We are aware of a locally fabricated, non-engineered, steel bridge that is about 50 ft (15 m) long and was constructed using I-beams. Also, catwalks with wood decking have been used.

Pre-stressed concrete bridges

Precast, pre-stressed concrete panels can be locally fabricated. Generally, two or more panels are placed side-by-side to form the bridge (fig. 30). Although the initial cost of this bridge may be low, they are usually heavy and require larger equipment to install and remove. It is important to make sure that the panels are engineered to handle the anticipated loads. Highway departments or local road authorities may be a source for used panels.

Figure 30.—*Pre-stressed concrete bridge.*

TEMPORARY WETLAND CROSSING OPTIONS

This overview of temporary wetland crossing options focuses on alternatives that 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 (fig. 31). While we define "short" as being less than 200 ft (61 m), the distance may depend on the initial cost to purchase or construct the selected option, the value of whatever is to be accessed, and the costs associated with other travel routes. Although a very long distance could be crossed when the option is matched to site needs, the cost may be prohibitive. The ability to reuse options makes them more viable, especially those with a higher initial cost.

Temporary wetland crossing options include wood mats, wood panels, wood pallets, bridge decking, expanded metal grating, PVC and HDPE pipe mats or plastic road, tire mats,

Figure 31.—*Wet area in a haul road.*

corduroy, pole rails, wood aggregate, and low ground pressure equipment. Low ground pressure equipment includes machines with wide tires, duals, tire tracks, bogies, tracks, light weight, and/or central tire inflation (CTI). We have chosen not to discuss road construction activities or wetland dredging and filling operations that are associated with constructing a new road or crossing over long distances. We have also not included cable yarding systems, helicopters, or balloons. Although use of frozen ground may be the most viable crossing option in many areas, that option is also not discussed.

Many of the options should not be placed on areas that have firm high spots (e.g., stumps, large rocks) to reduce bending stress and breakage during use. Hislop and Moll (1996) recommend blading the surface as flat as possible before installation. For sites with grass mounds or other uneven vegetation, blading should not disturb the root mat associated with the vegetation. The performance of any wetland crossing option is enhanced if there is a root or slash mat to provide additional support to the equipment.

Maintaining the root mat can also speed revegetation of the site following removal of the crossing. The performance of the crossing is also enhanced by use of a geotextile (fig. 32), which helps segregate the crossing from the underlying soil and provides additional flotation. Most of the options are best suited to be used in conjunction with hauling and forwarding, but not during skidding. If used during skidding operations, the options will wear faster and may move out of position when trees are dragged over them. Also, if a geotextile is used, it may become torn and displaced by skidding.

Figure 32.—*Applying a geotextile under a temporary wetland crossing.*

The length and width of a crossing option needed to achieve a particular wetland crossing will vary according to the site characteristics, soil strength, anticipated loads, and installation equipment available. The crossing option used should cover the entire length of area to be crossed so that ruts do not develop beyond the end of the option. Ruts may cause drivers to steer the vehicle out of a wheel path on the crossing option and to rut outside the edge of the crossing. On very weak soils that have a low bearing strength (e.g., muck, peat), the options may need to be wider than what is required on other soils. The additional width is needed to spread the weight over a larger area. Additional width may also be needed at road intersections and curves to provide necessary maneuvering room for vehicles.

Most of the options 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 of the option outside of the planned travel area. Traction loss may occur between the tires and the surface of the option, especially when the surface is wet. Slippage can occur between the crossing option and the geotextile below it. Because most wetland crossing options have a rough surface, they require a reduction of vehicle speed. They should be placed in areas where the speed is low or where there is good visibility and plenty of distance to slow the vehicle.

For the options constructed from wood (e.g., wood mats, wood panels, wood pallets), the ground surface should be fairly level before installation to reduce breakage of the wood members. Use of a dense hardwood species and treated timbers may extend the life of the crossing. However, use of treated timbers may not be cost-effective if the anticipated life and use of the panels do not require that application (e.g., only a short-term use is anticipated, skidding material over the option). Also, best management practices for the use of treated wood in aquatic environments should be used (WWPI 1996).

Each temporary wetland crossing option is briefly described below. Rummer and Stokes (1994) also discuss some of these options. As with stream crossings, there are several ways to accomplish each of the various options. Appendix 3 includes further information about many of the temporary wetland crossing options, including information about dimensions, product weight, and approximate purchase price. A list of some vendors of temporary wetland crossing options is presented in Appendix 1.

Wood Mats

Wood mats are individual cants or logs cabled together to make a single-layer crossing (fig. 33). A 10-ft- (3-m)-long, 4-in. x 4-in. (10-cm x 10-cm) cant or log is the recommended minimum size. Longer cants or logs may be needed to distribute the weight better on very weak soils or under heavy loads. Mason and Greenfield (1995) tested both 4-in.- (10-cm)- and 6-in.- (15-cm)-square cants on a silty sand soil within the Osceola National Forest in Florida. They found that while both mats worked well, the smaller mats cost less and were lighter weight, facilitating on-site installation.

Figure 33.—*Wood mat.*

Constructing wood mats consists of drilling holes 1/4-in. (6.4-mm) in diameter through each cant or log about 1 to 2 ft (0.3 to 0.6 m) from each end. Two 3/16-in. (4.8-mm) galvanized steel cables are then threaded through these holes to form the mat. Loops should be made at the end of each cable, extending beyond the last cant, and then secured with 3/16-in.- (4.8-mm)-diameter cable clamps (fig. 34). These loops are used to handle the mat during installation and removal. The connection between the cants should be tight to reduce any rippling or "wave" movement that might occur when vehicles pass. Improperly tightened cable clamps can lead to slip and loss of connectivity within the mat. We noted that a 10-ft x 12-ft (3-m x 3.7-m) mat constructed from 4-in. x 4-in. (10-cm x 10-cm) material over deep, organic, muck soil developed a rippling motion in front of the tires of a moving flatbed truck. This was caused by the mat sinking into the soil in the area immediately below the tire. We speculated that a wider mat with the cants more tightly connected may have avoided this problem.

Figure 34.—*Cable loop at the end of a wood mat.*

Hislop (1996a) reported that it took three people up to 3 hr to cut, drill, and cable together a 20-ft- (6.1-m)-long x 10-ft- (3-m)-wide mat. To reduce drilling time and errors in marking, she recommends making one set of drilling marks on the ground and ensuring that several hand drills are available. A welding torch or some other means of controlling cable end fraying will increase threading speed. The cost to initially construct a 10-ft x 12-ft (3-m x 3.7-m) mat using 4-in. x 4-in. (10.2-cm x 10.2-cm) cants is about $200 (including about $40 for labor) and the mat can be expected to last several years under normal use.

Individual mats can be connected to one another on-site to form the complete crossing. Limiting mat length to about 10 ft (3 m) reduces weight and facilitates installation. Shorter lengths may be needed if the mats are wider than about 12 ft (3.7 m). During installation, it is important to tuck the ends of all cable loops under the mats to avoid their being caught by a passing vehicle. If the surface of the crossing becomes slick during use, expanded metal grating (as described later in this report) can be added as a running surface 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. 35). The actual running surface may be on either side of the panel, unless the nails have gone all the way through it. The individual panels can be either preconstructed or constructed on-site. We constructed panels using 3-in.- (7.6-cm)-thick x 8-in.- (20-cm)-wide planks. A gap of about 1 in. (2.5 cm) was left between each plank during assembly. Each finished panel was 8 ft x 12 ft (2.4 m x 3.7 m).

Figure 35.—*Wood panel.*

Annularly threaded (ring-shank) or helically threaded (spiral) spikes can be used to attach the planks. For ease of construction, starter holes should be pre-drilled into the top board. To reduce withdrawal, spikes should be placed at slight angles from vertical with one spike angled toward the traffic and one away from it. To facilitate picking up the panels during installation and removal, loops can be created by attaching 3/16-in.- (4.8-mm)-diameter galvanized steel cables to each section using 3/16-in.- (9.5-mm)-diameter cable clamps. The initial construction cost of an 8-ft x 12-ft (2.4-m x 3.7-m) wood panel is about $150 (including about $40 for labor). Connectors and non-woven geotextile are extra.

Interconnecting adjacent panels in a crossing will help minimize the rocking that occurs when vehicles drive over the panels and will improve the overall flotation provided by the crossing. However, interconnecting panels will also increase the time required for installation and removal of the crossing. Adjacent panels can be interconnected using eye hooks screwed into the end of each panel with quick links or other heavy duty connectors through the hooks. If the panels won't be interconnected when installed, about 6 in. (15 cm) should be left between the individual panels to facilitate installation and removal.

Wood Pallets

Wood pallets for crossings are sturdy, three-layered pallets similar to those used for shipping and storage but specifically designed to support traffic (fig. 36). They are a commercially available product generally made from dense hardwood planks that are nailed together. They are specially designed so that they can interconnect, so that they are reversible, so that broken planks can be easily replaced, and so that nail points won't surface. Some pallets are designed so that the top and bottom pieces are already interconnected similar to a traditional pallet, while others are designed so that the top and bottom pieces are separate and interlock during installation to prevent longitudinal movement.

Figure 36.—*Wood pallet.*

Hislop and Moll (1996) indicated that the width of some commercial wood pallets is a disadvantage. Interconnection along their 8-ft (2.4-m) edge is too narrow for hauling roads. It may be necessary to cut commercial pallets in half to make two 4-ft- (1.2-m)-wide x 14-ft- (4.3-m)-long pallets. Each half-pallet would then be placed in a wheel path. Because the half-pallets weigh less, they are also less cumbersome to install. However, the smaller pallets may become too narrow to support equipment on undisturbed peat or very weak mineral soils. Pallets can be custom-made so that the interconnection is along the 12-ft- (3.7-m)- or 14-ft- (4.3-m)-wide edge.

Most commercial pallets are designed to be moved with a forklift, which is not a common piece of equipment in the woods. A thin choker cable can be run between the planks and hooked to lifting chains to facilitate installation with a front-end loader or backhoe (Hislop and Moll 1996). Before installation, the ground surface should be fairly level to reduce breakage.

Bridge Decking

The decking of a timber bridge can be used to cross a small wetland area. Bridge panel options that do not have steel or wood stringers, such as prefabricated stress-laminated, glulam, dowel-laminated, and nail-laminated bridges, may be most appropriate and available. Individual panels would be placed across the area with soft soil and approach ramps to the decking built.

Expanded Metal Grating

Machine weight can be distributed over a broader area by placing a rock crusher screen or a commercially available metal grating on top of a geotextile, parallel to the direction of travel (fig. 37). The two types of commercial grating that have been tested are expanded metal and deck span safety grating (Mason 1992). Of the two commercial products tested, only the expanded metal grating is recommended. It is made of regular (not flattened), non-galvanized (carbon) steel and comes in a variety of thicknesses with different opening sizes. The grating is relatively light, inexpensive, and the surface is rough enough to provide some traction.

Figure 37.—*Expanded metal grating over a geotextile.*

Expanded metal grating can be installed by hand once it is moved to the crossing area. Various amounts of steel are used in expanded metal grating, and it is sold on the basis of weight/square unit of area. Although the lighter weight steel can be placed by one person, it is more susceptible to movement as vehicles drive over it. The heavier weight steel can be placed by two people. Gloves are recommended during installation and removal. It takes about 1 hr for four people to install 100 ft (30 m) of geotextile and grating. During removal, a winch may be needed to remove sections if they become covered by tracked soil.

