# REDUCING LOG TRUCK TRANSFER OF MUD TO PUBLIC ROADS

by

James M. Keesee

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APPROVED:

R M Shaffer
R. M. Shaffer, Chairman

W B Stuart
W. B. Stuart

TW Reisinger
T. W. Reisinger

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Committee Chairman: Robert M. Shaffer

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## (ABSTRACT)

The objective of this research was to design and test devices for addition to log trucks that removed mud from the dual-tires before the trucks entered the public road. The four devices built were simple, inexpensive, and could be built by a logging or trucking contractor. The "bar and scraper" and "mud flap" removed 85% and 84% of the mud, respectively, that adhered to the dual-tires during the test. The "bar" and "rope" removed 78% and 40% of the mud, respectively.

# Acknowledgements

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# INTRODUCTION

The transfer of mud from muddy logging roads to the public roads by log trucks is an operational problem for loggers and the forest industry as a whole. Public pressure is turning this operational problem into a legal problem. Mud on public roads in not only unsightly, but poses a serious threat to the safety of motorists. Automobile accidents, injuries, and even deaths result when mud is unexpectedly encountered. Several civil lawsuits have resulted from accidents caused by mud from logging operations. Many county supervisors or road commissioners obtain court injunctions to halt logging if they become aware of the problem or receive complaints from citizens. Expensive fines or halted logging operations are sometimes the result.

The transfer of mud from logging operations occurs during the winter and early spring months when weather conditions are such that logging roads remain muddy most of the time. Even the frequent summer afternoon thunderstorm can cause the problem. As log trucks travel slowly over the muddy haul roads, mud from the road packs into the space between the dual-tires and sticks to the tire tread and sidewalls. When the wheels of the non-driven trailer axles sink in the mud to a depth approximately one quarter of their radius, the rolling resistance increases to the point where the tires slide rather than turn. This causes mud to pack more forcefully into the dual-tire space. As the trucks enter the public road and begin to accelerate, the mud is thrown from the dual-tire space, tread, and sidewalls by the increasing centrifugal force. The flexing of the tire sidewalls as they turn also loosens the mud packed into the dual-tire space. The larger chunks of mud are expelled at low speeds near the entrance to the road and as the trucks' speed increase the smaller and more cohesive particles are expelled.

Mud transfer can be eliminated in several ways. The most obvious method is to halt the logging operation. This is not a viable solution for most logging contractors in light of the high fixed expenses of some logging contractors and the production-based pay system used by the forest industry. Improved logging road location, formation, and the use of pavements can eliminate much of the mud transfer.

Location of roads on less cohesive and better draining soils will reduce some of the mud transfer. Improved formation of the road during construction to provide a more stable, better draining, faster drying road can reduce the amount of muddy roads trucks must travel. Compaction of the subgrade with a sheepsfoot roller during formation of a raised, crowned, or out-sloped road surface improves the road's strength and drainage qualities. The use of permanent and temporary pavements also reduces the contact between log trucks and muddy roads. Useful permanent pavements include crushed stone, alone and in combination with geotextiles, wood chips, sand, soil cement, and soil-hydrated lime mixtures. Temporary pavements include wooden, metal, and rubber mats.

Much of the timber harvested in the South is on private tracts of land of less than 100 acres. The economics of harvesting these small tracts eliminates all but the least expensive of these construction methods. Increased road building costs increase harvesting costs and reduce stumpage payments to private landowners. Therefore, only low cost temporary roads are constructed and retired after harvest. These are no more than a single lane road "brushed out" with a small dozer shortly before logging is to begin. Wooden mats or crushed stone may be used on these temporary roads. Road construction methods beyond this to improve access require significant lead times. Lead times reduce harvesting flexibility, require longer range planning, and further tie up a logger's capital.

When the mud transfer can not be eliminated easily or economically through road construction methods, loggers make an effort to clean the mud off the public road. Some use shovels and others scrape the mud from the road with a skidder. Some even rent or lease portable high-pressure water sprayers to wash the mud off the road.

In 1987, members of the Industrial Forestry Operations Research Cooperative at Virginia Tech identified "mud on the roads" as one of the major operational problems affecting the forest industry in the South. Four cooperators, Bowater Inc., Cheasapeake Corporation, Inland-Rome, Inc., and Procter and Gamble Cellulose provided funding for a thesis project to address this problem. The study began with a broad approach, including a literature review and several field trips to observe possible solutions to the problem.

Logging road construction and maintenance techniques as well as other innovative ideas were examined.

Ultimately, the study team narrowed the focus to designing and testing devices that, when attached to a log truck, would effectively remove the mud from the dual tires prior to entering the public road. Such a device, to be successfully adopted by logging contractors, must work well, be simple in design, easy to use, inexpensive to construct and mount, durable, and be built by a logger himself.

An experimental study was designed to test such devices under conditions simulating actual logging operations. The objective of the study was to evaluate the effectiveness of such devices in eliminating the mud transfer. Other evaluations included the ease and expense of construction and attachment to the truck and the ease of activating the devices for mud removal.

# LITERATURE REVIEW

This literature review will cover permanent and temporary pavements, tire and wheel modification, and any other methods found in the literature that provide a possible solution to the problem of mud on public roads. Some topics have more relevance than others to the specific problem, but all are worth consideration.

## Permanent Pavements

### Crushed stone.

One of the most common pavement types used on logging roads is #3 or #1 crushed stone, (2 to 5 inches in diameter), spread at the intersection of the logging road and the public road (Figure 1). It is spread for a distance of 50 to 100 feet into a logging road to give the log trucks a firm, solid area to enter and exit the logging road and prevent damage to the public road. Stone is also used to improve areas of the logging road that contain a weak subgrade, thus increasing the bearing capacity of the subgrade.

Figure 1. Crushed stone spread at the entrance to a logging road.

Crushed stone helps prevent "mud on the roads" in two ways. When used in "muddy" or wet areas, it prevents the trucks from contacting and picking up large quantities of the mud. If the stone is spread for 500 or more feet into the logging road , it may allow the truck to obtain speeds generating enough centrifugal forces to force the mud out of the dual-tires before entering the public road.

## Geotextiles.

"Geotextiles are synthetic, polymerbased engineered fabrics used in various applications such as: asphalt overlays, stabilization of subgrades, impermeable liner protection and many more" (Anonymous, 1988). Using reinforcement materials for roads dates back to ancient civilizations where straw and fiber mats were used to strengthen soil used in road construction (Sequerth, 1987). The oldest recorded use of a fabric in road construction in the U.S. dates back to 1926 when the South Carolina Highway Department placed a cotton fabric between an earth base course and a layer of asphalt (Schmidt, 1985). Petromat, introduced by Phillips Fiber Corp. in 1966, was the first commercially manufactured geotextile fabric (Anon., 1979). Presently, over 30 different companies manufacture 300 different types of fabrics to supply the North American market (Sequerth, 1987).

The most common fabrics available today are made from one of three types of raw materials - wood pulp, petroleum, or silica (Schmidt, 1985). Polypropylene, a petroleum based fabric, is the most popular choice because of its strength and handling ease (Thomas, 1985). Nonwoven fabrics as well as fabrics woven from monofilament and multifilament fibers are available (Schmidt, 1985).

Geotextile fabrics have been used in high standard public road construction for many years, but their use on low standard, temporary forest roads has begun only recently. When used in temporary road construction, the fabrics serve three main functions. They separate the aggregate layer from the subgrade soil preventing their mixing, filter soil particles from water passing through the fabric, and reinforce the road system by distributing vertical loads over larger surface areas while confining the aggregate layer through the tension forces developed in the fabric (Berden, 1978; Schmidt, 1985). The most important of the three functions are separation and filtration; while doubts exist concerning the reinforcement function of the fabrics when used on forest roads.

Fabrics are used in logging road construction to provide separation between the weak subgrade and the aggregate surface (Peddie, 1987). The subgrade soils of most concern are the saturated fine-grained silt and silty clay soils which usually have low load carrying capacities when wet (Bender, 1978). On roads without geotextiles, traffic weight presses the aggregate into the weak subgrade and causes the subgrade soil to rise to the surface. As a result of this mixing effect, the subgrade soil fills the pore space in the aggregate layer thus reducing its drainage and load bearing characteristics (Bender, 1978). More aggregate material is usually necessary as a result of this mixing.

The filtration function of the fabric is important to their use on forest roads. The fabric must be porous enough to allow water to pass through yet filter the soil particles from the passing water. Water flowing from a saturated subgrade into the aggregate layer, reduces the internal pore pressure, increases the bearing capacity, and increases the bulk density of the subgrade soil, thus creating a firmer base for the aggregate and fabric (Bender, 1978).

The extent of the fabric's reinforcement function is not as agreed upon as its separation function. H. L. Thomas (1985) writes that the fabric converts the compression load applied by traffic into a tensile stress in the fabric. Friction between the fabric and aggregate surface and soil subgrade prevents the fabric from slipping and collapsing into the subgrade under the compression load of the tires. In other words, the fabric behaves like a trampoline to support the traffic load.

The aggregate materials have little or no tensile strength themselves, but when placed over a subgrade, the friction between the two layers prevents one from slipping along the other. A geotextile fabric increases the friction forces between the two layers, thus increasing the load bearing capacity of the road (Bender, 1978). The fabric also reduces the horizontal strain forces at the interface of the aggregate layer and the subgrade by confining the aggregate and subgrade and preventing the depression of the aggregate and the "upheaval" of the subgrade (Bender, 1978).

Douglas and Addo (1986) disagree with the theory behind the reinforcement function when fabrics are used in construction of forest roads. The surface layer of the forest road above the geotextile is usually too thin to develop enough friction between the fabric, soil subgrade, and surface aggregate to create the tensile force required for reinforcement.

