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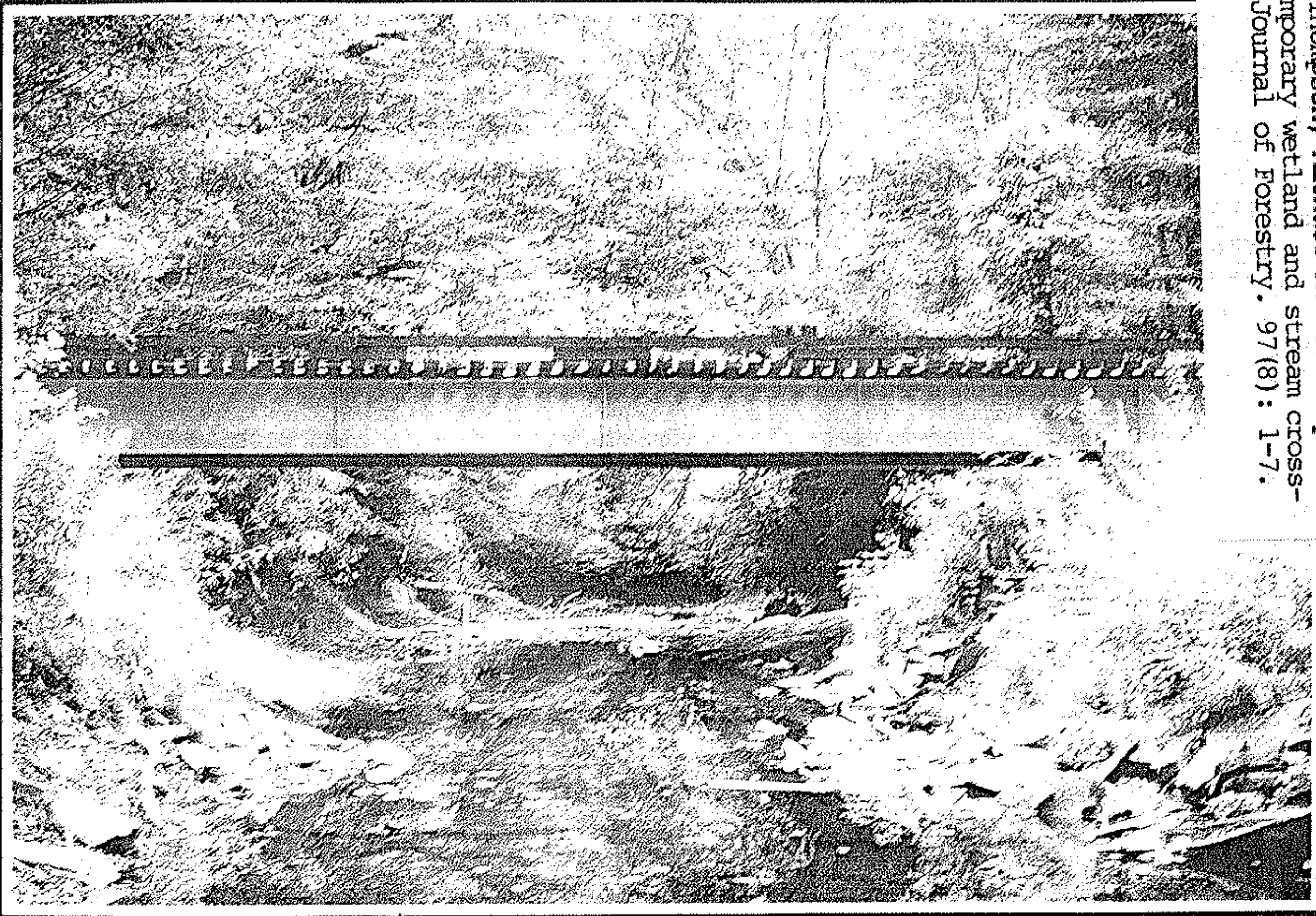

Forest Roads

How the media portray the issue

Reducing erosion

Predicting sedimentation

Redesigning problem roads

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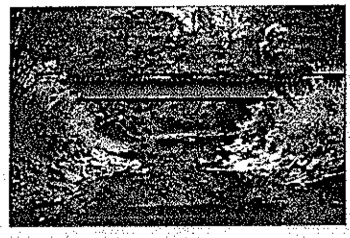

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As forest management activities intensify, so does the potential for damaging wetlands and streams with nonpoint source pollution. But how much damage do roads and stream crossings cause? Can we accurately quantify what does happen and predict what might happen? How can foresters working with small landowners protect water resources in a cost-efficient way?

This month's feature articles explore such questions and provide information you can use. And our Focus insert describes the variety of temporary and even portable wetland and stream crossing options that have been developed to protect aquatic resources.

But start on page 4 and see what fellow citizens think about forest roads. Public sentiment ebbs and flows, and yet certain trends are discernible. The forester who seeks to serve the public will take note.

Pages from the Past
See page 49

Focus on wetland and stream crossing options
See insert

FOCUS

Departments

education, and a conservation ethic to benefit society.