The grating sections will move during use if they are not interconnected. Adjacent sections can be connected using heavy duty connectors, such as quick links that are 3/8 in. (9.5 mm) in diameter or larger. Because the grating sections are likely to bend into the shape of a large shallow rut during use, they may need to be flipped periodically or when placed at a new site. This deformation of the grating does not harm it. A connector that is larger than 3/8 in. (9.5 mm) will be easier to install and remove if the grating becomes deformed. A crescent wrench may be needed during installation or removal of the quick links because soil will make it more difficult to close and open the link. Hislop (1996a) indicated that theft of the metal grating was a problem during tests in Florida.

PVC and HDPE Pipe Mats or Plastic Road

A portable, reusable, lightweight corduroy-type crossing can be created with PVC or HDPE pipe mats (fig. 38). An important advantage of

Figure 38.—*PVC or HDPE pipe mat in a road.*

using pipes is they provide a conduit for water to move through the crossing without further wetting the area. A pipe mat is constructed using 4-in.- (10.2-cm)-diameter Schedule 40 PVC or SDR11 HDPE pipes that are tightly connected using 3/16-in.- (4.8-mm)-diameter galvanized steel cables to form panels (fig. 39). A plastic road (fig. 40) is similar to pipe mats, except that pipe transition mats/panels are built into the design to ease the transition of tires ramping up and then back down again on the approach between the firm soil and the mat. Also, the various pipes in a plastic road are connected using 1-in.- (2.5-cm)-diameter Schedule 80 PVC. Complete instructions for constructing a plastic road mat are presented in Moll and Hiramoto (1996). It is important to drill round holes to avoid creating potential stress points that could facilitate pipe shattering.

Because standard PVC pipe is light-sensitive and will lose strength when exposed to sunlight, using PVC pipe that has been exposed to

Figure 39.—*PVC or HDPE pipe mat.*

Figure 40.—*Plastic road mat.*

the sun should be avoided. Strength of the crossing can be maintained by covering or painting PVC pipe or by using an ultraviolet-resistant type of pipe, such as HDPE. HDPE pipe also tolerates temperature extremes of -40° F (-40° C) better than PVC without becoming brittle or losing shock resistance and will return to its original shape after being deformed (Légère 1997). No published studies have evaluated the use of PVC or HDPE pipe mats or the plastic road option for wetland crossings during the winter in an environment where temperatures are consistently below freezing.

HDPE pipes may be more expensive than standard PVC and may need to be purchased through a vendor that specializes in plastic pipe sales. The thickness of many alternative plastic pipes is often specified using the term “standard dimension ratio” (SDR), which is calculated by dividing the average outside diameter of the pipe by its minimum wall thickness. For any given outside diameter, SDR will increase as wall thickness decreases.

Moll and Hiramoto (1996) reported that PVC plastic road panels and transition mats for an 8-ft- (2.4-m)-wide x 40-ft- (12-m)-long crossing were transported in a 3/4-ton pickup truck and assembled by two people in about 1 hr. Material costs for that crossing, including the non-woven geotextile, were about $2,000. The various panels in either the pipe mat or the plastic road crossing can be quickly hand-placed by two people. A tractive surface, such as expanded metal grating or wood panels, may be necessary depending on the length of the crossing and the grade. Once installed, the plastic road can be moved from site to site by attaching a chain to one end of the transition mats and then towing it with a pickup truck or logging equipment. The distance and surface over which the plastic road is dragged should be evaluated to avoid excessive wear and breakage. A prototype plastic road installation supported over 400 loaded 18-wheel log truck passes at two sites.

Tire Mats

A mat or panel of tires can be created by interconnecting tire sidewalls and/or treads with corrosion resistant fasteners (figs. 41 and 42). Mats of varying length and width can be developed. Consideration of the weight that can be handled by on-site equipment during installation and removal is important when deciding on mat length and width. Some designs include double layers of sidewalls, while others use a layer of treads topped by sidewalls. The mats conform to the area after placement. Anchoring may be needed to prevent lateral movement during use, especially in areas with a grade over about 5 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. However, if a skidder will be used to drag the tire mat into place, geotextile is not recommended due to the likelihood of bunching and tearing of the fabric. No running surface is needed over the mat, although gravel can be added to improve traction (MacGregor and Provencher 1993).

Mason and Greenfield (1995) reported that because the mats are heavy, large, and very flexible, on-site installation time can take

Figure 41.—*Tire mat.*

Figure 42.—*Another tire mat design.*

about 15 minutes to more than 1 hr per mat. Maneuvering room and the type of equipment used are critical to the amount of time required for placement. Placement is easier without the geotextile because the mats can be dragged instead of lifted into place. However, this will result in the loss of the separation and support provided by the geotextile. When installing the mats with a clam loader, it is important that the clam not close on any of the fasteners (e.g., bolts) used to connect the individual sections within a mat. Once the bolts are bent, the mat is more susceptible to coming apart, life expectancy is reduced, and/or its strength characteristics are diminished.

Overall site impacts will be reduced during installation and removal by having the proper equipment on-site to handle the mats and through the use of lighter mats. To the extent possible, installation machinery should work parallel to the direction of the crossing instead of perpendicular to it so that disturbance is minimized. However, depending on the configuration of the mats and the particular area where they are to be installed, they can be either positioned in front of the installation equipment, laid from a perpendicular position, or dragged into place.

Corduroy

Corduroy is a crossing made of brush, small logs cut from low-value and noncommercial trees on-site, or mill slabs that are laid perpendicular (most often) or parallel to the direction of travel (fig. 43). The effect of corduroy is to spread the load over the whole length of the log or slab, effectively increasing the load-bearing area. Flotation increases with increasing surface area, especially length, of the individual pieces of corduroy. Multiple layers of corduroy may be required in some crossings. Brush corduroy will provide less flotation than small logs or mill slabs (Arnold and Gaddum 1995).

Figure 43.—*Corduroy.*

Corduroy is not normally covered with fill. During installation, application of a non-woven geotextile is recommended to separate the brush, logs, or mill slabs from the underlying soil. The use of geotextile should result in less corduroy being required to accomplish the crossing. To facilitate removal of temporary corduroy, two cables can be laid below and perpendicular to the corduroy before installing the crossing. The ends of each cable would then be joined with a cable clamp or similar device forming two large cable loops. The loops are then pulled out after use of the crossing with available on-site machinery. Corduroy is usually not removed or reused, however.

Pole Rails

When attempting to support skidding or forwarding machinery equipped with high flotation or dual tires, one or more straight hardwood poles cut from on-site trees can be laid parallel to the direction of travel below each wheel (fig. 44). The poles can either be with or without limbs. If the poles are not delimbed, more flotation will be provided at the top of the tree where the diameter is smallest. The diameter of the poles should not exceed about 10 in. (25 cm) on the large end so that they penetrate the wet area to a sufficient depth that the tires come in contact with the soil. Two or more poles may need to be laid parallel to each other if only small diameter material is available or if sufficient flotation is not provided. If dense hardwood poles are used, large limbs facing upward may need to be removed to minimize the chance of punctures and other tire damage.

For a crossing that is longer than the length of one pole, additional poles may need to be laid in a linear manner. The larger end of the pole, or the top of the tree for full-tree material, should be placed in the end of the crossing with the weakest soil to maximize flotation. After placing the poles, it is important to drive across them a few times without carrying a load to get them properly seated in the soil. Remove the poles when there is no further need to cross the wet area. This option will not work well if the machinery is equipped with conventional width tires because they are too narrow and are operated at too high a pressure to stay on top of the poles. It takes about 15 minutes to build a 40-ft- (12-m)-long pole rail crossing using two precut 40-ft- (12-m)-long poles.

Figure 44.—*Pole rails.*

Wood Aggregate

Wood particles ranging in size from chips to chunks (fist-size and larger) can be used as a fill material for crossing soft soils (fig. 45). There are several advantages to using wood aggregate in wetland crossings. Wood is relatively light, giving it better natural flotation than other materials, such as gravel. Low grade, unmerchantable wood that is normally left in the woods can be used. Low grade wood can be easier and cheaper to obtain in areas where no gravel deposits exist. Also, wood will naturally biodegrade over time, eliminating the need to remove it from the crossing following use (wood aggregate is not considered reusable). Finally, chunk-size wood aggregate allows water to flow freely through it, causing no changes to natural hydrologic flows. Although chunk-size particles are better for fill material than chips, chips are more readily available as chunking machines have not yet been commercialized.

Figure 45.—*Wood aggregate.*

The depth of aggregate needed will depend on soil conditions at the site. Saturated organic and mineral soils generally require at least 12 in. (30 cm) of aggregate. Less is generally needed to stabilize soft sand. Wetzel (1997) describes the use of green wood fuel chips to stabilize haul roads on deep sand soils in northwest Florida. The chips were spread to a depth of 6 in. (15 cm). The cost of stabilizing this road with wood chips was about half the cost of using gravel.

Wood aggregate can be used with or without geotextiles underneath (fig. 46). A layer of geotextile will improve performance on any soft soil, reducing the depth of aggregate needed. Provencher (1991) recommends the use of geotextile over organic soils. The use of geotextile is more critical over deep, saturated, organic soils where the root mat supplies much of the support. In this case, a heavy geotextile with at least 24 in. (61 cm) of aggregate is recommended (Arola *et al.* 1991). This keeps the aggregate from being forced down through the root mat. Another layer of geotextile should be placed over the aggregate (MN DNR 1995), creating a floating subgrade, with additional surfacing placed on top. Surfacing may also need to be added during use to maintain acceptable performance. If use of the road is meant to be short-term, biodegradable geotextile should be used.

Mullis and Bowman (1995) evaluated several sawmill-generated wood aggregate materials for rutting potential and road stiffness. A woodwaste material depth of 18 in. (46 cm) was able to carry construction traffic in the muskeg areas but did not seem to provide a significantly stable base for extended use. Depths of woodwaste material greater than 24 in. (61 cm) performed well. It was noted that sawdust tended to break down under traffic loading. When sawdust was predominant in the section, deeper rutting tended to occur. Planer chips did not compact very well. Bark fibers tended to form a well-compacted layer. The woodwaste seemed to perform the best when placed in a good mixture of sawdust, planer chips, and bark fibers. Mullis and Bowman (1995) recommend frequent maintenance to repair the rutting and low-frequency washboarding that developed on the test sections.

Figure 46.—*Use of a geotextile under wood aggregate.*

Low Ground Pressure Equipment

The pressure exerted by a machine on the ground surface will affect trafficking ability and site impacts. Low ground pressure equipment reduces this pressure by reducing overall machine weight, or by increasing the contact area between the equipment and soil, spreading the weight over a larger surface area. By reducing ground pressure at each contact point, equipment flotation is enhanced, traction is usually improved, and road maintenance requirements, such as grading, can be reduced. Low ground pressure equipment can also reduce rut depth and compaction, and can result in reduced fuel consumption.

