork. The closer together with less air space between (higher bulk density) particles it's harder for something to push them even closer, i.e. there is a higher compressive strength. (Soil on construction sites for homes and roads is pre-compacted to increase its strength.) Bulk density of undisturbed in-place soils is generally lower near the surface because of the presence of roots and activity of organisms and freeze/thaw cycles, and higher at depth, especially if the soil is developed from underlying rock parent material.

Standard technical methods have been developed to measure the strength of soil, but the following may serve to get the general idea across. For a cube of dry soil (or other breakable bulk material such as wood, concrete or Styrofoam), strength can be measured by pushing down on the upper face of the cube sitting on a solid surface and increasing the force until the cube breaks or crumbles. The peak force (in pounds) divided by the area of the face of the cube (in square inches) is the strength (in pounds per square inch or psi). At higher moisture contents, most soils plastically deform rather than break. (Plastically means it doesn't rebound.)

A cone penetrometer provides a simple way of estimating the relative strength of a soil in place rather than in a lab. A cone, with point facing down, is pushed into the soil at a specified, very slow speed (ASAE 1999). The force (in pounds) required to push the cone, divided by the area of the base of the cone, gives the measure of strength (in psi). A "recording cone penetrometer" measures and records the force trace versus depth as the cone is pushed from the surface to the maximum depth tested and therefore provides much more useful information than does a peak reading or a "depth to refusal" at a given force (Figure C1).

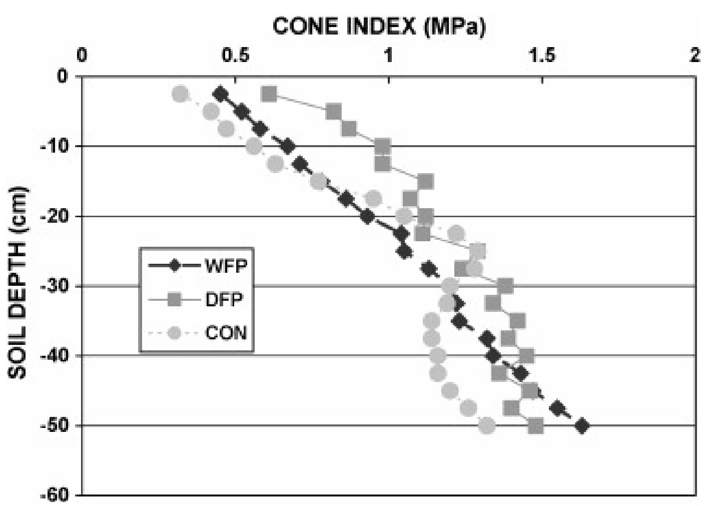

Figure C1. Comparison of cone index readings versus depth in a wet pine flat subjected to harvesting under two soil moisture conditions: wet (WFP) and dry (DFP), compared with a non-harvested control plot (CON), South Carolina (from Carter et al., 2007).

Cone penetrometers are generally not good tools for evaluating before/after treatment effects because the readings are so sensitive to moisture content which varies over time.

But they are excellent for helping determine whether soil will be compacted by vehicles of various weights and surface pressures.

For most in-place soils (sands are an exception), their compressive strengths are very high when they are dry (Figure C2). Particles sprayed with a sticky and grainy substance that keeps them together also helps prevent them from sliding by, over, or under their neighbors. The binder resists moisture to a certain point, but loses most of its effectiveness above some threshold moisture content.

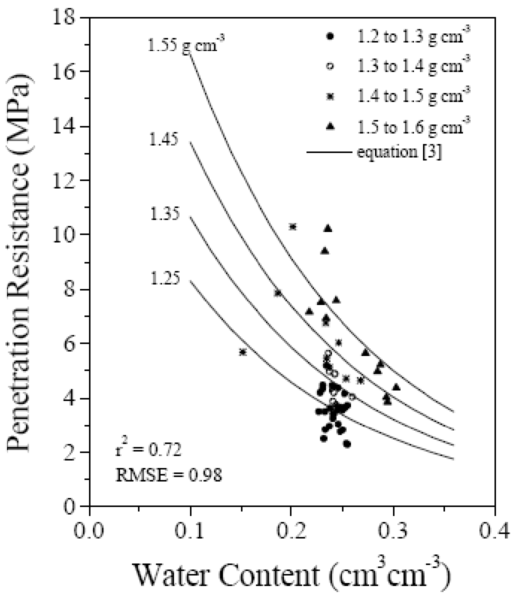

Figure C2. Example relationships of soil strength (actual and estimated cone penetrometer readings) to moisture content and bulk density (from Vaz, 2003).

In a soil, moisture content can vary greatly with distance from the surface. Immediately after a heavy rain, the surface soil may be saturated, but the soil may also be very dry below the wetting front. Late in a Tahoe summer, the surface is likely to be dry, strong, and often hydrophobic, but if the water table is not too deep soil within the zone of influence of surface traffic may remain weak and impressionable. Figure C3 shows an example of a soil, in this case on a reclaimed mine site, that is weaker at depth than near the surface. A recording cone penetrometer shows these effects, many other methods of measuring soil strength do not.

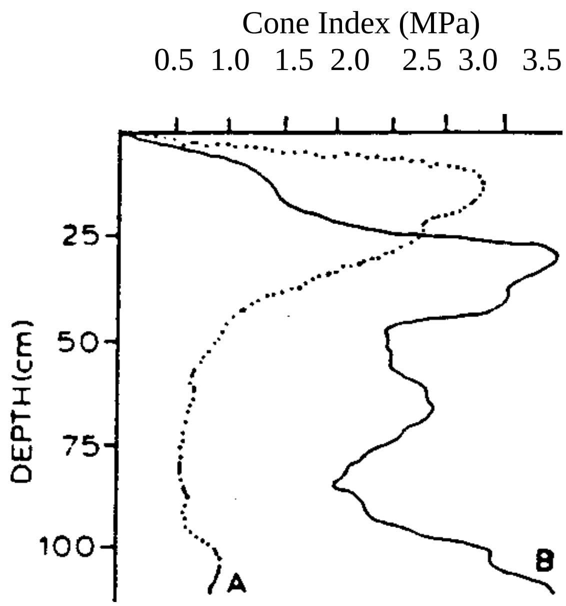

Figure C3. Representative cone penetrometer profiles of two reclaimed strip mine soils: (A) Topsoil over wheel-excavated/belt placed material, and (B) Topsoil over scraper-placed material (from Hooks and Jansen, 1986).

Strength also depends on other factors such as soil texture (sands are weaker than finer-grained soils) and structure, but the discussion has been simplified by focusing on bulk density and especially moisture content as key factors.