FOCUS

JOURNAL OF FORESTRY • AUGUST 1999

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Options for Temporary Wetland and Stream Crossings

Forest Engineering

Water and Soils

Forest management activities and environmental concerns have accelerated significantly in the past 10 years. Worldwide expansion of economies and population has increased the demand for forest products and other uses of forests. These demands have the potential to negatively affect wetlands and streams. Wetlands, as referred to here, are areas containing soil with poor load-bearing capacity and high moisture content or standing water. They include unstable sections on a haul road and are frequently affected by seasonal water fluctuations. Forest road and skid trail crossings of wetlands and streams have the greatest potential to affect water resources directly through soil compaction, rutting, or the placement of fill, and indirectly by funneling the movement of sediment, debris, and nutrients into the water body.

The best way to protect wetlands and streams is to avoid crossings. If this is not feasible, it is essential to minimize and mitigate the impacts of using the crossing. For any particular application, it is becoming increasingly difficult to select a crossing option that is cost-effective for the contractor and landowner, that adequately addresses society's environmental concerns, and that satisfies the wide range of regulatory constraints.

Below is information about reusable temporary wetland and stream crossing options and their reported environmental impacts. (A temporary crossing is one used for a maximum of three years before removal.) Space limitations prevent us from presenting all available options; a more comprehensive review of options is in Blinn et al. (1998).

Although the initial price of a reusable temporary option may be expensive, its reusability may make it the least costly in the long term. Moreover, some temporary options are more effective in reducing environmental impacts than the options frequently used today.

We recommend contacting vendors, contractors, and other sources for more detailed information on local experience regarding costs, installation and removal, the availability of specific options in your area, and additional options not covered in this article.

General Considerations

Before deciding to install a crossing, weigh the value of the resources to be obtained against the costs and potential negative impacts to the site. Crossings of wetlands and streams should be avoided whenever practical alternatives are available. If crossings are necessary, there should be as few of them as possible and their locations should be carefully selected. Use existing crossings if possible, unless their rehabilitation and use would be more damaging than establishing new ones.

A crossing should be as short as possible. Stream crossings should be located on a straight segment of the stream channel with low banks, perpendicular to the direction of streamflow. This will minimize the need to disturb the bank or alter the natural shape of the channel. It will also reduce the impact of turbulent water action against the crossing structure itself or against any portions of the bank disturbed during installation. Where there is risk of flooding, structures should be anchored at one end to allow them to swing out of the main channel without washing downstream or creating an obstruction.

Proper installation, maintenance, and site rehabilitation are essential for an effective crossing. All necessary permits should be obtained in advance and terms communicated clearly to the employees (or contractor) who install, use, and remove the crossing option. Structures installed in or over a stream should be cleaned (away from the water body) before each installation, to remove mud and other debris, especially if the structure is placed within the stream.

Monitor the condition of any crossing as long as it exists. Regular maintenance is needed to keep the crossing functional. Inspection and repair should be done as necessary before each installation and during use.

Application of Geotextiles

Temporary wetland crossings work best with a geotextile underlay. Geotextiles allow water to drain, provide additional support, and separate the structure from the native soil, making removal easier. We recommend nonwoven fabrics for use with temporary crossings because they are less slippery than woven ones and thus provide a more stable crossing. If punctured, they will not tear as easily as woven fabrics. Nevertheless, limit the number of high spots, such as rocks and stumps, to reduce the risk of punctures. Avoid damaging the root or slash mat in the area of the crossing; the mat will provide additional support during use and can speed revegetation following removal of the crossing option.

Depending on local regulations, the geotextile may need to be removed with the crossing. Soil and water may make the geotextile too heavy to be easily recovered in a reusable condition, so it may be beneficial to use shorter lengths of about 25 feet with the ends overlapped by 2 feet. If it will not be possible to remove the geotextile, a biodegradable fabric should be considered. Fiber options for biobased geotextiles include coir, jute, kenaf, flax, sisal, hemp, cotton, coconut, and wood fiber (English 1994). Paper machine felt, used carpet, and other ma-

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The authors' 1998 report, *Temporary stream and wetland crossings for forest management* (GTR-202) may be obtained free of charge from North Central Station Distribution Center, USDA Forest Service, One Gifford Pinchot Drive, Madison, WI 53705.

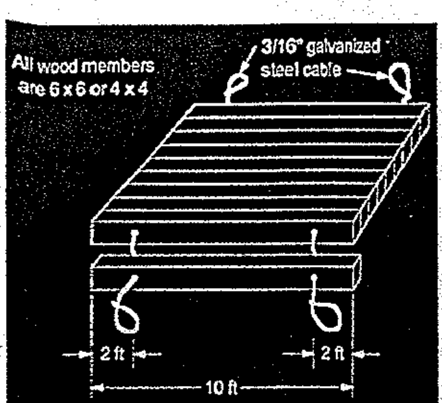
terials may be low-cost alternatives to geotextile. Check with the appropriate regulatory agencies before using substitute materials.

Temporary Wetland Crossings

The temporary options reviewed here are alternatives or supplements to crossing wetlands during frozen or dry conditions. The options can be applied to the surface of a wetland soil, including a wet spot on a haul road, to stabilize it for short crossing distances. Although we define "short" as less than 200 feet, the distance may depend on the initial cost of purchasing or constructing the selected option, the value of whatever resource is to be obtained, and the costs associated with other travel routes.

