

What We Know — and Don't Know —

...type of crossing. Limited, but the available literature indicates that significant amounts of sediment are produced during installation of fords and culverts; construction and use of temporary bridges have the least impact on water quality. This review of our current state of knowledge on the water quality impacts from crossings shows that we need data for a wide variety of stream sizes, soil types, terrain, and climatological conditions so that policymakers can develop scientifically sound best management practices.

By Steven E. Taylor, Robert B. Rummer, Kyung H. Yoo, Richard A. Welch, and Jason D. Thompson

Reduction of nonpoint source pollution of forest streams is a major issue in the forest products industry. Consequently, extensive research has been focused on documenting impacts of forest harvesting, road construction, and site preparation on water quality in forest streams. Researchers have found that roads create more pollution, in the form of sediment, than harvesting activities and that stream crossings are the most frequent sources of sediment introduction (Rothwell 1983). Swift (1985) stated, "The stream crossing is the most critical section of road influencing water quality. During and for some time after construction, raw and exposed fill reaches into the channel." To help foresters enter the forest in a more environmentally sensitive and cost-effective manner, this article reviews the knowledge base on water quality impacts from different types of forest road stream crossings and discusses recommendations for future work in this area.

Review of Recent Research

Constructing and maintaining stream crossings is one of the most expensive and challenging tasks in developing forest access systems. The primary stream-crossing structures used on forest roads include fords, culverts, and bridges. Although log crossings are still used occasionally, they are not generally recommended. Available information on the different crossing types is reviewed below.

Fords. These low-water crossings use existing or constructed stream bottoms to support vehicles when crossing the stream. Natural fords use native rock or gravel bottoms for the roadway. Sometimes additional gravel is used to strengthen the channel bottom. Constructed fords use additional materials

to strengthen the roadway. Strengthening techniques include placing logs or brush on the channel bottom or placing steel, concrete, wood, or rubber mats in the channel. Other techniques include using geotextile underlayment, a gravel-filled cellular confinement system (a three-dimensional network of polyethylene cells), or gabions (wire mesh baskets filled with stone) to support the roadway, and in some cases, forming a concrete roadway across the channel. Alternative fords were discussed by Blinn et al. (1998), Mason (1990), Milauskas (1988), and Tufts et al. (1994). Fords are considered "unvented" when the stream flows over the roadway and "vented" when culverts are placed in the ford and used to convey normal levels of streamflow under the roadway. With all fords, storm levels of streamflow pass over the roadway and may temporarily prohibit traffic through the ford.

Unless they are very large, fords are often the least expensive stream crossing to construct. However, the general perception is that fords have greater impacts on water quality than other crossings. Fords introduce sediment into streams during construction and during vehicle crossings. Also, they provide more opportunity for sediment-laden runoff to flow down the road approach into the stream.

Tornatore (1995) documented short-term impacts from Pennsylvania stream crossings. For a gravel ford installed on a haul road, she manually collected water samples before, during, and after installation and use of the crossing and also during periods of high streamflow from snowmelt. She found no significant differences between upstream and downstream sediment concentrations before, during, and after installation. Only during log truck use was there a significant differ-

about Water Quality at Stream Crossings

ence between upstream and downstream sediment; however, median downstream sediment concentration was only 6 milligrams per liter, which is very low. (In general, relating sediment concentrations to an acceptable level is difficult because background levels of sediment can be significantly different across different watersheds.)

Thompson and Kyker-Snowman (1989) evaluated impacts at crossings used for Massachusetts skidding operations. For an unmitigated ford crossing, they recorded large but statistically insignificant increases in turbidity levels immediately downstream. Also, there were no significant differences in pH, specific conductivity, or nitrate levels when samples taken before vehicle crossings were compared with those taken afterward. Changes in streamflow rate or traffic type did not affect turbidity.

