A. INTRODUCTION TO RECONSTRUCTION AND UPGRADING

Road reconstruction provides an opportunity to upgrade and improve a substandard road in one or more elements of its design. Culverts can be upgraded to current standards, additional drainage structures can be installed, the roadbed can be reshaped for improved surface drainage, and fills which exhibit instability can be removed and/or stabilized. In general, stream crossings, unstable fills and cut slopes, and poor road surface drainage present some of the greatest challenges to road reconstruction, and the greatest opportunities for future erosion prevention, water quality protection and aquatic habitat restoration.

Upgraded roads are sometimes referred to as “storm-proofed” even though they still retain the potential for flood damage. However, properly upgraded roads should have a significantly lower chance of failure and the failures that do occur should happen less frequently and are smaller in magnitude. Storm-proofed roads are significantly more resilient to storms and floods, and typically require less maintenance and lower reconstruction costs when and where they do fail.

B. RELOCATING PROBLEMATIC ROAD REACHES

Problem road reaches can occur on roads that are open and maintained, or closed and abandoned. Some of these roads contain especially severe problems and should be permanently closed and relocated to more favorable slope locations, rather than to be rebuilt and maintained. Examples of problematic roads or road segments include the following:

- Roads with excessively high maintenance requirements and costs.
- Roads that persistently cause environmental damage to streams and water quality and that cannot be economically corrected.
- Roads with frequent and significant slope instability that may result in intermittent road closure, including roadbed slumping,
roadbed debris slides, cutbank and hillslope failures, rock falls, or stream undercutting.

- Roads that have failed at one or more locations and cannot be rebuilt cost-effectively.
- Abandoned roads or road segments that have multiple road failures along their length.
- Abandoned roads or road segments that cannot be rebuilt because of regulatory or environment restrictions – if they were to be proposed for construction today they would not be permitted.
- Roads or road segments that are too steep for the desired land use activity or traffic types.
- Roads or road segments which are unsafe for users.

Road relocation consists of two activities: decommissioning and restoration of the road to be permanently closed, and rerouting the alignment to a more favorable location, using current design and construction standards (Figure 200).

When road reaches are closed they must be inventoried and assessed for existing and potential erosion and slope stability problems. Road closure and decommissioning treatments should then be implemented to prevent or greatly reduce the potential environmental effects of the road (see Chapter 7). These treatments include complete removal and restoration of all stream crossings, excavation or stabilization of all existing and potential road fill instabilities that could deliver sediment to stream channels, decompacting and/or permanently dispersing road surface drainage, and treating all other road-related sediment sources.

Road relocation is new construction, unless an abandoned or low standard road can be upgraded to access the desired location(s). All the same environmental regulations and permits pertaining to new road construction are required to relocate a road to a new location. The relocation process involves virtually all the steps already described for effectively planning, designing and constructing a new road.

**FIGURE 200.**
The road on the left used to go along a perennial stream and riparian zone, eventually reaching the ridge crest in the distance. To eliminate its impact, the riparian road was decommissioned and a new bypass route (right) constructed along a dry hillside to the same ridge crest location.
Relocating a road or road segment can be as simple as identifying, designing and constructing a nearby alternative route that avoids the environmental problems that occurred or existed along the old alignment (Figure 200). Alternatively, it might entail revising the local transportation plan and require the relocation of the problematic road, and the spur routes that it served, to more favorable, stable terrain. This will achieve the desired transportation needs while having a minimal impact on the environment. Rural roads may be more problematic to relocate, because of multiple land ownerships and property boundaries that could be involved in the relocated alignment. However, you should identify the most stable and environmentally friendly road alignment or route, and if this involves a neighbor’s property, at least talk with them about your ideas.

C. EVALUATING AND DESIGNING UPGRADES FOR EXISTING ROADS

One of the most common road-related activities for rural road systems, both from the perspective of road design and environmental protection, is the upgrading of existing roads and structures to current standards. In many locations in the USA, the core network of forest, ranch and rural roads has already been built, and new construction is a relatively minor part of overall land development and management. New roads are often those needed to access a new residential development or home sites, or spur roads that may be required to access a stand of trees proposed for harvesting, but the core network of primary and secondary roads is often already in existence.

Design standards for new road construction have evolved and improved substantially over the last several decades. This means that most of our existing roads need to be thoroughly analyzed and updated, both to reduce the potential for road failures and continuing pollution, as well as to implement road improvements that will reduce long term road maintenance requirements and costs (Figure 201).

Most existing roads on the landscape were constructed decades ago and the lower standards that were applied then are now seen as representing serious potential threats to downstream, off-site resources as well as to the infrastructure of the transportation system itself. Stream crossings are often considered the “weakest link” in wildland road systems and it is primarily in these locations that the lower standard designs are likely to still have the greatest adverse consequences.