Temporary wetland crossing options include wood mats, wood panels, wood pallets, expanded metal grating, polyvinyl chloride (PVC) and high-density polyethylene (HDPE) pipe mats and plastic road, bridge decks, tire mats, corduroy, pole rails, wood aggregate, and low-impact equipment. Such equipment includes lightweight machines or machines with wide tires, duals, tire tracks, tracks, and central tire inflation. Its purpose is to distribute the weight of the equipment over a wider area and increase tractive efficiency. Central tire inflation is possible for use on hauling trucks and may become available for in-woods equipment in the future.

Most of the wetland crossing options are best suited for use with hauling and forwarding activities but not skidding. If used during skidding, the options will wear faster and may move out of position when timber is dragged over the crossing. To avoid risk of breakage, do not place the mats or panels over firm high spots (such as stumps) or large rocks. Most crossings are best applied on road sections with straight alignments, grades up to 4 percent, and no cross slope. Steeper grades, cross slope, or curves may result in loss of traction or lateral movement outside the planned travel area.



Lola Hislop

Figure 1. **Schematic of a 10-foot-wide wood mat.**

The width of an option needed for any particular crossing will vary according to site characteristics, soil strength, anticipated loads, and installation and removal equipment available. On very weak soils (such as muck or peat) with a low bearing strength, the crossing may need to be wider than on other soils, to spread the weight over a larger surface area. Extra crossing width may also be needed at road intersections and curves to provide necessary maneuvering room for vehicles.

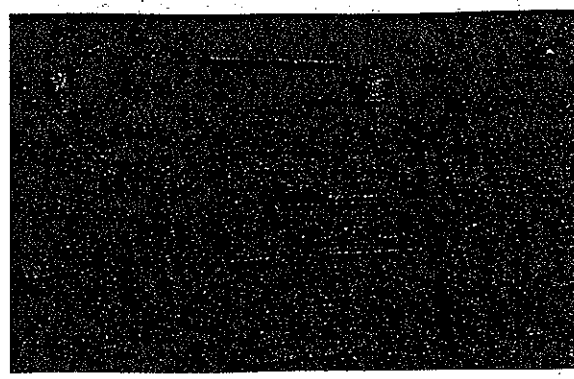

Charles R. Blinn

Figure 2. **Wood panel crossing option. Note the two layers of perpendicular planks.**

A brief description of wood mats, wood panels, expanded metal grating, polyvinyl chloride and high-density polyethylene pipe mats and plastic road, and tire mats follows. Commercial vendors sell some of the products, but most can be homemade.

Wood mats. Wood mats are individual cants or logs cabled together to make a single-layer crossing. Recommended minimum size of a cant is 10 feet by 4 inches by 4 inches. To construct wood mats, drill holes 1/4 inch in diameter through each log or cant approximately 1 to 2 feet from each end. Two 3/16-inch-diameter galvanized steel cables are then threaded through these holes to form the mat *(fig. 1).* Loops should be made at the end of each cable, extending beyond the last cant, and then secured with 3/16-inch-diameter cable clamps. The loops facilitate handling of the mat during installation and removal. Tightly connected cants may reduce any rippling movement over very soft soils. During installation, tuck the ends of the cable loops under the mats to prevent their being caught by a passing vehicle. A 10-foot-by-12-foot mat using 4-inch-square cants costs about $200 (including $50 for labor). Nonwoven geotextile costs extra. If the surface of the wood mat becomes slick during use, add expanded metal grating (see below) to provide traction.

Wood panels. Two-layer wood panels can be constructed by nailing parallel wood planks to several perpendicular wood planks where the vehicle's tires will pass *(fig. 2).* The actual wear or driving surface may be on either side of the panel. The number of reuses possible for panels will increase if the lumber is a dense hardwood. The individual panels can be either preconstructed or constructed on site. The authors constructed panels using 3-inch-by-8-inch planks. A gap of approximately 1 inch was left between each plank during assembly. Each finished panel was 8 feet by 12 feet.

Annularly threaded (ring-shank) or helically threaded (spiral) spikes may be used to attach the planks. For ease of construction, starter holes should be predrilled in the top board. To keep the spikes tight, place them at slight angles from vertical, with one spike angled toward the traffic and one away from it. Two loops of 3/16-inch-diameter galvanized steel cables may be attached to each constructed panel to facilitate handling during installation and removal. An 8- by 12-foot wood panel costs approximately $150 (including about $50 for labor). Cables, connectors, and nonwoven geotextile are extra.

If eye hooks are screwed into the ends of each panel, quick links or other heavy-duty connectors may be used to interconnect the panels. Thus the rocking that occurs when vehicles drive over each panel will be minimized and the overall flotation provided by the crossing will be increased. Installation and removal time will increase, however. If the panels are not interconnected during installation, leave about 6 inches between the individual panels to facilitate installation and removal.