Douglas (1986) explains that few tensile forces are generated in forest road applications because sufficient anchorage of the fabric is not present. The fabrics used in forest road construction are usually 10 to 15 feet wide, leaving 2 to 8 feet extending beyond the wheel tracks. Insufficient amounts of aggregate are spread outside the wheel tracks to anchor the edges of the fabric and create tensile forces in the fabric.

Geotextile fabrics can be economically used when the cost of the fabric is less than cost of the eliminated surface aggregate, the difference being a direct savings during initial road construction. Should more aggregate be necessary during use of the road, the frequency of these applications should be somewhat less than usually required.

Tests. Bender and Barenberg (1978) performed a test on road systems with and without geotextiles to determine the effect geotextile fabric properties had on the performance of road systems. A three-dimensional test was performed in an eight-foot wide test track twenty-five feet in diameter. It was determined that before extreme rutting appeared the vertical stress levels applied to a road must be six times the subgrade soil shear strength when expressed as its cohesion. Results of a two-dimensional test on a road system showed permanent rutting to be greater in the road system without a geotextile fabric. Rutting was less severe and stabilized to the point were further loading did not cause further rutting on the road system containing the geotextile.

Douglas and Kelly (1986) performed a test to determine the effect of anchoring the geotextile on road performance. Two geotextiles, one with a tensile modulus four and a half times the other, and a sheet of polyethylene film were used.

To justify their test, the authors briefly referred to the results of a previous test where the same two geotextiles and polyethylene film were used unanchored. Although the two geotextiles had different tensile moduli, they increased the stiffness of the road section by the same amount, 21 percent. The polyethylene film increased the road stiffness by 9 percent.

Douglas and Kelly noted that the first study left an unanswered question concerning whether the poor performance of the high modulus fabric was due to its lack of anchorage during the test. To answer that question, Douglas and Kelly designed and performed the same test using the same geotextiles and polyethylene film in a fully anchored condition.

The two fabrics and polyethylene film were used in a "road system" that consisted of a peat subgrade saturated to a water content of 500 to 800 percent and a 150 mm gravel surface. A load was placed on the "road system" by a 250 mm wide I-beam in two load cycles. The resultant road stiffness was measured as the slope of the curve of the average pressure applied plotted against the average vertical displacement of the I-beam.

The results of the anchored test showed that there was no significant difference between the performance of the road sections containing the low modulus and high modulus fabrics. The results also showed that the polyethylene film performed almost as well as the fabrics, and that neither the fabrics nor the polyethylene film greatly improved the stiffness of the subgrade. The stiffness of the peat subgrade was improved 45%, 52%, and 31% by the anchored woven fabric, nonwoven fabric, and the polyethylene film respectively. The difference between the results of the anchored and unanchored tests were very small. Anchoring the high modulus fabric increased the road stiffness by only 7% over the unanchored stiffness. The increase was only 2% for the low modulus fabric and only 3% for the polyethylene film.

Designs. Several articles reviewed design methods for construction of unpaved roads on poor load bearing soils using geotextiles.

A representative of Phillips Fiber Corporation notes three essential elements necessary to follow the design procedure for their Supac N line of geotextiles (Anon., 1984). The strength of the saturated subgrade soil six to fifteen inches deep measured using a cone penetrometer, vane shear, or a California Bearing Ratio (CBR) device is needed as well as the traffic type and tolerable rutting. A series of charts developed by Phillips can then be referenced to determine the required aggregate depth and fabric type.

Giroud and Noiray (1981) describe in detail the process for constructing tables and graphs necessary to determine the aggregate thickness and fabric type. The soil strength and vehicle load are needed for the design. Individual charts are developed for different vehicle loads, allowable rut depths, and tire inflation pressures. By choosing a chart, the recommended aggregate thickness can be determined for a specific CBR value of saturated soil, geotextile modulus, and probable number of vehicle passes.

A design method requiring soil strength and vehicle load information uses formulas and a graph to determine aggregate thickness (Bender and Barenberg, 1978). Several graphs to determine the aggregate thickness have been developed for specific wheel loads and soil strength values using the Mirafi-140 fabric.

The optimum-depth method is one of the simplest design methods for a geotextile-reinforced unsurfaced road (Haliburton and Barron, 1983). The design method for determining the aggregate thickness is independent of the subgrade strength and the wheel load. The aggregate thickness is only dependent on the vehicle tire size or contact area.

The optimum aggregate thickness can be determined using the simple formula, (0.33 x load area width). This method will give satisfactory results if the predicted stress at the depth of (0.33 x load area width) is less than the allowable stress of the subgrade. The predicted stress can be calculated by applying the Boussinesq's formula; knowing the maximum load on the wheel, the width of the tire print, the length of the loaded tire print; and applying the 50 percent Burmister stress reduction received from this type of reinforcement (Haliburton and Barron, 1983).

Forest industry use. Two examples of forest industry' use of geotextile fabrics and one use of paper machine wire were demonstrated. The first example is the use of the geotextile Mylar by Bowater Woodlands (Ramage, 1988). The fabric was used on a road through a section of silty-loam creek bottom, where the subgrade was weak and wet almost year round (Figure 2). The fabric was used in conjunction with a six inch variable-sized crushed stone surface.

The fabric kept the road passable during a two month period in the fall of the year without additional applications of stone. The fabric kept the stone separated from the silty subgrade soil and the only problem developed when the larger surface stones punctured the fabric under the weight of the trucks. Potholes formed in the road where the punctured fabric allowed the surface stone to push down into the subgrade and soil from the subgrade to rise up onto the surface.

Figure 2. Mylar used on a forest road by Bowater Inc., Calhoun, Tennessee.

The second industry use of a geotextile fabric on a logging road is by Proctor and Gamble Cellulose (Starling, 1988). Supac, a Philips Petroleum product, was used in areas of a heavily traveled road where it crossed small drainages, as the road was needed for year-round travel.

The fabric was placed over fill dirt where culverts were installed at the drainages (Figure 3). Fifty to seventy-five feet of the road was covered with the fabric on each side of the culvert. A six to ten inch surface layer of crushed "lime rock" was placed over the fabric. This combination of fabric and "lime rock" created a very compact road surface that withstood heavy travel in wet weather with little or no damage to the road.

The third industry example employed paper machine wire discarded from use during the paper making process (Ramage, 1988).

The machine wire was used as a geotextile on a road that contained a low poorly drained area containing a weak subgrade. The wire was placed directly over the subgrade and was covered with about two inches of gravel (Figure 4). The wire exhibited the two important properties of a commercial geotextile fabric - separation and filtration. The machine wire performed as well as the Mylar fabric mentioned earlier with the added advantage of being obtained at no cost. Whenever scrap machine wire can be obtained, it is an excellent tool for reducing road building cost.

Figure 3. Supac N used on a forest road by Procter and Gamble Cellulose, Oglethorpe, Georgia.

Figure 4. Scrap paper machine wire used as a geotextile by Bowater Inc., Calhoun, Tennessee.

The cost of geotextile fabrics may limit their use on logging roads, but they certainly have advantages that merit attention for solving the mud on the road problem. The most important advantage is its use in combination with crushed stone or other surface materials to reduce the amount of surface material needed. It reduces the amount of "muddy" road the truck tires have to come in contact with and reduces the chance of the dual-tires picking up mud.

### Highway Construction.

The basic layout and design principles used in public highway construction are also useful for forest road construction. Even though the financial outlays for public highway construction are usually not available for typical forest road construction in the Southeast, some similar construction techniques have been useful. The use of geotextile fabrics in combination with aggregates for road improvement is one method starting to appear on forest roads.

Subgrade soil stabilization may be another construction technique that is appropriate in forest road construction. "Soil stabilization includes any treatment of soil whereby it is made more stable" (Krebs and Walker, 1971). Examples of such stabilization treatments include the use of portland cement and hydrated lime.

Patents issued for mixtures of portland cement date back to 1917, but the use of lime stabilization is evidenced by lime/clay mixtures used by the Roman

Civilizations over 5000 years ago (Krebs and Walker, 1971). However, the first recorded use of lime stabilization in the U.S. dates back to 1920.

### Soil cement stabilization.

Soil cement, defined as a mixture of portland cement and natural soil (Krebs and Walker, 1971), is the most commonly used chemical mixture to increase soil stability (Lilley, 1973). It is primarily used as a base and subbase material for secondary road construction (Yoder and Witczak, 1975), but it is also used to upgrade a weak clay subgrade to prevent mixing with stone base material (Lilley, 1973).

The ability to stabilize native soils on site through mixing with portland cement offers a substantial cost savings during construction (Lilley, 1973). Portland cement can be used successfully with granular, silty, and clayey soils provided very little organic material exists (Yoder and Witczak, 1975). To receive equal strengths, larger amount of cement are required for finer textured soils than are required for coarser textured soils because of the larger particle surface area to volume ratios associated with fine grained soils (Krebs and Walker, 1971). Soils with kaolinite clays require less cement than soils with montmorillonite clays (Stewart, 1971).

During curing of the compacted wet soil cement mixture, two reactions occur giving the mixture strength (Krebs and Walker, 1971). Hydration of the cement and the formation of strong bonds between the soil particles gives the cement its greatest initial strength. The reaction of soil particles and calcium hydroxide (hydrated lime) given off during hydration of the cement strengthens the mix gradually over time.

An important application to log road construction is the use of portland cement to modify and improve the strength of the natural soil without forming a hard, rigid cementious layer (Yoder and Witczak, 1975). Soil cement has strengthened the subgrade soil on many higher standard road projects, and could be used to stabilize the soil layer that serves as the surface on most forest logging roads. Smaller amounts of portland cement are necessary to modify the soil rather than stabilize the soil. The cement modifies the clay particles in the soil, changes the water adhesion qualities of the clay particles, and reduces the soil plasticity (Yoder and Witczak, 1975).