For example, threatened or endangered fish cannot pass through many old culverts that were installed too high in the fill and are now barriers to their migration. Elsewhere, many stream crossing culverts that were installed...
twenty or more years ago are now seen either as dramatically under-designed (undersized), or rusted through and failing, or both. **Undersized or poorly designed or installed culverts are seen as “loaded guns” that can fail during even moderate size floods, costing both money to repair and severe downstream environmental degradation.**

Road drainage practices and goals have changed dramatically. For example, past engineering design “best practices” for road drainage called for collecting, concentrating and discharging surface runoff from the road so that the road and its infrastructure would not be damaged by erosion. Efficiently delivering road surface and ditch drainage off the road and into the nearest stream channel was considered the standard goal of road surface drainage. This design typically called for insloped roads with inboard ditches, and long ditch lengths between ditch relief culverts (Figure 202). At that time, the main concern was with protecting road infrastructure within the right-of-way; not downslope lands, downstream water quality or aquatic resources.

Today, road redesign and upgrading is intended to bring the road up to current standards by protecting the road infrastructure, but also minimizing the potential for environmental damage from road erosion and failures caused by substandard designs.

The most serious design flaws in older, existing roads include those that threaten road integrity, those that threaten to cause catastrophic road failures with significant downstream impacts, and those that contribute to persistent, chronic water quality pollution. Most of these design flaws were considered to be common and acceptable “field” designs and construction practices several decades ago, and their presence can be found along wildland roads in steep mountainous watersheds almost everywhere. Updated design standards and practices are now available to correct or remediate most of the potential problems created by old designs on existing roads. The most serious and threatening design problems for which updated design standards now exist include the following:

1. Non-standard stream crossing structures, including uncultivated fills, log culverts, log bridges, and poorly located or designed fords.

**FIGURE 202.** Three culverts on a rural road have developed (see arrows) long gullies below their outlets that connect the road to the stream channel at the base of the hillslope. The distance between ditch relief culverts was too long and each culvert carried too much flow. Additional ditch drainage is needed to disperse road runoff and prevent new gullies from forming.
2. Stream crossings whose drainage structures are under-designed (undersized) for the calculated 100-year peak flow, including sediment and floating woody debris passage.

3. Stream crossing culverts that are poorly aligned, too short, too high in the fill (not at grade), prone to plugging, or that are deteriorated or have suffered storm or mechanical damage since installation.

4. Stream crossings in debris flow channels that are not designed to withstand or pass debris flows without washing out or diverting.

5. Culverted stream crossings that have a diversion potential, especially those in steep midslope and lower hillslope positions such that if the culvert plugged, streamflow would be diverted down the road alignment and discharged onto unprotected hillsides or into other stream channels.

6. Stream crossings that are barriers to anadromous or resident fish migration.

7. Roads built by sidecast (cut-and-fill) construction techniques on steep, unstable inner gorge slopes.

8. Road fill slopes constructed on steep slopes that show signs of instability or potential instability, and that threaten to deliver landslide debris and sediment to streams or other water bodies.

9. Road fills built across steep headwall swales with visible signs of instabilities or emergent groundwater, especially in areas where debris torrents (flows) have originated in the past.

10. Poorly drained and insloped roads with widely spaced ditch relief culverts and road surface drainage structures that carry sufficient flow during storm events to develop large and long gullies on road surfaces or on hillslopes downslope from their outlets.

11. Hydrologically connected ditches and road surfaces, especially on mainline and main spur roads that have high traffic levels, significant commercial traffic or that are located in areas of highly erodible soils.

12. Roads built parallel to and immediately adjacent to stream channels, especially streams that support resident or anadromous fish populations or serve as domestic water sources.

Many existing forest, ranch and rural roads can be proactively upgraded and treated to help protect them and the downstream areas from potential impacts. However, a poorly located road can almost never be as effectively remediated or negated by implementing improved design standards, especially once the road has already been reopened and rebuilt. Regardless of advances in road design standards and road building techniques now available, some roads are not fit to be upgraded and should be permanently closed and decommissioned (Figure 203).

FIGURE 203. Sidecast constructed road built on a very steep inner gorge slope where a road should not have been built. Bulldozer constructed road perched large volumes of erodible spoil on the slope and debris slides have already delivered landslide debris to the stream channel below. This road is poorly located and upgrading will not reduce the failure potential. It is scheduled for permanent closure and the excavator (top of photo) is ready to begin decommissioning work.
This may be an economic decision, because of high maintenance and repair costs, but it should also be heavily influenced by the level of threat or potential impact represented by the road itself. Instead of developing and implementing updated standards for their reconstruction, landowners should evaluate their options for road closure and, if necessary, realign or relocate the road to more favorable, stable terrain.

D. REDISEIGN CONSIDERATIONS FOR ROAD RECONSTRUCTION AND UPGRADING

1. REDESIGNING AND UPGRADING EXISTING ROADS

Storm-proofing upgrade treatments to an existing road are designed to: 1) bring the road up to current standards following best management practice guidelines, 2) make the upgraded road more resilient to storms and floods, 3) lower the on-site and downstream impacts of any failures that do occur along the alignment, 4) reduce chronic road-related inputs of fine sediment to stream channels, and 5) reduce long term road maintenance requirements and costs.