Expanded metal grating. Machine weight can be distributed over a broad area if a rock crusher screen or metal grating is placed on top of geotextile. Expanded metal grating is made of nongalvanized (regular carbon, not flattened) steel, incised with diamond-shaped openings. The grating the authors evaluated came in 4 foot-

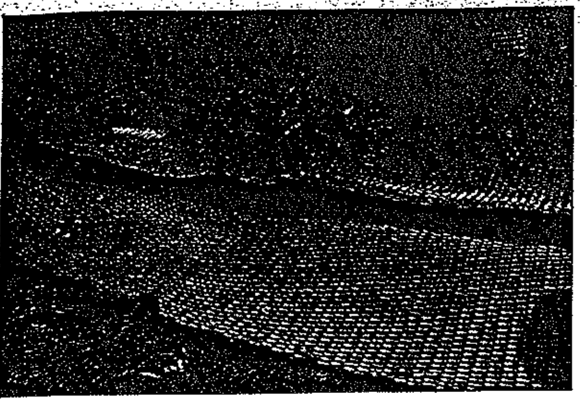


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Figure 3. **Expanded metal grating over geotextile.**

by-10-foot sheets with 1.33 inch-by-5.33-inch openings. The grating is relatively light and inexpensive, and its surface is rough enough to provide some traction. It works best on shallow wetland soils, sandy soils, and existing roads.

Expanded metal grating comes in various weights and can be placed by hand. Gloves are recommended during installation and removal. One person can place the lighter-weight steel, but it is more susceptible to movement as vehicles drive over it. Installing heavier-weight steel is a two-person job. It takes approximately one hour for four people to install 100 feet of geotextile and grating *(fig. 3)*. During removal, equipment may be needed if sections have been covered by tracked soil.

The grating sections will move during use if they are not interconnected. The sections may be connected using heavy-duty connectors, such as quick links, which are 3⁄8 inch in diameter or larger. With use, the grating will bend into a large shallow rut and should therefore be flipped periodically or when placed at a new site. The deformation does not harm the grating. A connector larger than 3⁄8 inch, or a short section of chain and a quick link, will make interconnection easier once the grating becomes deformed. A crescent wrench may be needed during installation or removal of the quick links, as the soil will make it more difficult to close and open the link.

Polyvinyl chloride and high-density polyethylene pipe mats and plastic roads. A portable, reusable, lightweight, corduroy-type crossing of varying length may be created using 4-inch-diameter Schedule 40 polyvinyl chloride or SDR11 high-density polyethylene pipes to form pipe mats or a plastic road. Because standard polyvinyl chloride is light-sensitive and loses strength when exposed to the sun, covering or painting the pipe or using an ultraviolet-resistant pipe, such as high-density polyethylene, may extend life expectancy. Polyvinyl chloride pipe that has been exposed to the sun should be avoided. High-density polyethylene tolerates temperatures down to –40°F and exposure to sunlight better than polyvinyl chloride without becoming brittle or losing its shock resistance, and it will return to its original shape after being deformed.

Both polyvinyl chloride and high-density polyethylene pipe are generally sold in multiples of 10 feet. To build a pipe mat that is, for example, 12 feet wide, first saw 20-foot pipes into 12-foot lengths and then saw the remaining 8-foot sections in half. The mat consists of alternating 12-foot sections and two 4-foot sections placed 2 feet from each other; the individual pieces are connected by 3⁄16-inch-diameter galvanized steel cables *(fig. 4)*.

Drill four 1⁄4-inch-diameter holes completely through the 12-foot pipes 2 feet and 4 feet from each end. Drill two holes completely through each 4-foot section, with the holes approximately 1 foot from each end. Loops should be made at the end of each cable, extending beyond the last pipe and secured with 3⁄16-inch-diameter cable clamps. Each cabled pipe mat should be relatively tight, so that the pipes act more as a unit that more evenly distributes the weight. Loops at the end of connecting cables should be covered so that they do not hook onto the underside of a passing vehicle.

The initial construction of a 10 foot-by-12-foot polyvinyl chloride pipe mat costs approximately $500 (including about $50 for labor). Expanded metal grating or wood panels may be necessary to reduce rippling of the pipe mat and to add traction, depending on the length of the crossing and the grade. The crossing surface needs to be sufficiently connected to the pipe mat so that it doesn't flip up under a crossing vehicle.

A plastic road mat is constructed of a single layer of pipes interconnected with small-diameter polyvinyl chloride pipe to form a panel *(fig. 5)*. The plastic road design includes transition mats used as ramps onto and off the mats from the firm soil. The mats can interconnect quickly and easily to cover any needed distance. Complete instructions for constructing a plastic road mat are in Moll and Hiramoto (1996).

Two people can quickly place the various panels in either the pipe mat or the plastic road crossing. Moll and Hiramoto (1996) reported that polyvinyl chloride plastic road panels and transition mats for an 8 foot-by-40-foot-long crossing were transported in a 3⁄4-ton pickup truck and assembled by two people in about an hour. Material costs for that crossing, including the nonwoven geotextile, were approximately $2,000. The plastic road can be towed from site to site with a pickup truck or logging equipment by a chain attached to the transition mats. The distance and surface over which the plastic road is dragged should be evaluated to avoid excessive wear and breakage.