### Lime stabilization.

The addition of hydrated lime (calcium hydroxide), in small quantities, has been used to strengthen soil. Lime is more effective on fine grained soils and is less effective on sands and soils containing organic materials. Kaolinitic and montmorillonite type clays react quickly with hydrated lime (Yoder and Witczak, 1975).

Lime reacts with soil in two ways. The most important reaction changes the water adhesion properties of the clay particles and binds soil particles (Yoder and Witczak, 1975), thus increasing the workability of the soil and improving its shrink-swell and plastic properties (Robnett and Thompson, 1976). The second reaction takes place only if siliceous and aluminous minerals are present in the soil. If present, the strength of the lime-soil mixture improves over time with the pozzolanic action and the formation of cementing silicates and aluminates (Yoder and Witczak, 1975).

### "Chunk-wood" and "chip" roads.

A variation of the geotextile fabric's uses mentioned previously is its in combination with a surface of wood chunks (not chips) one to two and a half inches is diameter (Burde, 1988). Researchers at the Forestry Sciences Laboratory in Houghton, Michigan, used low grade or small trees chopped into chunks as a surface material on low volume roads. Chunk-wood alone or chunk-wood mixed with soil was placed on the geotextile as the surface.

Advantages of chunkwood include the use of normally unharvested stems. Chunkwood could be used where other road surface materials are scarce or very expensive. The material for chunking could be obtained directly from the site eliminating expensive trucking of surface materials.

Whole-stem chips made from unmerchantable timber by a portable whole-tree chipper have also been used as road surfaces. The chip surface gives the traffic load flotation above a weak subgrade and prevents truck tire contact with mud. However, the chip road must be used before deterioration of the chips begins resulting in a slippery surface when wet.

### "Brush and sand" roads.

The "brush and sand" road has been experimented with and used by a few forest-based companies. Dating back to the construction of corduroy roads by the early Roman Civilizations, "brush and sand" road technology is used in areas with weak subgrade soils. The "brush and sand" road is built to give flotation and support the weight of the log trucks above the weak subgrade.

Union Camp Corporation (Franklin, Virginia) uses the brush and sand roads extensively (Burgess, Dalton, and Watson, 1988). Roads are constructed a layer of brush, at least six-inches thick (ranging in size from bushes and shrubs to trees six to eight inches in diameter), placed over the ground or existing road bed. Then a six to ten inch layer of sand or coarse well-draining soil is spread over the brush. The brush provides flotation above the weak subgrade by spreading the trucks' load over a large area. The sand is a porous surface that allows good surface drainage and doesn't become sticky and slippery when wet (Figure 5).

"Brush and sand" roads are a good low-cost alternative where temporary road is needed to haul timber on a road that would otherwise be impassable during winter months. The road construction method is also a good tool for reducing the contact between log trucks and muddy haul roads, therefore reducing the mud transfer to public roads.

Figure 5. "Brush and sand" road built by Union Camp Corporation, Franklin, Virginia.

# Temporary Pavements

## Wooden mats.

Wooden mats are also used to improve forest roads and allow travel over weak subgrades. Their use to support the weight of heavy truck traffic and prevent rutting dates back to their use during World War II. Their portability makes them an excellent low-cost method of improving soft spots in haul roads. Preventing the truck tires from contacting these soft muddy areas also reduces mud transfer to public roads by reducing mud accumulation in the dual-tire space.

Georgia Pacific (Emporia, Virginia) is one of many forest product companies using the wooden mats to improve access to harvesting sites (Scronce, 1988) (Figure 6). Although manufactured by suppliers such as Carolina Pallet, West Brothers Pallet, and Hunter Darden (in the Emporia, VA and Plymouth, NC area) in two foot length increments, the most popular mats are ten-feet wide and sixteen-feet long. An appealing advantage of the mats is their portability. They can be used on haul roads as a quick fix for a soft spot and removed when harvesting is complete. They withstand some rough use by logging equipment, but are eventually destroyed during use or transport.

Large wooden mats, similar to the ones built by Uni-Mat International, Inc. for temporary or permanent construction and drilling sites could also be used on logging operations. These eight by fourteen foot hardwood mats overlap and

Figure 6. Wooden logging mats used on a forest road by Georgia Pacific, Emporia, Virginia.

interlock to cover a large area and disperse the load over this area. Metal mats used for the construction of airport runways during World War II may also be useful during timber harvesting.

### Terra-Mats.

The Terra Mat Corporation has invented a rubber mat for improving forest roads (Terra Mat Corporation, 1989). Sidewalls cut from used bias-ply truck tires are bound together by stainless steel fasteners to form the Terra Mats. Used similar to wooden logging mats, they allow the transport of heavy loads over roads with weak subgrades. Terra Mats can be moved by logging equipment of dragged by light trucks for installation on logging roads.

## Tire and Wheel Modifications

### Central tire inflation.

Central Tire Inflation (CTI), a new research area involving truck transportation and timber products hauling, has recently gained a lot of attention. The CTI systems introduced by the military and the recent developments in tire design have allowed this technology to advance far enough to include the forest industry (Gilliland and Ryburn, 1986). A CTI system allows the driver to adjust the truck tire pressure from inside the cab using the truck's air compression system. The driver can match the tires' pressure to the hauled load, type of road surface, and road standard while the truck is in motion. By lowering the pressure, the tire surface in contact with the road is lengthened (not widened), thereby spreading the load over a larger surface area and reducing the ground pressure per unit area.

The U.S. Forest Service performed a "preliminary proof-of-concept test" in 1984 at their San Dimas Equipment Development Center to test the applicability of CTI technology to forest logging trucks (Gilliland and Ryburn, 1986). Their test using an 18-wheel log truck with tire pressures of 24 psi showed several advantages over higher tire inflation pressures. Besides safely and easily handling heavy loads, the low pressure tires actually helped heal deteriorating road surfaces. The wear on forest roads was found to be less as was driver fatigue and truck maintenance costs.

The Forest Service completed several structured and field tests to determine the effectiveness of CTI systems on forest roads and wood transportation. The findings of these tests were reported by Ashmore and Gilliland (1987) at the Logging Industry Research Association seminar in New Zealand. The first structured test at the Forest Service's Engineering Research Laboratory, in Auburn, Alabama, was performed to show the difference in maintenance costs on roads used by three trucks with different tire pressures. Pressures of 100, 65, and 30 psi (70 to 90 psi is normal) were used on the three trucks to give 10%, 20%, and 30% tire deflections, respectively. The tire deflection was measured as the difference in the section heights of the tires in a loaded and unloaded situation.

The road used by the 10% deflection (100 psi) tires failed after the 268 loaded and 90 unloaded test passes. The road used by the 20% (65 psi) and 30% (30 psi) deflection tires showed very little wear. A concrete culvert in the road used by 10% deflection tires was broken while culverts in the road used by 30% deflection tires were not.

A drawbar pull test was also performed at the same lab on a clay and a sand road to note the difference in mobility of trucks using lower tire inflation (Ashmore and Gilliland, 1987). A 20,000 pound load cell was mounted between the truck and a Franklin 170 skidder to measure the pull at which 100% slip occurred. The truck was used with three different tire pressures -- 100, 65, and 30 psi. Although no significant differences in pull were noted between tires with 65 and 30 psi, the 65 psi tires increased pull by 34% and 17% on the sand and clay road, respectively, over the 100 psi tires.

A test was performed on a 1.2 kilometer track containing several different surface materials and obstacles at the Nevada Automotive Test Center in Carson City, Nevada, using two identical 18-wheel log trucks. One truck was run with 90 psi in all tires while the other truck was run with 55 psi in the steering axles and pressure in all other tires that caused 21% deflection.

The results of the tests showed better tire wear and lower truck maintenance on the truck with the lower tire pressure. However, the high pressure tires gave 5% better fuel economy than the low pressure tires. The low pressure tires also smoothed out washboard bumps present while the high pressure tires caused them to become worse. The high pressure tires also destroyed the asphalt surfaced sections on the test track.

The Forest Service's three field tests reinforced the findings and conclusions of the structured tests. All three tests showed that fewer tire problems and lower failure rates resulted from lower tire pressures. Road maintenance and destruction were dramatically reduced. The truck drivers also felt that the trucks were more stable, comfortable, and easier to handle when lower tire pressures were used.

The Forest Service, in cooperation with the Army Corps of Engineers Waterways Experiment Station and the Federal Highway Administration, conducted an extensive test on central tire inflation during a 14 month period from September, 1988 to October, 1989 (USDA For Serv, Corps of Eng WES, FHA; 1988). The first test phase consisted of 3000 loaded and 3000 unloaded passes made by two trucks on parallel test tracks containing sections of different surface type and thickness. The two trucks also ran 18,000 passes on the paved-only sections of the tracks. One truck had tires inflated to 110 psi continuously, causing different deflections depending on the load, and the other ran tires inflated to pressures that gave a constant 21% deflection, depending on the load. The second phase consisted of 3000 loaded and 3000 unloaded passes on the entire test track by two trucks with 14% and 30% deflection, respectively.

The results of the tests were used to satisfy the following six main objectives:

1. Determine the effects of tire deflection on road deterioration rates.
2. Determine the effects of tire deflection on road maintenance.
3. Determine the possible percentage reductions in road surface depths for various deflections.
4. Determine factors that cause road surface deterioration.
5. Formulate a strategy to establish a new road design system for roads used by low pressure tires.
6. Determine the effect of tire deflection on road surfaces with weak subgrades.

CTI technology can be used by the forest industry personnel in many ways. Lower standard roads could be built at a lower cost. Existing roads would require less maintenance at extended intervals. Haul roads in use during winter or wet weather could be used longer before maintenance is required. However, the savings on road construction and maintenance may be gained by the forest landowners while the expense of decreased fuel efficiency and the cost of CTI equipped trucks and trailers are transferred to the logging contractors.