To achieve this, the upgrading treatments to existing roads should address three main treatment categories: 1) stream crossings, 2) road, landing and turnout fill slopes, and 3) road surface drainage. Other sites may need to be upgraded and addressed, but these three treatment categories are the ones most likely to threaten road integrity, erosion and sedimentation, water quality, and downstream aquatic habitat. When completed, treatments will have met certain design standards and performance characteristics for storm-proofed roads (see Figure 204).

Road redesigning includes 1) reopening and upgrading roads that have been closed or abandoned for some time, as well as 2) upgrading existing, maintained roads to current design standards. The upgrading processes are similar but deciding to reopen an old abandoned road will require additional economic and environmental analysis.

The most efficient equipment for road reconstruction and upgrading includes hydraulic excavators, bulldozers, water trucks, dump trucks and a grader for final road shaping. These versatile pieces of equipment can complete reconstruction with a minimum of soil disturbance and loss of vegetation. A standard size backhoe is generally too small to perform the excavations required for many stream crossing reconstructions and removal of unstable road and landing fills. Dump trucks are often needed to endhaul slide debris and spoil materials generated during reconstruction and upgrading, and compactors may be needed, depending on the type of expected traffic.

2. REOPENING AND UPGRADING OLD ABANDONED ROADS

Reopening and upgrading old “orphan” or abandoned roads, even if they have been unmaintained and are currently overgrown, is often preferable to constructing new roads. Applying new design standards to the old alignment usually has less environmental impact and will be less expensive than building a brand new road bench across unroaded terrain. The weak points and problem areas along the old alignment will already be evident. Cutbanks and fill slopes will have largely stabilized over the years and those that haven’t can be targeted for appropriate treatments. However, most of the constructed features along the old road will not be up to modern standards, and there may be a number of environmental risks along the road that must be treated. These will be identified during detailed field inventories and inspections.
CHARACTERISTICS OF STORM-PROOFED ROADS

Storm-proofed stream crossings
- All stream crossings have a drainage structure designed for the 100-year flood flow (including woody debris and sediment).
- Stream crossings have no diversion potential (functional critical dips are in place).
- Culvert inlets have low plug potential (trash barriers or deflectors are installed where needed).
- Culverts are installed at the base of the fill and in line with the natural channel.
- Any existing culverts or new emergency overflow culverts that emerge higher in the fill have full round, anchored downspouts that extend to the natural channel.
- Stream crossing culvert outlets are protected from erosion (extend culverts at least 6 feet beyond the base of the fill and use energy dissipation, where needed).
- Culvert inlet, outlet and bottom are open and in sound condition.
- Deep fills (deeper than a backhoe can reach from the roadbed) with undersized culverts or culverts with high plugging potential are fitted with an emergency overflow culvert.
- Bridges have stable, non-eroding abutments and do not significantly restrict 100-year flood flow.
- Stream crossing fills are stable (unstable fills are removed or stabilized).
- Approaching road surfaces and ditches are “disconnected” from streams and stream crossing culverts to the maximum extent feasible using road shaping and road drainage structures.
- Class I (fish-bearing) stream crossings meet State Fish and Wildlife and National Marine Fisheries Service fish passage criteria.
- Decommissioned stream crossings are excavated to exhume the original, stable, stream bed and channel sideslopes, and then stabilized with mulch and vegetation.

Storm-proofed road and landing fills
- Unstable and potentially unstable road and landing fills that could deliver sediment to a stream are excavated (removed) or structurally stabilized.
- Excavated spoil is placed in locations where eroded material will not enter a stream.
- Excavated spoil is placed where it will not cause a slope failure or landslide.

Storm-proofed road surface drainage
- Road surfaces and ditches are hydrologically “disconnected” from streams and stream crossing culverts. Road surface runoff is dispersed, rather than collected and concentrated.
- Ditches are drained frequently by functional ditch relief culverts, rolling dips or cross road drains.
- Outflow from ditch relief culverts does not discharge to streams.
- Ditch relief culverts with gullies that deliver to a stream are removed or dewatered.
- Ditches and road surface drainage does not discharge (through culverts, rolling dips or other cross drains) onto active or potential landslides.
- Decommissioned roads have permanent drainage and do not rely on ditches.
- Fine sediment contributions from roads, cutbanks and ditches are minimized by utilizing seasonal closures and installing a variety of surface drainage techniques including berm removal, road surface shaping (outsloping, insloping or crowning), rolling dips, ditch relief culverts, waterbars and other measures to disperse road surface runoff and reduce or eliminate sediment delivery to the stream.
When reopening roads that have been abandoned for many years it is possible that some large stream crossings or short sections of road on steep, unstable slopes may have entirely failed by past erosion or landsliding. These may not be worth rebuilding and it may be preferable to reroute the road alignment around the problem areas with a section of newly constructed, stable road using current construction techniques and standards. In other cases, washed out stream crossings may appear impassable and problematic but it is often comparatively simple and inexpensive to upgrade the crossing to current design standards (Figure 205).