Tire mats. A mat or panel of tires can be created with tire sidewalls connected

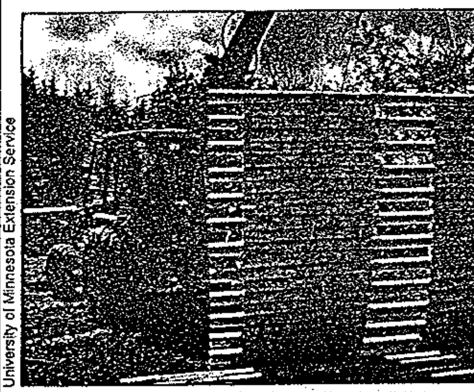

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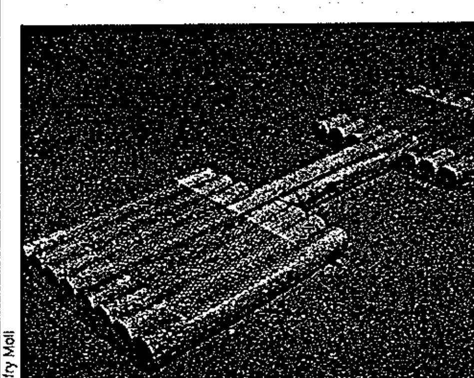
Figure 4. **Polyvinyl chloride pipe mat or pipe bundle being lifted into place.**



Jeffry Moll

Figure 5. **Polyvinyl chloride plastic road panel with an expanded metal grating surfacing.**

by corrosion-resistant fasteners *(fig. 6)*. Tire treads have also been used in some designs. Mats of varying length and width can be developed. Commercially manufactured mats are available.

Some designs include double layers of sidewalls, while others use a layer of

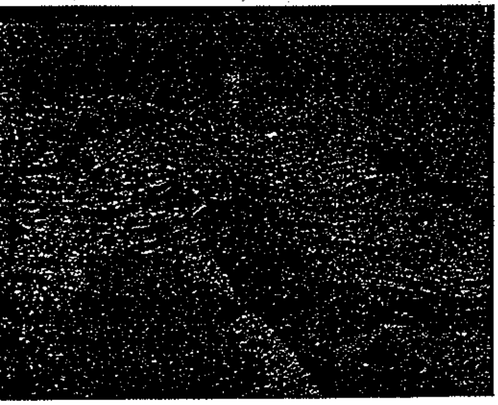


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Figure 6. **Tire mats over geotextile.**

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Figure 7. **Ford or low-water crossing.**

treads topped by sidewalls. No running surface is needed over the mat. The mats conform to the area after placement. Anchoring may be needed to prevent movement during use, especially in areas with a grade of more than 4 percent. The mats can be dragged into place with a skidder or installed using a knuckleboom loader. Tire mats can be placed on top of geotextile or corduroy to provide additional flotation. Dragging the tire mat into position is not recommended when a geotextile is placed under the tire mat, because the fabric will likely bunch or tear.

Temporary Stream Crossings

Stream crossing options include fords, culverts, polyvinyl chloride and high-density polyethylene pipe bundles, and bridges. Contact the local hydrologist to determine whether a permit is required. The permit may specify the type of crossing as well as when it can be installed or used. Properly designed and installed temporary structures can greatly reduce costs and help meet the concerns of regulatory agencies.

Approaches to stream crossings should be direct and have a low grade. Approaches on weak soils can be stabilized with corduroy, wood mats, wood panels, or expanded metal grating placed over a nonwoven geotextile. During use of the crossing, water diversion structures, such as a broad-based dip, should be constructed to direct water flowing down the road or skid trail away from the crossing and into a vegetated area to minimize the movement of sediment into the stream.

We recommend consulting a licensed engineer in the design of many stream crossings. However, engineering design information for some options is limited, and the additional costs for an engineered design may be considered exorbitant for a temporary crossing. Caution is necessary when using any crossing that has not been engineered and inspected between and during uses.

Except for bridges, temporary crossings generally should not be installed or removed while fish are migrating and spawning. Pipe bundles should be removed before fish migrate and spawn.

Fords. A ford or low-water crossing utilizes the streambed as part of the road or skid trail *(fig. 7).* Fords are best suited for short-term projects or for long-term but very infrequent access across a stream. Use should be limited to periods of low flow or when the channel is dry. A mucky or weak streambed is not acceptable as a base for a ford unless it is frozen. If the streambed or the approaches are not rock or firm, coarse gravel, alternative materials can be used to create a firm base:

- *Permanent fords.* Clean gravel or rock with or without geotextile, or a plastic cell webbing known as a cellular confinement system.
- *Temporary fords.* Mats made of wood, tires, expanded metal grating, logs or poles, or a floating rubber mat.

Use of a geotextile below any material (clean gravel, rock, wood, or tire mats) in either a permanent or a temporary ford can provide additional support to the crossing while separating the material from weak native soil. The appropriate regulatory authorities should approve use of the geotextile, however, because high water may push the geotextile downstream. Also contact the appropriate regulatory authorities if any material is to be excavated.

Culverts. A culvert conveys water under the access road or skid trail. Manufactured culverts come in many shapes (round, oblong, or arched), lengths, and diameters, and may be made of corrugated steel, concrete, or polyethylene. New culverts are available from a variety of suppliers. Used culverts suitable for temporary installations may be available from state and local road authorities or construction, pipeline, or drilling companies.