B. Shear Strength

Let's assume something is trying to displace the top layer of the army off the next layer by pushing horizontally on the top layer. The ability to resist this type of displacement is known as shear strength, which can also be measured and stated in psi. (Using a soil cube as an example, push sideways on the top half of the cube while holding the bottom half in place. The peak force required to shear the top half off, divided by the cross-sectional area of the cube, gives the shear strength.) Compressive and shear strength are related for soil: when one is high, so is the other.

C. Duff and Litter: Special Stuff

Due to reorganization in the soil particle army, some have been demoted to the duff and litter layer, and most of their compressive and shear strengths have been taken away. As a token benefit, they've been granted some ability to return to their original position if squeezed. It doesn't take much pressure to push them down, but they rebound when the pressure is released, so there is little permanent effect, even after multiple squeezes. The results of shear are quite different: a very small shear force can sweep particles away. Depending on the depth of duff and litter and the type of shearing action (a hand rake, branches or bole of a skidded tree or log, a tire or track slipping on the surface), bare mineral soil may be exposed in only one pass, or it may take multiple passes.

D. Loads Imposed by Humans and Other Vehicles

Soil is usually subjected to some combination of both compression and shear, and one or the other may be more important. Let's take some example cases of each, first on flat ground.

1. Nominal and Peak Surface Compressive Pressures on Flat Ground

An element of soil compresses if the peak (not average or nominal) applied pressure "felt" by the element exceeds the soil's strength.

Boots: Take a human hand-carrying a load off the ground as an example. Assume the human with load weighs 200 pounds and each boot sole has a surface area of 3" x 10" = 30 in^2. Nominal pressure with both feet fully on the ground is 200 lb/60 in^2 = 3 psi. But when walking, at times only the toe of one boot (maybe 3" x 3") might be on the ground. The average pressure at this instant is 200 lb/9 in^2 > 20 psi. With the toe angled forward, the peak pressure under the front of the toe is higher yet, maybe 30 psi.

The peak surface pressure affects only the soldier particles immediately in contact with the boot sole. Because the army works as a team, surrounding particles at or near the surface and in contact with those being pushed down under the boot pick up some of the load and distribute it to a wider zone of particles at greater depth. Because a boot sole is relatively small in area, the peak pressure drops rapidly with depth. (The rate at which pressure diminishes depends on the ratio of the length of the perimeter of the contact patch to the area of the contact patch. This is higher for a heavier vehicle than for a lighter one imposing the same surface pressure. An extreme case would be a uniform pressure covering the whole surface of the earth. This load would not decrease at all with depth.) While a weak soil may be compacted by a boot near the surface, compaction at depth is unlikely. If you're dealing with extremely weak soils, asking workers to wear large-soled boots would be one approach

Tracks: Nominal pressure is calculated by dividing the vehicle weight by the total track surface area. But in a similar fashion as for a boot, peak pressure depends on how much of the track is actually in contact with the surface and the distribution of the load. For example, if a steel track with grousers (cleats) is sitting on concrete, only the grousers contact the surface, creating pressures that may be roughly ten times higher than nominal. Or, if the center of gravity of the combined vehicle and load is ahead of the center of the track surface, the peak pressure at the front of the track may be double nominal pressure, even if the track is fully in contact with the ground. The ASV tracked front-end loader used at the Celio Ranch project has a nominal unloaded pressure of 3 psi, but peak pressure while unloaded is probably closer to 6 psi at the back of the track (because the center of gravity of the vehicle is behind the center of the track.) With a 2000 pound load in the log forks, the peak pressure is probably around 7 psi at the front end of the track. No matter what the condition, if you doubled the width of the tracks, you would in most cases reduce the peak surface pressure by about a factor of two. Pressure at depth would also be less with the wider tracks, but not by a factor of two.

Tires: Pneumatic tires are unique. On a hard surface with a treadless tire (such as a smooth bicycle tire), the average and peak surface pressures are relatively close to the inflation pressure, no matter how much load is on the tire: the air pressure pushing down on the tire's contact patch with the road must have enough contact area to carry the weight on the tire. If you double the weight, the tire will deflect so approximately twice as much tire area is in contact with the surface: contact pressure remains the same. If you deflate the tires to half the original inflation pressure, the contact pressure also decreases by a factor of two, reducing the potential for soil impact (Burt et al., 1982; Koger et al., 1982). Deflating a tire too much will damage it, but one can install larger tires on the same vehicle and run at a lower inflation pressure and therefore lower contact pressure. While standard forestry tires are designed for inflation pressures of 25-25 psi or so (e.g., http://www.firestoneag.com/tiredata/info/tables/table_j.asp), "high flotation" tires may be rated for 10 psi or less (e.g., http://www.firestoneag.com/tiredata/info/tables/table_h.asp).

With soils that are not dry and rock-hard, tire inflation pressure may well exceed the strength of the soil right at the surface, so the tire will "sink" somewhat into the surface: it is compressing the soil. Why doesn't the tire continue to sink? Compression increases the strength of the soil, providing more resistance, and the soil at depth may be stronger, resisting more compaction. But a primary reason is likely to be reduced contact pressure: as the tire sinks in, more of the rounded surface area of the tire contacts the soil. As a result, when soil deflects beneath the tire (rather than the tire doing all the deflection on a rigid surface), contact pressure is less than tire inflation pressure. As shown in Table C1 manufacturers sometimes quote nominal contact pressures (and different values for loaded and unloaded conditions) for vehicles with tires. These values, however, are for a specific amount of soil deflection, but this varies with soil strength and the weight on the vehicle, so actual contact pressure is hard to predict.

Whether you have boots, tracks or tires, if two vehicles have the same contact surface pressure, the heavier vehicle will generate higher pressure at depth than will the lighter vehicle. This is why humans – even though they can generate high surface pressures – are preferred in some situations to heavier vehicles that may produce the same or even lower peak surface pressures. The two relevant situations are those where: 1) surface pressure is much higher than surface strength, so soil compaction will propagate to greater depth with a heavier vehicle; or 2) soil is weaker (because it's wetter or looser) at depth and therefore a high pressure at depth will compact the deeper soil. While surface compaction is not too difficult to remedy, compaction at depth is problematic.

If compaction at depth is an issue, what are the tradeoffs in using a lighter vehicle? It probably has a smaller payload, so more passes over a trail will be needed to move the same volume. More passes probably means more time and higher cost per amount of material. Hourly costs don't decrease in direct proportion to machine capacity; for example, the operator's wages must be paid no matter how large the vehicle is.

How is compaction related to the number of passes? Under most conditions, most compaction in finer-grained soils occurs on the first few passes (Brais and Camiré, 1998;

Startsev and McNabb, 2000) if the equipment follows the same trail as closely as possible, because as noted above the initial compaction increases soil strength and brings into play stronger soil at depth. (Substantial additional compaction may occur with more passes if the soil is weaker at depth than at the surface.)