## Super-wide single tires.

Another potential method for reducing mud transfer to public roads exists when trailers equipped with super-wide single tires and rims (16.50 - 22.5) instead of the conventional dual tires and rims (11.00 - 22.5) are used.

McNeel (1988) describes the advantages and disadvantages of their use experienced by two mid-Georgia loggers.

After retrofitting and purchasing several trailers with S-W single tires and rims, both loggers agreed that the advantages of the set-up out numbered the disadvantages. The advantages include a reduction in trailer weight, lower wheel and tire maintenance, and reduced mud transfer onto public roads.

A trailer purchased with S-W single tires and rims weighs about 100 pounds less per axle than an identical conventional trailer. The weight can be reduced up to 450 pounds for a two-axle trailer if aluminum instead of steel rims are used. Halving the number of tires reduces the tire and wheel maintenance as there are only two tires and rims per axle instead of four. Using S-W single tires eliminates the space where mud accumulates between the conventional dual-tires.

The disadvantages include a slightly higher cost of a new trailer and a yet higher cost if retrofit. Retrofit trailers are also less stable at highway speed and in turns than conventional trailers. The cost of a trailer equipped with S-W singles is $35 to $50 more per axle than a dual-tire equipped trailer. However, the increased cost can be recovered through increased payloads allowed by reduced trailer weights. Retread 16.50 - 22.5 tires ($200), cost about $75 more than 11.00 - 22.5 retreads, but a trailer only requires half as many. The cost of retrofitting a trailer is much higher because the tires and rims must be purchased to replace the conventional dual-tires and rims. Equipping trailers with wheels with offset disks or wider axles would reduce some of the handling problems of retrofit trailers.

Approximately 10 miles travel is available after a flat or blowout before a problem develops with other tires on a loaded trailer equipped with conventional dual-tires. Equipping a loaded trailer with S-W singles reduces the travel distance before problems with other tires or damage the trailer develop. A tri-axle trailer equipped with S-W singles would increase allowable travel distance after a tire problem developed, but would increase overall tire wear due to increased drag during turning and increase trailer tare weight.

Consideration of the advantages and disadvantages of S-W singles makes them attractive for reducing operating costs. Using S-W singles would eliminate the dual-tire space that is the major culprit in the transfer of mud to public roads, allow increased operation during wet weather, and ease the pressure applied to the contractor to keep the public roads free of mud.

### Dual-tire cable.

An interesting idea reported by Tyson (1986) of Union Camp Corporation, could be used to reduce the amount of mud transferred onto public roads. A 5/8-inch cable placed between the dual-tires around the dual-tire spacers of the tandem axles removed pieces of wood created by a tree-length slashing operation that wedged between the tires and often punctured their sidewalls.

With the cables in place the blocks of wood were knocked out within one revolution of the tire past the cable.

## Summary

A broad review of the literature concerning road construction and truck tire and wheel modifications uncovered many methods useful for reducing mud transfer to public roads. Some require extensive planning or considerable financial outlays, while others can be implemented when needed. The findings of this review directed the research towards a new idea instead of studying and quantifying a method that has been in use for many years. A simple, inexpensive, portable, and durable device for reducing the mud transfer for addition to log trucks and trailers was desired.

# METHODS AND PROCEDURES

The objective of the study was to design, construct, and test a device or devices that effectively remove mud from log truck tires. The devices must be simple in design, easy to construct and use, inexpensive, and durable. Following a literature review, several trips to the field to observe possible solutions, and much work in the IFO Harvesting Lab at Virginia Tech, four such devices were designed, constructed, and prepared for field testing.

## Devices

### Rope.

The first device was based on the dual-tire cable. A 14 foot piece of 1/2 inch diameter polypropylene rope was used instead of cable to reduce the chance of tire or wheel damage during use. A loop was spliced in both ends making the total length 12 feet 8 inches. The rope was wrapped around the tire spacers between the dual-tires of the tandem axles and is connected by a quick-connect link (Figure 7).

Figure 7. Rope wrapped between dual-tires.

As the mud packed in the dual-tire space rotated with the tires to contact the rope stretching between the two axles, it was either scooped out or loosened so that centrifugal force could easily remove it.

This was the simplest and least expensive of the four devices costing approximately $5.00. The rope took less than one-half hour to construct and less than one minute to install on each side of the trailer.

### Bars.

The second device was a solid steel bar that hung vertically between the dual-tires to the rear of the axles to a point just below the center of the spacers (Figure 8). The one inch diameter bar was based on the bar used to knock rocks from the duals on large off-road dump trucks.

The only materials required for construction of the bar are a one inch diameter solid steel rod 36 inches long and a one inch piece of pipe 3-1/2 inches long welded perpendicular across the top of the bar (Figure 9). The total cost of the "bar" was less than $5.00 and took about one-half hour to construct.

The "bar" was designed to remove the mud similar to the way discussed previously with the "rope". As the dual-tires, packed with mud, rotate, the mud is forced out by the "bar" hanging down between them.

Figure 8. "Bars" hanging between dual-tires.

Figure 9. "Bar" showing pivot attachment.

## Bar and scraper.

The third device was similar to the "bar", with the addition of an adjustable rubber scraper mounted on a sliding pipe. A 1-1/8 inch diameter pipe over a 5/8 inch solid steel rod was used instead of the one inch steel rod. A piece of 3/4 inch heavy rubber bolted to angle-iron was welded to the 1-1/8 inch steel pipe. The angle-iron was welded perpendicular to the pipe so the rubber protruded from the pipe at a 45 degree angle (Figure 10). Two holes were drilled in the pipe for two bolts serving as locking set screws to screw in against the 5/8 inch solid steel rod. The pipe and rubber were adjusted up and down to contact the tire by loosening the set screws and were locked into position by tightening them.

The materials required for the "bar and scraper" include the following:

| | |
|---|---|
| 1 - | 30" piece of 1" diameter pipe |
| 1 - | 36" piece of 5/8" diameter solid rod |
| 1 - | 24" piece of 2" X 2" X 1/4" angle-iron |
| 1 - | 24" piece of 2" X 1/4" steel strap |
| 1 - | 3-1/2" length of 1" diameter pipe |
| 1 - | piece of 5" X 24" heavy 3/4" thick rubber |
| 6 - | 1/2" X 1-1/2" bolts with nuts and washers |
| 2 - | 1/2" X 1" bolts with 2 nuts each. |

The total material cost for each "bar and scraper" was approximately $25.00. Each "bar and scraper" required 4 to 5 hours to construct, and a total of four "bars and scrapers" are required to completely equip a trailer.

The "bar and scraper" worked similar to the "bar" with the addition of the heavy rubber material wiping the tire tread. The "bar and scraper" was adjusted so the rubber was

Figure 10. "Bar and scraper".

forced against the tires. The rubber wiped the mud from the tread surface while the bar knocked it from the space between the tires.

### Mud flap.

The fourth device was a modification of the mud flap trucks and trailers are required by law in most states to have installed behind the rear axles. This mud flap was made of 1/4 inch thick steel plate with a piece of heavy rubber attached perpendicular across the bottom of the steel plate and a triangular piece of one inch thick high-density polyethylene plastic attached perpendicular vertically in the middle (Figure 11).

The materials required for the construction of one "mud flap" include the following:

| | |
|---|---|
| 1 - | 24" X 36" piece of 1/4" steel plate |
| 2 - | 11" pieces of 1-1/2" X 1-1/2" X 3/16" angle-iron |
| 2 - | 18" pieces of 1-1/2" X 1-1/2" X 3/16" angle-iron |
| 2 - | 11" pieces of 1-1/2" X 3/16" steel strap |
| 2 - | 11" X 5" pieces of heavy 3/4" thick rubber |
| 1 - | 20" X 16" triangular piece of 1" H.D. polyethylene plastic |
| 4 - | 1/2" X 2" bolts with nuts and washers |
| 4 - | 1/2" X 1-1/2" bolts with nuts and washers. |

The total material cost for each "mud flap" was approximately $60.00. Construction and mounting time for each mud flap was approximately 8 to 10 hours.

Figure 11. "Mud flap".

In its working position, the rubber wipers scraped the mud from the tread as the tires rotated, and the polyethylene triangle forced the mud from the space between the dual-tires.

## Device mounting.

For field testing, the four devices were mounted on a 40-foot, double-bunk, frame log trailer. The "rope" device was looped by hand between the dual-tires and connected with the quick-connect link. The "bar" and "bar and scraper" were suspended from a pivot in a mounting box to allow movement from their working to retracted position (Figure 12). The mounting box had three holes drilled in it; one for the pivot, and two for pins to lock the devices into their working and retracted positions. The mounting box was suspended from two pieces of two inch angle-iron welded together forming a rail between the two rear bolsters directly over the tandem axles. The mounting box was attached to the rail to allow positioning of the devices over the dual-tires.

The materials required for its construction include the following:

2 - 10' pieces of 2" X 2" X 1/4" angle-iron
2 - 5" pieces of 3" X 3" X 1/4" angle-iron
4 - 1/2" X 1" bolts with nuts and washers
2 - 5" pieces of 4" X 6" box beam
2 - 4" X 6" pieces of 1/4" steel plate
4 - 1/2" X 1-1/2" bolts with nuts and washers
2 - 5/8" X 4" hitch pins.

Figure 12. "Bar" hanging from pivot mounting box.

The total material cost for the rails and mounting boxes was $50.00. The trailer was fitted with the rails and mounting boxes in 16 to 24 hours. Since the mounting of the devices will depend on the construction of the trailer and the loggers' preference, this cost should be used only as an estimate.

For testing, the "mud flap" was mounted from a bracket 16 inches only behind the rear axle on a hinge (Figure 13). A "bar and scraper" was mounted on the front axle and was connected to the "mud flap" by a 1/2 inch steel rod for activation.