In many cases, temporarily reopening a poorly built road (for a single summer season) may provide substantial positive environmental benefits if subsequent rehabilitation or decommissioning could reduce continuing or future erosion and sedimentation from the old alignment. All reconstruction work should be conducted in a manner that minimizes soil disturbance. Only areas which truly require earth moving should be disturbed. Typically, most of the old road surface will still be intact and require only minor grading to become passable. Ditches and cutbanks should be left undisturbed unless there are specific areas needing repair work or they are to be converted to an outsloped configuration. New sidecasting should be avoided in areas of steep slopes, near stream channels or where fills are unstable or oversteepened. As a general rule, landings should not be enlarged by new sidecasting.

**FIGURE 205.** Under-designed or unmaintained stream crossings on older roads are prone to failure during large storms. This 8 foot diameter culvert was partially plugged (note wood at entrance) and flood flows overtopped and washed out the fill. During road reconstruction, stream crossings should be redesigned as temporary (and then removed) or upgraded for the 100-year flood flow, including passage of debris and sediment loads. When reconstructed, this crossing would either be fitted with an upstream debris screen or debris deflector, or a bridge would be installed.
Decisions about reopening an abandoned road should be made on-site, after having inspected the entire route and reviewing the pros and cons of re-disturbing the area. As a general rule, it is often worth removing even abundant revegetation along the abandoned route if there are substantial erosion prevention projects that could be completed during or following reconstruction. That is, it is often preferable to remove vegetation than to leave the vegetation intact and not treat potential and ongoing erosion “hot-spots” along the old road alignment. Removing vegetation and regrowth from the road prism, by itself, rarely causes serious erosion problems. When in doubt, you should seek technical assistance and guidance from the experienced resource specialists (qualified geologists, engineering geologists, erosion control specialists, etc.) as well as input from regulatory agencies that will eventually have to approve any proposed project.

Some old roads may not be suitable for reopening and permanently upgrading. Those should be fairly self-evident upon field inspection and analysis. Only after careful consideration, weighing the economic and environmental benefits against the potential impacts, is it ever justified to reopen roads that 1) cross unstable hillslopes, 2) were constructed up the axis of a stream channel or valley, or 3) would require considerable earth moving with the potential for significant erosion and stream sedimentation. Some roads simply may not be located in a good hillslope location and there is little or nothing that can be economically done to improve their design or stability (Figure 206).

**FIGURE 206.** This rural road traversed a large unstable hillslope that showed widespread movement during an exceptionally wet winter. The road did not cause the instability but it is no longer useable. Alternative access should be developed wherever roads cross highly unstable terrain. This road should be decommissioned so no additional erosion and instability is caused by the road and its drainage structures.
a. Stream crossings

Existing stream crossings along the road alignment require close examination and analysis. If the road is to be permanent, all stream crossing drainage structures should be checked to determine whether or not they are properly designed and capable of passing the 100-year flood flow. Any stream crossings that require reconstruction should be redesigned for the higher level of protection. Any significant design flaws that could lead to stream crossing failure should be immediately addressed.

Washed-out stream crossings present one of the most common obstacles on older abandoned (orphan) roads that are to be reconstructed. Usually part, or all, of the fill has been eroded and lost downstream because the drainage structure was too small, not maintained, or not installed in the first place (Figure 207). Washed-out stream crossings are reconstructed just like new ones, with all the same techniques and requirements. If the fill was only partially eroded from the crossing, the remaining material in the channel bottom will likely need to be excavated (down to the original channel bed) before a new culvert is installed. This may include removal of sediment and buried stumps and logs.

Other stream crossings may still be completely intact, but have poorly constructed, undersized or worn out culverts that need to be replaced and/or upgraded (Figure 208). Some crossings may have buried logs or trash that was placed in the channel before it was filled in, and it is now characterized by sink holes (Figure 209). Even if the crossing is still intact, the fill should be excavated down to the original streambed and a new, stable fill and properly

FIGURE 207.
The culvert inlet on this abandoned (unmaintained) stream crossing partially plugged with wood and sediment. The culverted fill “washed out” (eroded) and continues to erode and deliver sediment to the channel and to downstream areas. “Walking away” from an old road does not prevent potential erosion problems, especially when they contain culverted stream crossings.
FIGURE 208. Typical upgraded culvert installation on non fish-bearing streams.

FIGURE 209. Sink hole in recently reconstructed seasonal road. The plastic culvert separated (see arrow) when the poorly compacted fill settled during the first wet season. Flow in the culvert caused the fill to erode and the sink hole to form. All the eroded sediment was delivered downstream.
designed and sized drainage structure should be installed (Figures 210a and 210b).

If a temporary or permanent bridge is to be installed, the entire fill should be removed from the old crossing, and the banks should be graded or excavated back to a stable angle. You can often tell that you have removed all the fill material from the former crossing when rounded boulders, old uncut logs and branches, roots, in-place stumps and other features of the original bed and banks are exposed during excavation.

**FIGURE 210A.**
This Class I (fish bearing) stream channel exhibits several previous upgrading attempts, none of which were designed to allow fish passage. The original crossing consisted of logs piled in the channel and covered with fill. When that plugged, a culvert was installed on top of the logs, and another smaller culvert was later installed above it, to add more flow capacity.