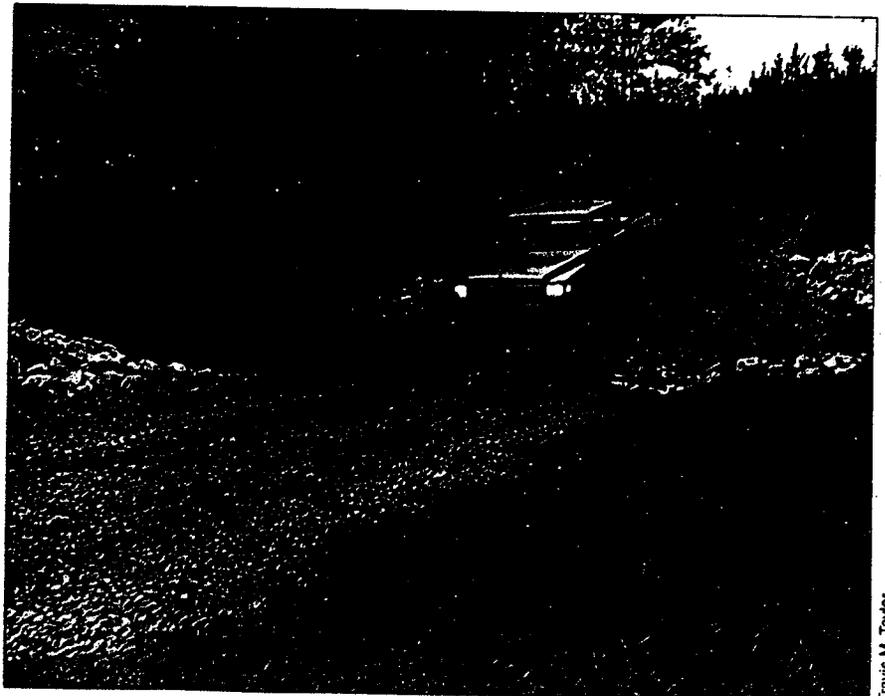
White Water Associates (1996) reported short-term impacts during installation of a 9-meter-wide gravel ford in Michigan. Because the stream bottom was sufficient to support vehicle traffic, no construction took place in the stream; bulldozing was limited, and crushed rock was added only at the stream channel edges. During construction, water samples were collected manually at several locations upstream and downstream from the crossing. Downstream sediment concentrations were significantly greater than upstream concentrations. The peak increase in downstream sediment concentration was 310 milligrams per liter and was taken 10 meters downstream from the crossing. The construction activity introduced 712 kilograms of sediment into the stream. Sediment concentration returned to background levels within approximately 18 minutes after construction stopped. Later, the ford was monitored during one day

of use by logging traffic (White Water Associates 1997). After crossings by pickup trucks and log trucks, downstream sediment concentrations were significantly higher than upstream concentrations, with a peak sediment concentration increase of 115 milligrams per liter. Extrapolated data showed that during logging (154 log truck crossings and 138 pickup truck crossings) approximately 83 kilograms of sediment would have been deposited 10 meters downstream from the crossing. These predictions were based on low streamflows and dry road approaches; wetter road conditions and higher streamflows would have produced more sediment.

Looney (1981) reported short-term results from different stream crossings in skidding operations. Fifty-three kilograms of sediment was introduced into the stream during five one-way

skidder crossings through a natural ford. At the same site, for a similar number of passes over a rubber mat dam bridge, 31 kilograms of sediment was introduced into the stream. At a second site, 208 kilograms of sediment was produced during eight one-way skidder passes through a ford and 82 kilograms of sediment was produced at a rubber mat dam bridge crossing.

Thompson et al. (1996) and Welch et al. (1998) presented long-term impacts from two gravel fords in northeast Alabama. They monitored the construction, use, and removal of the fords. Although the fords existed before the study, they were renovated before a timber harvest. Afterward, the road was closed and the fords removed. Water samples were collected at upstream and downstream locations using automatic water samplers that worked in an unattended mode. Also,



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For this new gravel ford, exposed soil was covered with mulch, and vulnerable portions of the stream banks were protected by riprap to reduce erosion.