Ground pressures of less than 5 or 6 PSI (34 or 41 kPa) are often considered high flotation. For reference, a typical adult applies about 3 PSI (28 kPa) to the ground when standing. Ground pressures lower than 4 PSI (28 kPa) may be needed to operate on wetland soils without significant impacts. The principal options for achieving low ground pressure on in-woods equipment include use of machines with wide tires, duals, tire tracks, bogies, tracks, light weight, and/or central tire inflation (CTI). CTI is an option for use on hauling trucks and may become available for in-woods equipment in the future.

Clambunk skidders and tree-length forwarders can move large loads while exerting a low ground pressure. A conventional cable skidder can operate like low ground pressure equipment on ground with intermittent soft spots by releasing its load, crossing to better ground, and winching the load back to the machine. Aerial systems that can either partially or fully lift logs off the ground, such as skyline cable systems, helicopters, and balloons, may also be an option.

While reducing load size when skidding, forwarding, or hauling is an option that doesn't require additional equipment or the retrofitting of existing machinery, many operators are reluctant to do this because of the loss in production and the resulting higher production costs. Forwarders may be able to maintain acceptable productivity and costs under situations where a reduced load is needed. Because a specific volume of material may need to be moved when skidding, forwarding, or hauling, more trips will be required to transport that volume under the reduced load scenario. Therefore, the net reduction in site impacts may be minimal.

A potential problem with low ground pressure equipment is that operators may build larger loads, given their increased traction and flotation. In weak soil conditions, this could result in impacts similar to traditional equipment. Therefore, the net positive environmental effect could be minimal unless operators keep their load size properly adjusted for soil conditions. Also, as machinery becomes bigger and heavier additional ground contact area is required to maintain the same ground pressure as smaller equipment with narrow tires. Therefore, as equipment gets bigger, the minimum size of high flotation tires will need to be increased to compensate for the added weight.

Equipment with wide tires, duals, bogies, and/or tire tracks

Wide tires, duals, bogies, and tire tracks improve flotation and mobility in soft ground by spreading the machine and load weight over a larger surface area. Wide (or high flotation) tires are wider than conventional tires (fig. 47). They are usually considered wide tires at about 34 in. (0.9 m) and are available up to about 72 in. (1.8 m) wide. Dual tires consist of two conventional width tires mounted on each end of an axle (fig. 48). Dual tires may be used on one machine axle (e.g., front or back axle, usually the back) or on all axles. It is also possible to add wrap-around tracks to existing, individual, conventional width rubber tires to make them wider (fig. 49). As an example, tracks can extend the width of a 30-in. (0.76-m) tire to either 42 in. (1.1 m) or 53 in. (1.3 m) and extend a 44-in. (1.1-m) tire to 65 in. (1.6 m).

Figure 47.—*Wide tires.*

Figure 48.—*Dual tires.*

Figure 49.—*Tire tracks.*

Figure 51.—*Tire tracks on a bogie.*

Although flotation is improved with wide tires and duals, these options have several disadvantages. The cost of purchasing and using wide tires and duals can be significantly greater than the cost of conventional tires. A good portion of this cost can be attributed to the heavy duty axles and transmissions that are usually required to carry the extra load from these tires. Because these options take time to install and remove, operators may keep them on the machines longer than necessary, reducing useful life and increasing costs. It is more difficult to transport machinery with wide tires and duals over some roads because oversize permits may be required. It may also be difficult to move equipment with wide tires down narrow roads or roads that have gates on them, unless the gate posts are wide enough apart or unless the machinery can go off the road around the gate. The turning radius of equipment outfitted with wide tires or duals is normally greater than that of conventionally equipped machinery.

A bogie is an axle system in which two tandem wheels with independent axles are mounted on a rocker frame and axle (fig. 50). If the wheels are driven, the bogie frame contains the appropriate devices to drive each wheel on the assembly. The bogie functions in two ways to reduce impacts to the site. First, the extra wheel adds contact area, reducing static ground pressure. Second, the rocking action of the bogie frame allows better contact with the broken ground surface, improving traction and lowering impacts. Further improvements in traction can be made by installing tire tracks around the adjacent tires on the bogie (fig. 51). These tracks are usually made of rubber with steel reinforcement. They are fairly easy to install and remove, especially relative to wide tires and duals. Also, tire tracks can be used on bald, worn-out tires to improve traction and extend their useful life.

Equipment with tracks

Tracked machines distribute the weight of the machine and load over steel or rubber tracks (fig. 52). These tracks are usually between 18 and 36 in. (46 and 91 cm) wide and 8 to 14 ft (2.4 to 4.3 m) long on each side of the machine. This provides a large area over which to distribute the weight of the machine and load, normally resulting in lower ground pressures than conventional equipment and better flotation. A disadvantage of these machines in skidding is they often travel at slower speeds than rubber-tired machines, which reduces productivity, especially for long skidding distances. Tracks are more commonly found on felling equipment where speed of movement is not as important, especially for designs that reach out to the tree. These designs also lower impact by not having to traverse as much of the site to access the area.

Figure 50.—*Bogie system.*

Figure 52.—*Tracked machine.*

Lightweight equipment

Lightweight equipment reduces ground pressure by reducing the weight of the machinery. In many cases, there is little change in contact area with the soil surface as compared to traditional-size equipment. An added benefit of smaller equipment is better maneuverability, which results in less damage to the remaining vegetation. This is especially important in thinning and partial cutting, which is becoming more prevalent across the country due to public concerns. By reducing the weight of the machinery, the machinery's ability to move large loads is also reduced. As a result, smaller, lightweight equipment has not been popular with producers in the past because the smaller loads have resulted in lower productivity and profitability. This will probably change in the future as land managers and landowners begin specifying the use of lightweight equipment to lessen impacts on their forests.

Equipment with central tire inflation

Central tire inflation (CTI) technology is a low ground pressure option for use on hauling vehicles equipped with radial tires (fig. 53). Most log trucks operate with very high tire pressure (around 100 PSI [690 kPa]) to allow heavy loads to be transported at highway speeds. However, problems such as damage to the road surface (Bradley 1993 and Hodges *et al.* 1987) can develop on unpaved roads during use of these high pressure tires. CTI allows a driver to automatically and uniformly vary the inflation pressure of a truck's tires while the vehicle is moving. With a CTI system, the tire pressure can be lowered to yield a tire with a larger footprint area (fig. 54), which reduces the vehicle pressures applied to the ground. As an example, the typical footprint length of a tire with 100 PSI (689 kPa) is 8 in. (20.3 cm), whereas the footprint of a tire inflated to 43 PSI (296 kPa) is 13 in. (33 cm) (Anonymous 1993, Greenfield 1992). That larger footprint translates into better flotation, increased traction, and reduced rutting in wet areas (Bradley 1997). The cost to retrofit a vehicle depends on the number of axles that are to be retrofitted. For an 18-wheel log truck with a three-zone system, the cost will probably exceed $16,000.

ECONOMIC CONSIDERATIONS FOR CROSSING OPTIONS

The temporary and portable crossing options identified in this paper differ greatly in cost. Some can be assembled on-site using native materials, while others require more sophisticated design and assembly, available primarily from commercial vendors. Each option has a limited range of conditions and applications

Figure 53.—*Central Tire Inflation (CTI) system.*

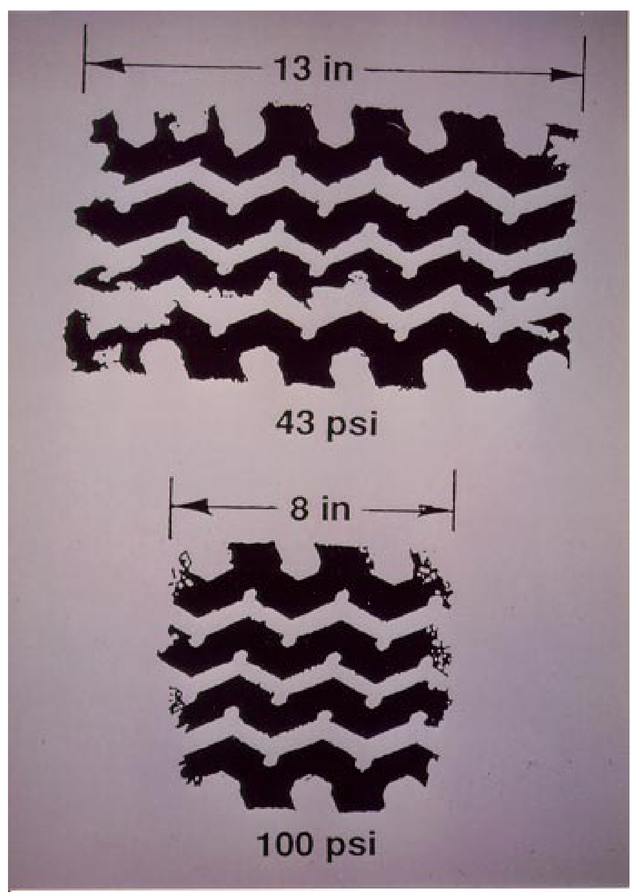

Figure 54.—*Tire footprint at two pressures.*

under which it is most effective. Several options may be considered effective for any particular application. Selecting the option(s) that best fit the normal applications and operating conditions for your company or agency requires careful consideration of many short-term and long-term factors. Investing in crossing options can control or reduce overall operating costs.

For example, a log stringer bridge constructed on-site may have the lowest initial cost, but a stress-laminated panel bridge that can be used and reused for several years may be the cheapest option over the long term. Internal factors affecting overall cost include initial cost; reusability; average time to replacement; time, labor, and equipment required for construction, installation, and removal; safety; and operational efficiency and effectiveness. External factors driving these decisions include product availability, public policy, regulatory agency acceptance, market conditions, and other site specific conditions or considerations. All these factors must be weighed carefully against actual out-of-pocket costs to determine the best long-term choices.

Most organizations invest in the options they anticipate using most often or that best meet their immediate need. Some options are too expensive for many companies or agencies to invest in, even though they may be the safest and most effective option for their needs. This may be because the initial cost is beyond their financial resources, or because the frequency of use is too limited to justify the major investment. Investment in a portable steel bridge may be one example. In these situations, it may be desirable for larger forest products companies and land management agencies to purchase these items and make them available for loan or rent to smaller organizations.

ENVIRONMENTAL IMPACTS ASSOCIATED WITH CROSSINGS

Environmental impacts associated with a broad range of forest management practices in areas near streams, and to a much lesser extent wetlands, have been extensively studied. These impacts can affect the aesthetics, biology (e.g., presence of plant and animal species, biomass), physical characteristics (width, depth, and shape of the stream or wetland, stream channel stability), temperature, and chemical composition (e.g., pH, turbidity,[6] conductivity[7]) of water bodies. Some of the reports that have summarized impacts from many studies include Brown and Binkley (1994), Campbell and Doeg (1989), Kahl (1996), Marcus *et al.* (1990), Meehan (1991), Salo and Cundy (1987), and Ward (1992).

Unfortunately, little information exists that focuses specifically on the environmental impacts associated with stream or wetland crossings. Most of the literature relates to the use of round culverts. Few studies have addressed the effect of stream crossings on stream quality other than from the standpoint of sedimentation. Few studies have examined impacts associated with the removal of the temporary crossings or have compared the long-term impacts associated with using a ford versus a temporary bridge. Questions still remain about what type of and how much impact is acceptable. The information that follows summarizes some of the studies that have reported environmental impacts resulting from these crossings.