**FIGURE 210B.**
The recent upgrading consisted of removing all the stream crossing fill (including the logs and old culverts) and installation of a large, embedded culvert to allow for aquatic passage.
b. Road and landing failures

Road and landing fill slopes along a road proposed for reconstruction should be examined and any that show signs of instability or potential instability, where fill slope failures would impact stream channels downslope, should be stabilized or removed (excavated) (Figure 211). Similarly, road surface drainage should be analyzed to ensure that road runoff is not adversely affecting the stability of fill slopes or hillslope areas below the road. Road shaping and drainage structures should be modified to protect slope stability, especially where slopes are steep and potentially unstable.

Failed road benches can present a serious obstacle to reconstruction. In areas of steep inner gorge slopes, failures of the entire width of the roadbed can extend all the way downslope to a fish-bearing stream. Side-casting into the void in hopes of developing a new road bench at the same spot will usually result in direct sediment delivery to the stream. The resulting fill would also be highly unstable. Road reconstruction, where failures have removed most, or all, of the former road bench, are likely to require an engineered solution such as a reinforced fill or a crib wall (Figure 212). A qualified geotechnical engineer or engineering geologist should be consulted to design solutions for these difficult reconstruction sites.

In many cases, the outer 10–50 percent of the road prism may have been lost as a result of fill slope or sliver fill failures along the former road, in which only sidecast materials have moved downslope. If there is sufficient road width remaining for vehicles to pass, the unstable area should not be disturbed. Where some additional road width is needed, consider cutting into the inside bank rather than trying to build the fill back out (Figure 213). If fill material has not moved off-site, but is showing signs of pending failure (e.g., scarps displacing or

FIGURE 211. Unstable landing fill excavation. Oversteepened fill is removed from the landing edge and endhauled off-site to a stable location (Adams and Storm, 2011).

FIGURE 212. Engineered fill constructed where a fill slope failure had removed the entire roadbed.
offsetting the road prism), and the failed soils will be delivered to a stream, then the unstable material should be excavated and hauled to a stable storage site for disposal (Figure 214).

Although a far less common practice today, unstable landing fills or fills around the outside of rock pits present similar problems on a larger scale, except that vehicle passage is usually not affected. Unstable landing fills on roads used several decades ago usually resulted from mixing soils and woody debris together in the uncompacted sidecast around a landing perimeter. The fill face was often oversteepened by continued blading and sidecasting of landing wastes over the outside face of the landing. On steep slopes, these unstable fills and waste deposits can saturate with water and develop into debris slides or fluid debris flows that travel great distances downslope and into larger stream channels, threatening downstream residences or other important habitat or infrastructure. In other cases, failed landing fill material may not be delivered to a stream channel, and only the

**FIGURE 213.**
Most road fill failures leave at least half (the cut half) of the roadbed intact and passable. If additional road width is required for vehicle passage, the most cost-effective solution is to widen the road into the cutbank, rather than building and engineered fill where the road slumped.

**FIGURE 214.** Unstable road fill excavation, before and after treatment.
“run-out” area is impacted through damage to regeneration and reduced site productivity.

Each unstable turnout, landing or rock pit fill should be evaluated to determine if it threatens downslope stream channels, human developments or other important resources. If it does, the unstable fill should be excavated and hauled to a stable storage site for disposal. Often, the inside of the landing or the rock pit itself is carved into bedrock and can serve as a suitable storage site for excavated fill materials.

Cut slope failures which block the road surface generally represent a less serious erosion and water quality problem than fill slope failures, since the roadbed may store much of the failed cutbank material and prevent it from moving downslope (Figure 215). Failed materials can usually be excavated off the roadbed and hauled to a suitable storage site. Unless slopes are gentle and the road is not close to a stream channel, debris should not be sidecast from the road surface and onto the slopes below. Sometimes the material can be spread or “drifted” over the roadbed, thereby raising the road surface and avoiding the need for expensive endhauling.

c. Road surface drainage

Road and ditch connectivity to streams should be minimized as an important part of any road upgrading and storm-proofing project. This might include road shape conversions (e.g., converting roads from insloped to outsloped), adding and relocating ditch relief culverts, adding rolling dips to disperse road surface runoff onto stable slopes below the road, and hydrologically disconnecting any connected gullies, ditches and any other drainage structures to the extent feasible.

Many older roads were initially constructed with an insloped surface and an inside ditch. If conditions are appropriate, the rebuilt road can be converted to a low-impact outsloped surface with rolling dips to disperse road runoff. In ditched road segments, ditch relief culverts should be endhauled or pushed to a stable storage site and not sidecast over the outside edge of the road. In some instances, a slope buttress may need to be designed and installed to prevent further instability and road closures.
and other surface drainage improvements should be made to quickly direct water off the road surface and into buffer areas downslope where it can infiltrate. Many older seasonal and permanent roads have an outside berm which has been created and perpetuated by years of poor grading technique (Figure 216). Poorly drained roads can often be dramatically improved by outsloping, berm removal and/or other surface drainage improvements.

d. Slash and spoil disposal

Reconstruction of abandoned roads often involves substantial vegetation removal from the road surface. Slash should not be mixed in and sidecast with soil materials. Instead, it can be piled and burned on landings, or windrowed along the outside edge of the cleared fill. Spoil materials generated from road reconstruction (largely from cutbank failures), should be safely disposed in a stable location where it will not erode or enter a watercourse. Spoil disposal techniques are the same as for new road construction (see Chapter 5, and sections on construction and erosion control, and reconstruction techniques, above).