Other materials are often used as substitutes for manufactured culverts on temporary forest roads and skid trails. Some examples are hollow steel piling, well casings, gas pipeline, wooden box culverts, and hollow logs.

Proper sizing and installation of culverts are critical. When determining the size of a culvert, consider both culvert diameter and length. The culvert must be long enough to extend at least to the toe of the fill slope. It should also be large enough to accommodate peak flows, which are frequently based on the predicted time between flood events (25, 50, or 100 years). A single, large-diameter culvert is better than two or more smaller culverts. Because of the need to clean culverts, 12 inches is generally the recommended minimum diameter. Confirm the size with a hydrologist or licensed engineer and the appropriate permitting authority.

Proper installation is essential if culverts are to function without significant maintenance problems. Fill should be added only a few inches at a time, and each layer should be compacted. This is particularly important around the lower half of the pipe. A culvert should be covered with fill to a depth of 12 inches, or half the diameter of the pipe, whichever is greater. This protects the pipe from being crushed and prevents damage to the pipe during grading of the road.

Polyvinyl chloride and high-density polyethylene pipe bundles. A pipe bundle crossing is constructed using 4-inch-diameter, Schedule 40 polyvinyl chloride or SDR11 high-density polyethylene pipes cabled together to form mats of varying length *(fig. 4).* This choice is most appropriate for streams with U-shaped channels. As noted above, high-density polyethylene may be preferable in many applications where exposure to sunlight or low temperatures may occur.

A pipe bundle is constructed like a pipe mat. Each cabled section should be relatively loose so that pipes can conform to the stream channel. First, geotextile fabric is laid down, and then a layer of connected pipes is placed on top of the geotextile. If necessary, loose or connected pipes should then be layered to the desired height. A layer of connected pipes should be the top mat. Using pipe bundles in place of fill around a large, temporary culvert is another possible application. However, to our knowledge, this has not been tested yet.

Loops at the ends of connecting cables need to be covered so that they do not hook onto the underside of a passing vehicle. A stiff surface is often laid over the top mat to limit pipe movement (wave action) and provide traction. The crossing surface should be sufficiently connected to the pipe so that it doesn't flip up under a crossing vehicle.

Bridges. By spanning the stream, bridges keep fill and equipment out of the water better than any other stream-crossing option. Designs exist for a wide range of span lengths and load capacities (pickup trucks, skidders and forwarders, or loaded semi-tractor trailers). Bridging options include ice, timber, used railroad cars *(fig. 8)* or flatbed truck trailers, steel *(fig. 9)*, or prestressed concrete.

Ice bridges are a common type of winter crossing over streams, lakes, and rivers in areas with extended periods of below-freezing temperatures. If the ice is thick enough, no construction is needed. Where construction is necessary, ice bridges are made by packing snow or pumping water onto the existing ice. Because an ice bridge takes longer to melt than the stream, a new channel may be cut around the bridge on streams with high spring flows.

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Figure 8. **Used railroad car crossing.**

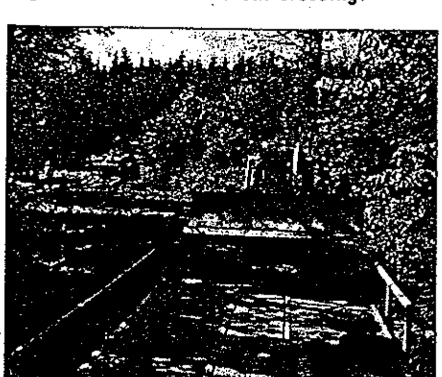

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Figure 9. **Steel bridge crossing.**

Timber bridges include log stringer, solid sawn stringers, and laminated options (stress-laminated, glued-laminated, dowel-laminated, and nail-laminated) *(fig. 10)*. Log stringer bridges are built by cabling together trees felled in the construction area. Solid sawn stringer bridges are built with new lumber, railroad ties, or demolition materials. For the laminated options, panels are placed side by side across a stream. An advantage of laminated panels and a solid sawn stringer design using new lumber is that the lumber is a known species and grade, and thus its structural properties are known; the engineer can then design a safe structure. Panels may also be more easily transported to the site than some other bridging options.

Railroad cars (flatcars and boxcars) and flatbed truck trailers can be retrofitted for use as temporary crossings. The main support beams must be reinforced so that they will support traffic. One steel bridge option is the hinged portable bridge, which folds up for transport. Another is a modular steel bridge, which consists of a series of individual panels that interlock to form a bridge of variable length. Precast, prestressed concrete panels can be locally fabricated. Generally, two or more panels are placed side by side to form the bridge.

Little site preparation is normally required when installing a temporary bridge. To provide stable, level support we recommend that bridges be installed on a log, railroad tie, or other similar abutment material on each side of a stream *(fig. 10)*. This also facilitates removal during the winter and minimizes disturbance to the stream bank. Specific site conditions, local statutes, or crossing permit requirements may specify more extensive abutments. Local statutes or crossing permit requirements may also specify the bridge's minimum clearance above the stream to accommodate peak flows or recreational use.