Background

Where a stream bank becomes destabilized as a part of constructing or removing a crossing, sedimentation can become a problem, especially in lower gradient systems that respond to increased flow by increasing stream width. Such problems will likely be more persistent than those associated with just the road crossing itself (Everest *et al.* 1987, Sullivan *et al.* 1987). Sedimentation is a concern in streams because of the change in habitat for fisheries and benthic fauna, and because of phosphorus input associated with soils and sediment. Establishing the crossing at an area with a stable stream bank and providing adequate bank protection are critical.

When a culvert crossing fails, extensive local scouring occurs with deposition and additional erosion downstream (Furniss *et al.* 1991). Culvert crossing failures that divert streamflow into nonstream areas are particularly damaging (Weaver *et al.* 1987).

[6] *Volume of suspended solids.*

[7] *Electrical resistance due to dissolved solids.*

Sediment can have lethal impacts on fish in several ways (Ward 1992):

- Increased suspended sediment limits photosynthesis of algae and rooted aquatic plants by reducing sunlight penetration into the water. This limits production of food for aquatic life.

- Spawning beds for many species (e.g., walleye, whitefish, brook trout) consist of cobble or gravel substrate where the eggs fall into the interstitial spaces between stone particles. In these spaces, the eggs are protected from predators while water flow ensures the exchange of gases needed for survival. Sediment from construction sites can change the substrate by blocking the spaces and reducing or destroying productivity.

- Suspended sediment can cause changes in fish feeding behavior because prey is less visible.

- Suspended sediment can harm incubating fish eggs or fry and reduce the abundance of insect larvae, a food source for fish. Many fish eggs have an adhesive surface to which suspended sediment can attach and block gas exchange, causing the egg to suffocate.

- High levels of suspended sediment lasting for many days can cause direct fish mortality.

In addition, all fish species do not spawn at the same time. While some species spawn in the spring, others spawn in the fall and the eggs then hatch during the following spring. Because fish spawn at different times and areas with cobble or gravel are a preferred spawning area for some species, any in-stream activity can impact fish habitat and populations.

Fish are particularly sensitive to changes in water quality, temperature, and oxygen. Suspended sediments can abrade or clog gill filaments and reduce visibility of insects, thus reducing feeding success. A comparative post-logging study of 10 moderate gradient (0.3 to 3 percent) streams in New Brunswick and Nova Scotia found a significant reduction in the biomass of Atlantic salmon, brook trout, and brown trout at stream crossings (Grant *et al.* 1986). It has been reported that a 17 parts per million (ppm) increase in sand bedload results in a 10 lb per acre decline in trout populations (Alexander and Hansen 1983).

The immediate effects of in-stream disturbance frequently cause fish populations to decline. Generally, these effects last less than 10 years and often only a year or two (Gregory *et al.* 1987). Within a watershed, the cumulative effects of multiple crossings or other disturbances may be more persistent. In contrast to most authors, Everest *et al.* (1987) suggest that some fine sediment may be beneficial to trout and salmon (salmonids) by contributing to increased invertebrate productivity, and that the adverse consequences of fine sediment introduction to trout streams have been overstated.

Crossings can cause loss of fish habitat within, above, or below the crossing (Marcus *et al.* 1990). Improperly designed and installed culvert crossings can block fish migration routes. Common problems include outfall drops that are too great, lack of resting pools below culverts, excessive water velocities, or insufficient water depth within culverts. Anderson and Bryant (1980) published an annotated bibliography of fish passage at road crossings. A number of considerations necessary to minimize potential effects of culvert crossings on salmonids have been suggested (Yee and Roelofs 1980). Culvert and bridge installers also need to consider whether they are creating an obstruction of a navigable waterway.

A stream adjusts its geometry to accommodate the water and sediment it carries. When the amount of water or sediment a stream must carry increases, channel geometry must change to accommodate the increase. When channel geometry is artificially changed, such as by an incorrect stream crossing, the stream will adjust by altering its geometry upstream or downstream of the change (Furniss *et al.* 1991). Road crossings that modify and restrict stream geometry least, such as bridges or low-water fords, are likely to have the least adverse effects on channel geometry.

Using treated wood products in and around water bodies can cause toxic substances to leach into the water. Best Management Practices for the use of treated wood near water have been developed (WWPI 1996). These practices should be followed when using treated wood in temporary crossings.

Studies of Stream Crossings

Thompson *et al.* (1996) evaluated sediment production from two gravel-bottom fords located on third-order streams in the Talladega National Forest in Alabama. Both permanent fords were being used for occasional administrative traffic before being cleaned out and gravel added in preparation for a timber harvest. Results from background samples taken before the sites were disturbed indicated that the old existing fords produced little sediment at base flow rates. The base flow rate during winter months ranged from 0.0038 m^3/sec to 0.051 m^3/sec for Ford 1 and from 0.0018 m^3/sec to 0.049 m^3/sec for Ford 2. During the renovation of the fords, the peak sediment concentration increases were 2,810 mg/l and 1,355 mg/l for Fords 1 and 2, respectively. Mean sediment concentration increases were 359 mg/l and 353 mg/l for Fords 1 and 2, respectively. The total sediment produced was 116.8 lb (53 kg) for Ford 1 versus 35.3 lb (16 kg) for Ford 2. The difference in sediment load was due to differences in stream flow rates.

Thompson *et al.* (1996) reported that the first storm after renovation of the two fords produced higher sediment loads than during construction. The rainfall, which measured 12.78 cm over a 50-hr period, resulted in peak sediment concentration increases of 585 mg/l and 745 mg/l for Fords 1 and 2, respectively. Total sediment produced at Fords 1 and 2 during the storm event was 2,107 lb (956 kg) and 374.7 lb (170 kg), respectively.

Tests showed that when a pickup truck drove through Ford 1 at base flow rate conditions, sediment concentrations increased by as much as 255 mg/l (10 minutes after the vehicles passed through the ford) and 110 mg/l (25 minutes after the vehicles passed through the ford) at sampling points that were 148 ft (45 m) and 302 ft (92 m) downstream, respectively, from the lower edge of the ford (Thompson *et al.* 1996). Sediment concentration levels returned to normal within 1 hr after the vehicles passed through the fords. It was projected that heavier vehicles with more wheels, such as log trucks, might generate more sediment load than the light vehicles used in the tests.

Water quality was monitored while installing a ford with a bulldozer in a stream with a moderate current (2.3 ft/s) [0.7 m/s] and a hard bottom (limestone bedrock, limestone cobble, and gravel) in Michigan (White Water Associates, Inc. 1996). Sampling stations were set up 66 ft (20 m) upstream of the ford (control) and 33 ft (10 m), 82 ft (25 m), and 164 ft (50 m) downstream. A total of 33 samples were collected at each station. The control station had significantly lower sediment load than the other stations ($p<0.001$). The total sediment loads produced by the ford installation at the stations 33 ft (10 m) and 82 ft (25 m) downstream were about 1,570 lb (710 kg) and 1,030 lb (470 kg), 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.

Water quality was monitored while installing a culvert on a stream that was 7.2 ft (2.2 m) wide, 9.3 in. (24 cm) deep, flowing 0.63 ft/s (0.19 m/s), and discharging 3.5 ft^3 (0.1 m^3) of water per second (White Water Associates, Inc. 1997). Monitoring stations were established at points 66 ft (20 m) upstream of the culvert (control) and at 33 ft (10 m), 82 ft (25 m), 144 ft (45 m), 331 ft (100 m), and 427 ft (130 m) downstream. Highly significant increases in sediment load were noted for each station except the one that was 427 ft (130 m) downstream, which had sediment loads that were equivalent to the upstream control. It was estimated that 482 lb (220 kg) of sediment were deposited between the stations 33 ft (10 m) and 427 ft (130 m) downstream of the culvert installation.

In a study conducted on Horse Creek in Idaho, 12.3 lb (5.6 kg) of sediment were contributed to a stream when right-of-way timber and debris were cleared from the stream channel and a temporary culvert was installed (USDA Forest Service 1981). When a permanent culvert was installed after the stream was diverted around the construction site, 0.2 lb (0.1 kg) of sediment were contributed to the stream as compared to 46 lb (20.9 kg) for a similar culvert installation where the water was not diverted.

Hornbeck *et al.* (1986) reported turbidity levels of 2,200 and 3,300 Jackson Turbidimeter Units (JTU) for a skid road culvert crossing in New Hampshire. A value of 10 JTU or less usually is considered desirable for drinking water. The high values, which occurred during summer harvesting activities, resulted from failure of the culvert.

Mason and Greenfield (1995) provide observational information about potential impacts due to PVC pipe bundle crossings. They indicate that soil may be picked up and later deposited into the stream if the crossing materials were stored on the ground before installation. Also, small fragments of pipe from cutting and drilling may remain inside the pipes and be deposited in the stream. During removal of a PVC pipe bundle crossing, sediment that had settled on the surface of the pipes can enter the stream. Removal of the geotextile caused disturbance. Indentations of about 0.5 in. (12 mm) were noticeable at the stream edges upon removal of a 25-ft- (7.5-m)-wide PVC pipe bundle crossing that was crossed once with a loaded 80,000 lb (36,230 kg) lowboy.

During two demonstrations that we conducted, depressions of about 0.5 in. (12 mm) were caused by a PVC pipe bundle crossing after about 20 passes with a loaded forwarder. When we used wood mats on the approaches, maximum rutting was about 0.5 in. (12 mm) as compared to areas beyond the approaches where maximum rut depth was about 8 in. (20 cm). No sediment was observed being stirred up while the pipes were being removed. However, removal of the geotextile did stir up a small amount of deposited sediment. Fisheries and waters biologists were impressed by the minimal impact caused by the crossing. Légère (1997) reported similar findings for two crossings where HDPE pipe bundles were installed. In one test, 70 passes were made by a forwarder. In the second test, 40 passes were made with a cable skidder.

Hassler *et al.* (1990) reported that there were no statistically significant differences between turbidity, pH, and conductivity samples taken above and below a stress-laminated timber bridge crossing. Thompson *et al.* (1994, 1995) reported that culverts contributed more sediment to the stream during installation and removal than the bridge crossings, which did not contribute any sediment. Pierce *et al.* (1993) noted that bridges usually are preferred because culvert installation and removal causes channel disturbance and produces sediment and turbidity.

Taylor *et al.* (1996) reported that the installation and removal of several glulam bridges was accomplished without operating any equipment in the stream or disturbing the stream channel or banks. Based on a visual appraisal, the authors reported no adverse impacts on water quality. Keliher *et al.* (1995) reported that some debris fell into the stream during skidding over a glulam bridge that consisted of two separate longitudinal panels. The 2-ft (0.6-m) gap between the bridge panels was partially filled with logs to reduce the amount of soil and vegetation dragged into the stream during skidding.

Without specifying the type of crossing that was constructed, Swift (1988) reported that road crossings over streams are the most critical points on a road because fills are larger, the road drains directly into the stream system, and opportunities for mitigating practices are limited. As an example, the author refers to three roads built in one watershed within the Coweeta Hydrologic Laboratory in western North Carolina during 1976 at a density of 1.26 mi/100 ac (5 km/100 ha). During the first year, all sediment collected in a stream weir originated from the roads, most of it from eight stream crossings during the first 2 months after construction began. Sediment measurements immediately below one crossing showed a cumulative total of 267.7 tons of soil entering the stream from each acre (600 metric tons of soil from each hectare) of roadway during those 2 months and 357 tons from each acre (800 metric tons from each hectare) of roadway in the first 2.5 years following construction of the crossing. About 80 percent of the soil washed into the stream remained in the channel and had not reached the weir located 2,362 ft (720 m) downstream after 2.5 years. However, portions of those deposits were still being transported out of the stream system 8 years later.