## Activation.

The "rope" was attached around the dual spacers manually before testing. The "bar" and "bar and scrapers" were also pivoted into position in the mounting boxes manually. To demonstrate the possibility of activating the "bar", "bar and scraper", and "mud flap" automatically, a pneumatic cylinder powered by the trailer brakes air system was connected to position the "mud flap"/"bar and scraper" combination. A similar system could be used by the truck driver to position the "bar", "bar and scraper", and "mud flap" from the cab.

Figure 13. "Mud flap" mounted on trailer.

# Study Site

## Location.

The study was conducted on timberland owned by Chesapeake Corporation in the Piedmont region of Virginia near Jetersville in Amelia County. The soil in the study area was classified in the Appling series (USDA, unpublished). To a depth of 11 inches, the surface layer was a grayish brown to light yellowish brown fine sandy loam. The subsoil, from 11 to 14 inches deep, was an olive brown sandy clay loam and from 14 to 37 inches deep was a yellowish brown and strong brown clay. A particle analysis conducted by the Soil Physics Lab at Virginia Tech showed a composition of 20% clay, 60% sand, and 18% silt by weight. The high clay content determined by the analysis indicated the soil used during the study was from the subsoil layer.

A 220 foot section of newly constructed logging road was chosen as the test site (Figure 14). The road had not been used for logging and stone had not been spread on the surface. Future harvest landings at each end of the 220 foot section served as turnarounds for the tractor and trailer. The test section was sprayed with water until runoff the night before and morning of the test by a fire suppression truck. A 30 foot, dry, "mud free" zone was left at each end of the test section and maintained during testing. The test section was periodically sprayed with water to maintain a fairly constant moisture content between 25% and 30%.

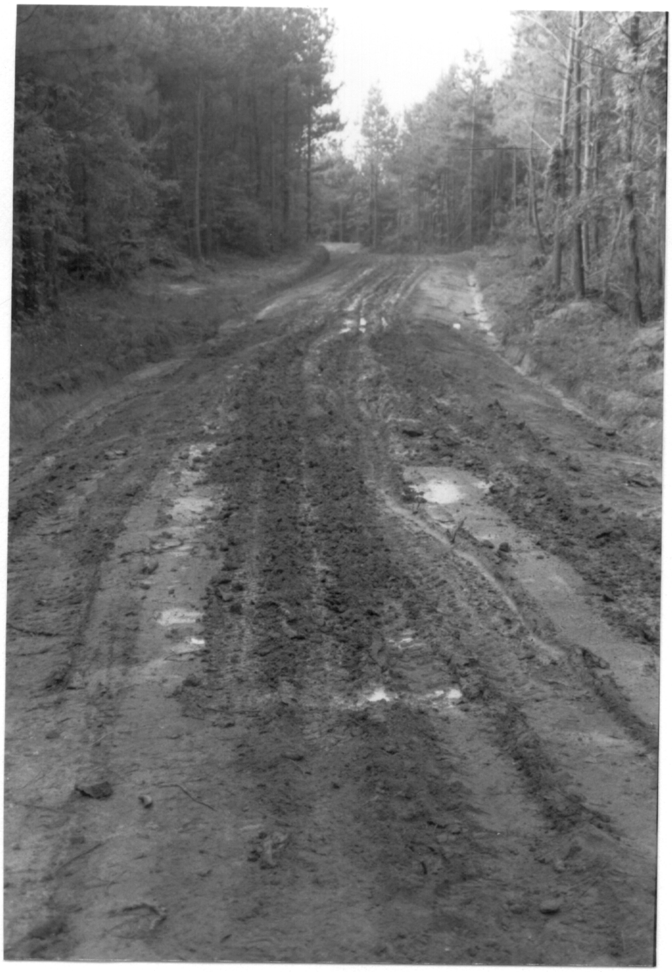


Figure 14. Test road on Appling soil series in Amelia Co., Virginia.

## Test Procedure

An attempt was made to make the testing as similar to actual logging conditions as possible. A 1978 Kenworth diesel powered road tractor pulled the trailer loaded with 10,130 pounds of hardwood pulpwood in the rear bunk.

Six replications of the four devices (treatments) and the control (no treatment) were preformed. The treatments were randomized using a random number table within the 6 replications and a set of each of the treatments was performed before starting the next replication. Two treatments were tested during each of the 15 passes through the mud for a total of 30 tests.

After exposure to the mud, the trailer was pulled through the 30 foot, dry, mud-free section allowing the tires about three revolutions and gave the devices an opportunity to clean the tires. This simulated the short sections of crushed stone or mats on haul roads at the entrance to the public road.

The trailer was pulled onto the eight foot by twelve foot heavy-duty plastic tarps placed in front of the tires at the end of the 30 foot mud-free section. The mud remaining on the tires was scraped by hand from the tire surface, the space between the dual tires, and from suspension and brake assemblies adjacent to the tires.

As the trailer was moved forward off the tarps, care was taken to scrape and collect any mud picked up from the tarp by the tires as they rolled forward.

The edges of the tarp were gathered and formed into a "bag" containing the mud by a rope looped around the top.

### Weighing device.

A 10,000 pound capacity electronic load cell was suspended from a chain hoist attached to a swivel boom mounted in the right rear standard of the trailer. The mud-filled tarp was tied to the load cell by the rope and lifted off the ground by the hoist, causing the load cell to deflect in tension (Figure 15). A signal amplifier, powered by a 12 volt lantern battery, was connected to the load cell to read the change in electric current passing through the load cell as it was deflected by the weight of the mud. The signal amplifier was calibrated so when read by a digital multimeter, one millivolt equalled one pound. Readings were taken in millivolts and directly converted to gross weight in pounds. The tare weight of the tarp and rope was subtracted from the gross weight to give the net mud weight.

### Data collection.

Mud weight and moisture content samples were collected for the six replications of the five treatments (Table 1 and 2). The moisture content corresponding to each test weight was used to convert the field collected weights to oven-dry soil weights to place all weights on a common basis for comparison.

Figure 15. A mud sample being weighed.

Table 1. Wet weight sample data.

| TREATMENT<br>REP | CONTROL<br>(LBS) | ROPE<br>(LBS) | BAR<br>(LBS) | BAR/SCRAPER<br>(LBS) | MUD FLAP<br>(LBS) |
|---|---|---|---|---|---|
| 1 | 261 | 429 | 175 | 23 | 25 |
| 2 | 326 | 396 | 42 | 103 | 104 |
| 3 | 451 | 23 | 85 | 42 | 49 |
| 4 | 419 | 176 | 57 | 106 | 66 |
| 5 | 461 | 268 | 110 | 74 | 15 |
| 6 | 434 | 144 | 62 | 10 | 113 |

Table 2. Moisture content sample data.

| TREATMENT | CONTROL | ROPE | BAR | BAR/SCRAPER | MUD FLAP |
|---|---|---|---|---|---|
| REP | MC % | MC % | MC % | MC % | MC % |
| 1 | 26.8 | 33.4 | 29.5 | 30.3 | 25.5 |
| 2 | 28.5 | 26.7 | 29.6 | 29.7 | 29.7 |
| 3 | 25.5 | 19.8 | 27.7 | 22.8 | 26.3 |
| 4 | 26.2 | 25.5 | 27.0 | 28.9 | 26.0 |
| 5 | 27.3 | 24.8 | 30.0 | 24.4 | 25.1 |
| 6 | 25.6 | 27.0 | 26.6 | 25.9 | 26.9 |

## Data analysis.

Oven-dry and wet mean weights were calculated from each device and control sample values (Figure 16). An analysis of variance (ANOVA) (alpha = .05) was performed on the oven-dry weight, wet weight, and moisture content means to determine if the five treatment came from the same population. The null hypothesis was that all five means were from the same population, and the alternate hypothesis was that they were from different populations.

Tukey's multiple comparison (alpha = .05) test was also performed on the oven-dry and wet weight means after the null hypothesis for the ANOVA was rejected. The null hypothesis was that all five means were from the same population, and the alternate hypothesis was that at least one mean was from a different population.

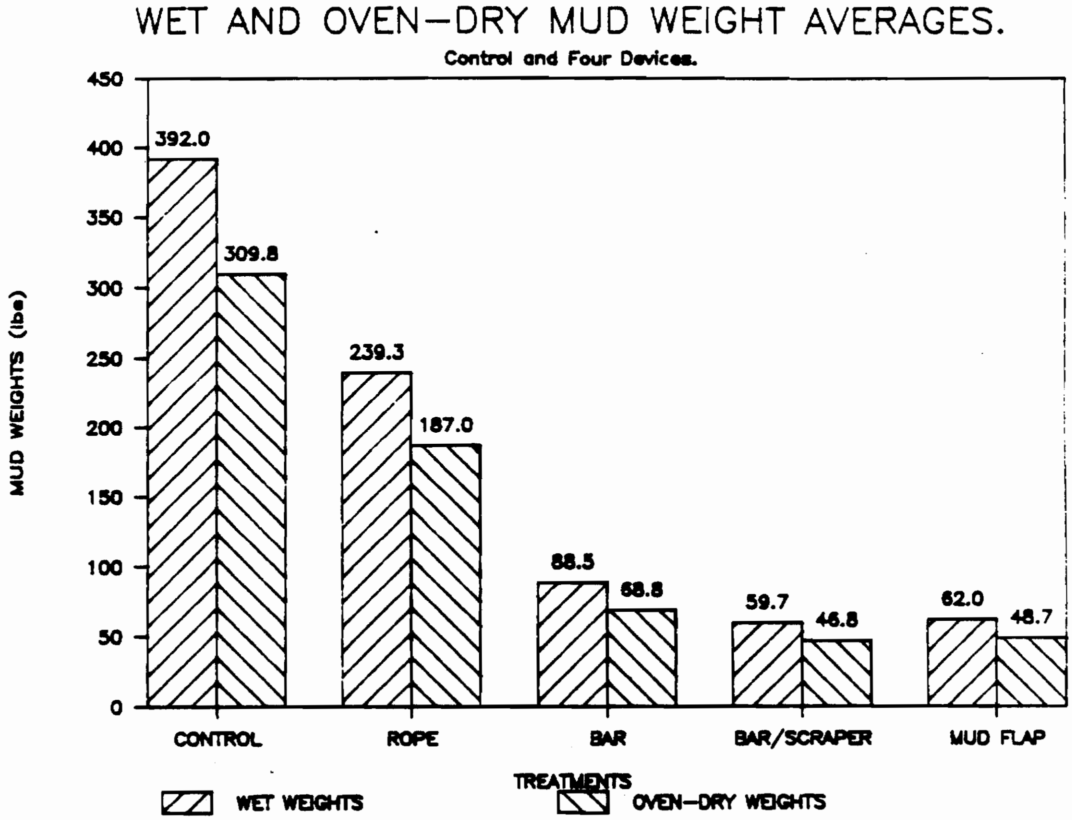


Figure 16. Bar chart of wet and oven-dry treatment means.