Some bridge designs are open in the middle or have holes or gaps in the traffic surface. Although these designs may be less expensive or easier to install, they also allow dirt and debris to fall into the stream. As a result, some jurisdictions do not permit their use. For structures with a gap in the traffic surface, it is recommended that a decking material, such as plywood or

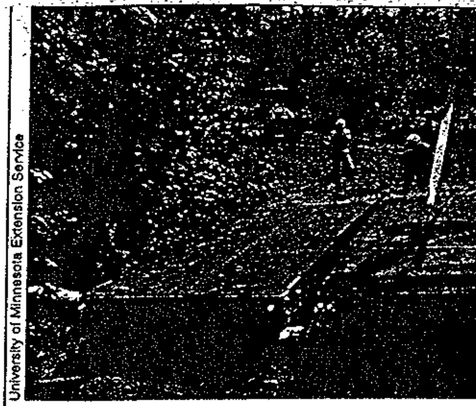

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Figure 10. **Abutment logs below a laminated bridge.**

lumber, be added to close the space.

A licensed engineer should review the design of any bridge fabricated from local materials to ensure that it is safe and adequate for the intended use. However, that review may be difficult to obtain or costly. Construction specifications have not been established for some materials, such as hardwood lumber; others, such as flatbed truck trailers, may be converted to a use for which they were not originally designed. Many materials or structures (railroad flat cars, flatbed truck trailers, concrete panels) have undergone substantial wear and tear before use as bridge structures, which may significantly reduce their strength or limit their remaining service life.

Environmental Impacts

Unfortunately, little information focuses on the environmental impacts associated with temporary wetland and stream crossings. Few studies have examined impacts of removal of the temporary crossings or compared their long-term effects. Questions still remain about what impact is acceptable. Below we summarize some of the studies that have reported environmental effects resulting from these crossings.

Wetland crossing impacts. Mason and Greenfield (1995) compared impacts in an area with silty sand soils on the Osceola National Forest in Florida, where wood pallets were used, to an area where pallets were not used. The soil moisture content in the area without wood pallets was typically 5 to 10 percent lower than in the area with the pallets. The rutting at the crossing without pallets was 6 inches to 10 inches. At the crossing with pallets, settlement was only about 0.5 inch. The wood pallets left no areas to hold and

Criteria to Consider When Evaluating Wetland and Stream Crossing Options

- Effectiveness in reducing potential impacts
- Relative safety of the option
- Compliance with safety regulations
- Compliance with other applicable nonsafety regulations, including permit requirements
- Potential conflicts with insurance coverage
- Seasons of use
- Length of time the crossing will be needed
- Ability to handle anticipated traffic loads and speeds
- Purchase price or construction cost
- Maximum distance of crossing or maximum span distance
- Bridge abutment requirements
- Availability of engineering specifications, especially for bridging options
- Local availability
- Ease of transport, installation, and removal with available labor and equipment
- Installation and removal time and costs
- Number of reuses possible
- Anticipated future need for a particular option
- Maintenance requirements
- Driving surface traction under anticipated operating conditions
- Potential costs avoided, such as purchase and placement of fill or need to divert stream flow during culvert installation or removal
- Anticipated fluctuation in water level during use
- Site conditions: soil type, hydrology, amount of rock present, stream width and depth, volume of water or types of aquatic organisms in the stream, permit requirements
- Potential values of the resource within the area
- Landowner's management objectives
- Rehabilitation requirements following removal

channel water or places where high compaction or rutting occurred.

Within the Osceola National Forest, areas with geotextile and expanded metal and deck-span safety grating showed less soil rutting than those with no grating (Mason and Greenfield 1995). After approximately 130 round trips by log trucks over the crossing, rutting in the area with grating was about 0.5 inch to 1 inch, compared with up to 1 foot of rutting in areas without grating.

Hislop (1996) tested wood pallets, wood mats, and a metal grating on a silty sand soil within the Osceola National Forest. A nonwoven, needle-punched geotextile was placed beneath each option. After 240 passes by a log truck, the maximum rut depth was 8 inches on a control section and 1.5 inches on the wood pallet and wood mat section. After 75 passes, the maximum depth on a control section was 15 inches, versus 5 inches for the metal grating.

Following approximately 20 passes by an unloaded flatbed truck with a loader on a deep black muck soil in Michigan, the authors noted the following maximum rutting depths: wood mat, 12.5 inches; expanded metal grating, 8 inches; tire mat, 6.5 inches; wood plank, 4.5 inches. A single pass in a control area produced ruts of 11.5 inches. Following approximately 20 passes with a loaded forwarder on a ponded histosol (a bog soil) in Minnesota, the maximum rutting depths were tire mat, 21 inches; wood plank, 6.8 inches; wood mat, 5.1 inches; expanded metal grating, 4.8 inches; polyvinyl chloride pipe mat, 1.3 inches. A nonwoven geotextile was placed below all options. Soil penetrometer readings at both sites did not show any differences in soil strength.

Stream crossing impact. One study evaluated suspended solids and turbidity for haul roads and skid trails associated with different stream crossing options at two locations in Pennsylvania (Tornatore 1995). Based on the findings, the author recommended constructing crossings during dry or low-flow periods to reduce the extent of downstream impacts. The study concluded that culverts for both skid trails and haul roads are viable if installation time is minimized, approaches and stream banks are adequately protected, and the culverts are properly maintained. The study also suggested that if mud and debris are not allowed to accumulate on top, portable bridges and wooden cross-tie bridges would outperform culverts in protecting streams.