A series of 1-day post-harvest assessments of 78 recently completed timber harvesting sites was conducted in Vermont to evaluate Acceptable Management Practice compliance, soil erosion extent, and water quality impacts (Brynn and Clausen 1991). The crossings were accomplished with either a metal or wooden culvert, ford, bridge, or brush. Some of the crossings were permanent. Comparisons of impacts between crossing types were not conducted. Over 60 percent of the crossings were made by a ford. Stream crossing sedimentation and debris were above background levels on 57 and 55 percent of the sites, respectively. The impacts of increased woody debris were judged not to be major.

Brynn and Clausen (1991) reported that stream crossings for trucks on perennial streams had adequately sized bridges or culverts 60 percent of the time. Also, 60 percent of the fords had stable approaches and stream beds. Stream crossings were made at right angles 81 percent of the time. Temporary stream crossing structures were removed and the channel restored 77 percent of the time. The study recommended that stream crossings over brush or pole fords[8] should not be allowed because the brush was infrequently removed and restoration may result in increased sedimentation. The seeding and mulching of the stream crossing approaches was completed on only 2 percent of the sites. Newton *et al.* (1990) recommended that fords of perennial streams should not be allowed except under unusual circumstances (e.g., the crossing is too wide for any other option).

Suspended solids and turbidity were evaluated for several stream crossing options on haul roads and skid trails at two locations in Pennsylvania (Tornatore 1995, Tornatore *et al.* 1996). At one site, four skidder crossings were installed: a culvert with shale fill, a culvert with log fill,[9] a portable hinged steel bridge, and a plastic ford that was constructed using a GEOWEB® cellular confinement system with shale fill underlain by geotextile fabric. An unmitigated crossing was also evaluated at that site by having a bulldozer pass directly through the stream at an area with a rocky bottom and a gradual approach. At the second site, three hauling crossings were installed: a culvert with gravel fill, a bedrock-based gravel ford, and a wooden cross-tie bridge that used rejected railroad ties as the cross supports and oak lumber spaced 2 in. (5 cm) apart for the decking. Stream samples were taken at sites above and below each crossing before, during, and after installation, during the use of the crossings, and during high flows due to snow melt.

Tornatore (1995) and Tornatore *et al.* (1996) reported that installation of all skidder crossings at the first site caused significant increases in suspended solids and turbidity. The level of impact to the stream was less severe during installation of the portable bridge versus the culvert. Installation impacts were reduced to insignificant levels within 24 hr following bridge installation versus 96 hr following installation of the culvert with the log fill.

Increases in suspended solids occurred downstream from all skidder crossings at the first site (Tornatore 1995, Tornatore *et al.* 1996). Increases below the portable bridge appeared to be a result of debris (leaves, twigs, and bark) falling through gaps in the bridge planking. Despite this, the portable steel bridge showed lower increases in suspended solids than either the culvert with shale fill or the culvert with log fill. To reduce debris, it was recommended that the bridge deck be kept reasonably clean. The culvert with shale fill performed better than the culvert with log fill. Suspended solids below the culvert with log fill resulted primarily from increased inorganic sediment that may be related to the stability of the approach area and stream bank. Two skidder passes made within 15 minutes of each other at the unmitigated ford crossing increased sediment solids by 350 times.

The ford with the GEOWEB® cellular confinement system protected and supported what otherwise would have been a wet, muddy depression in the haul road (Tornatore 1995, Tornatore *et al.* 1996). Use of the gravel-based ford resulted in greater increases in suspended solids and turbidity on haul roads than the

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[8] *The poled ford (also known as corduroy) was installed by filling the stream with logs or poles that were longer than the width of the equipment using the crossing. The poles were laid parallel to the flow of the stream with sufficient space between logs to allow the stream to pass through. To improve stream flow through the ford, two 10-ft- (3-m)-long sections of 16-in.- (41-cm)-wide ductile iron pipe (a high-carbon pipe designed to withstand pressurized gas) were placed in the poled ford without backfill.*

[9] *The culvert with log fill was "filled" with 4 to 5 in. (10 to 13 cm) diameter pole-size timber taken from the immediate vicinity of the crossing. The poles were laid parallel to the culvert until both the culvert and the area 2 to 3 ft (0.6 to 0.9 m) on either side were covered by a 8 to 12 in.- (20 to 30 cm)-deep log fill buffer.*

culvert with shale fill and the cross-tie bridge crossings. Approach stability was important for all skidder and haul road crossings.

Tornatore (1995) recommended constructing crossings during dry or low flow periods to reduce downstream impacts. Also, the study concluded that culvert use for both skid trails and haul roads is a viable means of crossing streams if care is taken to minimize installation time, if approaches and stream bank areas are adequately protected, and if the culverts are properly maintained. The study also suggested that if sufficient care is taken to prevent the accumulation of mud and debris on top of portable bridges and wooden cross-tie bridges, those crossing options would outperform culverts in protecting streams.

Miller *et al*. (1997) evaluated environmental conditions above and below 70 forest road crossings (40 culvert, 21 bridge, and 9 ford) in Pennsylvania. Only crossings 2 years old or older were evaluated. The study reported that only 35 of the 814 comparisons of mean environmental conditions above and below the crossings were found to be significantly different ($p<0.05$). Significant differences found were related to increased levels of fine sediment, reduced basal area, and increased herbaceous vegetation in the immediate vicinity of the road crossings. Successional- and disturbance-related factors seemed to be responsible for the vegetation changes typically found in the crossing area. Based on the measurements made in their study, the authors suggested that severe long-term impacts due to crossings are not common.

Thompson and Kyker-Snowman (1989) evaluated both short- and long-term impacts at an unmitigated stream crossing as well as mitigated crossings constructed with a portable bridge, a poled ford with a ductile iron culvert, and concrete slabs with hay bales. The unmitigated crossings provided no protection from disturbance of the stream or its banks. No clear effect of season (flow level) or equipment type (rubber-tire cable skidder vs. dual rear axle forwarder) on turbidity levels was documented. The effect of mitigation was dramatic. Unmitigated crossings generally caused large increases in turbidity at 15 and 100 ft (4.6 and 30.5 m) downstream of the crossing. No significant differences between before- and after-crossing values were found for pH, specific conductivity, or nitrate levels. Nitrate levels were negligible and in no case did they come near the allowable drinking water limit. For both unmitigated and mitigated crossings, there were no significant differences between turbidity values measured at 1,000, 2,200, 2,640, or 5,280 ft (305, 671, 805, or 1,609 m) below the crossings from samples taken at upstream locations.

Of the mitigated crossings, Thompson and Kyker-Snowman (1989) reported that the bridge was the most effective and the concrete slabs with hay bales the least effective at reducing crossing impacts. Measurable impacts with a portable bridge extended less than 100 ft (30.5 m) downstream. Measurable effects with other crossing options rarely extended as far as 1,000 ft (305 m) downstream. Although a natural ford was not included as a mitigated crossing in the study, the authors concluded that this option would be an acceptable mitigation from observational evidence of active and inactive harvesting sites. The study concluded that the largest impacts occurred as a result of unmitigated crossings, crossings that did not meet Best Management Practices (BMP) standards, and unstable approach areas adjacent to some of the crossings.

Thompson and Kyker-Snowman (1989) noted that poled fords used in winter can become a problem if they freeze into the stream and become difficult to remove. The temporarily abandoned ford can act as a dam during spring runoff, possibly causing the stream to overflow its banks and increase erosion. They suggested that ductile iron pipes might carry the spring floods through the ford and facilitate earlier removal.

Looney (1981) compared the use of a rubber mat dam bridge to a ford and a culvert crossing. While whole-tree skidding, the rubber mat dam bridge yielded a significant reduction in the amount of suspended solids being carried downstream, as compared to a ford crossing. During 1.33 hr of use at one site (5 one-way crossings with the first, third, and fifth crossings being loaded), the ford crossing resulted in 155 lb (52.7 kg) of sediment as compared to 92 lb (31.2 kg) of sediment for the dam bridge. During 2 hr of use at a second site (8 one-way crossings, every other one being loaded), the ford crossing resulted in 613 lb (208 kg) of sediment as compared to 242 lb (82.3 kg) for the dam bridge. The author also noted that the dam bridge provided considerable flotation to the skidder as compared to the ford crossing. Installation and removal of a culvert crossing added 583 lb (198 kg) of sediment to the stream. Water quality protection was given paramount importance during the culvert installation. To accomplish that goal, sandbags were used to divert the water flow into the culvert during backfilling around the culvert and the fill material was of superior quality. The author indicated that a dam bridge falls somewhere between a ford and a culvert in terms of stream protection.

Studies of Wetland Crossings

Mason and Greenfield (1995) compared the impacts associated with using or not using wood pallets over a silty sand soil in the Osceola National Forest in Florida. The soil moisture content in the area that did not have wood pallets was typically 5 to 10 percent less than in the area that contained the pallets. After 150 passes with a loaded log truck that had a gross vehicle weight of 80,000 lb (36,300 kg), the rutting that occurred at the non-pallet crossing was 6 to 10 in. (15.3 to 25.4 cm) deep. The wood pallets had settled about 0.5 in. (12 mm). The authors reported that the use of wood pallets left no specific areas to hold and channelize water or specific areas of high compaction or rutting.

Hislop (1996b) tested wood pallets, wood mats, and an expanded metal grating on a silty sand soil within the Osceola National Forest in Florida. A non-woven, needle-punched geotextile was placed beneath each option. After 240 passes with a loaded log truck that had a gross vehicle weight of 80,000 lb (36,300 kg), the maximum rut depth was 8 in. (20 cm) on a control section and 1.5 in. (3.8 cm) on the wood pallet and wood mat section. After 75 passes, the maximum depth was 15 in. (38 cm) on a control section versus 5 in. (13 cm) for the expanded metal grating.

On a silty sand soil within the Osceola National Forest, areas with geotextile under expanded metal and deck-span safety grating showed less soil rutting as compared to areas with no grating (Mason and Greenfield 1995). After about 130 round trips with loaded log trucks that had a gross vehicle weight of 80,000 lb (36,300 kg), rutting in the area with grating was about 0.5 to 1 in. (1.3 to 2.5 cm) as compared with up to 1 ft (0.3 m) in areas without grating.

After about 20 passes with an unloaded flatbed truck with a loader on a deep black muck soil in Michigan, we noted the following maximum rutting depths: wood mat—12.5 in. (32 cm), expanded metal grating—8 in. (20 cm), tire mat—6.5 in. (17 cm), and wood plank—4.5 in. (11 cm). A single pass in a control area produced ruts 11.5 in. (29 cm) deep. On an upland area at that site, the flatbed truck became stuck and had to be pushed with a bulldozer. Once it was pushed onto the first test section of expanded metal grating that led from the upland area to the wetland, traction was regained and the vehicle was able to drive up and back down the slope without any trouble.