E. STREAM CROSSING UPGRADES

When upgrading and storm-proofing any low volume forest, ranch or rural road, stream crossings are one of the most important elements to evaluate and upgrade. The field inspection and office analysis will tell you what needs to be done to bring the crossing up to current design standards and to reduce its failure potential. These actions can be summarized in a discrete number of “actions” that are undertaken to upgrade and make each stream crossing more resilient to storms and floods, contribute less to chronic fine sediment delivery, and have a minimal impact on aquatic organism passage (Figure 204).

As a start, map analysis and field inspections will tell you if the culvert is undersized for the design flood flow (100-year return interval), and inspections will help inform you if bridges or other non-standard stream crossing structures

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**FIGURE 216.**
Surface runoff problems caused by wet weather use of a bermed, unsurfaced, seasonal road. The running surface is rutted and this acts to collect runoff and cause additional erosion. Lack of waterbars or rolling dips, together with the berm along the outside edge of the road, now act to keep surface runoff on the unsurfaced roadbed.
need to be replaced. Most older, culverted stream crossings (those built more than about 10 to 20 years ago in many western states) will be undersized for the 100-year peak flow. At 20 years old, many of these will be showing signs of rust and wear and will likely need to be replaced anyway. If the culvert is undersized, displays any rust holes in the bottom, shows signs of leakage or internal separation, or has a dented or ripped inlet it will likely need to be upgraded (Figures 217a and 217b).

In upgrading a stream crossing culvert, make sure to determine if the stream is fish-bearing.

FIGURE 217A. Culverted stream crossing on a permanent forest road before upgrading to the 100-year design standard (including debris and sediment). The before and after photos of the culvert outlet are taken from the same location.

FIGURE 217B. The same stream crossing after culvert upgrading. The culvert has been set in the original streambed and the fill dipped to prevent stream diversion.
and, if so, to provide for passage for all life stages of the species that use the channel at any time of the year. Some large culverted streams may be candidates for installing a bridge, a plate arch or an arch culvert instead of an embedded round culvert (Figures 218a and 218b). Ask the regulatory agencies with jurisdiction for the protection of aquatic species, including fish, for comments on your proposed design before you start planning for construction.

If the stream channel shows signs of past culvert plugging or significant transport of large woody debris during flood events, you will want to provide increased protection against future plugging of your new installation. This can be done by upsizing your culvert even larger than required to carry the 100-year peak discharge, by using an arch culvert instead of a round one, or by installing a bridge, ford or plate arch (bottomless arch) instead of a culvert. Suggestions for culvert sizing methods and calculations to account for passage of organic debris during floods are described in Appendix A.

Finally, stream crossing upgrading also involves upgrading road surface drainage on the approaches to each crossing. Road surface runoff and ditch flow should be diverted off the road as close to the stream crossing as possible.
as is possible without runoff entering the stream somewhere downslope. The remaining connected road surface should be rock armored, or mulched and seeded if the road is a seasonal, native surfaced road.

The road surface over the crossing can be insloped or outsloped, as long as the remaining local road surface runoff is not directed over the new fills and the bare fills are protected from erosion with seeding, mulch, and/or erosion control blankets. Rock armor is typically installed around the culvert inlet and outlet to protect it from erosion, and that armor also serves to trap any sediment eroded from the new fill before it can be delivered to the stream. Ultimately, revegetation of the fills will provide for long term erosion control and fill slope stability.

F. TRENCHLESS TECHNIQUES FOR CULVERT REPLACEMENT

Trenchless technology can be defined as the use of construction methods to install or repair underground infrastructure without digging a trench or opening an excavation cut. Rapid development and expansion of trenchless technology has been observed over the past several of decades due to the desire to cost-effectively install or rehabilitate stream crossing culverts with minimal environmental impacts.

Culvert-lining methods are classified as a specialized trenchless rehabilitation method for repairing certain existing stream crossings without having to excavate and replace the existing culvert pipe. Although mostly confined to use in culvert replacements on public roads, where traffic cannot be closed, the simplest trenchless methods are also suitable for some large culverted fills on forest and rural roads.

The trenchless techniques suitable for rural roads can be divided into techniques for installing new pipes and techniques for rehabilitating existing pipes. New pipe installations are completed using pipe jacking or earth boring methods. Alternatively, pipe rehabilitation is accomplished using lining methods or by applying maintenance repairs to the existing culvert. The increasing cost of replacing long culverts under high fills warrants an evaluation of all repair techniques currently available.

Maintenance of culverts may include major repairs of corrosion and abrasion damage to the culvert invert. Techniques employed for metal culverts may include recoating; lining with concrete, cement grout, and plastics; plugging of leaks with expanding bands, grouting, and welding; and insertion of a smaller diameter pipe (sleeving). Concrete culverts may be repaired by relining with grout; removal and replacement of deteriorated concrete; with the insertion of clay or plastic liners; and by applying polymer coatings.