Trees or logs on the ground: Compressive stress equals weight divided by contact area. For simplicity, assume a log is a perfect rigid cylinder and is sitting on a rigid flat surface. The contact area between the rounded surface of the cylinder and the flat surface is zero, so pressure is infinite. (The same is true for a rigid wheel.) But this is not realistic; as with a pneumatic tire on deformable soil, the soil gives way and contact area increases until the contact pressure equals the soil strength. How much soil strength is required to support a log of a given diameter if a given soil deflection is acceptable? For a given wood density (let's assume 50 pounds per cubic foot), log weight per foot of log increases as the square of diameter. Contact surface depends on deflection depth and log diameter. Let's also arbitrarily assume a soil deflection of a half inch at the deepest point under the log. Calculating the contact pressure (and required soil strength) is a geometric problem, but Figure C4 shows the results for the stated conditions:

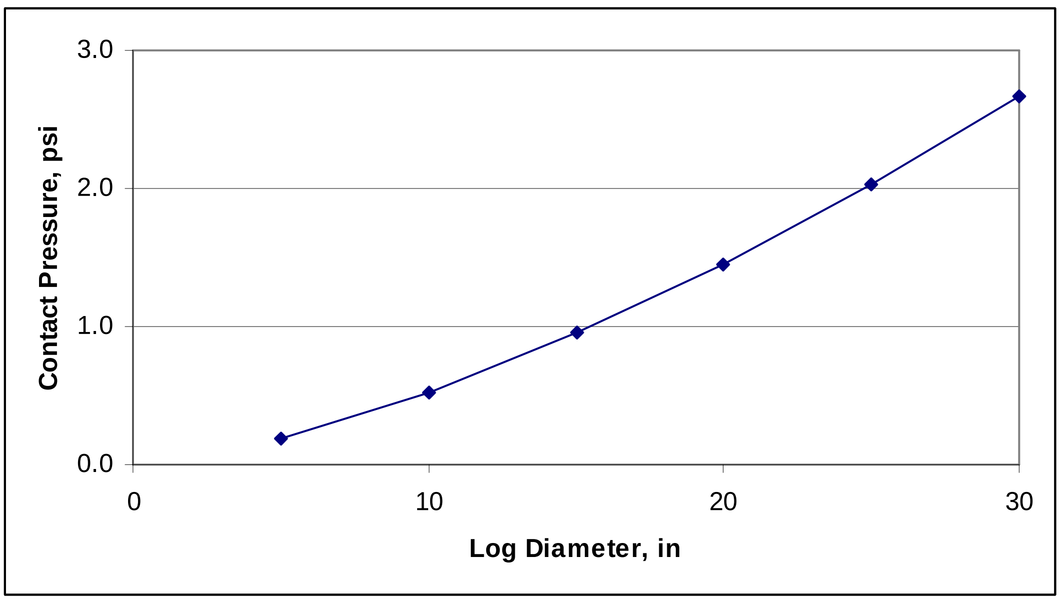

Figure C4. Nominal contact pressure for maximum soil deflection of ½ inch and log density of 50 pounds per foot.

These pressures are quite low, even for rather large logs. As for boots or other vehicles, these are nominal values and assume the whole weight is supported by the soil and the whole length is in contact with the ground, as with end-lining. Higher values will be needed if all the weight is supported by only a part of the length of the log, say, being dragged over a bump. The situation will also be different if one end of the log is suspended by a skyline system or an integral or towed arch: less surface will be in contact, but less of the log's weight (much less than half if the heavier end of the log or tree is suspended, as is usually the case) will be supported by the ground. The widths of the contact areas are also rather small, so pressure should diminish rapidly with depth. In summary, compaction by logs rather than vehicles is very unlikely, especially on soils that are dry near the surface.

Operating over chips, slash or snow diminishes the pressure seen by the soil surface by distributing the compressive force over a larger area, in the same manner that soil shares the load at depth. But the effectiveness of these measures depends on aspects that may be hard to control or maintain, especially the depth of the cover layer. For snow, the strength of a given thickness also varies substantially with snow conditions, and the underlying soil will be relatively weak if not frozen and if moisture content is near field capacity.

E. Shear Loads on Flat Ground

Soil Displacement (parallel to soil surface) occurs when shear stress exceeds the shear strength of the soil. Loads that create shear stress include:

- Plowing (by a bulldozer blade, tree butt or log end)
- Dragging of loads across the soil surface
- Tractive forces (from boots, tires or tracks)
- Turning (primarily a consideration with skid-steer vehicles)

Assuming a bulldozer blade is not in use, butts of logs and trees are the plowing culprits because they may apply large shear stresses, but over rather small areas (the contact patch between the butt end and the soil). With ground-lead winching (end-lining), where the pull is parallel to the soil surface, the butt end of the log or tree will be in contact with the soil (unless on a bed of logs – rather unlikely) and will displace the duff and litter in its path and some mineral soil if the latter's strength is low. Highlead logging, including that by a tong thrower (where the pull angle is above the horizontal but the load is not usually suspended) will still cause some plowing by the butts. Suspending the front end of the load with a skyline system or any piece of tractive equipment that can elevate the front of the load even slightly (a log skidder is an example) eliminates plowing.

As noted above, dragging a load across the soil surface – whether one or both ends are suspended – will rapidly remove duff and litter contacted by the load, because this layer is so weak. Shear stresses are relatively small for small trees and logs, generally on the order of half the compressive stress applied by the dragged load, so displacement of mineral soil is unlikely even if soil strength is rather low.

Shear by plowing or dragging can move material a long way because the loads are moving a long distance over the surface.

Boots, tracks and tires place almost no shear force on relatively hard soil on flat ground, especially if all the tires and tracks are powered, e.g. a 4WD vehicle versus a 2WD tractor, and the vehicles aren't towing or dragging any loads. If soil is soft, however, tracks and tires (but not boots) need to push forward through the soil and therefore must push back on (apply shear force to) the soil. If a load is being dragged by a human (or a vehicle), the human must also push back on the soil to pull the load. If some wheels or tracks are not powered, they must be "towed" by the others, increasing the required shear force. (All the above are known as tractive forces.) Since shear stress is force divided by area, the tractive stresses can be reduced by increasing the contact area in the same way that compressive stresses can be reduced. On flat ground, however, shear stresses from tires and tracks will in almost all cases be less than the compressive stresses. (Shear stresses are limited by the coefficient of traction – generally around 0.5 – between the wheels or tires and the ground.)

In contrast to displacement by plowing or dragging a load, soil displacement by boots, wheels or tracks is relatively short in terms of distance per pass. The maximum distance depends on the slip between the device and the ground. Consider walking up a slope with loose soil. If your pace is 30” on each step but you slide 3” on each so you only gain 27”, the slip is 10%. Similar calculations apply to tires and tracks. Unless slip is very high, material cannot be displaced very far on each pass. (In the worst case – 100% slip – a tire would spin or a track would move, but the vehicle would not. This condition obviously can displace a lot of soil.)