After about 20 passes with a loaded forwarder on a ponded histosol soil in Minnesota, we noted the following maximum rutting depths: tire mat—21 in. (53 cm), wood plank—6.8 in. (17 cm), wood mat—5.1 in. (13 cm), expanded metal grating—4.8 in. (12 cm), and PVC pipe mat—1.3 in. (3.3 cm). A non-woven geotextile was placed below all options. Soil penetrometer readings at both sites did not show any differences in soil strength.

Wolanek (1995) monitored downslope water quality for 25 months after constructing a road using mill-generated bark and wood fiber as primary fill material on the Tongass National Forest in Alaska. Overall, the study found minimal effects on stream water quality. The parameter most effected was pH, increasing significantly by 0.2 to 1.5 pH units in the naturally acidic streams. Dissolved oxygen in the streams remained unaffected. All observed effects were within the limits of Alaska water quality standards.

Goudey and Taylor (1992) and Taylor (1994) examined the toxicity of aspen wood leachate to aquatic organisms. They reported that leachate from aspen wood chips and wood piles was very toxic to aquatic life. Aspen wood leachate can be produced in any season when the wood is exposed to water and the temperature is above freezing. Karsky (1993) reported that the short-term potential leaching of tannic acid from cedar and some other species must be considered when constructing a chunkwood road close to a stream. No studies have reported leachate toxicity in wetland roadbuilding using chunkwood.

Bradley (1995) and Foltz (1994) reported that central tire inflation can reduce sediment runoff from unpaved roads. In a 3-year study that evaluated CTI on test loops, sediment runoff was reduced by as much as 80 percent on road sections that were used by CTI-equipped vehicles (70 PSI [480 kPa] on the steering axle and 30 PSI [210 kPa] on the other axles), as compared to vehicles using 90 PSI (620 kPa) in all tires. Little rut development occurred after 1,205 passes with a CTI-equipped loaded log truck.

SUMMARY OF SOME STREAM AND WETLAND CROSSING STATUTES

Each State and Province has enacted statutes to reduce nonpoint source pollution and to protect wetlands. As a result, there is no uniformity in regulations across the Great Lakes basin. In addition, many local jurisdictions (e.g., county, shoreland zoning ordinances) within a State or Province have implemented additional statutes to further regulate nonpoint pollution sources. A summary of some of the key State/Provincial statutory regulations on stream and wetland crossings in Michigan, Minnesota, New York, Pennsylvania, Wisconsin, Ontario, and Quebec is presented below. This information was gleaned from a review of the statutes as well as from contact with individuals in the appropriate regulatory organization in each State or Province. Regulators from each State or Province reviewed draft copies of the summary for their jurisdiction, and their revisions were then incorporated. If you are interested in additional information, contact the appropriate regulating body in that State or Province. Contact information for each State and Province is provided in table 5.

Michigan

Stream quality, cost, and season of use are evaluated when deciding what type of crossing to allow. Bridges are the preferred crossing method for streams, especially designated trout streams and their tributaries. During winter, it is acceptable to place native material or an ice/snow bridge across the stream when a frozen water crossing is not practical. When determining culvert size and the minimum clearance height for bridges, the height of the 100-year flooding frequency is considered.

A permit is required anytime a stream is to be crossed. The minimum permit fee is $50 and the maximum $2,000. Most permits cost $50. Permits may be granted or denied within 60 days after an acceptable application has been received. No permits are required for wetland crossings. However, the operator should follow voluntary BMP's.

Areas that have high-quality fish spawning beds or that contain threatened and endangered species should be avoided for crossings. Waterbars may be required on the approaches of stream crossings to divert water off the road before it reaches the stream.

Minnesota

The type of crossing is determined based on site-specific needs. Crossings of protected waterbasins or wetlands are allowed only where there is no feasible and practical alternative. It is more difficult to obtain a permit to cross a designated wild and scenic river, a designated trout stream or one of its tributaries, or a protected wetland. Ice bridges do not require a permit. Other crossings that do not require a permit are described below.

Provided that all conditions are met, a permit is not required for a low water ford crossing on a stream when the site is not an officially designated trout stream, wild, scenic, or recreational river, or officially designated canoe or boating route; no special site preparation is necessary; normal summer flow does not exceed 2 ft (0.6 m) in depth; normal low flow is not restricted or reduced; the crossing conforms to the shape of the natural stream channel; the original stream bank is no higher than 4 ft (1.2 m); the ford is constructed of gravel, natural rock, concrete, steel matting or other durable, inorganic material not more than 1 ft (0.3 m) thick; the graded finished slope is not steeper than 5:1 (horizontal to vertical); and graded banks are re-seeded or mulched.

A permit is not required for a temporary bridge on a stream when the crossing is consistent with floodplain, shoreland, and wild, scenic, or recreational river ordinances; the stream bank

Table 5.—*Central office contact information for water regulatory authorities in Michigan, Minnesota, New York, Pennsylvania, Wisconsin, Ontario, and Quebec*

State or Province	Organization and address	Telephone number
Michigan	Department of Environmental Quality Land and Water Management Division P.O. Box 30458 Lansing, MI 48909-7958	(517) 373-1170
Minnesota	Department of Natural Resources Division of Waters 500 Lafayette Rd. St. Paul, MN 55155-4032	(651) 296-4800
New York	Department of Environmental Conservation Division of Regulatory Services 50 Wolf Road Albany, NY 12233-1750	(518) 457-2224
	Adirondack Park Agency P.O. Box 99 Ray Brook, NY 12977	(518) 891-4050
Pennsylvania	Department of Environmental Resources Bureau of Dams, Waterways and Wetlands P.O. Box 8554 Harrisburg, PA 17105-8554	(717) 783-1384
Wisconsin	Department of Natural Resources Bureau of Water Regulation and Zoning Box 7921 Madison, WI 53707-7921	(608) 266-8034
Ontario	Director, Forest Management Branch Ministry of Natural Resources Suite 400, Roberta Bonda Place 70 Foster Drive Sault Ste. Marie, ON Canada P6A 6V5	(705) 945-6660
Quebec	Ministere des Ressources Naturelles Direction de l'environnement forestier 880 Chemin Sainte-Foy, 5e étage PQ Canada G1S 4X4	(418) 643-2922

can support the bridge without pilings, foundations, culverts, excavation, or other special site preparation; nothing is placed in the bed of the stream; the bridge can be removed for maintenance and flood prevention, the bridge is firmly anchored at one end and can swing away during flooding; and there is a minimum 3 ft (0.9 m) of clearance between the lowest portion of the bridge and normal summer stream flow.

All other crossings require permits. The application fee for a permit ranges from $75 to $500, depending on the size or cost of the project. Once an application is declared to be complete, the average turnaround time before a decision is made concerning a permit is 45 to 60 calendar days.

New York

The New York Department of Environmental Conservation (DEC) has jurisdiction over stream crossings throughout the State. Within the Adirondack Park, wetlands are regulated by the Adirondack Park Agency. Outside of the Park, the DEC regulates wetlands. Crossings are determined on a case-by-case basis by evaluating factors such as season, cost, and local conditions. The Talbot formula (Merritt 1983) is used to size culvert and bridge openings for temporary stream crossings that will be in place during periods other than low summer flow. A 2 in./hr (5 cm/hr) rainfall is assumed, unless conditions warrant consideration of a larger rainfall. Multi-span bridges may be acceptable. Skidding or winching of logs or trees in or along the axis of tributary channels or across wild rivers is prohibited.

Outside of the Adirondack Park, permits are required for all protected stream crossings where disturbance will occur to the stream bank or stream bed or within 100 ft (30 m) of wetland crossings in regulated wetlands that are 12.4 acres (5 ha) or larger in size. A wetland smaller than 12.4 acres (5 ha) in area may be regulated if it is determined to have unusual local importance. For some small stream crossings, permits may be issued on-site. There is no cost for filing any permit application.

Stream and wetland crossing applications are classified as either minor or major using review criteria contained in the Freshwater Wetlands Permit Requirements Regulations. Review time frames, procedures, and requirements for public notice of applications differ for minor and major projects. For stream crossings, a minor permit application is one where the length of the stream bed or bank to be impacted does not exceed 50 ft (15.2 m). There are many other criteria in these regulations that are used to assess whether a wetland crossing is minor or major.

Minor permit applications require up to 45 calendar days for a decision on the permit after the application is declared to be complete. A decision on a major crossing permit application can take up to 90 calendar days if no public hearing is held. Major permit applications require publication in the New York Department of Environmental Conservation’s Environmental Notice Bulletin and a designated local newspaper to solicit public review and comments.

Within the Adirondack Park, the DEC rules specified above apply to stream crossings. Any wetland within the Park that is 1 acre (0.4 ha) in size or larger, or any size wetland adjoining an open water body that has a free interchange of water at the surface, falls under the jurisdiction of the Adirondack Park Agency. Skid trails and other roads may be constructed without a permit within a wetland if they do not involve a material disturbance to the wetland (e.g., cut and fill). Permits are required for all other activities within a wetland. Before a permit is denied, a public hearing must be held.

Pennsylvania

Two different types of crossings, minor road crossings (GP-7) and temporary road crossings (GP-8), are recognized. A minor road crossing is a road constructed across a wetland where the length of the crossing is less than 100 ft (30 m) and the total wetland area disturbed is less than 0.1 acre (0.04 ha), or a road constructed across a stream and an adjacent wetland using a bridge, culvert, or ford crossing where the watershed drainage area is 1.0 mi^2 (259 ha) or less and the total wetland area disturbed is less than 0.1 acre (0.04 ha). A temporary road crossing would consist of a road installed for a period of time not to exceed 1 year across a wetland or along a stream that uses a pipe culvert or a series of culverts, a bridge, a causeway, or a ford.

If the crossing of a wetland cannot be avoided under a minor road crossing, the crossing must be undertaken at the narrowest point of the wetland and shall not exceed 100 ft (30 m) in length and 0.1 acre (0.04 ha) in disturbance. The total wetland impact for all minor road crossings installed on an individual property or project, including phased projects, cannot exceed 0.25 acre (0.10 ha).

For a temporary road crossing, skidding across fords and multiple-span bridges is prohibited. Also, temporary fords are prohibited within 2,000 ft (610 m) upstream of all high quality and exceptional value watersheds and watersheds tributary to drinking water intakes or public water supply reservoirs. Within a temporary road crossing, culverts must be installed with a depressed roadway embankment so that overtopping of the roadway will occur within the stream channel. If a temporary road crossing across a wetland cannot be avoided, the crossing is permissible if it is located at the narrowest practicable point of the wetland and the length of the crossing within the wetland does not exceed 200 ft (61 m). Temporary road wetland crossing surfaces must be stabilized by appropriate means, such as removable, temporary mats, pads, or other similar devices.

Instead of using a specified flooding frequency when sizing culverts, knowledge of local conditions and season(s) of operation are considered. A permit is required for all minor road and temporary road crossings, unless the drainage area is less than 100 acres (40 ha). Within wetlands, the regulations specified above apply. There are two different types of permits: a general permit and a joint permit. For forest management activities, an application for a joint permit would be filed only when the general permit is not applicable. While joint permits may offer an alternative to a denied general permit, the detailed environmental assessment requirements make them unattractive for most forest management practices. If neither a general permit for a minor road (GP-7) nor a temporary road crossing (GP-8) is applicable to a certain location, the only option is to apply for the joint permit application.