As the name implies, these methods have the ability to retrofit or completely replace a pipe with minimal trenching, and therefore minimal effect to the roadway traffic. Project sites that favor trenchless technology for a pipe rehabilitation include sites with deeper cover, larger pipes, and longer detour routes. The hydraulic analysis for a rehabilitated pipe should be the same as required for a new pipe or culvert. Any type of liner used to rehabilitate a culvert will reduce the diameter of the pipe, thus reducing capacity. However, due to the smoothness of the new liner, the improved efficiency of the pipe may compensate for the lost capacity.

A number of rehabilitation methods are available which can restore structural integrity to the pipe including: fold and form, sliplining, tunneling, horizontal directional drilling, and pipe jacking, among others. Most are designed for highway use and only a few of these would be cost-effective for forest, ranch or rural roads.
Various types of liners can retrofit the pipe interior. One of these techniques is called ‘fold and form’ and involves pulling a folded HDPE pipe through the existing (host) pipe. The liner pipe is then inflated with hot air or water so the liner molds itself to the host pipe, thereby sealing cracks and creating a new pipe within a pipe. Another method is a close-fit folded lining or a fold-and-form lining. Before installation, a polyethylene liner is heated and folded to reduce cross-sectional area for insertion. The folded liner is then inserted into the host culvert and pulled into place with a winch. Once in place, the liner is reformed to a shape, with applied heat and pressure (generally steam), that forms a close fit with the host culvert (Figure 219).

Sliplining is a technique that involves inserting a full round pipe with a smaller diameter into the host pipe and then filling the space between the two pipes with grout (Figure 220). It is the most common and easiest lining method and costs range from $25 to $200/ft. Sliplining involves inserting a flexible, usually thermoplastic, liner of smaller diameter directly into a deteriorated culvert. Liners are inserted into the host by either pulling or pushing the liner into place. After insertion, the space between the existing culvert and liner is generally grouted with a cement material providing a watertight seal (Figure 220).

Continuous sliplining involves the lining of a deteriorated culvert with a continuous liner. No couplers are required so this allows for a larger diameter liner. Liners are generally made from polyethylene or high-density polyethylene pipe segments that are butt fused (melted) together. The continuous liner is pulled, pushed, or simultaneously pushed and pulled into the host culvert. Sliplining works best if the original pipe is already larger than the required culvert diameter for the 100-year flow, so the smaller pipe insert will still pass the design.
discharges. While the smaller diameter lining may reduce the flow capacity of the culvert, the smooth interior surfaces may make up for some of the flow loss caused by the pipe insert.

Fish passage through newly lined pipes may become an issue if velocities are increased enough in the smooth walled pipe that fish cannot swim upstream.

**Tunneling** is typically more expensive than the other methods of in-situ culvert replacement, but it allows for installing a larger diameter culvert than currently exists at a site. It involves auguring through the fill and simultaneously inserting a new, larger culvert as the auguring progresses (Figure 221). There must be good access for heavy equipment to the upslope (inlet) side of the stream crossing fill (Figure 222).

**FIGURE 221.** Tunneling is sometimes used to install a culvert in a deep road fill without opening an excavation or disrupting traffic. The large, powdered soil auger drills and removes soil materials and fill from the hole and the new steel pipe is hydraulically jacked into the hole.

**FIGURE 222.** New pipe section is welded to the previous “jacked” section and the process is repeated until the outlet is exposed at the base of the outside fill slope. Guides along the ground are used to keep the pipe and auger aligned and straight. Soil removed by the auger is endhauled to a spoil disposal site.
Pipe jacking or ramming is probably the most widely known and most commonly used method. Pipe Jacking is done to install pipelines and culverts under roadways, railroads, runways, canals and other immovable structures. In roadway projects the pipe jacking operation is commonly used to install piping with minimal or no interruption to the vehicular traffic or any type of utility service. Pipe jacking requires sufficient surface area to provide an access pit. This pit is used to set up jacking equipment and to remove the earth excavated from the jacked pipe. All utilities must be located prior to commencing the jacking operation. This method advances pipe through the ground with thrust from hydraulic jacks (Figure 223).

Pipe diameters less than 48 inches can be jacked both economically and easily. Excavated material is usually removed through the jacking pipe installation in carts or by a conveyor system. Once the installation is complete, soil cement, grout or sand is pumped into the void between the excavated bore and the outside of the pipe. Design and construction guidelines, and engineering oversight, are required to accomplish pipe jacking in a cost-effective manner.

G. ROAD DRAINAGE UPGRADES—ROAD SHAPE CONVERSIONS

In past decades, classic road engineering on forest, ranch and rural roads in many parts of the country was to construct insloped roads with ditches. The theory was to be able to have complete control over road surface runoff; where to collect it, how much to accumulate, where to direct it, and where to get rid of it. Runoff was also collected from swales and small, ephemeral streams along the inside edge of the road and diverted to the inside ditch. Runoff was almost always directed to the nearest stream crossing culvert inlet as the preferred way to get it off-site quickly and effectively. Streams were considered as the best place to dispose of road runoff without harming the road prism. The road right-of-way was considered the most important part of a road and protecting the right-of-way infrastructure was paramount. Little consideration was given to the impact this might have on downslope or downstream areas or the consequent environmental impacts.