Vehicles have different means of turning. Most wheeled forestry vehicles have an articulation joint near the center so the front of the vehicle can be angled to the left or right with respect to the rear. This turning action puts very little shear load on the soil because the tires roll in the directions they are pointed rather than sliding. Some small wheeled vehicles steer by skidding, as do essentially all tracked vehicles with two tracks. The wheels (or track) on one side of the vehicle are driven faster in one direction than the wheels on the opposite side, so the vehicle turns toward the side with the slower wheels. Wheels on one side may be stopped or even driven in reverse of those on the other (“turning on a dime”). The amount of soil disturbance will be higher if the radius of the turn is tighter and if the wheelbase (or track length) of the vehicle is longer, and if turns are made over a larger percentage of the total area. Disturbance from steering with a skid-steer vehicle can be avoided by traveling in as straight a line as possible.

F. Compression and Shear on Steep Terrain

What happens when a horizontal surface is tilted? If we have the same equipment or load, compression forces and stresses all drop somewhat because a smaller component of the weight acts perpendicular to the soil surface as slope increases. In the extreme – a 90-degree slope – there is no compressive force, although on a 60% slope the reduction in normal force is only about 15%.

Shear is more complicated. Under a dragged load (log or tree), the shear force is proportional to the normal force on the soil surface, so under the same operating conditions (log size, ground-lead, one-end suspension, soil strength and surface properties) there should be slightly less shear stress and displacement on a slope, if the load is moving uphill. If moving downhill, the shear stress from the load combines with shear created by the soil’s own weight on the slope. As on flat ground, plowing effects from log butts could be substantial if logs are pulled in ground-lead over weak soils.

Tilting the plane under a vehicle (not towing or dragging a load) always increases the shear forces on the soil because the boots, tires or tracks must now develop additional traction to resist the gravitational force trying to pull the vehicle down the hill. At some threshold slope (which depends on the properties of the soil and boots, tires or tracks), the tires will spin out or the boots or tracks will slide if the vehicle tries to travel uphill, and the vehicle will also slip when attempting to move downhill on approximately the same threshold slope. It is reasonable to expect lots of soil disturbance (except on very strong soils) when near the threshold, either uphill or downhill.

A vehicle towing or especially dragging a given load can travel downhill on a given slope with less tractive shear force than when traveling uphill with the same load because gravity assists in moving the load downhill and reduces the required pull force from the vehicle. This also means that the threshold slope for dragging a load is steeper downhill than when traveling uphill.

G. Generation of Fines on Trails

If you pound bare, dry soil with a hammer, you'll destroy its structure and create a loose mix of sand, silt and clay particles. When mineral soil is exposed and the surface is dry (or dries after it has been exposed), traffic can pulverize a little of the soil on each pass. More traffic by boots, tracks, tires or especially of dragged loads will create more readily erodable material, including a powder of fines on the surface. This effect is most common with ground-based whole-tree skidding on drier soils because the dragged whole trees sweep down to mineral soil, the skidder tires or tracks do the hammering, and skidders carry smaller loads than do forwarders, so more passes are required to move the same wood.

H. Impacts to Vegetation

High-strength soils can easily withstand vehicle, tree and log traffic, but vegetation has a much tougher time. The best way to avoid damage is to minimize contact between retained vegetation and equipment, trees and logs. Type of equipment has some bearing. For example, some cable systems can't avoid moving logs over much of the surface area and therefore would cause excessive damage to remaining vegetation. But careful planning and diligent operators are the most important prerequisites for good results.

II. Basic Tools for Avoiding Impacts

In all but the harshest climates there is almost no benefit, yet substantial additional cost, in putting twelve inches of insulation in the walls of a home rather than six inches. Similarly, little compaction will occur if soil strength is greater than the pressure applied by a given vehicle, so additional investment in the vehicle to reduce a negligible impact would be wasteful. But what soil strength and machine pressure do not make a good match? The following presents some basic tools for remedying threshold cases where compaction or displacement might occur, in our suggested order of priority.

To minimize soil compaction when it would otherwise be unacceptable

#1: Increase soil strength by letting it dry. This is by far the most effective and least expensive tool if the soil is in the low-strength portion of its moisture content versus strength curve.

#2: Minimize the percentage of the treatment area affected

- Confine traffic to designated trails
  - Use boom-equipped fellers or harvesters versus drive-to-tree machines
  - If trees are hand-felled, require end-lining
- Locate trails farther apart
  - Use longer-reach booms on fellers or harvesters

#3: Increase contact area with the soil surface

- Reduce inflation pressure. This may require bigger tires or more tires.
- Switch to tracks or larger tracks

#4: Reduce load force perpendicular to the surface

- Use a lighter vehicle with the same contact pressure or even better the same contact area

#5: Increase contact area with the soil surface

- Operate over chips, slash or snow

#6. Eliminate the vehicle

To minimize soil displacement when it otherwise might be a problem

#1: Increase soil strength

#2: Minimize the percentage of the affected treatment area

#3: Suspend at least one end of the load to eliminate plowing

#4: Increase surface and/or grouser contact area with the soil surface

#5: Reduce force parallel to the surface

- Lighter vehicle with the same pressure or contact area
- Eliminate the vehicle
- Carry part or all of load rather than dragging it

#6: Other measures that could be important, depending on the base situation

- Power all the wheels and tracks on the vehicle
- Use vehicles with articulated or other non-skid steering
- Don’t turn with skid-steer vehicles

In some cases, the effects of concentrated traffic near landings could present problems. Examples include powdering of soil on trails, breaking through a snow layer, and the “clearcut effect” due to converging trails or corridors. To minimize these, use more landings closer together along the road. This technique is common in skyline thinning, where corridors are generally parallel to each other and spaced at approximately 150-foot intervals, rather than fanning out radially from a landing.

III. Mechanical Treatment Systems and Techniques

As noted previously, not all equipment of the same generic type, e.g., CTL forwarder, is created equal, nor will good equipment generate acceptable results in the hands of a careless or unskilled operator. Because of this it is important to prescribe results rather than equipment. Defining what the result should look like is also a better way to encourage innovation that may reduce costs.

Recent experiences from the case studies presented at the Workshop suggest a diverse range of equipment can be used with little impact if soil conditions are appropriate and the equipment is used properly. At the Heavenly SEZ site, the soil was apparently dry enough to support traffic from a fairly heavy harvester and forwarder. At Celio Ranch, soil moisture was rather high in one part of the unit, but light, low-ground-pressure machines seemed to produce little negative effect even though they were on skid-steer undercarriages. The tong thrower tested at Homewood demonstrated that highlead logging – generally considered to generate higher soil disruption and vegetation damage than skyline systems – may have created minor and readily mitigated effects over short observed distances (up to 200 feet) in rather open reserve stands.