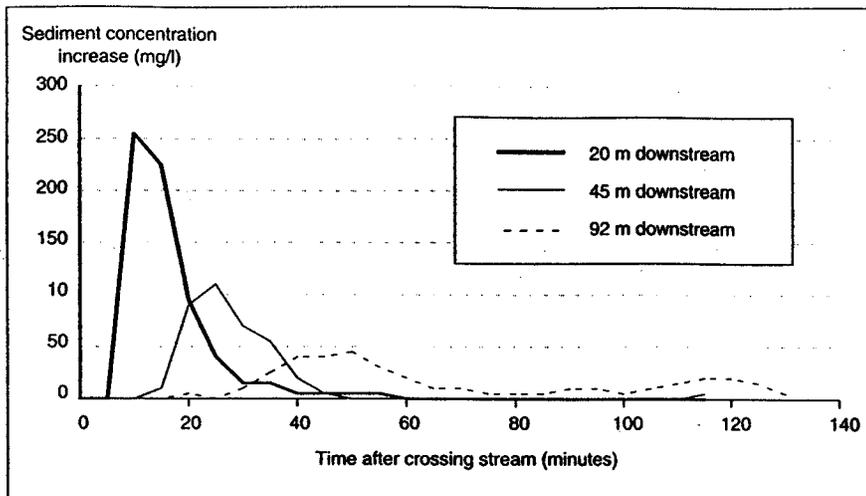


Figure 1. Sediment concentration increase (downstream concentration minus upstream concentration) versus time after vehicles crossed a gravel ford, as reported by Thompson et al. (1996).

electronic data loggers recorded continuous rainfall and streamflow data.

Before the fords were renovated, Thompson et al. (1996) conducted vehicle crossing tests to document sediment production and movement. To illustrate sediment production from ford use, *figure 1* plots the sediment concentration increase at three downstream sampling locations after two pickup trucks drove through the stream. The peak sediment concentration increase occurred 20 meters downstream 10 minutes after the vehicles passed through the ford. As the sediment plume moved farther downstream, its concentration decreased. They noted that higher streamflow rates would transport greater sediment loads and heavier vehicles would generate more sediment load than observed in these tests.

Thompson et al. (1996) reported that to renovate the ford, a crawler tractor cleared trees and brush from the area immediately surrounding the road approaches, cleaned out the ford, and spread gravel in the stream. Although actual construction time was only two hours, the renovation was done over a two-day period. *Figure 2* illustrates sediment production during stream-crossing construction, and *figure 3* illustrates sediment production during rainfall after construction. *Figure 3* shows the streamflow hydrograph and the corresponding sediment concentration levels during a two-day, 12.78-centimeter

rainfall. Upstream and downstream sediment concentrations for the ford are plotted in this figure. At the start of the storm it appears that the rain washed into the stream an initial flush of sediment, which came from exposed soil left from construction activities. Subsequent rain during this period resulted in noticeable rises in streamflow and corresponding sediment production increases. During high flow periods, there was little difference in sediment levels at different locations downstream because enough energy was available to transport sediment farther downstream. They estimated that total sediment produced during the storm was 956 kilograms, compared with 53 kilograms during construction.

When log trucks used the fords during a two-month timber harvest, mean and peak sediment concentration increases measured immediately downstream from the crossing were 50 and 1,200 milligrams per liter, respectively (Welch et al. 1998). The road was closed after harvesting, and a crawler tractor deconstructed the fords by removing gravel down to the original stream bottom level. During removal, peak downstream sediment concentration was 20,761 milligrams per liter, and 31 kilograms of sediment was introduced into the stream.

Culverts. Culverts are hydraulic structures that conduct streamflow under a roadway. A culvert is placed in the stream channel and soil backfill is

typically placed around the pipe. Most culverts are manufactured from corrugated steel, concrete, or polyethylene pipes. Sometimes box culverts are constructed from concrete or timber. A variation on the culvert is the pipe bundle, which has been used for temporary stream crossings (Mason 1990; Blinn et al. 1998).

Although culverts are more expensive to install and maintain than fords, their water quality impacts are generally perceived to be less than those of fords. During culvert installation and removal, sediment is introduced into the streamflow. Also, disturbed soil around the culvert installation can erode and enter the stream. Culverts that are not properly designed or maintained can clog and wash out, and the fill around the culvert enters the stream (Hagans and Weaver 1987). If culverts are improperly installed, excessive outfall from the culvert outlet may lead to scour and erosion. Culverts also may inhibit movement of aquatic life through the stream.

Thompson et al. (1995) manually collected paired water samples upstream and downstream during installation of a corrugated metal pipe culvert 1.2 meters in diameter in eastern Alabama. During the six-hour installation, mean and peak downstream sediment concentrations were, respectively, 344 and 950 milligrams per liter higher than upstream samples, and 26 kilograms of sediment was introduced into the stream. During storms after installation, mean downstream sediment concentration was 340 milligrams per liter higher than that of upstream samples (peak downstream concentration levels neared 2,250 milligrams per liter).

Two other studies documented short-term impacts from culvert installations. When a culvert was installed on a 2.2-meter-wide stream in Michigan, peak sediment concentration increase was 1,350 milligrams per liter, and 219 kilograms of sediment was introduced to the stream (White Water Associates 1997). Looney (1981) reported that during a culvert installation and removal, 198 kilograms of sediment was introduced into the stream.