# RESULTS

The ANOVA (alpha = .05) found that the 5 treatment oven-dry weight means were from different populations. Tukey's multiple comparison test (alpha = .05) showed that the mean oven-dry weights for the "bar", "bar and scraper", the "mud flap" were from the same population but were from populations different from the "rope" and control. The mean mud weights for the "rope" and control were from populations different from each other as well as from the other three treatments (Table 3).

The same statistical tests were performed on the wet weights. Again, the ANOVA (alpha = .05) found that the five treatment means were from different populations. Tukey's multiple comparison test (alpha = .05) performed on the wet weights showed similar results as the one performed on the oven-dry mud weights (Table 4). Mean weights for the "rope" and control were from populations different from each other as well as from the other three treatment means. Means for the "bar and scraper", "mud flap", and "bar" were from the same population.

Table 3. Multiple comparison test results for oven-dry mud weights (lbs.). Means were ranked from low to high.

```
==========================================================
 TREATMENT  BAR/SCRAPER  MUD FLAP    BAR     ROPE  CONTROL

   MEAN        46.8        48.7     68.9    187.0   309.8
               -------------------------    -----   -----

     * UNDERLINE DENOTES MEANS FROM THE SAME POPULATION

     * MEANS ARE RANKED FROM LOW TO HIGH
==========================================================
```

Table 4. Multiple comparison test results for wet mud weights (lbs.).

```
===========================================================
 TREATMENT  BAR/SCRAPER  MUD FLAP    BAR      ROPE  CONTROL

   MEAN        59.7        62.0     88.5      239.3   392.0
               --------------------------     -----   -----

     * UNDERLINE DENOTES MEANS FROM THE SAME POPULATION

     * MEANS ARE RANKED FROM LOW TO HIGH
===========================================================
```

An ANOVA (alpha = .05) was performed on the moisture content means. All moisture content means were from the same population (Table 5). The moisture contents did not affect the rankings of the oven-dry and wet weight means or the population groupings, but did affect the mean weight values.

Table 5. Analysis of variance test results for the sample moisture contents.

```
============================================================
 TREATMENT  CONTROL   ROPE     BAR    BAR/SCRAPER  MUD FLAP

   MEAN       26.7     26.2    28.4      27.0         26.6
              -------------------------------------------

     * UNDERLINE DENOTES MEANS FROM THE SAME POPULATION

============================================================
```

# DISCUSSION

During testing, it was observed that the dual-tires on the drive tandems of the tractor did not pack with mud. The exact reason for this was unclear, but it may have been caused by tire spin. During the majority of the passes through the mud, the tractor became stuck and was pushed through by a John Deere 450 crawler. Mud that collected in the dual-tire space was thrown out by centrifugal force developed by the spinning tires. Adding weight over the drive tandems would have increased traction and reduced the tire spin. This may have reduced the amount of mud thrown out of the drive tandems.

The centrifugal force created by the spinning drive tires threw mud from the duals up onto the front of the first bolster, the bottom of the load, and trailer frame. This mud would vibrate loose and fall onto the public road during transport. Mud flaps and fenders would prevent the mud from collecting on the trailer and load, but mud would still accumulate on the mud flap and fender.

## Further Research

Further research into the problem of mud adhering to fenders and mud flaps on drive axles is needed. This mud is distributed for greater distances down the public road from the logging site than is the mud from the trailer dual-tires, but is still a problem deserving attention. Different designs or manufacturing materials for fenders and mud flaps may be useful.

## Study Design Changes

Increasing the number of samples collected for each treatment would not cause any change in the ranking of effectiveness of the four devices. It would have reduced the variances of the treatment means, possibly finding that the sample means were from a larger number of populations.

The field work would not be changed. Performing the study during the drier summer season and creating the mud for the study was an excellent choice over performing it during the wetter spring season. The isolation of the mud in the test area allowed equipment mobility over the rest of the site during the test. The muddy conditions over the entire site caused by an afternoon thunderstorm halted the study on one occasion.

Performing the study on a different type of soil in a different geographical region would demonstrate the effects of soil type on the results. The same rankings of effectiveness would occur, but the amount of mud removed would change the weight means.

# Device Modifications

The mounting box and rail configuration used with the "bar" and "bar and scraper" and to mount the pneumatic cylinder was designed for convenience during testing. The mounting configuration on an operational trailer would have to be altered to prevent damage during use.

The "rope" device could be improved in two ways. A larger diameter rope that was slightly smaller than the space between the duals would be more effective. It would force more mud out of the space by allowing less mud to adhere to the tire sidewalls and slip by the rope.

The attachment of the rope should also be changed. As it was mounted, the mud was removed from the rear axle tires slightly forward of the top of the tires. The mud that was removed fell to the ground in front of the rear tires and was picked up again. The dual-tire space of the rear axle was not cleared of mud because of this recycling action.

To improve its performance, the rope should be attached to the trailer forward of the front axle and behind the rear axle instead of looped around the axles. This would clean the mud out behind the rear tires, eliminate the recycling of mud on the rear axle, and facilitate attachment of the rope to the trailer (Figure 17).

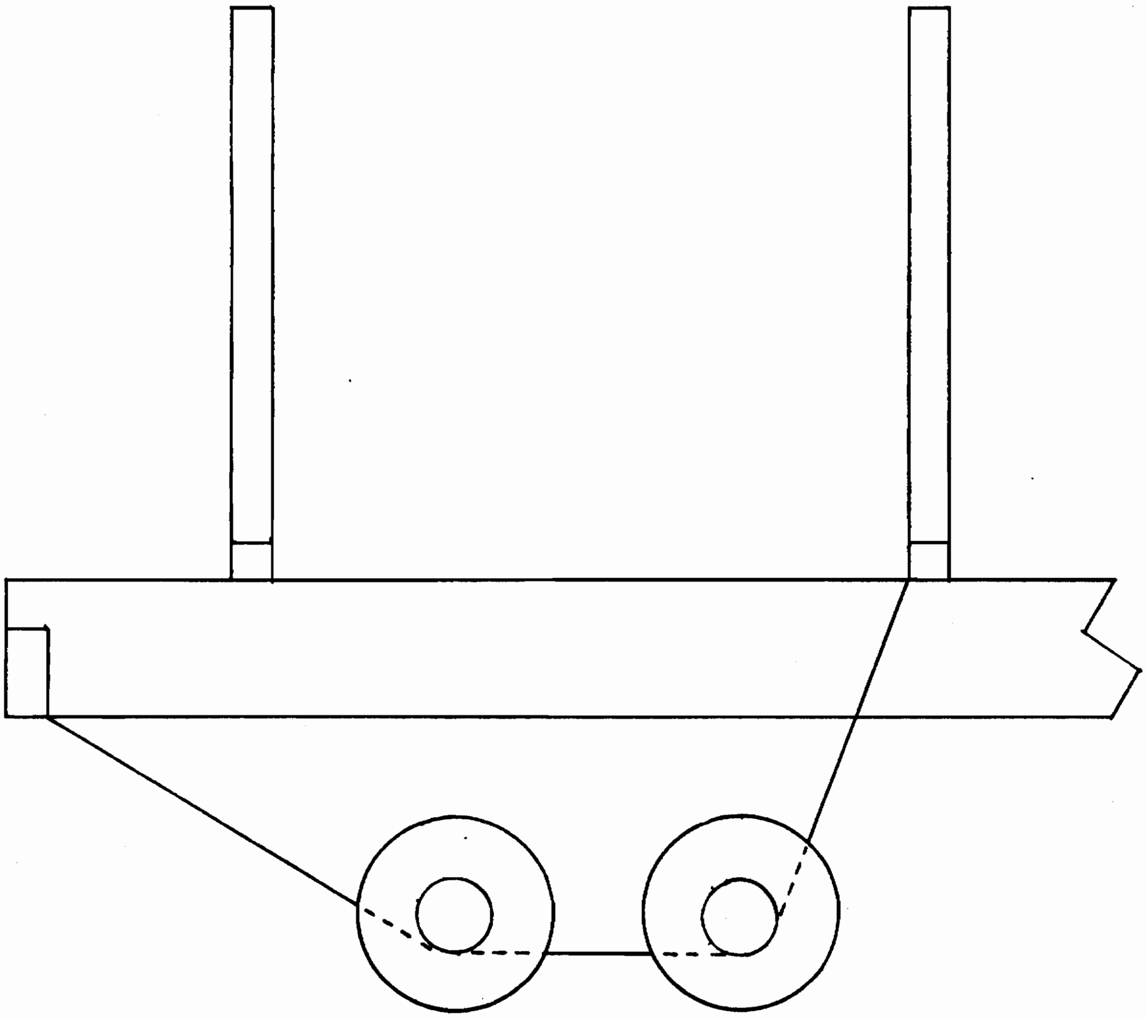


Figure 17. Modification of the "rope" attachment.