For both minor road and temporary road crossings, a general permit would not be granted under a number of situations. As an example, for both crossing types, a general permit would not be usable where any of the following conditions were present: historic, cultural, or archaeological sites were identified; stocked trout streams from March 1 to June 15, wild trout streams from October 1 to December 31, and Lake Erie tributaries from September 1 to December 1 unless written approval is obtained from the Fish Commission's Division of Environmental Services. During these periods, the general permits for minor road and temporary road crossings and a joint permit can be used. However, no in-stream work can occur during those dates.

Minor road crossings of wetlands both under the general permit (GP-7) and the joint permit application require a wetland delineation and a replacement plan. If the permanent impact to the wetland is less than 0.05 acre (0.02 ha), no replacement is required under the State's deminimus policy. There is no application fee for a general permit, unless the crossing is to be established across submerged water lands of the Commonwealth. In that case, the license fee for occupying submerged lands is $50/0.10 acre ($50/0.04 ha) of disturbance with a minimum charge of $250/year.

Wisconsin

Culvert crossings on navigable waterways[10] must be designed to pass a 100-year flood frequency without causing an increase of 0.01 ft (1 cm) or greater in the regional flood elevation if flooding easements are not obtained from affected upstream property owners before a permit will be issued. Gravel or concrete plank fords and clearspan bridges are preferred over culverts. For multi-span bridges, bridge piers may be permitted, as long as they don't create upstream flooding on property where an easement cannot be obtained. Ice bridges can be used on a case-by-case basis. A clearance of 5 ft (1.5 m) or more may be required for bridge and culvert clearance on waterways that may be used by other than lightweight craft (e.g., powerboats). Clearance on other navigable waterways is evaluated on a case-by-case basis.

[10] *A waterway is navigable if it has beds and banks, and if it is possible to float a canoe or other small craft in the waterway on a regular recurring basis, even if only during spring runoff.*

Permits are required whenever crossing a navigable waterway or grading and/or removing top soil from the bank of any navigable waterway where the area exposed will exceed 10,000 ft^2. The minimum cost for a permit, $30, is applicable to ford crossings. Culvert and bridge crossings and grading or removal of top soil from the bank of a waterway for an area more than 10,000 ft^2 require an application fee of $100. The permit cost for crossing a stream wider than 35 ft (10.7 m) is $300. A permit is required to remove or dredge material from navigable and non-navigable streams. The permit costs $100 if less than 3,000 yd^3 are removed and $300 for larger removals.

After receiving a complete application, the DNR Water Regulation and Zoning staff will provide the applicant with language for a public notice of intent that the applicant must have published in local newspapers. After a 30-calendar day comment period, the crossing could be approved if objections were not filed against it. If objections are filed, it may take 6 months or longer before the permit might be approved through a hearing process.

Ontario

Every 5 years, a forest management plan must be prepared or renewed for approval by the provincial government. This plan identifies activities (e.g., access, harvest, renewal, and maintenance) that will take place over the next 20 years, although specific plans are required only for the upcoming 5-year period. As a part of the planning process, public input is solicited at three different times. Once a plan is approved by the government, a company must annually submit a work schedule showing specific locations and a time frame for activities that will occur within the next 12 months. All of those activities must fall within the scope of the 5-year plan. An approval to begin operations is issued when the annual work schedule is approved. As part of the approval, specific stream and wetland crossings are authorized. There is not a separate application process or cost associated with securing permission to make a crossing.

In lieu of developing statutes, Ontario has produced several different sets of guidelines that must be followed as a part of timber management. Each set of guidelines is designed to establish standards and to provide practical advice for ensuring minimum disturbance to the natural environment. Most of the decisions about what to apply in a specific instance are left for the professionals and operators to make on-site. Operators must stay within the guidelines, unless an exception is granted. Areas where the approach deviates from the guidelines are to be clearly noted on the plan. If the variances are approved, they must be closely monitored by the contractor. The Ministry of Natural Resources also monitors variances on-site and/or through an extensive reporting process.

No crossing options are excluded by the guidelines. All water crossings must be sized using hydrological analysis techniques approved by Ministry of Natural Resources engineers. Design flows on access roads are typically for a 10- to 50-year flooding frequency, with the lower frequency for culverts and the higher for major bridges. All bridges must be designed by a qualified professional engineer to meet bridge design codes and Ministry standards. Bridge proposals must be reviewed and approved by the Ministry engineer. The Ministry provides design aids and training for in-house staff and the forest industry.

Quebec

Before harvesting within a publicly owned forest, a company must submit a 25- and 5-year plan to the provincial government for approval. Public consultation is also mandatory during the development of these plans. Annual plans delineating areas to be harvested within the upcoming year must also be submitted. The 25-year, 5-year, and annual plans must be approved by a forest engineer. Roads must be indicated on the plan (only access roads are usually shown). Except for crossings, any road that is to come within 197 ft (60 m) of a stream or lake must be clearly indicated, justified, and protection measures identified. The location of bridges, along with their size, must appear on the annual plan. All bridge designs must be approved by a civil engineer, although they can be constructed by a forest engineer.

Logs can be used on each side of the stream to stabilize the approach. If logs are used for this purpose, they must remain in place after use. A goal is to achieve zero particles deposited into streams. Therefore, the use of geotextile is mandatory for permanent stream crossings and strongly suggested for temporary stream crossings.

Fording a stream is not allowed, even in winter. Bridging or ice bridges are acceptable on winter roads. Logs can be incorporated into the ice bridge, as long as they are securely cabled to a tree or other nearby secure structure. Both types of structures must be removed at the end of the work, except for the log mats used to stabilize the banks on either side of the stream.

Culverts are sized on a 10-year flood frequency, if the watershed is less than 14,830 acres (6,000 ha). On larger watersheds, culverts are sized on a 20-year flood frequency. The smallest culvert that can be used in a stream is 18 in. (45 cm) diameter. Prescribed or equivalent stabilization techniques must be used during the installation and removal of the culvert. Wooden culverts are acceptable only if their span does not exceed 3.3 ft (1 m) wide. Stream enlargement is prohibited. When constructing either a culvert or bridge crossing, the width of the stream can be reduced by up to 20 percent or, if calculations based on flood frequency allow it, by up to 50 percent. Only bridges are acceptable when crossing a lake or bay within a lake.

A stream crossing (bridge or culvert) cannot be constructed in or within 164 ft (50 m) upstream from a spawning ground indicated on the annual plan. When designing a crossing in a stream where fish migrate, installation of a structural plate culvert or construction or improvement of a bridge cannot be conducted during the upstream migration of fish, as determined by the Ministry of Environment.

RESEARCH AND EDUCATION NEEDS

The growing worldwide demand for forest products will increase the probability of harvesting in areas that are adjacent to or that contain streams and wetlands. Appropriate crossing options are needed to avoid negative impacts to these water bodies. Unfortunately, little research is currently available that has evaluated and compared the various crossing options. Also, little information has been compiled to make people aware of how to best use each option so that it meets their operational requirements and provides adequate environmental protection. As a result, we have identified the following research and education needs:

- Relatively few studies have evaluated the impacts of different stream and wetland crossing options. Further examination of the impacts associated with stream and wetland crossings, especially those that result from the removal of a temporary crossing, is needed.

- The various studies that have evaluated impacts to streams and wetlands from use of different crossings have applied different methodologies and evaluated different parameters to derive their results. There is a need to develop and apply a standard approach so that results can be more easily compared.

- Maintaining the hydrologic function of a wetland is key to sustaining its integrity. Severe rutting may impede subsurface flow of water across a wetland. There is a need to evaluate the impacts to subsurface water movement across a wetland that result from application of different crossing options.

- From the operator's perspective, there are costs and benefits associated with using any crossing option. Costs can include the installation, maintenance, and removal of an option. Benefits may include improved access, shorter roads and skid trails, extended time of operability, increased productivity, reuse, and reduced maintenance. The limited available research is largely focused on quantifying the installation and removal costs associated with use of culverts in streams without considering any benefits that may be derived. There is a need to quantify the net costs (total costs minus total benefits) to the operator associated with the variety of different options that are available for use in streams and wetlands. That analysis needs to consider the life cycle costs and benefits.

- While each crossing option may accomplish its intent, different options may perform better in some instances and worse in others. There is a need to identify the optimal range of site and operating conditions for each option. As a part of that process, the temporal dimension of "temporary" needs to be addressed.

- There are costs and benefits to the operator, to the landowner, and to society associated with using the various options. Individuals who make on-the-ground decisions about what crossing option(s) to allow need better information about these costs and benefits to make sure that their prescription is appropriate to each particular crossing.

- An economic analysis (that includes pay-back analysis) comparing non-reusable options with reusable options needs to be done. The analysis should consider all costs associated with each option, including labor and materials, over the expected life of the crossing option.

- Several options are available to cross streams and wetlands. Most operators are either unaware of the variety of options available or lack sufficient information to correctly install, maintain, and remove the options or rehabilitate the site following removal. Training materials are needed to help them properly accomplish these tasks.

- Appropriate institutional arrangements between organizations need to be identified to assist with the purchase of some options. Many large landowners may have a continual need for reusable options on their land, but many operators may not be able to afford the initial investment for some of these. If these larger landowners obtained the options outright, they could then make them available to operators through a variety of mechanisms, to be reimbursed for the investment. Owners could also share their crossing options through other arrangements.

SUMMARY

Streams and wetlands are broadly recognized as valuable ecosystems. Timber harvest and forest management activities have the potential to adversely impact these systems. A variety of reusable temporary stream and wetland crossing options are available that can reduce impacts to water bodies while providing long-term cost advantages and day-to-day operational benefits. Before implementing any of the options, be sure to compare their capabilities and costs to actual needs. We highly recommend using a non-woven geotextile fabric below most temporary wetland crossing options. We also recommend using a geotextile fabric with some stream crossing options placed within the stream as well as beneath any temporary materials used to protect the approaches on the stream banks. However, the use of geotextile with a stream crossing option should be approved by the appropriate regulatory authorities because there may be concerns about impacts if the geotextile moves downstream. Various studies have reported that bridge crossings contribute less sediment to the stream than culvert crossings during installation. Various studies have reported that the options were effective in improving trafficability and reducing rut depth. Contact us for additional information about any of the options or to inform us of others that are not identified in this publication. The e-mail address for the first author is cblinn@forestry.umn.edu.

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APPENDIX 1

PARTIAL LIST OF COMMERCIAL VENDORS FOR TEMPORARY CROSSING OPTIONS

This is not a complete list and some information provided may be inaccurate or out-of-date. Many vendors provide a variety of products but are listed under only one category. Although the listing for a company may not be from your area, there may be a local distributor who can supply information and materials.