Tornatore (1995) reported sediment production from 0.38-meter-diameter culverts installed on skid trails and haul roads using both shale backfill and log backfill. All crossings had significant increases in downstream sediment concentration and turbidity. After the culvert with shale fill had been installed on the skid trail, stream sediment took approximately 96 hours to return to insignificant levels. The culvert with shale fill produced less sediment than the culvert with log fill. For the culvert with log fill, median increase in downstream sediment concentration was 412 milligrams per liter, while peak sediment concentrations were over 1,000 milligrams per liter.

Bridges: Bridges are generally the most expensive stream crossings. However, they can span the stream without inhibiting streamflow and aquatic movement, and they can be installed without extensive soil backfill. They are therefore perceived to have lower water-quality impacts. Bridges can be permanent or temporary and can be constructed of steel, concrete, or timber. Typical designs use longitudinal girders or stringers that span the stream with a bridge deck placed on top. Often, shorter-span bridges use slab-type, or longitudinal, decks constructed of steel, concrete, or timber to span the stream.

Portable bridges are gaining popularity because they can be installed with minimal site disturbance and water quality impacts. Several researchers have presented information on the design and use of portable bridges on forest roads (Hassler et al. 1990; Mason 1990; Taylor et al. 1996). If installed and removed in a way that minimizes site disturbance, they can alleviate many water quality problems. Hassler et al. (1990) described using a portable stress-laminated timber bridge on a logging road in West Virginia. They found no significant changes in stream conductivity, pH, or turbidity, based on water samples collected downstream of the bridge beginning two days before and lasting until three days after installation.

Thompson et al. (1995) reported negligible sediment production during installation of two portable glue-laminated timber bridges, because no

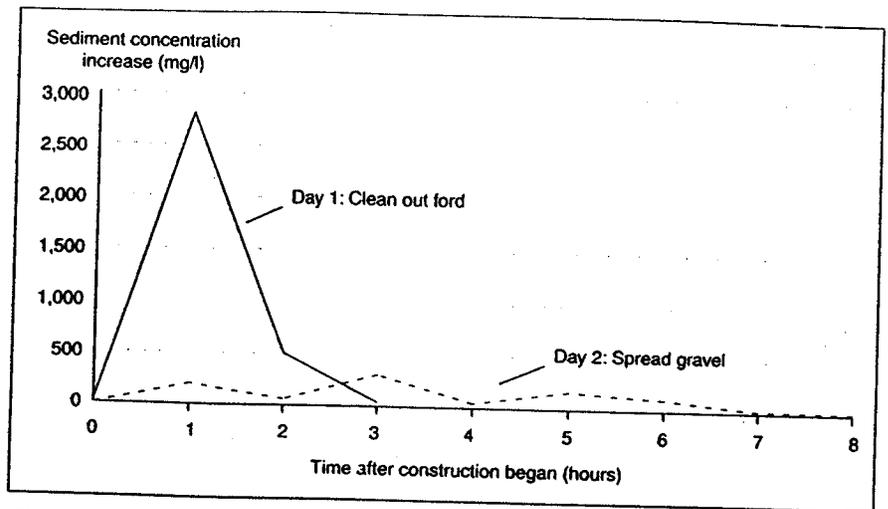


Figure 2. Sediment concentration increase (downstream concentration minus upstream concentration) versus time for the renovation of a gravel ford, as reported by Thompson et al. (1996).