# SUMMARY

The objective of this research was to design, build, and test a device or devices to remove mud from the log trailer tires during muddy logging conditions. The design of the devices needed to be simple and easily built and attached by a logger.

Four devices were built. A "rope" with a quick-connect link, a "bar", a "bar and scraper", and a pneumatically operated steel "mud flap" were built and tested on a 40 foot log trailer loaded with 10,130 pounds of hardwood pulpwood in the rear bunk.

The results of the testing showed that the "bar and scraper" and the "mud flap" were the most effective devices. They reduced the mud left on the tires by an average of 85% and 84% respectively.

# CONCLUSION

It can be concluded that the problem of mud transfer to public roads can be significantly lessened by use of these devices, but the solution should not be limited to these. The ideas and principles of these designs could lead to other useful devices or modifications.

A prototype of an early design of the "bar" is currently being used by a contract logger for Bowater Woodlands in Calhoun Tenn. without equipment damage. The logger used the principle of the "bar" to design and attach his own device (Figure 18).

The devices selected or designed and built by other loggers will depend on their log trailer design as well as their personal preferences and imagination.

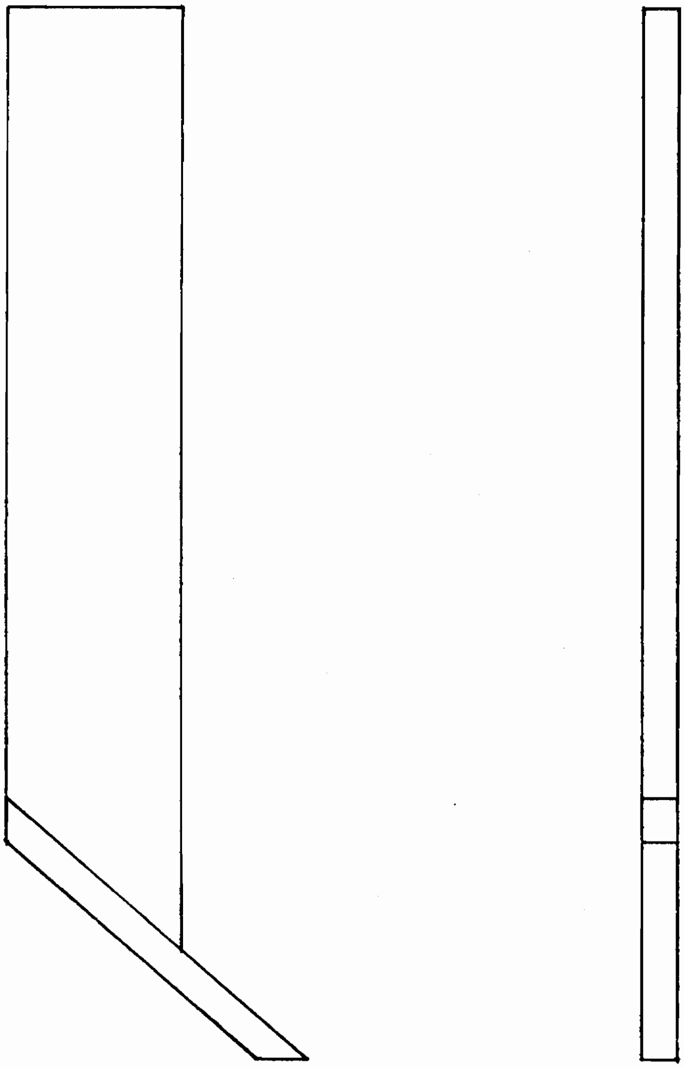
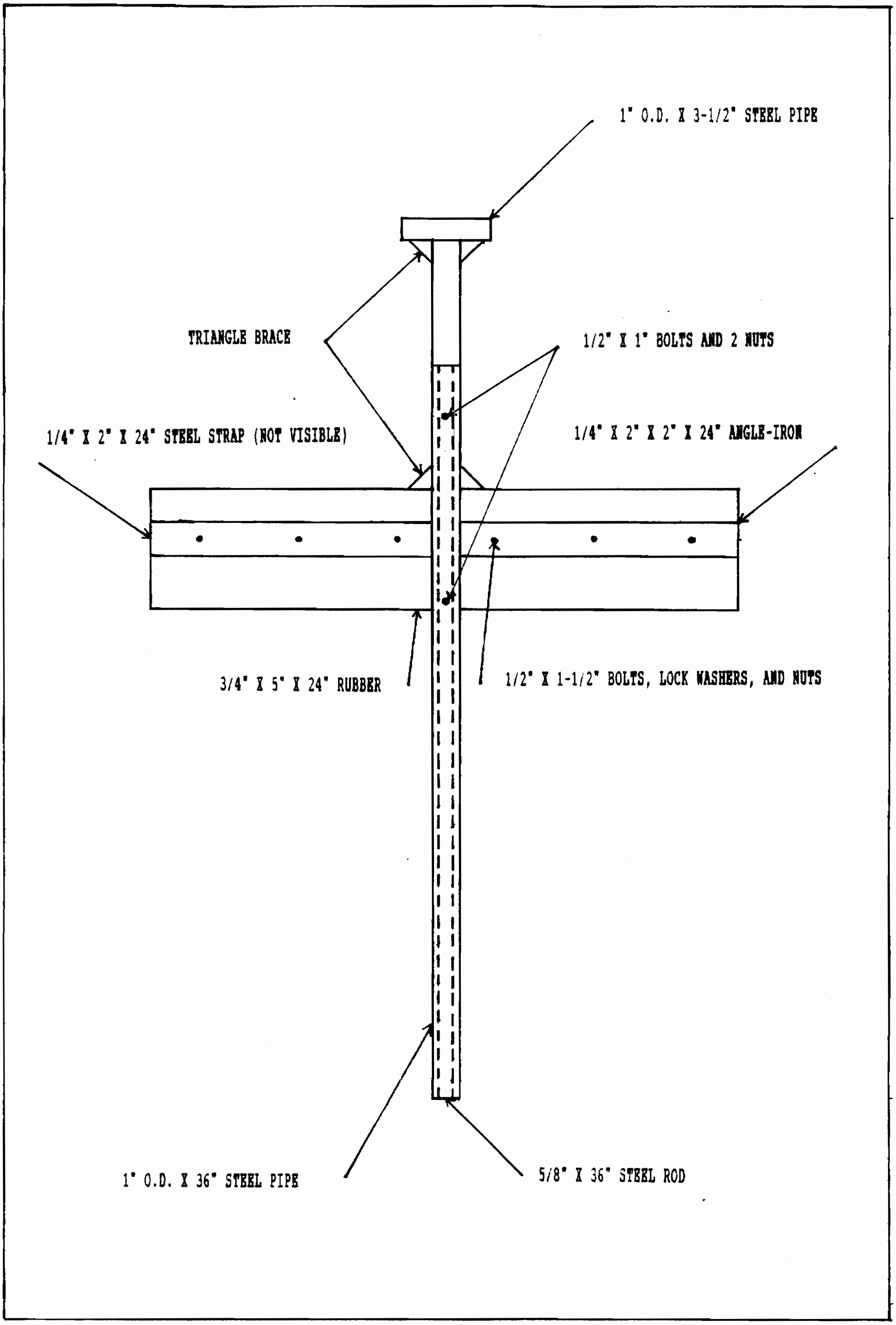
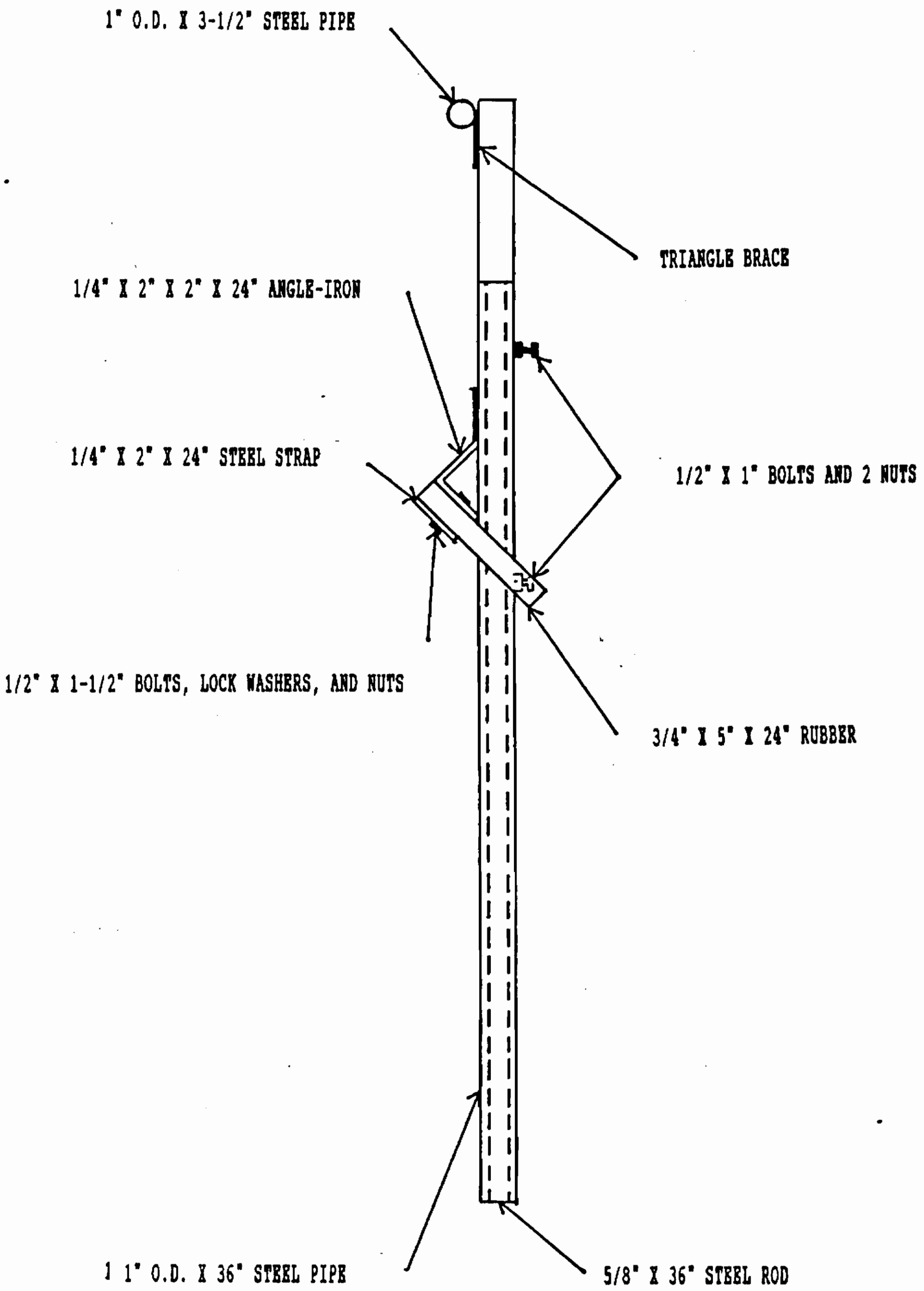