Several questions must be answered when selecting a harvesting system. Some of the more important in addition to soil conditions and slope include:

- What is to be removed (versus left): boles only, limbs and tops as well? The answer should consider fire hazard, organic matter, nutrients, carbon emissions and economics. If everything is to be removed, it's usually much less expensive to employ a system that leaves the residues on the boles until the material reaches the point where it will be chipped.
- How are residues left on-site to be treated: lopped and scattered or chipped and/or burned?
- What products should be made from material removed: logs, firewood, chips for fuel or mulch? It is generally best to let the market decide this, although in many cases the best options require some assistance. For example, a push to build a biomass-fueled facility in or near the Basin would decrease transport cost and increase the attractiveness of producing fuel chips. If logs have little additional value relative to fuel chips due to long transport distance for the former, consider using a relatively inexpensive system to produce only chips.
- What access is or could be available? Locations of roads are very important for all terrain, but critical for operations on steep ground.

While it's important to prescribe results rather than equipment, a planner must have some idea if, given the constraints, anything is feasible. We believe there are many possible alternatives for the Tahoe Basin and provide the following examples of what might work and why. Hardly any of these are new, and in that sense do not qualify as innovative technology or techniques. For example, as Sue Norman (personal communication) mentioned at the Workshop, the Forest Service has been using CTL equipment in upland areas since the mid-1990s, shortly after it was first tested in California (Hartsough et al., 1997).

Each system may have several elements, each with a different impact, so it's important to consider whole systems. We'll cover stump-to-roadside elements, then transport.

A. Stump-to-Roadside Systems for SEZs

1. Systems Employing Forwarders

The primary benefits of CTL with respect to physical impacts on soils are two: no dragged loads (the result of forwarding rather than skidding), and the potential for the harvester to place slash on the forwarding trails. The primary disadvantage is the large load capacities and therefore heavy vehicle weights of some forwarders. (As noted, not all forwarders are created equal in terms of weight, but loaded forwarders are generally heavier than loaded skidders.) Because the benefit of the slash mat – distributing the load – counteracts the heavy vehicle weight, the clear benefit of CTL has to do with carrying rather than dragging the load, and for this reason we prefer to classify by forwarding versus skidding, if soil impacts are the primary consideration.

Forwarders transport suspended loads (logs or trees) off the ground, so there is no soil disturbance from plowing or dragging. Forwarders range in total weight and load capacity, so if soil strength near the surface or at depth is marginal, larger low-pressure tires or tracks, smaller payloads and/or smaller machines could be used.

a) The standard Cut-to-Length (CTL) system includes two machines: a harvester (carrier, boom and head) and a forwarder. Both machines travel on trails that are spaced approximately twice the reach of the harvester's boom. Harvesters come in various sizes, but they are generally irrelevant from the soils impact standpoint because the loaded forwarder is the heavier machine. The harvester fells, limbs, bucks and tops the trees, leaving logs windrowed along the trail and slash either on or near the trail. The forwarder picks up and transports the logs.

The CTL system leaves residues – lots of very small pieces – on site. This is fine if that's the objective, but it's very expensive to collect the small bits if they are then to be removed. Leaving the woody residue counteracts the project's reduction of overall fire risk. There are at least two approaches for collection of wood residues: use the log forwarder to pick up and transport the residues. This is very expensive because it takes a lot of time to pick up the small pieces, and the residues are fluffy, so the forwarder fills to its volume capacity long before it reaches its weight limit. Sue Norman reported that, at the Heavenly SEZ project, approximately half the cost was associated with collecting and transporting the residues in this way. Another option, developed in Scandinavia, is a slash bundler. This machine, on a forwarder chassis, picks up the residues (still a slow process), compresses and binds them into uniform bundles, then drops the bundles for pickup by the forwarder. The forwarder is then used more efficiently, and the bundles can be transported on highway without being chipped first. This method is still costly and requires an additional machine – the bundler.

b) Whole-tree or tree-section forwarding. Let us suggest a possible modification to the above system that might use the same equipment but allow some or most of the residues to be removed with the boles. This approach is especially attractive if all material is to be chipped. The harvester (or a less expensive machine that just felled) would fell but not process the trees. Those short enough to be carried by the forwarder would be left in one piece; longer trees would have the lower logs bucked until the rest of the tree was of acceptable length. Similar approaches have been used in Nordic countries (Jylha, 2004; Kvist, 1988). In some cases the forwarders have been equipped with grapple saws to buck the trees to shorter lengths when necessary. The forwarder would transport material to the landing, where it would all be chipped (easiest) or processed into logs and residues by the harvester. The forwarder load weights would be reduced because of the fluffiness of the whole trees, but this would be offset somewhat by the longer lengths carried. Jylha (2004) obtained load weights of 56% of capacity on a forwarder transporting whole-tree sections of Scots pine. Zundel (1986) found that log trailers loaded with whole-tree Jack pine carried only 44% of the merchantable volume on trailers loaded with limbed tree lengths. A forwarder could be extended (longer models are available commercially as well) to accommodate whole trees or whole-tree sections.

c) Cut some to length. Another option would be to cut and process any valuable sawlogs along the trail and leave unlimbed logs of marginal value intact with tops to be chipped. All material would be collected by the forwarder, in mixed or separate loads at the contractor's preference. This would avoid the need for further processing of sawlog material at the landing, and still remove a substantial portion of the residues from the site.

2. Systems Employing Skidders

Skidders can transport whole trees, limbed and topped tree lengths or bucked logs.

a) The standard whole-tree system employs a feller-buncher to cut and pile trees, a grapple skidder to drag the trees (with one-end suspension) to the landing, and a processor to delimb and buck at the landing. Feller-bunchers can be classified as drive-to-tree or boom-equipped. Either type may be mounted on a skid-steer or other type of carrier. If conditions dictate that the trafficked percentage of surface area be minimized, boom-equipped machines are preferable because they can reach to the side of a designated trail as does a harvester. Skid-steer drive-to-tree feller-bunchers can disturb a lot of soil because they usually must turn sharply to cut and bunch trees. Boom-equipped skid-steers can generally travel in fairly straight lines, and therefore should not generate substantial soil disturbance if operated well.

A grapple skidder and the load it carries are generally lighter than a loaded forwarder, so compressive pressure at depth may be less than for a forwarder. But skidding tends to sweep the soil surface free of organic matter after one or more passes. When surface soil is dry or dries during the operation, the combination of wheels or tracks and dragging whole trees will in many cases produce a powdery layer of soil that will increase with the number of passes. Skidding may be acceptable if little total traffic runs over each trail, e.g., where the amount of material to be removed on each trail is small. This might be the case for narrow SEZs where roads run parallel to and adjacent to (or within) the SEZs.

b) To eliminate most of the dragging and associated surface disturbance, a skidder might be equipped with either a towed arch that lifts the tops of the trees or a telescoping dolly that could be extended back and under the load, lifting the load mostly off the ground. We don't know of any such dolly, and the efficacy of one would have to be tested.