More recently, as the on-site and off-site environmental impacts of road surface drainage practices have been identified and quantified,
and their causes clearly revealed, practices have changed significantly. Dispersing road surface runoff is now considered the best and most environmentally sound engineering practice for managing road surface runoff. The theory is to make the road as hydrologically invisible as is possible, such that runoff from upslope is taken directly across the road alignment and any runoff generated from the road itself (including the cutbank, roadbed and fill slope) is dispersed and discharged onto the native slope below the road as quickly as is possible. The only caveat is that when directing runoff onto those downslope areas, it might cause slope instability or other serious problems. There is a place for insloped, ditched roads but their historic prevalence on the landscape is usually far greater than needed or desired. Ditches are needed where emergent water and runoff from the cutbank needs to be collected so it will not damage the road subgrade or surface. Where cutbanks are dry and free from emergent water, most roads can be outsloped for more effective surface drainage. High maintenance insloped roads can be converted to low maintenance outsloped routes as one method for improving road drainage and reducing hydrologic connectivity (Figures 224a and 224b).

FIGURE 224A. Ditched, gullied, deeply rutted, and bermed seasonal road before being converted to an outsloped road with rolling dips.

FIGURE 224B. The same road after being converted to an outsloped road with rolling dips to improve road drainage and decrease maintenance requirements and costs. The road was also gravel surfaced so it could be used during wet weather periods.
Road shape conversions may be part of a fill slope stabilization project, where potentially unstable fill material is excavated from along the outside edge of a road and then used to fill the ditch at that or another location (assuming the material is suitable) (Figures 225a and 225b). Typically, the most common conversion is changing an insloped road to an outsloped road with rolling dips. This type of conversion is often performed on the road approaches to stream crossings, as a method of eliminating the inside ditch and hence eliminating its connectivity with the stream (Figures 226a and 226b).

Excavated fill material needed to fill the ditch may be derived by excavating the outer half of the road bench (using an excavator and/or a bulldozer with hydraulic rippers and a 6-way...
blade), or it may be hauled to the site from a nearby borrow site. The roadbed is ripped (decompacted) and fill is placed, shaped and compacted in the ditch and along the inside edge of the road bench. A dozer, and then a grader, are used to provide a final, even outslope to the new outsloped road bench. The new shape should be watered (if it is too dry) and a vibratory rolling compactor can be used to harden the materials and the driving surface. As with any outsloped road, you will need to construct regular rolling dips along the alignment to make sure you achieve regular, dispersed road surface drainage.

Depending on site conditions, other road shape conversions can be employed. If a ditch is needed, the insloped road bench can be converted to an outsloped road while the ditch is retained to collect and drain surface runoff.

**FIGURE 226A.** Rural subdivision road was insloped and rutted prior to treatment. Runoff from the eroding roadbed was delivered directly to a stream channel.

**FIGURE 226B.** The same road was converted to an outsloped shape, with broad rolling dips constructed at regular intervals, to disperse road runoff onto the adjacent grass covered slope and to disconnect road runoff from the nearby stream. Note that the ditch was filled and gravel was added to the low maintenance road surface.
and clean emergent water from the cutbank. This is an excellent method of “cleaning” ditch flow so that it can be safely discharged into a nearby stream crossing culvert inlet without adding the fine sediment or turbidity that would have come from road runoff.

Similarly, an insloped road could easily be converted to a crowned road, and the crown could be moved from the traditional centerline position of the roadbed to a location closer to the inside of the road. The crown still provides the safety factor sometimes needed on rural roads that get an occasional winter snow cover, but greatly diminish the amount of fine sediment and turbid runoff that would otherwise enter the ditch from a fully insloped road surface.

H. EROSION CONTROL

Erosion prevention and erosion control can actually be improved by road reconstruction. Upgrading or removing stream crossings and removing unstable fills can significantly reduce the likelihood that road failures will occur and sediment will be delivered to stream channels. Even the temporary, single reuse of an abandoned road can serve as an opportunity to perform erosion control and erosion prevention when the road is then permanently closed.

Erosion control during reconstruction of permanent and seasonal roads is largely the same as for new construction. Surface erosion can be minimized by keeping excavation and soil exposure to a minimum, and by retaining as much roadside vegetation as possible. The largest potential erosion prevention benefit will be at reconstructed stream crossings. Use of temporary bridges, as well as protective measures at culvert inlets, culvert outlets, road surfaces, and fill slopes will help reduce the potential for accelerated erosion on reconstructed roads (see Chapter 5 (I) and Chapter 6 (E)).

The timing of reconstruction and upgrading, especially stream crossings, can also help prevent and control unnecessary erosion. Stream crossing reconstruction and upgrading should be performed during low water conditions. Wet season road work should only be performed during dry periods and when erosion control measures (mulching, waterbars, etc.) can be installed concurrently with road rebuilding. Large sections of road should not be “opened” during the wet season without performing concurrent erosion control work.