Miller et al. (1997) evaluated environmental conditions above and below 70 forest road crossings in Pennsylvania. Only crossings two or more years old were evaluated. Culverts were the most common type of crossing. The study reported that only 35 of 814 comparisons of mean environmental conditions were found to be significant ($p < 0.05$). Significant differences were related to increased levels of fine sediment, reduced basal area, and increased herbaceous vegetation within the immediate vicinity of the road crossings. Successional and disturbance-related factors seemed to account for the vegetation changes typically found in the crossing area. Based on the measurements in their study, the authors suggested that severe long-term impacts of crossings were not common.

White Water Associates (1996) monitored installation with a bulldozer of a ford on a stream with moderate current (2.33 feet per second) and a hard bottom of limestone bedrock, limestone cobble, and gravel at stations 66 feet upstream (control) and at 33 feet, 82 feet, and 164 feet downstream from the ford. Thirty-three samples were collected for each station. The control station had significantly lower ($p < 0.001$) sediment load than the other stations. The total sediment loads produced by the ford installation at the stations 33 feet and 82 feet downstream were approximately 1,570 pounds and 1,030 pounds, respectively. The total suspended sediments returned to near zero soon after discrete disturbance events occurred. The interval between disturbance and return to near background level took about 18 minutes for the two disturbances that had sufficient time between them and the next disturbance.

Installation of a culvert was monitored on a stream that was 7.2 feet wide with an average depth of 9.3 inches, stream velocity of 0.63 feet per second, and stream discharge of 3.5 cubic feet per second (White Water Associates 1997). Monitoring stations were established at points 66 feet upstream (control) of the culvert and at 33 feet, 82 feet, 144 feet, 331 feet, and 427 feet downstream. Highly significant increases in sediment load were noted for each station except the one 427 feet downstream. The most distant sampling point downstream had sediment loads equivalent to the upstream control. It was estimated that 482 pounds of sediment was deposited between the stations 33 feet and 427 feet downstream of the culvert installation.

Hassler (1990) reported no statistically significant differences between turbidity, pH, and conductivity samples taken above and below a stress-laminated timber bridge crossing. Thompson et al. (1995) reported that culverts contributed sediment to the stream during installation and removal, while the bridge crossings did not.

Mason and Greenfield (1995) provided observations about potential impacts of polyvinyl chloride pipe bundle crossings. They indicated that soil could be picked up and later deposited into the stream if the crossing was stored on the ground before installation. Small fragments of pipe from cutting and drilling could remain inside the pipes and be deposited in the stream. During removal of a polyvinyl chloride pipe bundle crossing, sediment that had settled on the surface of the pipes could enter the stream. Removal of the geotextile caused disturbance. Indentations of approximately 0.5 inches were noticeable at the stream edges on removal of a 25-foot-wide polyvinyl chloride pipe bundle crossing that a loaded, 80,000-pound lowboy had crossed once.

During two demonstrations that we conducted, a polyvinyl chloride pipe bundle crossing caused depressions of approximately 0.5 inches after approximately 20 passes by a loaded forwarder. By using wood mats on the approaches, we found maximum rutting was approximately 0.5 inches, compared to areas beyond the approaches, where maximum rut depth was approximately 8 inches. We observed no sediment stirred up during removal of the pipes. Removal of the geotextile did cause a small amount of already-deposited sediment to be stirred up, however. Fisheries and water biologists were impressed by the minimal impact caused by the crossing. Légère (1997) reported similar findings for two crossings where high-density polyethylene pipe bundles were installed. In one test, a forwarder made 70 passes. Another test involved 40 passes by a cable skidder.

Economic Considerations

The temporary and portable options identified in this paper vary greatly in cost. Some can be assembled using native, onsite materials. Others require more sophisticated design and assembly and are primarily available from commercial vendors. Although each option is most effective in a limited range of applications, several options may work for a given application. Selecting the option that best fits the general operation of a company or agency requires careful consideration of many factors, both long- and short-term, including the overall operating costs.

A corduroy road section or log bridge constructed on site may have the lowest initial cost. However, a high-density polyethylene plastic road or a manufactured steel bridge that can be used for several years may be cheapest in the long term because it is reusable. Other factors specific to each company or agency may include the ease of and time required for installation and removal, safety, and operational efficiency and effectiveness. External factors, such as public policy, regulatory agency acceptance, market conditions, and unusual site-specific conditions, are also important. All factors must be weighed carefully against initial out-of-pocket costs to determine the best long-term choices.

Most organizations invest in the options that they anticipate using most often or that best meet their immediate needs. Some options are too expensive for most companies or agencies to invest in, even though they may be the safest and most effective in some situations. The initial cost may be beyond their financial resources, or the frequency of use too limited to justify the investment. A high-density polyethylene plastic road and a portable steel bridge are two examples. In these situations, it may be desirable for larger forest products companies and land management agencies to purchase the items and make them available for loan or rent to smaller companies, agencies, or logging businesses.

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Contact the authors for additional information about any of the options or to apprise them of other options that are not identified.

CORRECTION

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