3. Variations on Felling Prior to Forwarding or Skidding

Standard harvesters can reach approximately 25 feet or so, but long-reach booms with reaches of 40 feet or more are available. Trials in riparian reserves in Canada with a harvester equipped with a long-reach telescoping boom found the machine to be as productive as standard-reach machines and to cause no notable soil disturbance (Desrochers, 2007).

Trafficked trails can be spaced farther apart if trees are felled (and limbed if residues are to be left on site) by hand and endlined (winched) to the trail by a skidder or forwarder equipped with a winch. Winching will produce some plowing and/or surface disturbance, but the process may involve only one or a few dragging passes over any specific location.

4. Lighter Skidding and Forwarding Equipment

If surface strength is adequate but the water table is high, hand felling and a very light vehicle such as the walk-in-front Iron Horse tracked skidder described by Steve Rheinberger (personal communication) might be employed instead of hand-carrying or hand-piling.

Somewhat larger and more productive devices for skidding hand-felled trees include small skidders and farm tractors, but these might have to be equipped with low-pressure tires if compaction is a main concern. Dragging effects can be reduced or minimized by adding a towed arch or trailer such as those described by Dunnigan (1990) or Folkema (1987).

5. Cable systems

Where adequate deflection is available, a small skyline system (Yoader, small tower or swing yarder) could be employed to provide one-end or even full suspension of hand-felled trees within SEZs. Cable systems eliminate the effects of vehicle traffic within the yarded area, and produce little (one-end suspension) or no (full suspension) surface disturbance from dragging loads. However, successful cable operations require the right topography (adequate deflection), careful analysis, access for the yarder to appropriate landing locations, and the availability of adequate anchors and (sometimes) lift trees. Setup costs for cable systems can be a substantial part of the total yarding cost, and total costs per acre are generally higher for skyline systems than for ground-based systems because of the less efficient use of labor as well as the setup.

6. Working in narrow SEZs

While the methods above can be applied in SEZs of any width, other options may be useful in narrow zones.

a) “Shovel logging” is one possibility: Trees are felled by any method, then a log loader on an excavator base travels into the area. It reaches out and grapples the logs farthest from the road, then rotates and drops the logs closer to the road. The loader covers the unit in several swaths, moving each log multiple times until all are at the road. This method can be employed where soil strength is adequate to resist the compressive stresses from the machine. Shovel logging produces little shear stress on flat terrain and requires only a single pass of the machine. The loader swings a lot, however, so damage to reserve vegetation will probably be unacceptable in dense stands.

b) Winching. If the impacts of dragged logs (minor in terms of compaction) are acceptable but machines are not, a couple of options may be feasible for removing hand-felled trees or logs. The worst-impact case would be groundlead endlining with a winch on a skidder. A high-lead system such as a tong thrower would be preferable to groundlead, although the tong thrower itself is more applicable in clearcuts or heavy thinnings than in cases where reserve stands are denser. But an excavator equipped with a single winch can be used in a similar highlead fashion by relying on a human or a small winch (maybe mounted on an ATV) to pull the cable out to the trees. Recently developed synthetic ropes have the same strength as steel ropes of the same diameter, yet weigh about one-seventh as much, making it easy to carry or pull the line a few hundred feet from a winch on a skidder or excavator.

Lightweight skidding pans, sleds or cones can be placed under the butt ends of small logs yarded with ground-lead or highlead methods. These devices eliminate most of the plowing effects of the butts.

c) When SEZs are less than a few hundred feet wide, it may be possible to use a long-reach feller or harvester located outside the SEZ to mechanically cut and remove all or most of the trees inside the SEZ.

7. Moving Wood by Hand

All the systems above rely on equipment to move the wood. This is much more productive than moving wood by hand, and is therefore the way to go if limited season of operation and limited labor pools are factors. A few systems that combine partial hand transport with machines follow.

a) The system tested by Martin Goldberg (personal communication) at Celio Ranch involved hand piling of short logs after hand felling, limbing and topping. The careful planning of the hand piling allowed a skid-steer ASV loader to collect the logs without substantial turning. The loader traveled forward into the stand, picked up a load, then backed out. This avoided the soil disruption that could result from turning such a vehicle. Although the intent was to stay on existing truck trails, the ASV apparently did travel off these at times, as must happen with machines such as this that are not equipped with booms.

b) Baling and removal might be considered as an alternative to piling and burning. A hand-loaded baler for use in the WUI, to produce dense rectangular bales that can be easily transported on relatively small vehicles (Lanning et al., 2007) is currently under development; albeit is not yet commercially available.

c) While a conveyer is an ideal device for moving material – it can transport continuously and can be loaded to capacity all the time (if material is available to it) – the problem is getting the conveyer to the wood or vice versa. The zig-zag cable yarding system (Miyata et al., 1986; tested in several places in California including the Shasta-Trinity NF, Shingletown and Tahoe NF during the late 1980s and early 90s), which can be used on flat or steep ground, has the same benefits and disadvantages. In addition, conveyers and zig-zag systems require substantial setup time.

8. Over-the-Snow Operation

As Richard Adams (personal communication) stated at the Workshop, California State Parks successfully employed over-the-snow logging in the Tahoe Basin for 15 years. He noted that, as for prescribed fire, one must be willing to delay operations when the conditions (in this case snow depth, density and temperature) won't allow an acceptable result. Michael Hogan (personal communication) suggested operating during the spring so heavy snows during the operating season won't bury the felled trees. Just-in-time felling can prevent this problem. In any case, snow operations in the Basin cannot be counted on with certainty. They may be of use by adding a second season and therefore allowing a contractor to treat more area per year, but the uncertain prospects and idle time will probably increase the costs. Real-time monitoring would be crucial for over-the-snow treatment, because soil strength is likely to be very low and therefore soils would be very susceptible to both compaction and displacement if vehicles break through the snow cover.

Groundlead or highlead transport over snow would be effective over a longer season than would vehicular operations. A synthetic rope and snowshoe- or ski-equipped human haulback would allow yarding up to a couple hundred feet from the road.

B. Stump-to-Roadside Systems for Steep Slopes

With the exception of two-drum (skyline and mainline) skyline systems, all methods mentioned here can also be employed on flat or gentle terrain. Several have already been mentioned for use in SEZs.

As described previously, shear stress and attendant soil movement become relatively higher concerns on steep terrain. In addition, careful planning is critical, especially for longer-reach cable systems, but for traction equipment as well.

1. Shovel logging, as described by Steve Rheinberger (personal communication), might be employed to yard uphill or downhill on slopes less than 35% (logs tend to roll or slide on steeper slopes), in cases where reserve stands are relatively sparse and yarding distances to roadside are less than about 400 feet. We have no personal experience with this method.

2. Tractive Systems for Downhill Yarding on Slopes < 40%

Equipment such as skidders and forwarders should not be used to move loads up steep slopes, for two reasons. Travel with a load up a hill is much slower and therefore more costly because the machines must work against gravity. For skidding, wheels or tracks slip more and therefore create more soil disruption when moving uphill than down, because of the extra tractive force required to drag skidded loads.