Figure 18. Bowater Inc. contract logger's device.

# Appendix A. Sketch of "Bar and Scraper"

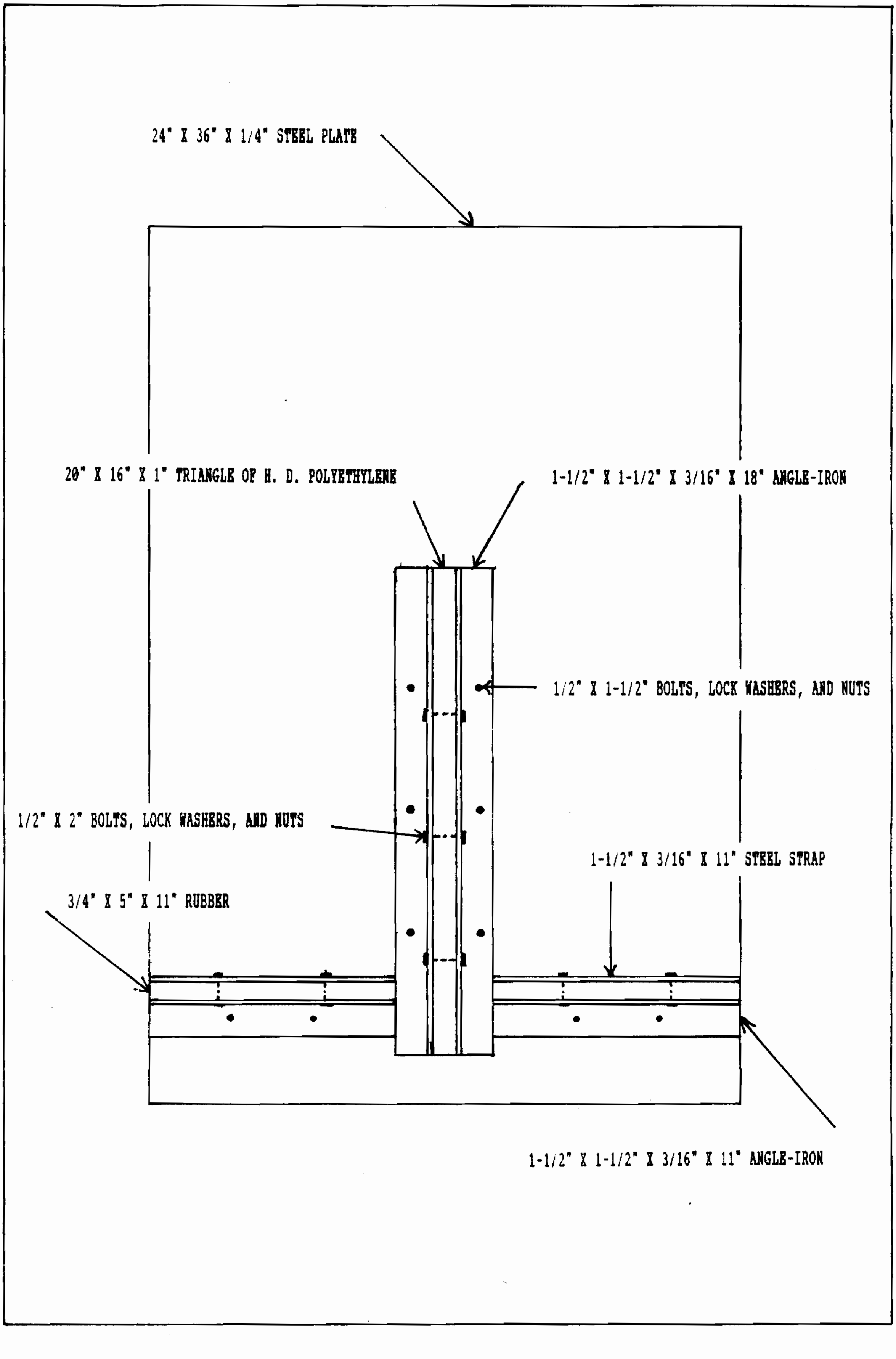


**Appendix A. Sketch of "Bar and Scraper"**

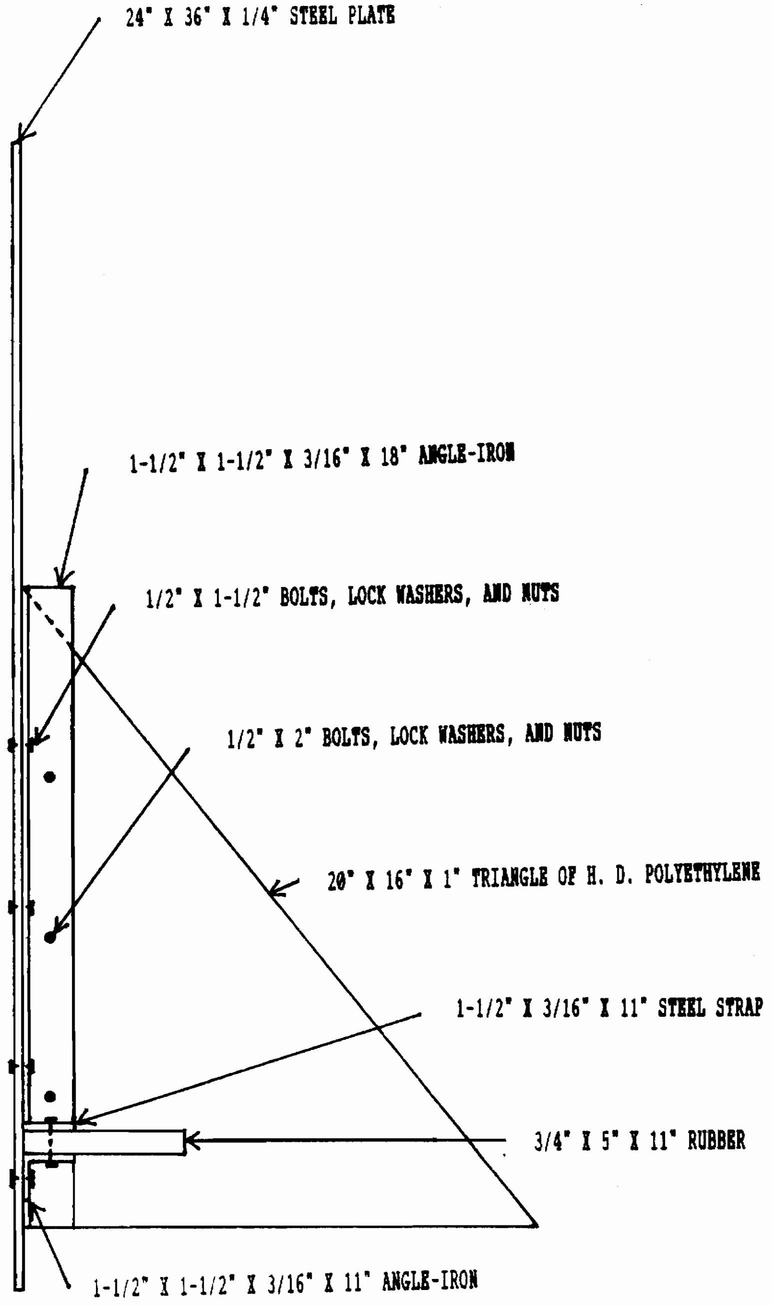


**Appendix A. Sketch of "Bar and Scraper"**

# Appendix B. Sketch of "Mud Flap"



**Appendix B. Sketch of "Mud Flap"**



**Appendix B. Sketch of "Mud Flap"**

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# VITA

The author was born on April 15, 1965 in Martinsville, Virginia and was raised in rural Patrick County, Virginia. While enrolled at Virginia Tech in the Industrial Forestry Operations undergraduate program, the author completed two summer forestry internships with Chesapeake Corporation. After graduating with a Bachelor of Science in November 1987, he enrolled in the Industrial Forestry Operations graduate program at Virginia Tech as a research assistant.

The author has been employed by Bear Island Paper Company, L.P. since September 1989 and graduated with a Master of Science in Forestry in 1990.

James M Kessee