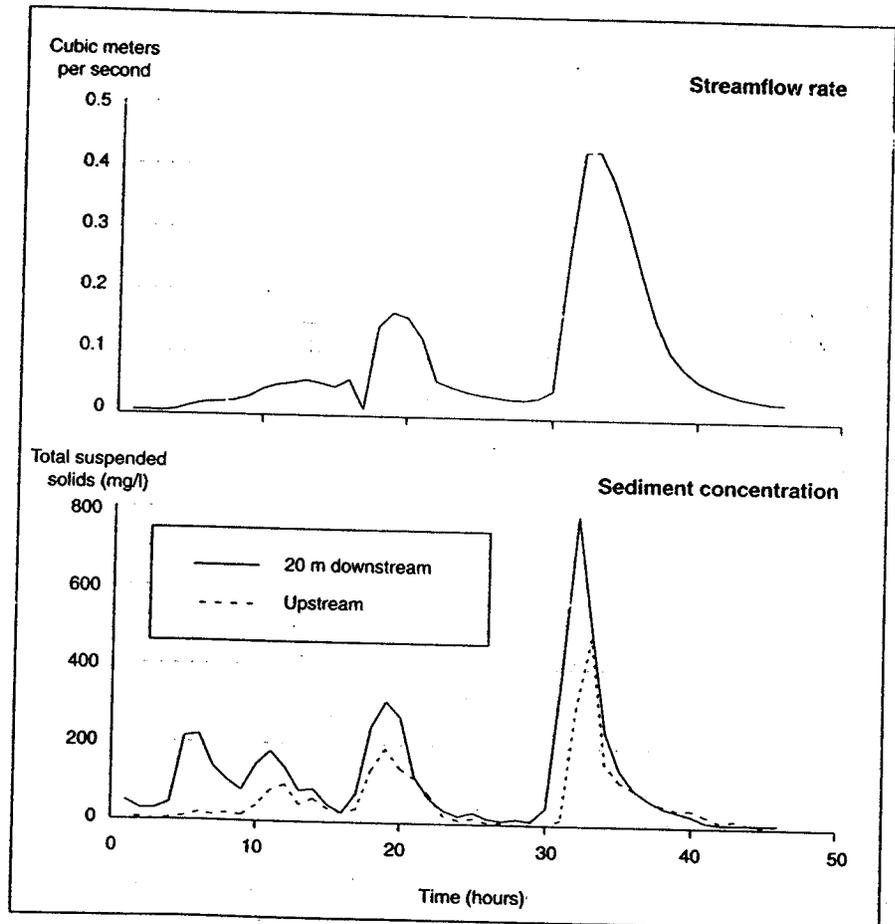
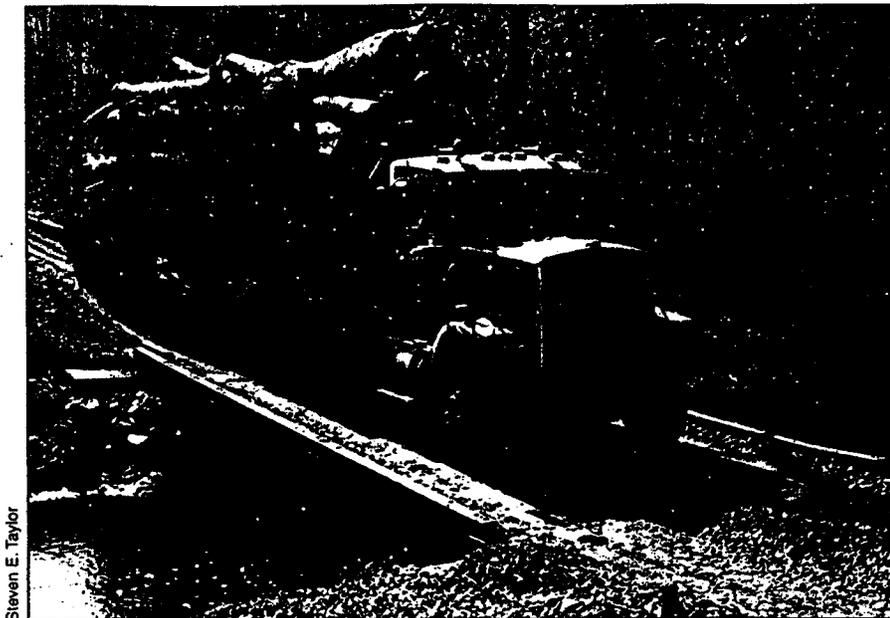


Figure 3. Streamflow hydrograph and sediment production resulting from a sample storm event after renovation of a gravel ford, as reported by Thompson et al. (1996).

equipment operated in the streams, the stream channels were not disturbed, and no soil was introduced into the streams. From water samples taken during storms after construction, mean sediment concentration increases mea-

sured at the crossings were 67 milligrams and 38 milligrams per liter.

Tornatore (1995) discussed installation of a folding steel bridge on a skid trail, and a temporary wooden bridge on a haul road. During installation of



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This portable bridge is used as a temporary stream crossing in timber harvesting operations. The bridge consists of two 6-by-40-foot glue-laminated timber deck modules. The bridge modules are resting on timber sills placed on the stream bank.

the steel bridge, peak downstream sediment concentration values approached 1,000 milligrams per liter. Downstream sediment concentration returned to insignificant levels within 24 hours of bridge installation. During skidding, median sediment concentrations were 2.0 and 13.5 milligrams per liter for upstream and downstream samples, respectively. For the bridge on the haul road, she found no significant differences in upstream and downstream sediment concentrations. However, the small number of samples and timing of sampling may have contributed to the statistical results. Overall, she concluded that although culverts were viable stream-crossing structures, temporary bridges resulted in lower environmental impacts than other types of stream crossings.