Because steep terrain is more broken than flatter ground, planners must carefully locate trails for skidders and especially for forwarding. CTL harvesters are no more sensitive to slope than feller-bunchers or skidders, but forwarders have high centers of gravity and therefore to prevent rollovers must travel directly up or down steeper slopes when loaded.

a) Forwarders: A harvester and a forwarder can work well on slopes up to 40%. This system would be a good option if site managers prefer to leave residues on site. As described for SEZ systems, a standard-length or longer forwarder could transport tree sections or whole trees if it is considered preferable to remove tops and limbs from the site.

b) Skidders: A combination of boom-equipped feller-buncher and grapple skidder may suffice on these slopes, especially if only a few passes are necessary on each trail so surface disturbance is not excessive.

3. Cable Systems

Cable systems – where the transport machine remains on the road – are typically used on steep terrain because they eliminate the shear stresses that would be applied by traction equipment. But slope is not a requirement, except for two-line (skyline and mainline) skylines: other cable systems can be employed anywhere the terrain and other conditions allow. Cable systems generally are more expensive than traction equipment where the latter can be employed, however, for the reasons mentioned previously.

Where traction equipment cannot be used, trees are felled (and limbed and topped if residues are to be left on site) with chainsaws. Several means can be used to move the felled trees to roadside.

Given the success of the tong thrower at Homewood, systems that produce similar or lesser impacts when soils are dry should be acceptable. The tong thrower is a short-distance high-lead system – logs are fully in contact with the soil if at some distance from the machine – so systems that produce true one-end or full suspension will have less soil impact. Use of any high-lead system at longer distances will probably produce plowing/rutting due to the essentially ground-lead pull direction, although use of the skid pans/sleds or cones mentioned earlier would help avoid this.

a) Tong throwers yard very inexpensively and effectively for situations where reserve stands are fairly sparse and yarding uphill over distances less than 200-300 feet. They should not be used to pull downhill on steep slopes because yarded logs will tend to slide and roll, damaging reserve vegetation. They can only yard in a line-of-sight direction (unless snatch blocks are used).

b) As on flat ground, short-distance thinning of denser stands can be accomplished with an excavator equipped with a single winch, fairlead, synthetic rope and a human haul-back or small haul-back winch. As for a tong thrower, this configuration is not applicable for downhill yarding on steep terrain. It yards in the line-of-sight and therefore requires trees to be felled close to the line of pull. This system is also a high-lead device and will not provide true one-end suspension.

c) If terrain is not too broken and logs are to be yarded directly uphill, a two-drum (mainline and haul-back) high-lead system equipped with a skidding pan or cone (mentioned previously) or a wheeled dolly might effectively yard at longer distances while providing one-end suspension and therefore eliminating plowing by the front ends of the logs or trees. We know of no operational use of a dolly, although such a concept was patented several decades ago.

d) For longer distances or where suspension is needed to avoid soil rutting or sweeping, skyline systems may be employed. Many variations are available, from small fixed towers, to converted excavators, to swing yarders. Again, managers should specify results rather than equipment, but planners must know what range of equipment might be available locally because a layout planned for equipment with certain capacities – a maximum reach of 2000 feet for example – will be useless for yarders with only 1000 feet of skyline capacity.

Skyline systems with lateral yarding capability, i.e. to either side of the skyline as well as along the skyline, should be used in thinnings. Lateral yarding can be accomplished with two-drum (skyline and mainline) machines with locking (ok) sequencing (better) or motorized (even better) carriages if yarding uphill, or three-drum running skyline or four-drum live or standing skyline machines with mechanical slackpulling carriages for any condition.

Take a brick and a seven-foot piece of string. Tie the midpoint of the string to the brick. Now invite a friend to hold one end of the string while you hold the other. Stand right next to each other and both pull straight up on the string ends so the brick is just completely off the ground. This won't take too much tension (pull) on the string ends. Now pick up the brick by hand and set it on a standard-height table. Stand on one side of the table with your friend on the opposite side. Each of you hold your end of the string against your shoulder. Both of you back up until both parts of the string are tight, then back up a little more until the brick is just lifted off the table. Hopefully, you'll find that the tension (pull) required to lift the brick off the table was a lot higher than that needed to lift the brick off the ground. The reason is, when you were on either side of the table, most of your pull was "wasted" in that it was opposing the pull from the other person instead of contributing to useful lifting. The closer the two sides of the string are to a horizontal line between the two ends, the more tension is needed to lift a given load. Another way of stating this: if the center of the string is deflected further below a straight horizontal line, a bigger load can be carried with the same amount of tension. Deflection is essential for skyline systems: terrain with a straight (whether horizontal or not) profile will allow little deflection and therefore result in low load capacity, while U-shaped terrain offers lots of deflection and big payloads. If a skyline unit is planned badly and does not have adequate deflection, log ends will drag on the soil surface, creating furrows or ruts, or they may not be able to be moved at all.

Planning for cable systems is much more involved than for tractive systems because of the need to analyze deflection and lift capacity, and other issues such as guyline anchors, tailholds and multispan support trees.

In most thinning situations, logs should be yarded uphill, so roads must be at the top of the areas to be cable yarded. Logs yarded downhill or across slope when suspended by one end will sweep downhill or swing out of control, damaging reserve vegetation. It is possible to yard downhill or cross-slope without excessive damage if logs are short and fully suspended, although full suspension is difficult to obtain with small yarders unless the terrain is ideal. The Tahoe Basin does have some areas with concave terrain that might allow full suspension. Another option: attach the trailing ends of logs to a trailer on the skyline carriage so the logs won't swing around and damage the reserve stand.

Even when yarding wood to a road at the bottom of the skyline, two-line (skyline and mainline) systems require the yarder to be located at the upper end, so planners need to include a means of getting the yarder there. Some sled-mounted yarders can pull themselves up a hill, while others might be carried in by helicopter or towed over low-standard trails.

e) Helicopters can also yard on essentially any terrain. Other than substantial carbon dioxide emissions, helicopters have small environmental impacts. Helicopter logging became popular during the 1970s, but planners soon learned to employ other systems such as skylines where possible, to avoid the very high costs. Helicopters have less lift capacity at higher elevations such as those within the Basin, due to lower air density, further increasing costs. Retired Forest Supervisor Bob Harris (personal communication) noted two problems that limited the use of helicopters when they were employed for salvage logging on the east side of the Basin one year during the 1990s. In much of the area, logs had to be flown over highways, which could only be closed at night. The helicopters were committed to fire suppression duties as top priority, and that service overlapped with two-thirds of the expected operating season in the Basin.

In a recent effort in British Columbia to reduce yarding costs in areas with smaller trees, a feller-buncher was custom-built to be separable into eight pieces which can be flown into a unit to be harvested (Dunham, 2006).