Geotextiles

Amoco Fabrics and Fibers Company
900 Circle 75 Parkway, Suite 550
Atlanta, GA 30339
Voice: (800) 445-7732
(770) 984-4444
Fax: (770) 956-2430

Cascade Distribution Ltd.
15620 - 121A Ave.
Edmonton, AB Canada T5V 1B5
Voice: (800) 565-6130
(403) 454-2400
Fax: (403) 451-0911

Layfield Plastic
14604-115A Ave.
Edmonton, AB Canada T5M 3C5
Voice: (403) 453-6731
Fax: (403) 455-5218

Synthetic Industries, Inc.
4019 Industry Dr.
Chattanooga, TN 37416
Voice: (800) 621-0444
(423) 899-0444
Fax: (423) 899-7619

Belton Industries
8613 Roswell Rd.
Atlanta, GA 30350
Voice: (800) 225-4099
(770) 587-0257
Fax: (770) 992-6361

Fireflex Division, SEI Industries
7400 Wilson Ave.
Delta, BC Canada V4G 1E5
Voice: (604) 946-3131
Fax: (604) 940-9566

Linq Industrial Fabrics, Inc.
Geotextile Division
2550 West 5th North St.
Summerville, SC 29843-9669
Voice: (800) 543-9966
(803) 875-8277
Fax: (803) 875-8276

TC Mirafi
365 S. Holland Dr.
Pendergrass, GA 30567
Voice: (800) 234-0484
Fax: (800) 333-6205

Cellular confinement systems

A. G. H. Industries, Inc.
4600 Post Oak Place
Suite 111
Houston, TX 77027
Voice: (713) 552-1749
Fax: (713) 552-1147

Nilex Corporation
6810 South Jordan Rd.
Englewood, CO 80112
Voice: (800) 537-4241
(303) 766-2000
Fax: (303) 766-1110

GeoCHEM, Inc.
106 Lake Ave. S.
Seattle, WA 98055
Voice: (425) 227-9312

Presto ProductsCompany
P.O. Box 2399
Appleton, WI 54913-2399
Voice: (800) 548-3424
(920) 738-1118
Fax: (920) 738-1432

Tenax Corporation
4800 East Monument St.
Baltimore, MD 21205
Voice: (410) 522-7000
Fax: (410) 522-7015

Erosion control products

American Excelsior Company
P.O. Box 5067, 850 Ave. H East
Arlington, TX 76005-5067
Voice: (800) 777-SOIL
(817) 640-1555
Fax: (817) 649-7816

BonTerra America, Inc.
355 West Chestnut St.
Genesee, ID 83832
Voice: (800) 882-9489
Fax: (208) 285-0201

Canadian Forest Products, Ltd.
Panel and Fibre Division
430 Canfor Ave.
New Westminister, BC Canada V3L 5G2
Voice: (800) 363-8873

Conwed Fibers
219 Simpson St.
Conover, NC 28613
Voice: (800) 366 1180
Fax: (704) 328-9826

Erosion Control Systems, Inc.
1800 McFarland Blvd., Suite 180
Tuscaloosa, AL 35406
Voice: (800) 943-1986

Finn Corporation
9281 LeSaint Dr.
Fairfield, OH 45014
Voice: (800) 543-7166
(513) 874-2818
Fax: (513)874-2914

Greenfix America
P.O. Box 62, 604 E. Mead Rd.
Brawley, CA 92227
Voice: (800) GREENFX
(800) 929-2184
(760) 344-6700
Fax: (760) 344-4305

Nedia Enterprises
89-66 217th St.
Jamaica, NY 11427
Voice: (888) 725-6999
(718) 740-5171
Fax: (718) 740-1049

North American Green, Inc.
14649 Highway 41 North
Evansville, IN 47711
Voice: (800) 772-2040
(812) 867-6632
Fax: (812) 867-0247

RoLanka International, Inc.
365 Toccoa Place
Jonesboro, GA 30236
Voice: (800) 760-3215
(770) 506-8211
Fax: (770) 506-0391

PPS Packaging Company
204 N. Seventh St.
P.O. Box 56
Fowler, CA 93625
Voice: (209) 834-2011

Verydol Alabama, Inc.
P.O. Box 605
Pell City, AL 35125
Voice: (205) 338-4411

Steel/aluminum culverts

Atlantic Industries Limited
Dorchester, NB, Canada
Voice: (506) 379-2455
Fax: (506) 379-2290

Contech Construction Products, Inc.
1001 Grove St.
Middletown, OH 45044
Voice: (800) 338-1122
(800) 363-3873

Culverts and Industrial Supply Co.
7242 W. Yellowstone
Casper, WY 82644
Voice: (307) 472-7121
Fax: (307) 577-4914

Johnston Fargo Culverts, Inc.
3575 85th. Ave. NE
St. Paul, MN 55126-1186
Voice: (651) 780-1760
Fax: (651) 780-1763

Polyethylene culverts

Advanced Drainage Systems
3300 Riverside Dr.
Columbus, OH 43221
Voice: (800) 733-7473
(614) 457-3051
Fax: (614) 459-0169

Crumpler Plastic Pipe
P.O. Box 2068, Highway 24 West
Roseboro, NC 28382
Voice: (800) 334-5071
Fax: (800) CPP-PIPE

Hancor, Inc.
401 Olive St.
Findlay, OH 45839
Voice: (800) 537-9520
(419) 423-6913
Fax: (419) 424-8337

Soleno SPD, Inc.
1160 Rt. 133, C.P. 147
Iberville, PQ, Canada J2X 4J5
Voice: (800) 363-1471
(514) 347-8315
Fax: (514) 347-3372

High density polyethylene pipe

CSR Polypipe
P.O. Box 390
Gainesville, TX 76241-0390
Voice: (800) 433-5632
(817) 665-1721
Fax: (817) 668-8612

Fluid Controls
3435 Stanwood Blvd. NE
Huntsville, AL 35811
Voice: (800) 462-0860
(205) 851-6000
Fax: (205) 852-6005

Forrer Supply
P.O. Box 220
Germantown, WI 53022-0220
Voice: (800) 255-1030
(414) 255-3030
Fax: (414) 255-4064

Harvel Plastics
P.O. Box 757
Easton, PA 18044-0757
Voice: (610) 252-7355
Fax: (610) 253-4436

Plastic Pipe and Supply
100 Glen Rd.
P.O. Box 8066
Cranston, RI 02920
Voice: (401) 467-9370
Fax: (401) 461-9520

Plexco Performance Pipe Division
Chevron Chemical Company
1050 IL Route 83 - Suite 200
Bensenville, IL 60106-1048
Voice: (630) 350-3700
Fax: (630) 350-2704

Stress-laminated bridges

Forestry and Wildlife Consult. Serv., Inc.
Rt. 1, Box 531
Gretna, VA 24557
Voice: (804) 656-6684

Hughes Brothers
210 N. 13th St.
Seward, NE 68434
Voice: (402) 643-2991
Fax: (402) 643-2149

Dowel-laminated bridges

Wheeler Lumber, LLC.
P.O. Box 26100
St. Louis Park, MN 55426
Voice: (800) 328-3986
(612) 929-7854
Fax: (612) 929-2909

Glued-laminated bridges

Structural Wood Systems, Inc.
P.O. Box 250
Greenville, AL 36037
Voice: (334) 382-6534
Fax: (334) 382-9860

Modular steel bridges

Acrow Corporation of America
P.O. Box 812
Carlstadt, NJ 07072-0812
Voice: (800) 524-1363
(201) 933-0450
Fax: (201) 933-3961

Big R Manufacturing
P.O. Box 1290
Greeley, CO 80632
Voice: (800) 234-0734
(970) 356-9600
Fax: (970) 356-9621

Hamilton Construction Company
P.O. Box 659
Springfield, OR 97477-0121
Voice: (541) 746-2426
Fax: (541) 746-7635

Modular Bridge Systems
8035 Alexander Rd.
Delta, BC Canada V4G 1C6
Voice: (604) 946-1524
Fax: (604) 946-1514

Van Straten and Sons Manufacturing
RFD #1, US 41 North
Baraga, MI 49908
Voice: (906) 353-8177
(906) 353-6490
Fax: (906) 353-7115

Hinged bridges

ADM Welding and Fabrication
Pennsylvania Ave. West Ext., Rear
Warren, PA 16365
Voice: (814) 723-7227
Fax: (814) 723-7227

Concrete decked steel bridges

SureSpan Bridge
Suite 216
545 Clyde Ave.
West Vancouver, BC Canada V7T 1C5
Voice: (604) 925-3377
Fax: (604) 925-3394

Railroad flatcar bridges

Rick Franklin Corporation
101 Industrial Way
P. O. Box 365
Lebanon, OR 97355
Voice: (800) 428-1516
(541) 451-1275
Fax: (541) 258-6444

Expanded metal grating

Alabama Metal Industries, Inc.
P.O. Box 3928
Birmingham, AL 35208
Voice: (800) 366-2642
Fax: (205) 780-7838

McNichols Co.
1951 Lively Blvd.
Elk Grove, IL 60007
Voice: (800) 237-3820
Fax: (847) 640-8388

Brown-Campbell Steel Co.
14290 Goddard St.
Detroit, MI 48212
Voice: (800) 521-4512
(313) 891-2390
Fax: (313) 891-2903

Wood mats/panels

Carolina Mat Company
P.O. Box 339
Plymouth, NC 27962
Voice: (800) 624-6027
(919) 793-4045
Fax: (919) 793-5187

Clemons Forest Products
P.O. Box 982
Amite, LA 70422
Voice: (504) 748-9079
Fax: (504) 748-9719

Wood pallets

Uni-Mat International
503 Martin St.
Houston, TX 77018
Voice: (800) 445-7850
(713) 697-3585
Fax: (713) 697-1227

Tire mats

Terra Mat Corporation
462 Arbor Circle
Youngstown, OH 44505
Voice: (330) 759-9412
Fax: (330) 759-7679

Unique Tire Recycling, Inc.
155 LaFarge Rd.
Kamloops, BC Canada V2C 6T5
Voice: (800) 446-5955
Fax: (604) 573-3492

High flotation tires

Ardco-Traverse Lift, LLC.
322 Riley Rd.
Houston, TX 77047
Voice: (713) 433-6751
Fax: (713) 433-5655

Continental General Tire Co.
1800 Continental Blvd.
Charlotte, NC 28273
Voice: (704) 583-3900
Fax: (704) 583-8540

Firestone Agricultural Tire Co.
730 E. Second St.
Des Moines, IA 50309
Voice: (515) 242-2306
Fax: (515) 242-2329

OTR Wheel Engineering
Box 5811
Rome, GA 30162-5811
Voice: (706) 235-9781
Fax: (706) 234-8137

Rolligon Corporation
10635 Brighton Lane
Stafford, TX 77477
Voice: (281) 495-1140
Fax: (281) 495-1145

Toyo Tire USA Corporation
300 W. Artesia Blvd.
Compton, CA 90220
Voice: (310) 537-2820
Fax: (310) 604-1519

United Tire & Rubber Company
275 Belfield Rd.
Rexdale, ON Canada M9W 5C6
Voice: (416) 675-3077
Fax: (416) 675-4337

Single and bogie tire tracks

Hultdins, Inc.
22 Morton Ave. East
Brantford, ON Canada N3T 5T3
Voice: (519) 754-0044
Fax: (519) 754-1569

Pedno Tracks, Inc.
3641 rue des Forges
Laterriere, PQ Canada G0V 1K0
Voice: (418) 678-1506
Fax: (418) 678-9748

Central tire inflation equipment

Eaton Air Control Products
1303 Durham Rd.
P.O. Box 241
Roxboro, NC 27573-0241
Voice: (910) 503-6411
Fax: (910) 503-6425