General observations on stream crossings. Miller et al. (1997) studied site conditions upstream and downstream of 70 Pennsylvania stream crossings. Overall, they found little long-term impact on habitat quality, channel stability, vegetation, wetland width, and channel embeddedness attributable to stream crossings. At a few sites, they found significant differences in increased levels of fine sediment deposition in and around the stream and increased herbaceous vegetation and re-

duced basal area in the immediate vicinity of the crossing.

In research on compliance with Vermont's best management practices, Brynn and Clausen (1991) reported on 78 postharvest site assessments. Sedimentation from stream crossings was above background levels at 57 percent of the crossings.

Information Needs

A review of our knowledge of the water quality impacts of stream crossings shows that several areas need additional study. Needs begin with expanding the database on sediment production from different types of crossings and quantifying sediment production over the life cycle of the crossings. Although we cited several studies of stream crossings, relatively few reports document short- and long-term impacts from the installation, use, and removal of fords, culverts, and bridges. The studies on long-term impacts of low-water crossings appear well directed; however, we need similar studies to document sediment production from other crossing types throughout their life cycle. Data are needed for a wide variety of stream sizes, soil types, terrain, and climatological conditions. Once the database is more complete,

the policymakers will have enough information to develop more rational best management practices.

Researchers have used different methods for determining impacts from stream crossings, including measuring turbidity of the stream at the site and collecting samples for subsequent laboratory analysis of suspended solids. Samples are collected by manual sampling techniques or automated water samplers. For short-term studies (e.g., determining sediment production from a culvert installation), manual sampling techniques are adequate. However, for long-term studies where information is desired on life-cycle sediment production, automated sampling is required. *Figure 3* shows that even if we travel to the site sometime during a storm (which is often difficult), taking only one or a few samples does not fully characterize the sediment production history. Regardless of study objectives, we can improve the database on stream crossing impacts if we develop "standard" measurement methods.

Although a few studies have quantified sediment movement downstream from crossings, we need more studies to better understand *long-term* downstream sediment movement. Even if we determine that a ford installation resulted in 50 kilograms of sediment or a storm caused 1,000 kilograms of sediment, we do not know how far this sediment moves over time and what its long-term impact on the stream will be.

The stream crossing is accepted as the most critical location for sedimentation. Sediment produced at these sites originates from two primary sources: the stream-crossing structure, and the road approaches to the crossing. Yet the literature has not documented the proportions of sediment attributable to each, and further study is needed.

Finally, while the database is being expanded for sediment production from various types of crossings, there is a concomitant need to determine impacts on stream ecology from crossings. Researchers have examined biological impacts of other forest op-

erations, such as prescribed burning, site preparation, or harvesting; however, these techniques have not been applied specifically to quantify impacts from stream crossings.

Summary

Forest road stream crossings are a major sediment source in forest streams because crossings serve as focal points for introducing sediment-laden runoff into streams. Although the literature contains information on sediment production from crossings, the number of studies and their scope are limited. Most studies quantified short-term impacts of the installation and use of fords, culverts, and temporary bridges. Only one study cited was a long-term investigation of stream-crossing impacts.

The literature reports significant amounts of sediment produced during installation of fords and culverts. Also, rainfall can cause even greater amounts of sedimentation when disturbed soil is washed into streams. From the literature, we can conclude that portable bridges can be installed and used with fewer impacts on streams. Next, culverts appear to be preferable over fords in terms of water quality impacts.

Decisions about which type of crossing to install do not depend solely on water quality concerns, however. Forest operations professionals are faced with many other site-specific concerns and cost considerations—and solutions to these concerns are not readily available in the literature. To help provide these solutions, we need additional, coordinated research to (1) document sediment production from crossings installed in different site and climatological conditions, (2) document long-term impacts of crossings and sediment movement, (3) differentiate sediment produced by crossings from that produced by road approaches, and (4) document the impacts of crossings on biological functions of streams. We have much to learn to develop a complete picture of how stream crossings affect streams and then to recommend appropriate methods to prevent those impacts.

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