C. Miscellaneous

1. Why would you consider using a walking vehicle? There are three possible reasons.

a) Rutting may be an issue even if the related compaction is not. In most of these cases the problem to avoid is channeling of runoff, which can be mitigated by waterbarring the trail. In theory, rutting can be avoided by walking rather than using tires or tracks which by their nature must cover the whole trail between points A and B. But the feet must be placed in the same spots on subsequent passes or the footprints may soon coalesce into ruts, as they do on soggy hiking trails.

b) Walking can reduce displacement due to shear stress on steep slopes by avoiding the rolling resistance encountered by wheels or tracks.

c) A backpacker sometimes walks on high or strong spots rather than on random spots, for example when fording a creek or hiking on a muddy trail. On steep or wet terrain, a machine might place its feet on stumps, assuming the root systems would distribute loads over more soil, so as to reduce compaction on wet soils and shear on steep terrain.

Where can you get such a device, other than a human?

Walking or semi-walking vehicles are available for special purposes. Walking excavators are really hybrids between wheeled and walking vehicles; they still have wheels that roll over the ground, but they use legs for stability and to assist when traveling (very slowly) on steep terrain. The wheels and legs can be raised or lowered to keep the chassis level when operating on a slope. These vehicles are best adapted to activities where the work doesn't involve a lot of travel, e.g., digging a trench. They have been used to fell or harvest trees on steep terrain.

The Plustech prototype forestry machine was a true walking device, equipped with six legs, capable of traveling at reasonable speeds. We aren't aware of any continued development of this prototype, but a video is available at www.unoriginal.co.uk/footage32_6.html.

2. Radio controls can reduce the labor requirements and therefore the costs of some operations. They are especially useful for machines equipped with single-drum winches such as skidders and small chippers, and are standard on motorized carriages for skyline

systems. Radio controls sometimes also allow the operator to remain nearer to the load being pulled and thereby avoid damage to reserve vegetation.

D. Chipping (or Grinding)

As Ken Anderson (personal communication) mentioned at the Workshop, most of the public would love to see material chipped (and removed or left) rather than burned on site. If it is to be left distributed on trails or over the site, either self-propelled woods-mobile chippers or masticators, or small towed chippers can be employed. A number of the former seem to be available close by (Homewood, Meeks Bay, Northstar), and CTL Forest Management – the contractor with the majority of the recent mechanical treatment experience in the Basin – owns both a chipper and a masticator.

If material is to be chipped and removed from site, the standard practice in North America is to chip or grind the material at roadside, directly into bulk chip containers (usually vans). This generally requires a relatively large landing. In parts of Scandinavia, self-powered chipper-forwarders travel within the stand, chipping material into a bin on the back of the machine. Loaded bins are carried to roadside and dumped into roll-on/off containers or other means for transport.

The largest potential impact from stand-mobile chippers is compaction, and compressive stress depends on machine weight and surface contact area as for any other machine.

The smallest chippers are fed by hand, some units have winches to assist, and the most productive have loading booms and grapples. Chippers with infeed decks and conveyers are best for handling a mix of whole trees and residues, while those without decks are fine for trees but not very productive when chipping slash.

As mentioned earlier, a fully mechanized system for producing only whole-tree chips can be rather simple and inexpensive per acre: a feller-buncher, grapple skidder or whole-tree forwarder and a chipper. If the at-roadside value of logs is not substantially higher than chips, or if the total volume of logs is small, chipping all the material may be the most economic alternative.

E. Transport

The cost per mile for a truck is not affected much by the size of the truck, because much of the cost is for the operator. Also, as one moves from a smaller to a larger truck, payload capacity increases much more rapidly than does the purchase price of the truck. As a result, the cost per ton-mile is least if material can be hauled on trucks with the largest standard legal payloads of approximately 25 tons. For a truck with half the maximum payload and on longer hauls, the cost per ton-mile is almost double that for a standard vehicle. Large trucks, especially chip trucks, require higher-standard roads (especially shallower curves) than do smaller vehicles, and spots where they can turn around at or near the landings.

If roads or landings are not up to eighteen-wheeler standards or if large trucks are objectionable, roll-on/off chip containers or log bunks offer a more expensive (per ton) option. A single roll-on/off container may hold 10-12 tons, so cost per ton-mile would be roughly twice that for a full-sized truck. Rectangular bales can be carried on flat-bed trucks, small to large.

F. Roads and Other Access

Roads are expensive to build, as expensive to remove, and generally create more environmental impact than all the harvesting carried out from the road, assuming the harvesting is planned and conducted carefully. It is therefore important to utilize the existing road and trail network as much as possible. For example, use of an existing road in the drier portion of a SEZ would almost certainly be preferable to locating a new road just outside the SEZ. Most of damage associated with a properly maintained existing road has already taken place.

We are not aware of a comprehensive evaluation of road network in the Basin, although a quick perusal of maps and anecdotal information presented at the Workshop gives the impression that many flatter areas have roads nearby. Dave Fournier's more rigorous analysis of Forest Service roads in condition categories 3-5 indicates that only a small percentage of National Forest land in the Basin is accessible, especially the steeper terrain. Tahoe Basin agencies might want to consider obtaining new data that would permit a comprehensive evaluation of the existing and retired road net-work. Aerial data acquisition systems such as LIDAR (bare earth return signal) and the associated post-processing can provide detailed information about historical roads regardless of vegetation cover. For some high priority projects, these retired roads may provide an effective means for completing mechanical treatments with a minimum of ground disturbance.

Cable systems are the most likely candidates for mechanical removal on steeper terrain, and, in thinnings, create the least damage to reserve vegetation when loads are pulled uphill, implying that roads should be at the tops of steep treated units. As noted previously, this is not always the case, and clever planning and operation may allow for full suspension during downhill yarding to valley-bottom roads.

If only a single entry for mechanical removal is anticipated in steep areas where roads are not in the right location, one alternative for some areas might involve what is known in harvesting parlance as "swinging." Low-standard forwarder trails with slopes of up to 30% where needed, could be constructed from existing roads to access the tops of the treatment areas. A yarder would pull material from within the areas to the trails. A forwarder would then "swing" or transport the wood along the trail to the road. This extra step is not cheap, but may be less expensive in terms of dollar cost and environmental impact than that of constructing a higher standard road for a single entry.

We fully endorse Steve Rheinberger's (personal communication) suggestion to engage an experienced forest engineer/harvesting specialist to participate in a Basin-wide planning exercise to identify where the limited resources should be employed for prescribed burning only, mechanical treatment with or without underburning, and as a consequence for any new roads. An appropriate access network is critical. Planning any new access should involve large-scale analysis of where best to use the limited resources. This would involve modeling the impacts of treatments on potential wildfires as well as the costs of access and impacts of the fuel reduction operations themselves.

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